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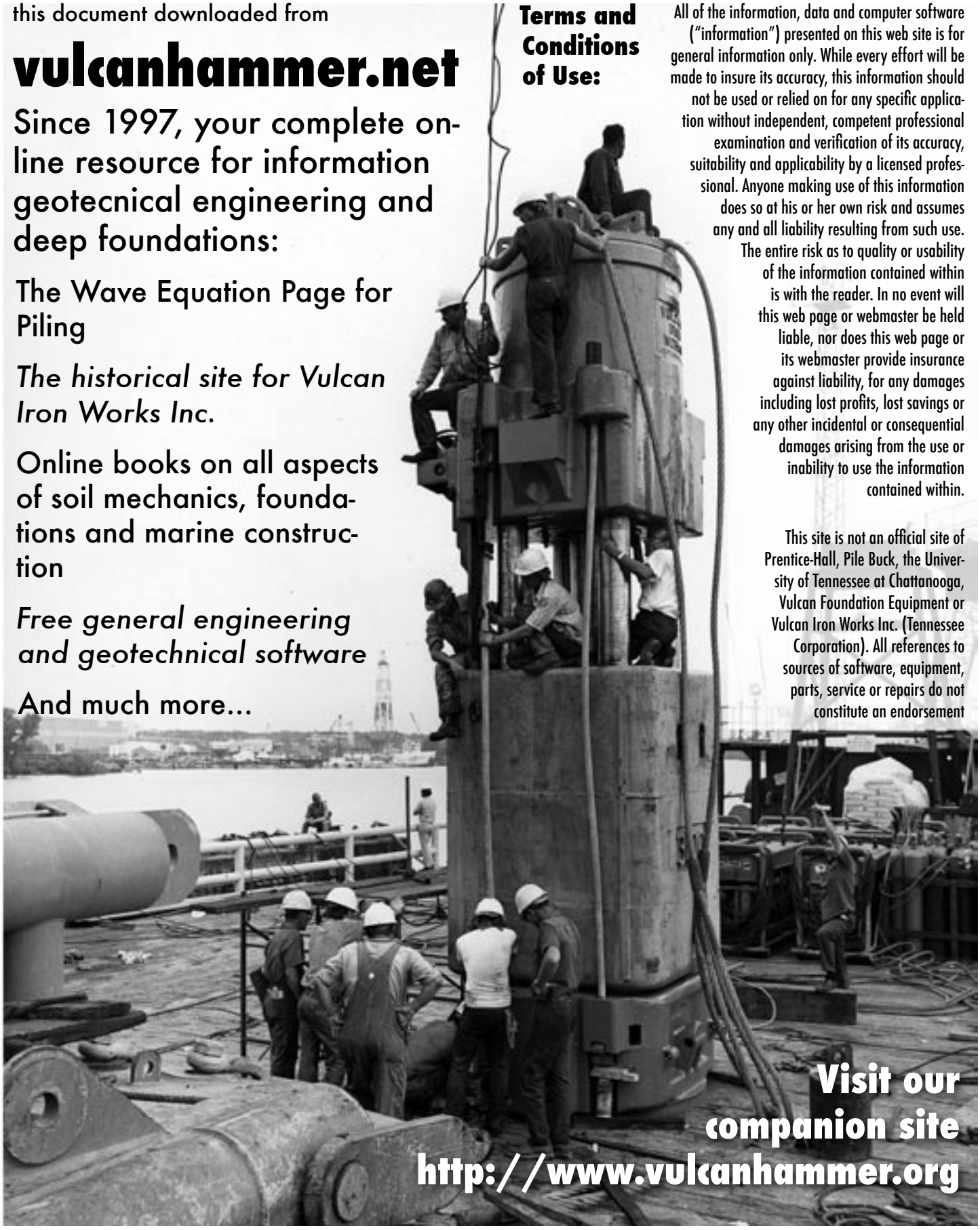
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**NAVFAC P-990**

**MAY 1995**

# CONVENTIONAL UNDERWATER CONSTRUCTION AND REPAIR TECHNIQUES

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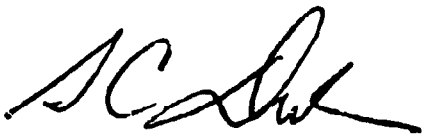
# FOREWORD

NAVFAC P-990 is primarily intended as a guide for the Navy's Underwater Construction Teams (UCTs) in conducting conventional underwater construction, maintenance, and repair. It is based on experience gained during UCT operations conducted world-wide and on relevant commercial practices. The Conventional Underwater Construction and Repair Techniques Manual was first published in 1993 and since then has received wide distribution. The seven chapters and appendixes contained herein cover project preparation and documentation; site survey techniques; maintenance, repair, and installation methods; tool selection; and pertinent technical references and sources of related equipment and materials.

This manual is certified as an official publication and has been reviewed and approved in accordance with SECNAV Instruction 5600.16A.

Two companion publications for the UCTs are the "Expedient Underwater Repair Techniques Manual," NAVFAC P-991 and the "UCT Arctic Operations Manual," NAVFAC P-992. Other relevant NAVFAC publications are cited throughout the manual.

This manual is subject to continual update as new knowledge is gained. Comments and suggestions may be forwarded by using the franked form provided.



S. C. DUBA
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Director
Naval Ocean Facilities Program

## RECORD OF DOCUMENT CHANGES

**Instructions:** Discard this sheet and insert new record of document changes sheet as issued.

This is an inventoryy of all changes made to this publication. Each change is consecutively numbered, and each changed page in the manual includes the date of change that issued it.

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## ACKNOWLEDGMENTS

NAVFAC P-990 was first published in 1978 from information collected and organized by Han Padron Associates of New York in conjuction with input and editing by the NFESC (then NCEL). This revision remains the organization style and much of the technical content of the original manual. New sections have been added and original text has been updated. The updated draft was reviewed by Han Padron to provide the latest commerical technologies. The manual includes the latest available tools, techniques, and regulations that are applicable to Naval Construction Force divers engaged in maintenance and repair of Naval facilities. P-990 is not intended to be an engineering manual. Instead, it provides guidance on applicable tools, equipment, and repair techniques. The selection of repair techniques for a particular situation should be conducted by appropriate engineering personnel. The following personnel contributed technical information used in the preparation of revisions:

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# Chapter 1

# INTRODUCTION

## 1.1 SCOPE OF MANUAL

This manual has been prepared as a guide for the Navy's Underwater Construction Team (UCT) personnel, the diving Seabees of the Naval Construction Force (NCF), in conducting conventional operations. It is based on analysis of past UCT operations and equivalent commercial practice. It is to be viewed as a living document, subject to continual revision and updating as new or improved equipment and work techniques are developed. Feedback to the Naval Facilities Engineering Service Center (NFESC) of UCT field experience in using the techniques described herein, or modifications of these techniques, is strongly encouraged so that all UCT personnel can benefit from the experience of the individual team members.

The procedures and techniques described in this manual must be carried out in conformance with the U.S. Navy Diving Manual, standard UCT procedures, and other Navy practices, with safety as the primary concern. Thus, this manual is to be used as a supplement to standard Navy diving rules and procedures and not as a substitute. It is also not a substitute for the judgment of experienced field personnel actually performing the tasks. A document such as this can only provide general guidance for typical situations. Almost every assigned task will have special requirements and problems that must be evaluated and resolved by the personnel familiar with the particular situation.

References and cited material in the text that describe specific work techniques in greater detail than contained in this manual are listed in Chapter 7. These references include planning and completion reports from past UCT/FPO-1 (FPO-1 now NFESC Code ESC55) operations, other Navy manuals, and specific equipment operation manuals. The reader is encouraged to use these valuable sources of information.

## 1.2 NAVAL OCEAN FACILITIES PROGRAM

The missions of the components of the Naval Ocean Facilities Program (NOFP) are described below. The interrelationships of the various components are illustrated in Figure 1-1.

### Naval Facilities Engineering Command (NAVFAC, NAVFACENGCOM, or NAVFACHQTRS):

#### *Director, Naval Ocean Facilities Program (Code 15E)*

- Manages the Naval Ocean Facilities Program through capability development of personnel, engineering/technology base, and ocean construction equipment.

- Coordinates utilization of this capability for planning, design, construction, installation, inspection, maintenance, repair, and removal of fixed ocean and underwater facilities and hyperbaric facilities.

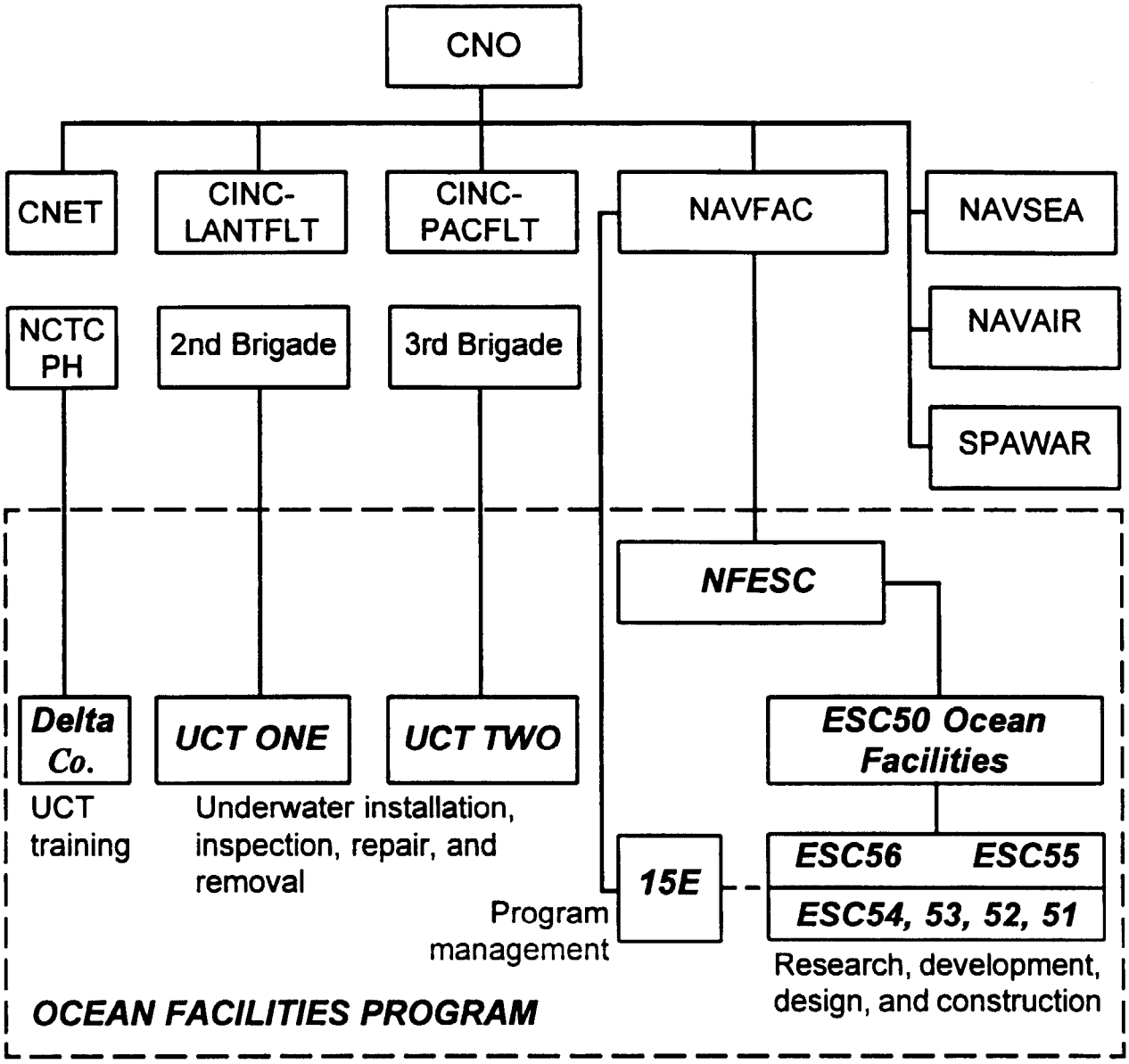



Figure 1-1
Naval Ocean Facilities Program.

Director Naval Ocean Facilities
Program (Code 15E)
Naval Facilities Engineering Command
200 Stovall Street
Alexandria VA 22332-2300

(Physically located at the NFESC East Coast Detachment, recommend using the NFESC Code ESC56 mailing address.)

Tele: (202) 433-5596
DSN: 288-5596
FAX: (202) 433-2280

Message Address:
COMNAVFACENGCOM
ALEXANDRIA VA
(Recommend using the NFESC ESC56 message address.)

**UCT Program Officer, Seabee Support Division (Code 1232F)**

Working within the NAVFAC Seabee Support Division, the UCT Program Officer is responsible for:

- Coordination of UCT Enlisted Community Management and management of the UCT's Table of Allowance.

- Acting as the NCF technical advisor on all matters pertaining to the UCTs, including UCT Doctrine and Policy, Mission, and Required Operational Capabilities and representing the UCTs at the Headquarters level on all matters pertaining to equipment, manning, mission, etc.

UCT Program Officer
SEABEE Support Division
(Code 1232F)
Naval Facilities Engineering Command
200 Stovall Street
Alexandria VA 22332-2300

Tele: (703) 325-9132
DSN: 221-9132
FAX: (203) 325-0053
Message Address:
COMNAVFACENGCOM
ALEXANDRIA VA

**Naval Facilities Engineering Service Center (NFESC or ESC):**

***Ocean Facilities Department (Code ESC50)***

- Seafloor Engineering Division
  Code ESC51

- Ocean Systems Division
  Code ESC52

- Ocean Engineering Division
  Code ESC53

- Support Operations Group
  Code ESC54

- Ocean Construction Division
  Code ESC55

- Naval Ocean Facilities Program Office
  Code ESC56

Responsible for developing, improving, and implementing the Navy's capability to plan, design, construct, inspect, maintain, repair, and dispose of ocean facilities. Example programs and facilities include:

- Marine Geotechniques
- Anchor Systems
- Mooring Systems
- Underwater Cable Facilities
- Ocean Structures
- Ocean Construction
- Magnetic Silencing Facilities
- Underwater Inspection
- Coastal Facilities
- Pipeline Integrity
- Hyperbaric Facilities

**Codes ESC51, ESC52, ESC53, and ESC54 are at West Coast Headquarters:**

Commanding Officer
Code ESC50W (or ESC51 through ESC54)
Naval Facilities Engineering Service Center
560 Center Drive
Port Hueneme CA 93043-4328

Tele: (805) 982-1163
DSN: 551-1163
FAX: (805) 982-1409
Message Address:
NFESC PORT HUENEME CA

**Codes ESC50, ESC55, and ESC56 are at the East Coast Detachment of the NFESC (NFESC ECDET):**

OIC NFESC ECDET (Code ESC50, ESC55, or ESC56)
Bldg 218 Room 300
901 M Street SE WNY
Washington, DC 20374-5063

Codes ESC50 and ESC 56:

Tele: (202) 433-5365
DSN 288-5596
FAX (202) 433-2280

Code ESC55:

Tele: (202) 433-5365
DSN 288-5365
FAX (202) 433-2280
Message Address: NFESC EAST COAST DET WASHINGTON DC

**Ocean Construction Equipment Inventory (OCEI) Support Facility:**

Provides inventory control, handling, shipping, storage, maintenance, repair, and disposition of equipment, including operator and maintenance training, for the Ocean Construction Equipment Inventory (OCEI), and related logistics support to the NOFP.

Ocean Construction Support Facility
Building 252 Code 552JS
Saint Juliens Creek Annex
Portsmouth VA 23702-5002

Tele: (804) 485-6403
DSN: 961-6403
FAX: (804) 485-0302
Message Address: None
Address via NFESC EAST COAST DET WASHINGTON DC

**Underwater Construction Teams (UCTs):**

Provide a responsive military capability for the construction/installation, inspection, repair, and removal of ocean facilities.

***Underwater Construction Team One (UCT ONE):***

Commanding Officer
Underwater Construction Team One
1465 Hewitt Drive
Norfolk VA 23521-2523

Tele: (804) 464-7447
DSN: 680-7447
FAX: (804) 464-8142
Message Address: UCT ONE

***Underwater Construction Team Two (UCT TWO):***

Commanding Officer
Underwater Construction Team Two
4643 Dock Road Building 524
Port Hueneme CA 93043-4321

Tele: (805) 982-5948
DSN: 551-5948
FAX: (805) 982-3246
Message Address: UCT TWO

**Naval Construction Training Center (Port Hueneme):** Delta Company - Special Schools Division

Provides basic and advanced underwater construction training courses, and specialized short courses, primarily for the Underwater Construction Technicians in the NOFP.

Commanding Officer
Naval Construction Training Center
Delta Company

363 White House Way
Port Hueneme CA 93043-4303

Tele: (805) 982-3713
DSN: 551-3713
FAX: (805) 982-1425
Message Address: NAVCONSTRACEN
PORT HUENEME CA

## 1.3 ORGANIZATION OF MANUAL

This manual is divided into eight chapters and five appendixes:

- **Chapter 1** describes the purpose and scope of the manual, the preparation required before starting a project, and the documentation required upon completion.

- **Chapter 2** describes the various underwater work techniques used by the UCTs in carrying out specific inspection, survey, repair, and installation tasks.

- **Chapter 3** describes the specific tasks for inspections.

- **Chapter 4** describes the specific tasks for site surveys.

- **Chapter 5** describes the specific tasks for maintenance and repair.

- **Chapter 6** describes the specific tasks for new installation.

- **Chapter 7** is a list of references, organized by sections of the manual, which provide additional information on specific subjects.

- **Chapter 8** is a glossary of words and phrases commonly used in underwater construction operations.

- **Appendix A** contains a list of names and addresses of manufacturers and suppliers of equipment and material often used by the UCTs that are not available from Navy sources.

- **Appendix B** contains technical information useful to UCT personnel.

- **Appendix C** provides sample site investigation checklists.

- **Appendix D** provides a discussion of underwater electrical safety.

- **Appendix E** provides information regarding National Oceanic and Atmospheric Administration (NOAA) bathymetric map products.

## 1.4 PREPARATION BEFORE DEPLOYMENT

### 1.4.1 Presurvey

A project can only be successful if it is well planned before deployment. An important source of planning information is the: **NMCB Operations Officers Handbook - COMCBPAC/COMCBLANT Instruction 5200.2A.The U.S. Navy Diving Manual** is a source of planning information. Chapter 4 of Volume I of the Diving Manual is a valuable resource for planning any diving operation, including underwater construction projects.

The first step in the planning process is familiarization with the nature and details of the task and the conditions to be encountered at the site. This familiarization process will almost always require a visit to the site to conduct a presurvey. The presurvey site visit allows an opportunity to obtain project planning information nec-

essary for a successful project. A general site investigation checklist for overseas project planning is included as Appendix C. **During this presurvey all available information about the project should be obtained including:**

- Scope of the task (number of piles to be repaired, area to be surveyed, etc.)
- Details of the facility (type of fleet moorings, materials used in the structure (steel, concrete, timber), use of the structure, etc.)
- Availability of local construction support (enclosed storage/work space, work platforms, boats, concrete pump, etc.)
- Availability of personnel support (messing, berthing, communications, vehicles, office space)
- Location of nearest available recompression chamber and dive locker
- Availability of utilities (freshwater, electric power, sanitary system, high-pressure air)
- Availability of consumables (fuel, aggregates, etc.)
- Drawings of the facility showing the original construction and any alterations
- Up-to-date charts and maps of the area
- Clearance requirements for diving, photographs, etc.
- Local restrictions on special operations (blasting, dredging, sandblasting, etc.)
- Local tides, currents, water quality, winds, temperature, visibility, and daylight hours
- Location of sewer outfalls and other hazards
- Ship traffic to be expected
- Other diving activities in the area
- Other local operations that may preclude diving, i.e., ammo loading, fuel transfers, etc.

The local **Public Works Officer** (PWO), **Resident Officer-in-Charge of Construction** (ROICC), or **Officer-in-Charge of Construction** (OICC) can usually provide most of the information listed above or can provide guidance in obtaining the information from other sources.

The **Port Operations Officer** (or his representative) should be contacted as the PWO or ROICC will have little if any knowledge of harbor operations.

> **NOTE**
> **The site visit must include a call on the local commanding officer to discuss the nature of the project as a courtesy and to enhance relations and support.**

The **Coast Guard Captain of the Port** (COTP) should be contacted as a valuable source of information. The COTP can help the Detachment coordinate "notice to mariners" and establish traffic patterns around the diving area. Contacting the COTP can

eliminate a lot of confusion about the dive area.

Survey the local shoreline for visible cable vaults and cable crossing signs. **Other potential sources of local information include:**

- Coast Guard (Captain of the Port)
- Port pilots
- Port authority
- Harbormaster
- Oil companies
- Fishermen
- Marine contractors
- National Park Service
- Local utility companies (telephone, power, water)

If the task involves work near buried cables or pipelines, do not rely completely on charts to indicate their exact location because repairs may have been made or additional cables may have been laid outside the limits indicated on the charts. **Refer to Appendix C for a checklist for pipeline specific information required during a presurvey.** Check with the local military command, Coast Guard, or public utilities (telephone, water, and power) to determine the exact locations of buried cables and to inform them of the intended operation.

### 1.4.2 Project Execution Plan

With the task defined and the existing conditions established, the project execution plan can be developed. User-friendly computer programs are available to assist in project planning. The planning and estimating for the project should follow the sequence indicated in the arrow diagram in Figure 1-2. The initial step includes:

1. Determining resource availability.
2. Identifying the activities.

The determination of resource availability is required so that an evaluation can be made regarding work methods and time to be used in carrying out the operation. The identification of activities is obtained through a study of the technical drawings, worksheets, and project completion reports for previous projects, as well as a joint discussion by those persons who are familiar with the project. Activities are clearly definable quantities of work.

After the activities have been identified, three processes should start.

- One process is the construction of a logic diagram called the network. It is used to represent any sequencing of priorities among the activities of an operation. Constructing the network forces the planners to "think through" the tasks to be performed and to determine the order in which they should be performed.

- The second process is the determination of the resources, including manpower, technical assistance, equipment, and tools, required for the operation based on the activities that are to be performed. **Sources of equipment and tools available to the UCTs include:**

- Table of Allowance (TOA)
- Ocean Construction Equipment Inventory (OCEI)
- Naval Facilities Engineering Service Center (NFESC)
- Emergency Ship Salvage Material (ESSM) Pool
- Public Works Centers (PWCs)
- Public Works Departments (PWDs)
- Construction Battalion Center (CBC)
- Construction Battalion Units (CBU)

- Naval Mobile Construction Battalions (NMCB)
- Amphibious Construction Battalions (ACB)
- Commercial Rentals

NFESC Code ESC50 may be contacted for information on additional sources or for special requirements. When equipment is to be used underwater, such as electrical or explosive powered, only equipment and tools Authorized for Navy Use (ANU) should be used. If other equipment or tools must be used, the Detachment Officer-in-Charge (OIC) via the Commanding Officer Chain of Command must obtain a concurrence or waiver in advance from the Chief of Naval Operations (CNO) through the Naval Sea Systems Command (NAVSEA) Code OOC. The current policy is for the teams to request a waiver via Code ESC53 NFESC. NFESC Code ESC53 personnel will then review the request for potential safety matters and make a recommendation to NAVSEA OOC.

The third process is the determination of the materials required. This must be done early in the planning process to allow "long lead" materials to be ordered. (Appendix A of this manual contains a list of the names and addresses of some manufacturers and suppliers of equipment and material frequently used by the UCTs.)

Once the initial plan has been developed, it should be reviewed by the Operations Officer and any necessary revisions incorporated. Materials can then be ordered and a delivery schedule established.

After the resources and materials have been determined for the activities to be performed, the activity duration can be estimated. The activity duration is best estimated on the basis of experience of UCT personnel who have previously performed similar tasks. The logic diagram and activity duration estimates are used to compute the network, particularly the "critical path" for the operation. The critical path is the longest logical sequence of activities through a project; any delay in the critical path will result in an overall delay to the project.

When all information regarding resource availability, network logic and tasking requirements, and material delivery dates has been compiled, it is usually necessary to adjust the project execution plan. A piece of equipment that was counted on in determining the duration of an activity may not be available for use. The network must then be adjusted and the resources rescheduled so that the project can still be completed in a reasonable amount of time.

The importance of planning for contingencies cannot be overemphasized. Resource requirements should be listed and activity durations should be estimated with careful consideration of contingencies that may be encountered, particularly at remote locations where additional supplies are unavailable.

### 1.4.3 Gantt Chart

A time-oriented bar chart schedule, or Gantt chart as it is commonly referred to, is suitable for measuring, reporting, and reviewing construction progress. When developed as a result of the planning and estimating network in Figure 1-2, much of the information can be directly projected from the logic diagram to the schedule. Gantt charts can be easily prepared when planning using a computerized project planning program.

The Gantt chart schedule should be long enough to include the required level of task breakdown, but it should not be so big that it cannot be used by all project personnel. The Gantt chart schedule is constructed so that the earlier jobs are at the top of the

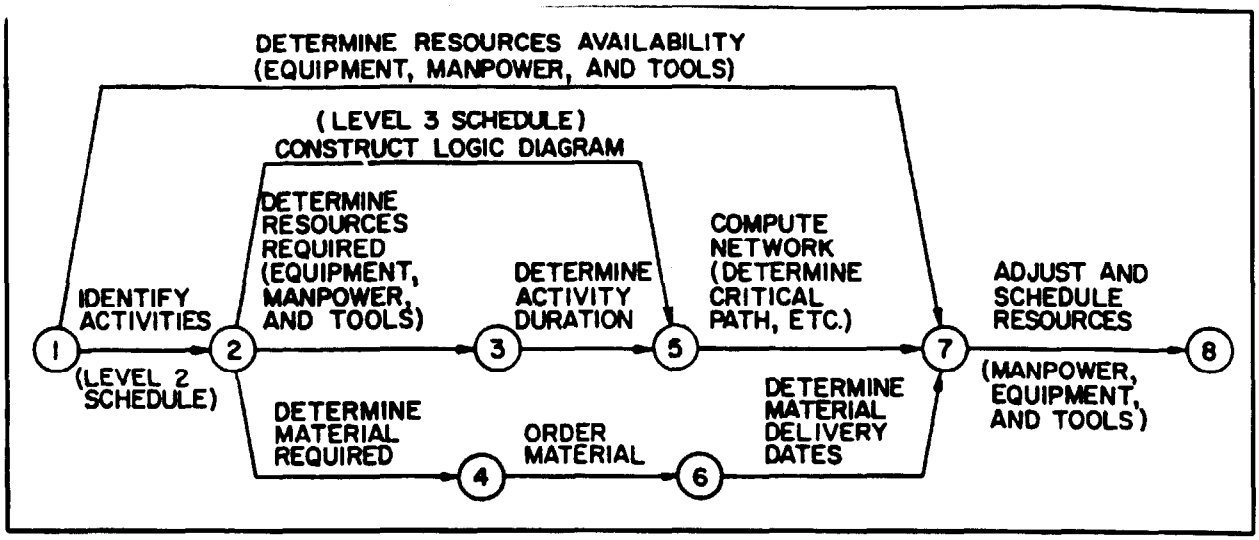



Figure 1-2
Project planning arrow diagram.

schedule, with the earliest "critical" activity the first activity on the schedule. Activities that can start after the first critical activity is completed, including the second critical activity, are plotted under the first critical activity in a horizontal fashion. This format is continued until all tasks have been arranged and plotted to illustrate the anticipated "flow" of the work to be performed.

A typical Gantt chart schedule is illustrated in Figure 1-3. The project description should be placed on the top of the schedule and should include all supervisory personnel. Each activity should be labeled and allotted two lines: the first line is used to plot the estimated progress at the onset of the job, while the second line is used to track the activity during the course of the project. Critical activities should be marked with an asterisk. These activities, if delayed, will delay the entire project. Each line should include start and finish dates. This allows comparisons to be made after the task has been completed, which will allow future projects to be planned more accurately. The percent completion column allows a quick comparison of how the project is progressing. The blank lines on the bottom of the schedule should be used to plot any activities that had to be performed but were not predicted at the beginning of the job.

### 1.4.4 Environmental Authorization

OPNAVINST 5090.1A sets a policy for implementing the National Environmental Policy Act (NEPA). NEPA provides a means for establishing environmental policy and encourages the participation of Federal and State involved agencies and affected citizens in the environmental assessment process. The instruction places the responsibility of complying with NEPA on the entire Navy chain of command. This section will assist all those in the chain of command to understand the administrative and procedural responsibilities necessary to fulfill the requirements of the OPNAVINST and NEPA. **Examples of environmental concerns requiring permits are:**

- Air Pollution
- Dredging
- Water Pollution
- Alteration of Coastline
- Noise Pollution (including subsurface)

- Visual Aesthetics
- Hazards to Navigation
- Personnel Safety
- Waste Minimization
- Discharging of Hazardous or Potentially Hazardous Materials
- Protection of Threatened and Endangered Species
- Protection of Natural, Historic, and Cultural Resources
- Interference with Commercial or Recreational Activities

The NEPA requirement of "coordination" with local, State, and Federal agencies is strictly administrative. A Federal agency that is planning to conduct an activity which may affect the environment, must consider the effects of that activity on the environment. **A Federal agency documents the effects "considered" in one of three ways:**

- Activities which will significantly affect the environment require an Environmental Impact Statement (EIS).

- When a Federal agency is unsure of the impact to the environment, an Environmental Assessment (EA) is written in order to analyze the activity. EIS and EA documents are long, detailed documents and are usually written by an environmental professional.

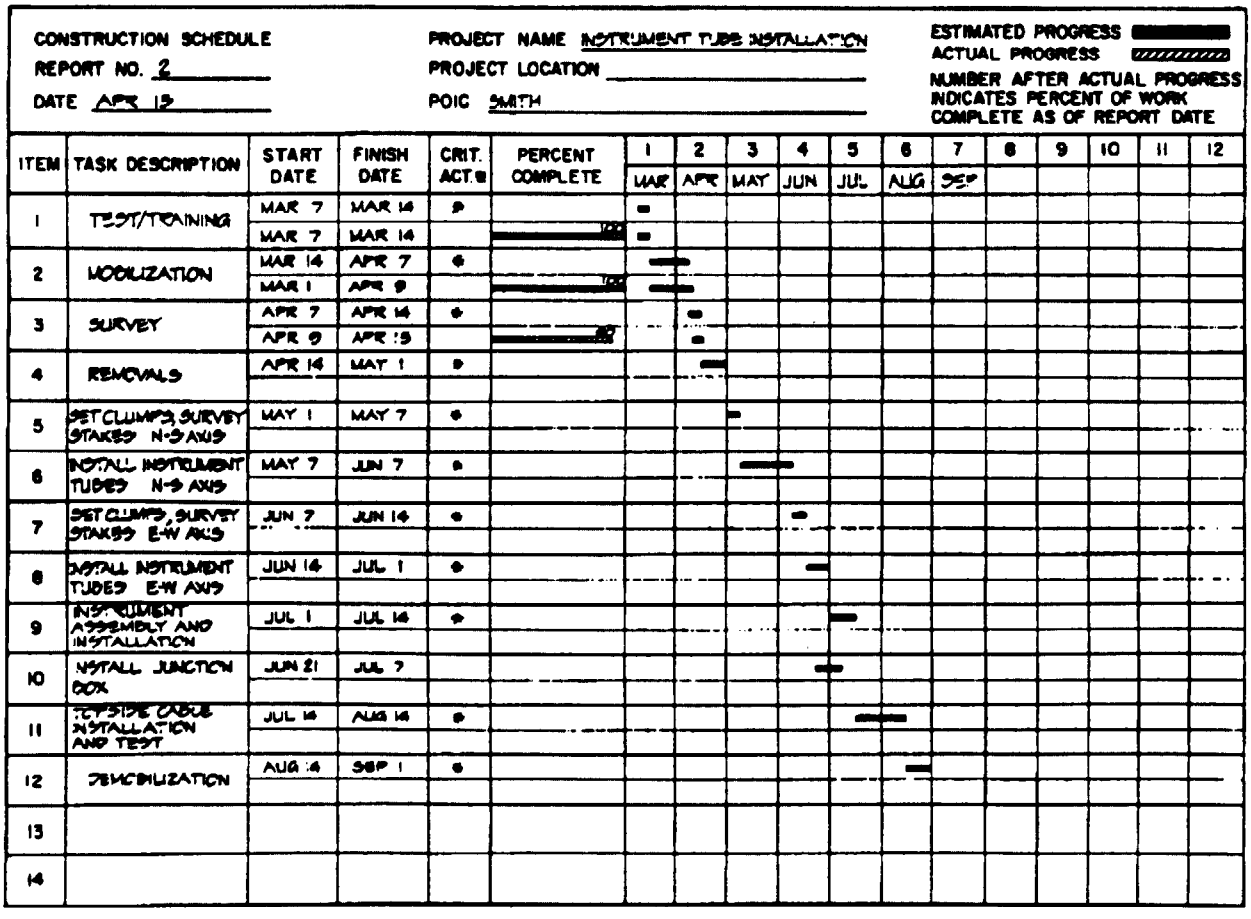



Figure 1-3
Construction Gantt chart schedule.

• The last type of documentation, and most widely used, is a Categorical Exclusion, which is used when the activity will not significantly affect the environment. The NEPA requirement for such an activity is to document that the activity falls within the description of one of the Categorical Exclusions listed in OPNAVINST 5090.1A.

OPNAVINST 5090.1A also states that any activity undertaken by the Navy or Navy contractor will follow local, State, and Federal regulations. Agency authorization is necessary for almost every type of underwater construction activity. This includes local, State, and Federal authorization. In some cases, authorization from one agency may cover all three agencies, but more often than not, it is necessary to obtain authorization from multiple agencies.

Many different factors determine the appropriate agency to contact. Some agencies have authority over the type of activity no matter where it takes place. For example, the Army Corps of Engineers has authority over all discharging of dredged material into waters of the United States. Other agencies govern only within the boundaries of an area no matter what the activity. An example of this type of agency would be a National Park or Ecological Reserve.

Authorizations differ from agency to agency as well. Some agencies issue a Permit, others forward a Letter of Permission (LOP) or Letter of Authorization, while others require site approval. Regardless of the type of authorization, copies of all paperwork should be kept on or near the job site at all times.

### 1.4.4.1 How to Contact

• **Finding the Correct Agency** - If contacts cannot be obtained by the local military installation's Environmental Office, most agencies are listed in the phone book under Federal, State, and Local Government listings. The U.S. Coast Guard is always listed in the phone book. A local contact for the Army Corps of Engineers can usually be obtained from any Army Corps office. The local water quality control board is usually a county agency and may be titled differently. Keep in mind that more rural areas tend to have one agency to cover a multitude of environmental expertise. The Coastal Zone Management Act of 1972 encouraged each State to implement its own management program for coastal issues. The majority of coastal States therefore have a specific coastal zone agency or have a division within another agency to regulate coastal issues.

The local NAVFACENGCOM Engineering Field Division Environmental Office may also provide the necessary agency contacts or assist with obtaining consent for the local authorities.

• **Type of Communication** - Verbal communication is the best way to find the appropriate staff member to answer questions. Most agencies require that a written request or application be mailed or faxed. Written requests should include at least a brief project description, the date and time of the activities, and a map of the vicinity. Most local agencies require a minimum of 2 weeks notice prior to the start of operation. It is advisable to allow 6 months. Federal agencies may require 30 to 90 days notice (more than likely, this can take 6 months to a year).

**1.4.4.2 Who to Contact.** Table 1-1 provides some examples of environmental permitting contacts. In many cases, help can be sought from the Environmental Office (sometimes a division of Public Works) of the military installation closest to the

location of the project. In cases where the Environmental Office is unavailable or the project is not located on or near a military installation, use the following guidelines obtain the appropriate authorization.

- **Interference with Navigable Waters** - Any activity which may in any way interfere with navigable waters must be reported to the Army Corps of Engineers, the U.S. Coast Guard (USCG), and the local marine authority (i.e., harbormaster or patrol office). This includes the addition or modification of marine structures, the ocean floor, or the capacity of the waterway. The Army Corps jurisdiction extends from shore to 3 nm while the USCG regulates all Federal waterways.

- **Alteration of Structures** - All alterations of structures, natural and manmade, including maintenance and construction, must be reported to the local coastal zone management agency if the structure is within State waters, and the Army Corps of Engineers if such construction may affect navigable waters.

- **Dredging** - The Army Corps of Engineers (ACOE) authorizes the discharge of dredged material into the waters of the U.S. as well as alteration of the seafloor by dredging.

- **Discharging** - The Army Corps of Engineers also regulates the discharging of dredged or fill material. All other discharging of potentially hazardous material (i.e., oil or rust contaminated water, laboratory chemicals, or unknown substances) into the water requires authorization from the local water quality control board. If any other discharges occur, the local Coast Guard COTP or MSO should be notified.

- **Miscellaneous** - Always remember that any area may be an area of special interest. For example, the use of land on an Indian reservation or breeding ground for an endangered species is regulated. Check with local authorities prior to undertaking any activity. The U.S. Fish and Wildlife Service and State Fish and Game Department should be contacted if there is a potential for harm to any animal species. An Army Corps permit will sometimes include authorization from other agencies.

## 1.5 PLANNING AND ESTIMATING GUIDES

To assist in the planning and estimating process, information regarding the manpower, productivity, equipment, and materials required to carry out various tasks is provided throughout the manual. This information has been developed from a variety of sources including past UCT operations, NFESC and proprietary test results for specific equipment, manufacturers' recommendations, and commercial practice. The information obtained from these sources has been adjusted to conform with typical UCT operations. The information provided is intended to be a helpful reference and is not intended to establish new procedures.

**All UCT operations must be carried out in accordance with established UCT procedures and the U. S. Navy Diving Manual.**

The planning and estimating information herein must be used with sound judgment and modified as the user's experience suggests. Every task is different and there is no substitute for hands-on experience in planning new operations.

Table 1-1
Example Potential Contacts for Environmental Permitting

| Agency | Local Office | Responsibility |
|---|---|---|
| **Federal** | | |
| Army Corps of Engineers | Ventura Office (805) 641-2935 | Discharging, dredging navigable waters |
| United States Coast Guard | Long Beach Office of Aids to Navigation (310) 980-4383 X501 | Publish "Notice to Mariners" Marine safety |
| NAVFACENGCOM (WESTDIV) | San Bruno Environmental Office (415) 244-3713 | Environmental assistance |
| **State** | | |
| California Coastal Commission | San Francisco Federal Consistency (415) 904-5280 | Manage and preserve California's coastal zone |
| California Department of Fish and Game | Long Beach Environmental Services Office (310) 590-5174 | Protection of marine animals |
| California Water QualityControl Board | Los Angeles District (213) 266-7500 | Water quality, discharging |
| **Local** | | |
| Channel Islands Nat'l Park | Ventura Harbor (805) 658-5700 | San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands |
| Channel Island Nat'l Marine Sanctuary | Santa Barbara (805) 966-7107 | All resources 6 miles out from the islands mentioned above |
| Port Hueneme Port Operations | (805) 982-8561 | Harbor operations |
| Ventura Harbor Master | (805) 642-8618 | Harbor operations |
| Santa Barbara Harbor Master | (805) 564-5520 | Harbor operations |

### 1.5.1 Manpower

Manpower or crew size estimates provided in this manual include direct labor only (i.e., only the labor that is actually expended directly on assigned construction tasks). Direct labor is that which is used to produce the end product itself. These estimates do not include overhead labor, which does not contribute directly or indirectly to the work.

### 1.5.2 Productivity

Productivity estimates are based on good working conditions, a UCT with average experience and capability, and the assumption that the entire crew has completed at least the Underwater Construction Basic Technician training course. In general, the UCTs should be familiar with and have some experience working with all of the equipment and tools listed for the task. The estimates do not account for the extra time that will be required to carry out the first few tasks as the "bugs" are worked out. Productivity decreases can be expected at the end of a long work day or when the divers have been in the water, particularly cold water, for a long period of time.

The U.S. Navy Diving Manual and experienced UCT personnel should be consulted to determine productivity factors for unusual operational situations. In calculating the total time required to complete the project, the productivity must be adjusted to suit the actual conditions anticipated. Allowances must be made for setup and prefabrication time, startup time, relocation time, equipment downtime, weather downtime, ship traffic downtime, cleanup time, and packing time. The productivity rates should not be taken at face value but should be adjusted based on sound judgment and the user's experience. Have experienced personnel review the estimates.

### 1.5.3 Equipment

Equipment listed includes only the major pieces required specifically to carry out a task. The lists do not include: the tools and gear required to conform with standard UCT procedures and the U.S. Navy Diving Manual; the tools and equipment that should be taken on virtually every construction project, such as welding and cutting equipment, rigging equipment, etc.; and the tools required to maintain the equipment. For these tools refer to the operation and maintenance manuals for the specific equipment. When equipment is listed, all of its support equipment should also be included (e.g., oxygen arc cutting torch should include oxygen regulator, oxygen cylinders, supply hoses, DC welding machine, DC safety switch, grounding clamp, and welding cables).

### 1.5.4 Materials

Materials listed include only those directly required for the specific task and do not include those required to conform with standard UCT procedures and the U.S. Navy Diving Manual. Fuels and lubricants, welding rods, nails, and other consumables that are required on virtually every construction project also are not listed.

## 1.6 SHIPPING AND HANDLING PROCEDURES

All UCT equipment and material is normally shipped via the military transportation system and thus must conform with established regulations. Normally, equipment is shipped in lockable TRICON equip-

ment shelters, which measure 8 feet long by 6.5 feet wide by 8 feet high.

Personnel should be assigned the responsibility for preparing a "Pack-Out List" for the project. The standard Pack-Out List form is shown in Figure 1-4. All equipment, tools, and project specific materials that may be required must be included on the Pack-Out List. The list should be checked by maintenance personnel to ensure the availability of adequate tools and spare parts. Once the Pack-Out List is completed, it is used as a checkoff list for preparing shipping documents and tracking availability and location of equipment.

> **NOTE**
> **The Commanding Officers must ensure that personnel involved in shipping and handling hazardous materials (HAZMAT) have the proper knowledge and training to comply with congressionally mandated public laws.**

The person in charge of the detachment has the responsibility to ensure that all HAZMATs are properly labeled, packaged, and shipped in accordance with the rules and regulations. Ship HAZMAT in accordance with American Trucking Association Hazardous Materials Tariff Manual (ATM III-M). **Ship HAZMAT separately.** Material Safety Data Sheets (MSDS) should be available for all hazardous chemicals available on site. The MSDS can be provided by the material manufacturer and should be requested at the time of purchase. The requirement for the **MSDS is mandated in Title 29 CFR 1910.1200(g) and hazardous materials are defined in accordance with Title 29 CFR 1910.1200(d).**

Enhanced public awareness has resulted in much stronger enforcement of HAZMAT rules by agencies such as the Coast Guard, Federal Aviation Administration, and Federal Highway Administration than has ever been experienced in the past. Department of Defense personnel are not immune to the civil and criminal penalties that can result. HAZMAT can include explosives, flammable liquids, compressed gas, corrosive material, aerosol sprays, fuels and lubricants, batteries, and chemicals. HAZMAT must be packaged separately from other project equipment. The following publications provide essential information for compliance with current HAZMAT rules:

- Title 49 CFR (Code of Federal Regulations) Parts 100-177 covers domestic and international requirements for carriage by rail, air, water, and motor vehicle.

- NAVSUP Publication 505 covers packaging, marking, labeling, and preparation of HAZMAT for shipment aboard military aircraft.

- NAVSUPINST 4600.70 (Chapter 33 - HAZMAT, Chapter 34 - Sensitive Material) provides procedures and responsibilities for freight and passenger traffic within the CONUS.

- International Civil Aviation Organization (ICAO), Technical Instructions of Dangerous Goods by Air, covers detailed technical instructions for shipping dangerous goods by international air.

- International Maritime Organization, International Maritime Dangerous Goods Code (IMDGC), is designed to assist compliance with the general requirements of the international convention for the safety of life at sea regarding the carriage of dangerous goods.

Date _____

Project _____

| Item Description | UI | Qty | NSN | Date Ordered | Received | Staged | Packed | Received | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
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Page _____ of ____

Figure 1-4
Material takeoff and pack-out list.

- American Trucking Association, Hazardous Materials Tariff Manual, ATM III-M.

Once the material arrives on site it should be checked against the Pack-Out List to ensure that all material shipped has arrived. The person assigned is responsible for maintaining and controlling deployed material and equipment and should conduct periodic inventories during the deployment.

After the work is completed, all equipment and material should be inventoried and packed for shipment. It is extremely important to clean, lubricate, and perform required maintenance on all equipment before packing. Failure to do so could lead to corrosion of the equipment, which would render it worthless in the time it takes to ship the equipment back to storage.

## 1.7 COMPLETION DOCUMENTATION

All projects carried out by the UCTs, whether they are inspections, surveys, repairs, or installations, should be documented with a completion report. The completion report is the responsibility of the detachment leader and documents the work done for future reference or action. It should be frank and realistic, and should clearly and accurately describe the results of the task and the condition of the facilities upon completion. It will be a historical and practical document that will serve a useful purpose for planning future similar projects or modifications to this task.

The following is a sample outline of a completion report:

### I. STATEMENT OF PROJECT

This section should describe the nature of the project, the authorization to carry it out, the reason the work is required, and information on the team carrying out the task. Specific items discussed should include but not be limited to:

- Customer command requesting assistance, tasking, job order number.
- Number of personnel deployed (divers/support personnel).
- Dates of project.
- Nature of project (inspection, survey, repair, new construction, salvage, demolition, etc.).

### II. STATEMENT OF PROJECT CHARACTERISTICS

This section should describe the characteristics of the project and the physical conditions under which the work was carried out. Specific items discussed should include but not be limited to:

- Structural description (e.g., H-pile with concrete cap, type of mooring, buoy description).
- Materials of construction.
- When was it built.
- How is it used (e.g., material handling dock, free-swing buoy, etc.).
- Construction to be performed, design agent (if any), ROICC (if any).
- Tide, current, visibility conditions.

## III. INSPECTION/CONSTRUCTION TECHNIQUES USED

This section should describe the procedures, techniques, equipment, and tools used to carry out the project. It should provide a complete description of all tasks performed. Specific items discussed should include but not be limited to:

- Method of inspection (details).
- Weather conditions during inspection/ construction period.
- Equipment/tools used.
- Criteria for selecting areas for photo coverage.
- Criteria for selecting frequency of piles to be inspected.
- Blasting/trenching techniques.
- Material handling techniques.
- Support and coordination with other units.

## IV. FINDINGS AND RECOMMENDATIONS

This section is applicable to all inspection projects and should present the complete results of the work done including recommendations for further action, such as a more detailed inspection, emergency repairs, future repairs, etc. It should include photographs, sketches, inspection records, etc. Findings and recommendations should be of an objective nature providing detailed information that can be used by engineering personnel to assess structural capacity. UCT personnel normally do not make engineering recommendations as to structural capacity or soundness of structure. The exception is in an expedient/wartime environment which is covered in NAVFAC P-991. Specific items discussed should include but not be limited to:

- Overall condition assessment.
- Type and general extent of deterioration or damage found.
- Should a structural analysis be made?
- Missing or severely damaged structural elements.
- Identify problem areas of the structure that may cause future concern ... or are existing problems.
- Can a section/portion/leg of chain be repaired?
- How would you recommend repairing it?
- Detailed crack or spalling and crack measurements (with sketches or photos of all areas, carefully annotated).
- What effects have tides and waves had on the structure?
- Does the structure have a protective coating and is it working? Is it scratched?
- Is a cathodic protection system provided and, if so, what is its condition?
- Fender condition (percent in need of repair).
- Photos, sketches, data sheets, name plate data (if applicable).

- Overall site layout (photo or chart).

- Site survey results including maps, profiles, photos, sketches.

- Include reference documents used to make any assessments.

## V. LESSONS LEARNED

This section should cover everything about the project that has not been covered in the previous sections. It is intended to provide guidance for future UCT projects and should be prepared in considerable detail and with great care. Specific items discussed should include but not be limited to:

- Daily notes. What was accomplished during the day including problems encountered and solutions.

- Ideas for improvements.

- Any and all items of interest to the Team, customer, Naval Construction Training Center (NCTC), etc. These will be edited out and routed to appropriate command at the Officer-in-Charge (OIC)/Assistant Officer-in-Charge (AOIC) level.

- Include **all** items regardless of how minor they may seem, for example:

  - Manifolds to be repaired (or were repaired)
  - Training that would have been nice to have
  - Tools that would have been nice to have
  - Problems with gear/equipment
  - Important command coordination at the project site
  - Special logistic considerations
  - Special personnel problems/considerations
  - Environmental problems encountered (i.e., strong currents, high waves, etc.)

In addition to the completion report, it is standard procedure to conduct a debriefing with local Public Works or OICC personnel before demobilizing. It is important that local personnel be well aware of the nature of the work performed by the UCT on their facilities. Slides, photographs, and video tapes are often helpful in illustrating the work. All questions raised by local personnel should be resolved at this time.

# Chapter 2

# UNDERWATER WORK TECHNIQUES

## 2.1 SCOPE

The UCTs are often tasked with inspecting, maintaining, and repairing cables, pipelines, fleet moorings, piles, cathodic protection systems, and other marine facilities. They also carry out a number of different types of site surveys and often install new facilities, especially cables, pipelines, and shallow water ranges. Many underwater work techniques and procedures are common to inspection, survey, maintenance, repair, and installation tasks and are described in this chapter. The technique and procedure descriptions provided below are general in nature and are not intended to satisfy every situation that may be encountered. Sound judgment by the personnel on site must always be exercised when applying any underwater work technique.

The work techniques described in this chapter include:

- Underwater tools (Section 2.2)
- Removing marine growth (Section 2.3)
- Thermal cutting and welding (Section 2.4)
- Lift bags (Section 2.5)
- Excavating (Section 2.6)
- Controlled blasting (Section 2.7)
- Anchoring (Section 2.8)
- Remotely-operated vehicles (ROVs) (Section 2.9)
- Concreting (2.10)
- Grouting (Section 2.11)
- Protective coating application (Section 2.12)

## 2.2 UNDERWATER TOOLS

Underwater construction can be more effectively conducted with the proper selection and use of tools. Over the past 20 years, a wide variety of power tools have been developed to support construction and salvage diving.

Almost all hand tools can be used underwater and a wide variety of power tools are specifically designed for diver use. Table 2-1 provides a summary of construction-specific tools that are available for Navy diver use. Some of these tools have special construction-related characteristics and uses which are described in separate sections. For detailed descriptions on how to use and maintain the tool, refer to the specific operations and maintenance manual.

## Table 2-1
## Summary of Construction-Related Underwater Power Tools

| Tool | Power | Function | Section |
|---|---|---|---|
| Air Lift | Pneumatic | Excavates bottom sediments to uncover pipelines/cables | 2.6.1 |
| Buried Chain Locator | Battery | Locates ferrous metal objects buried in mud | 2.2.8 |
| Cable Tracker | Battery | Diverprobe used to find cable tracks | 5.2.3 |
| Chain Saw | Hydraulic | Model CS-11 cuts wood and DS-11 cuts reinforced concrete | 2.2.7 |
| Dredge, Jet | Diesel | Moves bottom sediments | 2.6.2 |
| Dredge, Suction | Diesel | Excavates bottom sediments | 2.6.3 |
| Epoxy Grout Dispenser | Pneumatic | Mixes and dispenses two-part epoxy grout for installing fasteners | 2.11.2.2 |
| Explosives | Chemical | Cutting metal/wood/rock, demolishing, and excavating | 2.7.4 |
| Field Detector | Battery | Diver probe senses stray electrical fields | 2.2.5.2 |
| Grinder | Hydraulic | Cuts rods/bolts, grinds metal; cleans marine growth | 2.3 |
| Ground Fault Interrupter | Electric | Electrical safety circuit for shock protection | 2.2.5.1 |
| Hammer (Rock) Drills | Hydraulic | Drills holes in seafloor rock | 2.2.3 |
| Impact Wrench | Hydraulic | Drills/taps metal/wood and tightens/loosens bolts | NA |
| Liftbags | Pneumatic | Provides buoyancy for moving objects underwater | 2.5 |
| Magnetic Partial Tester | AC | Locates stress cracks in steel electrical | 3.4.5.2 |
| Pile Cutter | Hydraulic | Cuts timber piles up to 13 inches in diameter | 2.2.7 |
| Pipe Cutter | Hydraulic | Mill cutter, cuts and bevels pipe | 5.3.4.3 |
| Portable Band Saw | Hydraulic | Cuts armored cables, ropes, and metal up to 3.5 inches | 2.2.7 |
| Rebar Locator | Battery | Locates rebar in concrete | 3.6.4.1 |
| Rebound Hammer | Battery | Surface hardness tester for concrete | 3.6.4.3 |
| ROV | Electric | Used to inspect and also support diver operations | 2.12 |
| Seawater Tools | Hydraulic | Environmental compatible diver tool system: band saw, grinder, and impact wrench | 2.2.4 |
| Stud Driver | Power velocity | Drives fasteners into metal plates and rock | 2.2.6 |
| Thermal Cutting | Shielded-Arc<br>Oxy-Arc: | All metals to 2 inches thick<br>Metals, concrete, rock, coral, etc. | 2.4.1 |
| Chipping Hammer | Pneumatic | Removes heavy mollusk growth | N/A |
| Ultrasonic Concrete Tester | Battery | Evaluates general condition and uniformity of concrete | 3.6.4.3 |
| Ultrasonic Metal Thickness Meter | Battery | Measures thickness of metal | 3.4.5.1 |
| Underwater Voltmeter | Dry cell battery | Measures voltage potentials for corrosion assessment | 3.4.3 |
| Water Jet Cleaning | Hydraulic | Pressure water jets for removing marine growth | 2.3 |
| Welding | Electrical | Both carbon steel and stainless steel | 2.4.2 |

Working with tools underwater presents special problems especially when diving with scuba gear. The near neutral buoyancy of the diver makes applying leverage and handling reaction forces difficult. When using any tool which requires leverage or force, the diver should be braced with feet, free hand, or a shoulder.

Some diver power tools are listed in **NAVSEAINST 10560.2C, Diving Equipment Authorized for Navy Use (ANU).** Not all tools need to be authorized for use. The basic requirement for tool-ANU applies to **Category II equipment** - non-life support equipment which is potentially hazardous to the diver (e.g., explosively actuated tools, surface-powered electrical tools, hydraulic chain saws, etc.). Approval is provided by the Naval Sea Systems Command, Code OOC.

**Category III equipment** is non-life support accessory equipment which enhances mission accomplishment but is not considered hazardous or essential to safe diving operations. This equipment is supported by the supply system and has been tested or developed by the Navy. Other nonsupply system commercial items are authorized provided they are properly maintained in accordance with the manufacturer's requirements.

**CAUTION**

**Use caution when using tools underwater that have trigger locking mechanisms. These locking mechanisms should be removed before diving, especially if the tool can produce reaction forces or present entanglement problems with the diver's personal gear.**

**CAUTION**

**Do not energize tool power sources until the divers are at the work site and signal topside when they are ready to work. De-energize power to the tool when the diver is transiting between underwater work sites.**

**CAUTION**

**The U.S. Navy Diving Manual requires using voice communications with the Dive Supervisor when using scuba gear with powered tools.** Surface-supplied diving gear is assumed to have working communications.

**NOTE**

**Where practical, the surface-supplied diving system (SSDS) should be used when working with powered tools (scuba should only be used as a last resort).**

### 2.2.1 Pneumatic Powered Tools

Pneumatic tools can be effectively used underwater but are generally **NOT attractive to use for several reasons:**

1. The power required (gas volume and pressure) increases with increasing depth of the dive.

2. The exhaust bubbles often obscure vision of the work surface and the escaping gas causes pressure waves, which can nauseate the diver.

3. The exhausts are not sealed which allows seawater to enter the tool mechanism when the tool is not operating.

Because internal components (bearings, seals, and gaskets) are generally not compatible with seawater, pneumatic tools are considered expendable when used in seawater. As a minimum, the tool should be disassembled, cleaned, dried, and oiled immediately after use.

Most pneumatic tools require 90 psig (over bottom pressure) to operate effectively. One advantage of pneumatic tools is that they can be powered from a scuba bottle using a first stage breathing regulator adjusted to reduce tank pressure to 90 psig. A 10-SCFM tool would operate for 7 minutes at the surface and less than 3 minutes at a 60-foot depth using a 72-SCF scuba bottle. Another advantage of pneumatic tools is that they require only one hose and the hose is flexible and relatively small in diameter.

**CAUTION**

**Systems that use compressed gas are inherently dangerous. If a hose breaks or is cut, the released energy can cause the loose end to violently whip back and forth. The result can be personnel injury.**

All pressure hoses and vessels should be **inspected and certified** in accordance with:

- NAVSEA S6430-AE-TED-010, Piping Devices, Flexible Hose Assemblies (Volume 1).

- Planned maintenance as applied to specific equipment.

- NAVFAC MO-324, Inspection and Certification of Boilers and Unfired Pressure Vessels.

It is recommended that pneumatic hoses be provided with chafing gear where necessary. Also, tie off hoses to stationary objects to prevent whipping should they become severed.

### 2.2.2 Oil Hydraulic Tools

Oil hydraulic tools are the most common of the powered tools used by commercial and Navy working divers. There is a wide variety of underwater oil hydraulic tools and the user should be sure to specify the underwater application when purchasing the tools. Underwater versions of land oil hydraulic tools usually have additional seals and substitute materials to exclude water from certain areas and minimize corrosion.

Oil hydraulic tools require two hoses: one to supply the fluid to the tool, the other to return the oil to the topside power source. The relatively stiff dual hoses make tool handling more difficult than with pneumatic tools. To provide easier handling at the work site the tools are equipped with smaller diameter, more flexible hoses usually referred to as tool whips (or jumper hoses).

**CAUTION**

**Hoses should be in good condition and inspected in accordance with Planned Maintenance System (PMS) and NAVSEA S6430-AE-TED-010.**

The connections between the tool whips and supply/return hoses are usually quick

disconnect couplings. The couplings should have integral sleeve locking mechanisms to prevent accidental disconnect during transit or while in use.

> **CAUTION**
> **It is NOT good practice to tape the couplings closed to prevent accidental disconnect.**

The ability to rapidly disconnect is an important safety feature for underwater tool use.

> **CAUTION**
> **A flow diverter should be installed in the hydraulic hoses approximately 10 feet from the tool.**

A common misconception while using hydraulic tools is that increasing system relief or unloader valve pressure will increase tool power. When the tool is in use the supply line pressure is a function of the load on the tool and frictional losses from oil flow in the hoses. Poor performance may be related to hose restrictions, worn tools, improper flow rate, or improper viscosity of the hydraulic fluid.

Take care to be sure that the return hose diameter is large enough to prevent return flow restriction and subsequent retardation of tool operation. The return hose acts like an accumulator which can cause sluggish tool operation. This phenomenon is very noticeable when operating with oil hydraulic rock drills. The result is that tool performance may be severely degraded. Increasing system flow rate will not correct this problem - instead select a larger diameter return hose and check that oil viscosity is not too high.

Another characteristic noticed with long hoses is that energy is stored in the supply hose when the tool is not in operation. This is typical with a closed-centered oil hydraulic system (flow stops when the tool valve is off). As a result, when the tool is first operated it will run faster until the supply hose pressure matches tool demand. The tool may run at a high power level for a few seconds. This is normally not a problem but the operator should be aware that this condition exists.

> **WARNING**
> **Care must be taken when operating any hydraulic tool to be sure the power source flow rate and pressure relief valves have been adjusted to the recommended values for the tool. Hydraulic tools are very powerful and can self destruct if too much flow or pressure is provided.**

For example, a tool designed to operate at 4 gpm with 1,500 psi will deliver approximately 3.5 horsepower regardless of the water depth (the tool is basically pressure compensated because the fluid is an incompressible liquid). If the flow is inadvertently set at 8 gpm, the tool will try to deliver up to 7 horsepower and the rotary or impact speed will be doubled. The high speed and extra available horsepower could cause tool damage, personnel injury, bit breakage, or damage to the work in progress.

Operators must ensure that the hydraulic oil used is compatible with the tool and power source. Tool manufacturers provide specific recommendations in the maintenance manuals.

An important factor is hydraulic oil viscosity (thickness). If the fluid viscosity is too low (thin) tool damage can occur, or if it is too high (thick) the tool may become sluggish or inoperable. Fluid viscosity is greatly affected by operating temperature,

as shown in Figure 2-1. A fluid used at arctic temperatures will not be suitable for use in the tropics. Also, in cold climates the hydraulic oil may need to be warmed up before the power source is started. At arctic temperatures (-20 to -60°F), viscosity may be so high that internal pump components may break if the fluid is not prewarmed before system operation.

Hydraulic fluids must be kept clean and free of water or seawater. Sometimes it is necessary to change the hydraulic fluid because of operational temperature, contamination, or unavailability of the fluid in use to top up the power source reservoir. **Mixing different hydraulic fluids is not recommended.** The proper procedure is to drain the reservoir and tool umbilicals and refill with the same fluid. Check with the fluid manufacturer if mixing fluids is necessary.

Hydraulic fluid is considered hazardous material and must be handled properly.

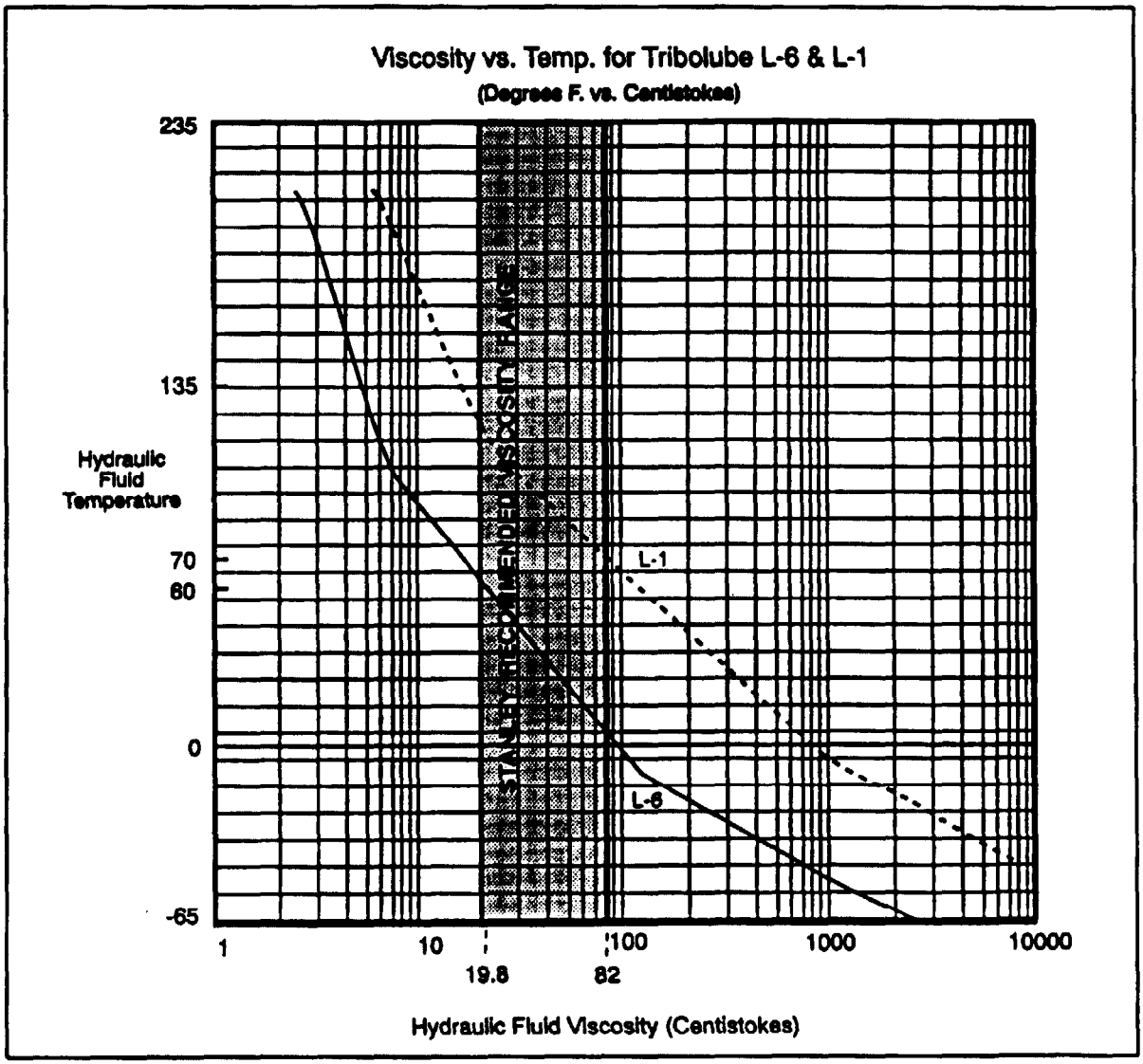



Figure 2-1
Shaded area shows viscosity range recommended for hydraulic tools.

**WARNING**
**Dispose, handle, and transport hydraulic oil in accordance with hazardous materials procedures.**

### 2.2.3 Rock Drills

Rock drilling is necessary for many UCT operations. Cable and pipeline stabilization may require that rockbolts or U-bolts be used to anchor an armored cable or split-pipe protection system to the seabed. A hole is drilled in the seabed rock or coral into which an anchoring device is inserted. In some cases, grouting of anchors is required (refer to Section 2.11 for a discussion of grouting techniques). Rock drilling may also be necessary in explosive excavation operations. If a trench must be excavated or an obstruction removed so that a cable or pipeline can be laid, holes are drilled into the rock or coral and an explosive charge is placed in the hole and detonated (See Section 2.7.7 for a discussion of explosive excavation).

Drilling holes in seabed rock is best done with hydraulic rock drills. Pneumatic rock drills were used in the past, but have proved undesirable because of high maintenance requirements and the percussion waves produced by the exhaust gas. Also, in cold weather the pneumatic equipment tends to freeze up.

Commercially available underwater hydraulic rock drills are extensively used by the UCTs. These tools come in three models:

- A light-duty hammer drill
- A heavy-duty hammer drill
- A sinker drill as illustrated in Figures 2-2, 2-3, and 2-4, respectively.

These tools are capable of drilling holes up to 3 inches in diameter and up to 20 feet deep. Hydraulic rock drills should be powered by sources capable of 10 gpm and pressures up to 2,000 psi.

If rock drills **must** be used while diving with scuba, it is advisable to wear a wet suit hood to minimize the effects of the noise generated by the equipment (scuba should only be used as a last resort).

**CAUTION**
**The U.S. Navy Diving Manual requires the use of voice communications with the Dive Supervisor when using scuba gear with powered tools.** Surface-supplied diving gear is assumed to have working communications.

Drilling rates vary with the type of drill, diameter of the hole, hardness of the rock, skill of the diver, and the working conditions. Average drilling rates for sound rock

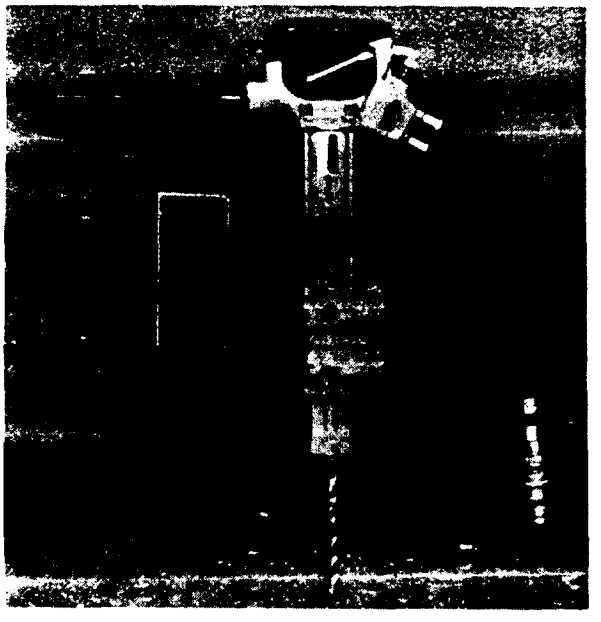


Figure 2-2
Commercial light-duty hand drill.

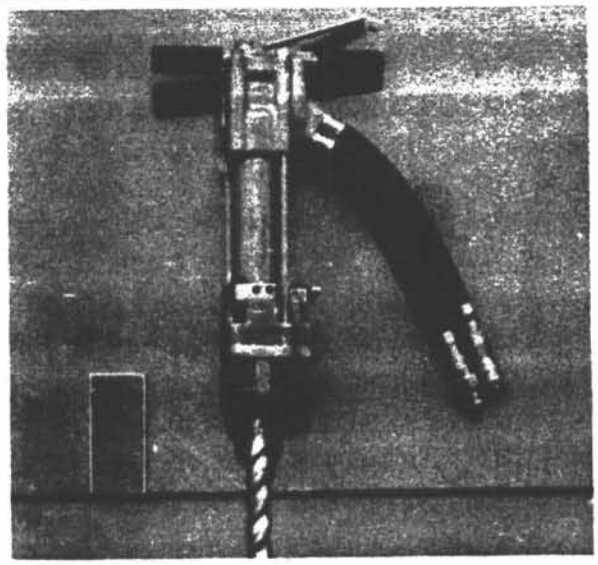


Figure 2-3
Commercial heavy-duty hand drill (Stanley HD-45).

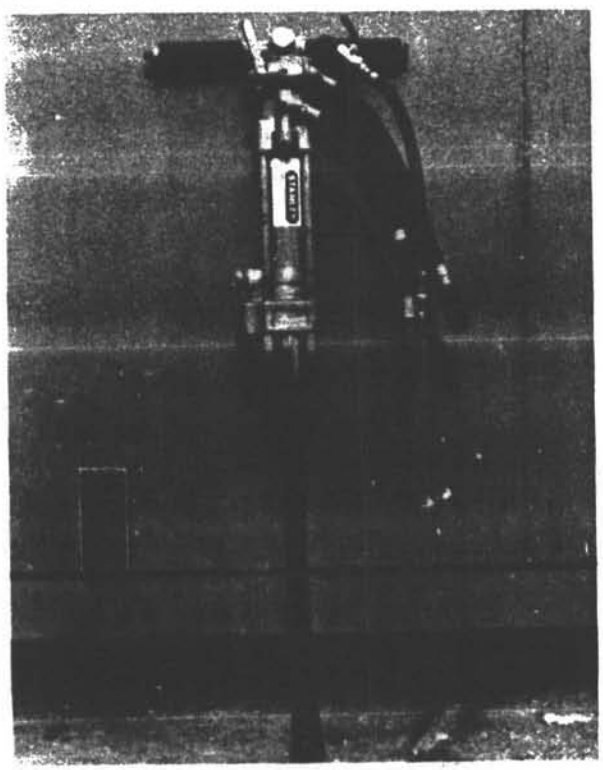


Figure 2-4
Commercial sinker drill (Stanley SK-58).

for the various model drills and drill diameters, assuming good working conditions and an experienced diver/operator, are given in Table 2-2.

Table 2-3 provides a summary of characteristics for the three rock drills. Of all the oil hydraulic tools used underwater by the UCTs, the rock drill performance is most heavily dependent on providing adequate flow and pressure at the tool. Drilling rate can be seriously reduced by both flow restriction in the return hose and high fluid viscosity (thickness). For this reason, a 3/4-inch minimum inside diameter is recommended for the return hose. Pressure in the return hose should be maintained below 150 psi.

When the tool is in use, the supply line pressure is a function of the load on the tool and frictional losses in the hoses. Poor performance may be related to hose restrictions, a worn tool, or improper viscosity of the hydraulic fluid.

The performance of oil hydraulic rock drills is sensitive to the configuration and physical arrangement of the hydraulic circuit. A common misconception with hydraulic tools is that tool performance can be corrected by increasing system pressure and flow rate. The rock drills, however, are sensitive to fluid viscosity and back pressure in the return hose. Care must be taken to be sure the return hose diameter is large enough to minimize return flow restriction. The return hose acts like an accumulator that can damp out movement of internal mechanisms.

It is also important to ensure that the hydraulic oil used is compatible with the tool and power source (see Section 2.2.2). If the fluid viscosity is too high (thick), the tool may become sluggish or inoperable. It may be necessary to change to a lower viscosity fluid in cold climates. Follow proper procedures when changing or dis-

posing of hydraulic fluids as most are considered hazardous materials.

In extremely cold climates the hydraulic oil operational temperatures tend to run cooler than normal, which can result in higher hydraulic viscosity and sluggish performance. Tool manufacturers recommend maintaining operational viscosity between 20 and 85 centistokes. Figure 2-5 shows how hydraulic oil viscosity varies for oil operational temperature. At very low temperatures, fluids may need to be preheated to avoid damage to the tools.

**REMEMBER that hydraulic rock drills are equipped with rotary bits. Use extreme care when carrying the tool to avoid the drill bit becoming entangled in the divers dress.**

Recommend that the power supply flow be off before moving the drill. This can be done either at the topside power source or by using the bypass valve installed in the hose 10 feet from the tool.

Table 2-2
Rock Drilling Production Rates

| Tool | Bit Size (in.) | Penetration Rate (in./min) |
|---|---|---|
| Commercial Light-Duty HD-20 | 1/2<br>1<br>1-1/2 | 7.9<br>5.1<br>0.8 |
| Commercial Heavy-Duty HD-45 | 1/2<br>1<br>1-1/2 | 9.1<br>5.5<br>2.7 |
| Commercial Sinker Drill SK-58 | 1-1/2<br>2-1/4<br>3 | 5.5<br>1.8<br>1.1 |

Table 2-3
Rock Drill Specifications

| Model | Weight (lb) | Length (in.) | Flow (gpm) | Maximum Pressure (psi) | Hole Capacity Diam (depth) |
|---|---|---|---|---|---|
| Light-Duty HD-20 | 28 | 21 | 7 - 9 | 2,000 | 1/2 - 2" (30") |
| Heavy Duty HD-45 | 45 | 23 | 7 - 9 | 2,000 | 1 - 2' (30") |
| Sinker Drill SK-58 | 67 | 26 | 7 - 9 | 2,000 | 3/4 - 3" (20') |

### 2.2.4 Seawater Hydraulic Tools

Using oil hydraulic systems in and around water poses several hazards. Oil leakage results in environmental contamination, poses a fire hazard, and threatens personal safety. The most serious hazard is to the environment. Spilled oil is especially critical when working in ecologically sensitive areas such as estuaries, lakes, or potable water reservoirs. In addition to normal equipment downtime, these environmental hazards can prevent completing the mission on schedule.

Many of the disadvantages of oil hydraulic tools can be eliminated by using seawater/water hydraulic tools. Seawater, or freshwater, is an environmentally acceptable alternative to toxic hydraulic oils. Seawater hydraulic tools should be the first choice when working in environmentally sensitive areas.

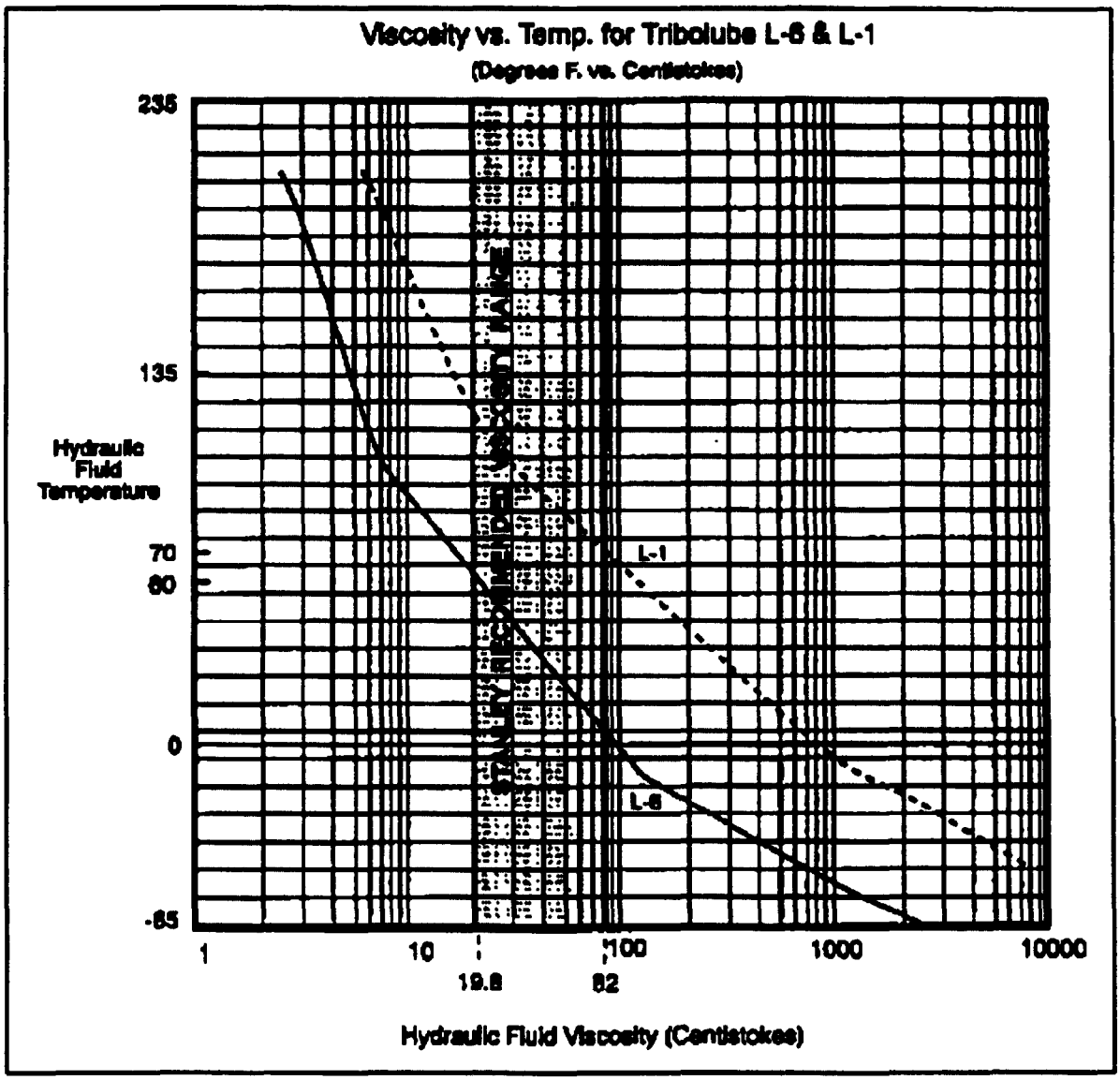



Figure 2-5
Operate oil-hydraulic tools at the viscosity range.
(Shown in the shaded area.)

Seawater hydraulic tools offer the construction diver increased productivity and improved handling. The diver is better able to move about the work site because of decreased hose drag from the single hose, particularly when working in a current. Further, seawater is readily available at the work site eliminating the logistic burden of transporting hazardous hydraulic oil.

The Multi-Function Tool System (MFTS) (Table 2-4) is a seawater hydraulic-powered tool set that provides environmentally safe tools that meet operational needs. The MFTS consists of a diesel-driven power source with two hose reels, a rotary disk tool, a rotary impact wrench, and a bandsaw. A hand-held, small hole rock drill is under development.

Each MFTS package includes sufficient spare parts for one operational season and a complete operation and maintenance manual. Built-in commonalty of tool components provides for quick repair with a minimum of spare parts. Each tool is designed so that it can be field repaired in minimum time. The MFTS is designed to be transportable by conventional means such as aircraft, truck, or shipboard.

The seawater hydraulic tools require little field maintenance; unlike oil hydraulic tools, no routine maintenance of the O-rings and seals is required - just a daily freshwater rinse. The impact wrench requires fluid level check of the water soluble oil mixture used to lubricate the impact mechanism. For the bandsaw, spray lubricant applied to the drive chain is necessary at the end of the day.

**2.2.4.1 Seawater Hydraulic Power Source.** The skid-mounted unit (Figure 2-6) uses a 41-hp diesel engine coupled to a radial piston pump to supply filtered seawater to the hose reels. A secondary pneumatic system supplies low pressure air to power the seawater lift pump that is used to fill the system reservoir. This gives the system self-priming capabilities but also allows use of pneumatic tools for topside work. From the hose reel, seawater is supplied to the tool through 250 feet of 1/2-inch-diameter thermoplastic hose. Each hose reel provides independent tool flow and pressure controls. Two tools may be operated from the power source simultaneously.

Table 2-4
MFTS Component Description

| Component | Flow (gpm) | Pressure (psi) | Weight (lb) | Shipping Total Cube/Weight |
|---|---|---|---|---|
| Power Source | Max 14 | 2,000 | 2,000 | 64/2,000 |
| Hose Reel | --- | --- | 250 | 15/730 |
| Disk Tool | 7 | 1,200 | 20 | 2/40 |
| Impact Tool | 4 - 6 | 800 | 22 | 2/40 |
| Bandsaw | 5 - 7 | 800 | 33 | 6/70 |

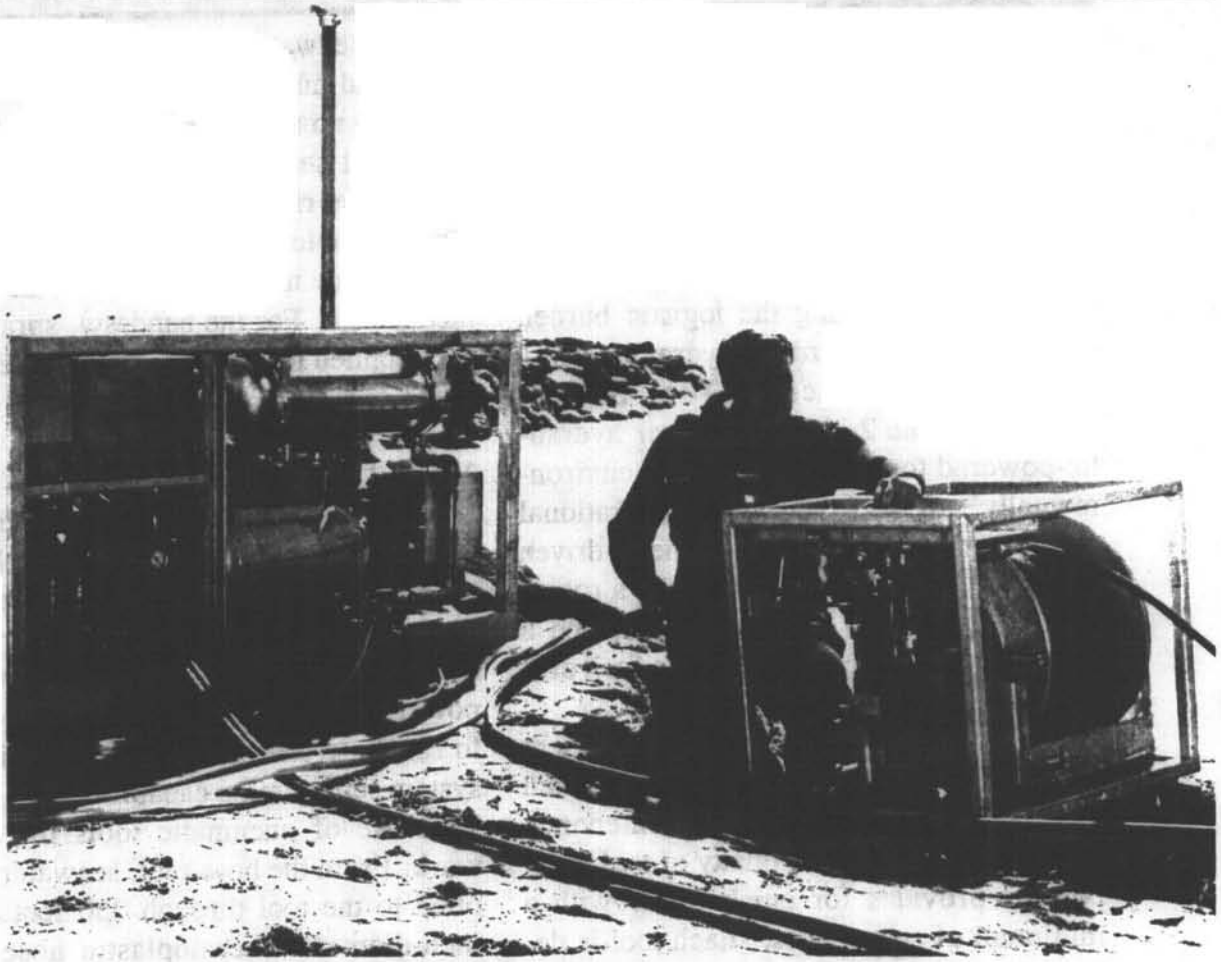


Figure 2-6. Skid-mounted seawater power source.

**2.2.4.2 Rotary Disk Tool.** The rotary disk tool (Figure 2-7) provides grinding and cutting capability for metals, concrete, wood, cable, etc. This tool is constructed primarily of plastic material for a strong, lightweight tool that is resistant to corrosion and wear. The seawater exhausts in a fan spray pattern onto the back of the abrasive disk. The spray serves to reduce disk drag and to flush loose material away from the work surface. A disk guard covers the 7-inch abrasive cutting wheel to protect the diver from injury. A bayonet style handle allows rotation of the grinding head for adaptability to grinding or cutting tasks for both left- and right-handed divers.

**2.2.4.3 Rotary Impact Tool.** The rotary impact tool (Figure 2-8) can be configured with a 1-inch-square drive anvil used for tightening or loosening fasteners. It may also be equipped for a 5/8-inch quick change internal hex chuck for drilling in wood or metal. When drilling holes larger than 0.5 inch in metal, a hole saw is recommended over a twist bit because of tool impacting. The tool is capable of delivering up to 800 foot-pounds of torque so regulation of the torque is necessary to prevent damaging the work. The commercial impact mechanism is maintained in a sealed housing filled with a water-soluble oil for lubrication and cooling. The oil should be checked daily and flushed at the end of the mission.

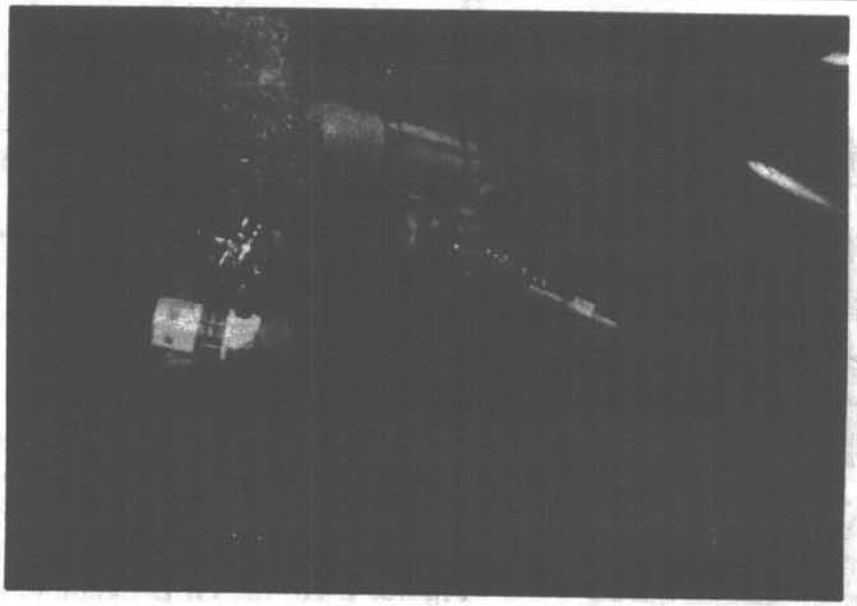


Figure 2-7
Rotary disk tool being used to clean split pipe.

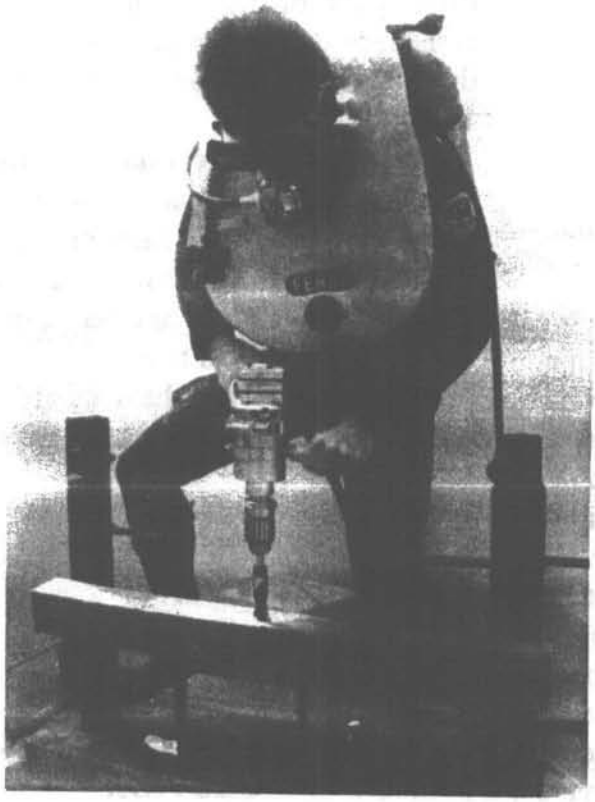


Figure 2-8
Rotary impact tool with drill chuck adaptor.

**2.2.4.4 Bandsaw.** The bandsaw (Figure 2-9) is designed for cutting metals and other materials. Seawater exhausts at the gear box and flows over the pulley drive chain to flush away debris. The pulley drive chain should be lubricated daily to maintain its condition. The blade pulleys are wrapped with friction material that allows the blade to slip if binding occurs. The blade is angled in the throat area to allow cuts up to 8 inches deep on materials up to 4.5 inches thick. A guard protects the blade when the saw is not in use.

**2.2.4.5 Rock Drill.** The rock drill combines bit rotation with high impact energy for drilling holes up to 2 inches in diameter in rock and coral. The tool accepts both twist bit and cross bit drill steels. Currently not released, development continues on improving the reliability of the impact mechanism. Tool weight and operating figures are not available at press time.

### 2.2.5 Electrical Tools

Electricity can be safely used underwater provided the divers are protected from



Figure 2-9
Bandsaw being used to cut steel cable.

electrical shock hazards. Diver electrical safety can be achieved by using common sense, education, preventive maintenance, properly designed underwater electrical equipment, and using the safety equipment.

Appendix D provides a discussion of electrical safety for divers and should be reviewed when electrical equipment is to be used on the underwater construction site.

Underwater tools and equipment that use electrical power are available for use with divers. Most commonly used equipment includes underwater lights, video cameras, nondestructive inspection equipment, communications, and remotely operated vehicles (ROVs).

**WARNING**
**Surface-powered electrical tools must be Approved for Navy Use in accordance with NAVSEAINST 10560.2C.**

Submersible battery-powered tools should be reviewed to ensure they meet diver safety criteria.

**2.2.5.1 Ground Fault Detection System.** A ground fault detection (GFD) and shutdown system is available to protect divers from electrical shock hazards. Shown in Figure 2-10, the GFD monitors the insulation resistance of the load circuit being used by the diver. When the ground fault resistance drops to a predetermined level, the GFD shuts off power to the load within 10 ms.

**There are two versions of the GFD available: the standard and the Arctic version.** Both have the same operating characteristics as shown below. The Arctic unit is newer and lighter and has components that can operate in a temperature range of -40 to +95°F while the standard unit operates in a range of +30 to +95°F.

**GFD SPECS**

2.5 kVA output
115 VAC, 60 Hz
20-amp max output current
10-msec max shutdown time

**CAUTION**
**Certain types of electrical equipment will not operate with the GFD or the GFD may damage the equipment connected to it. Qualified electronics technicians must review circuit diagrams before using electrical devices with the GFD.**

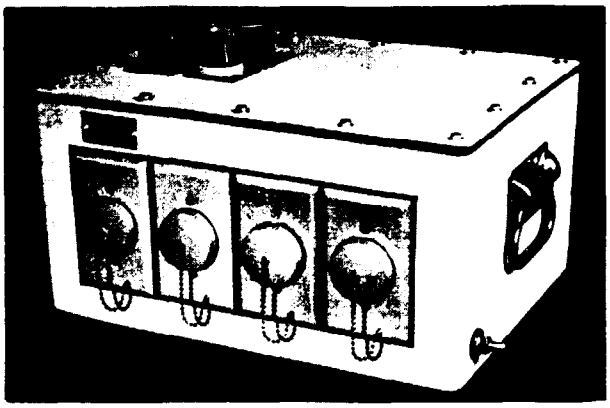


Figure 2-10
2.5-kVA ground fault detector.

Some electrically operated equipment such as ROVs, video equipment, and communications gear may have built-in ground fault detectors. Using this equipment with the GFD may cause both circuits to malfunction and not provide shock protection. A qualified electronics person should review the system for potential problems.

**2.2.5.2 Underwater Electric Field Detector.** The Underwater Electric Field Detector (UEFD) (Figure 2-11) was designed to be carried by the diver. The UEFD senses a voltage across three electrodes located in the tip of the probe and provides a warning when the diver enters the presence of an electrical field.

The UEFD provides the diver with a method of surveying underwater equipment and facilities to locate potential electrical hazards. The probe can also be used to test the water before the diver enters.

**WARNING**
**The UEFD does not protect the diver after he swims into a dangerous electrical field.**

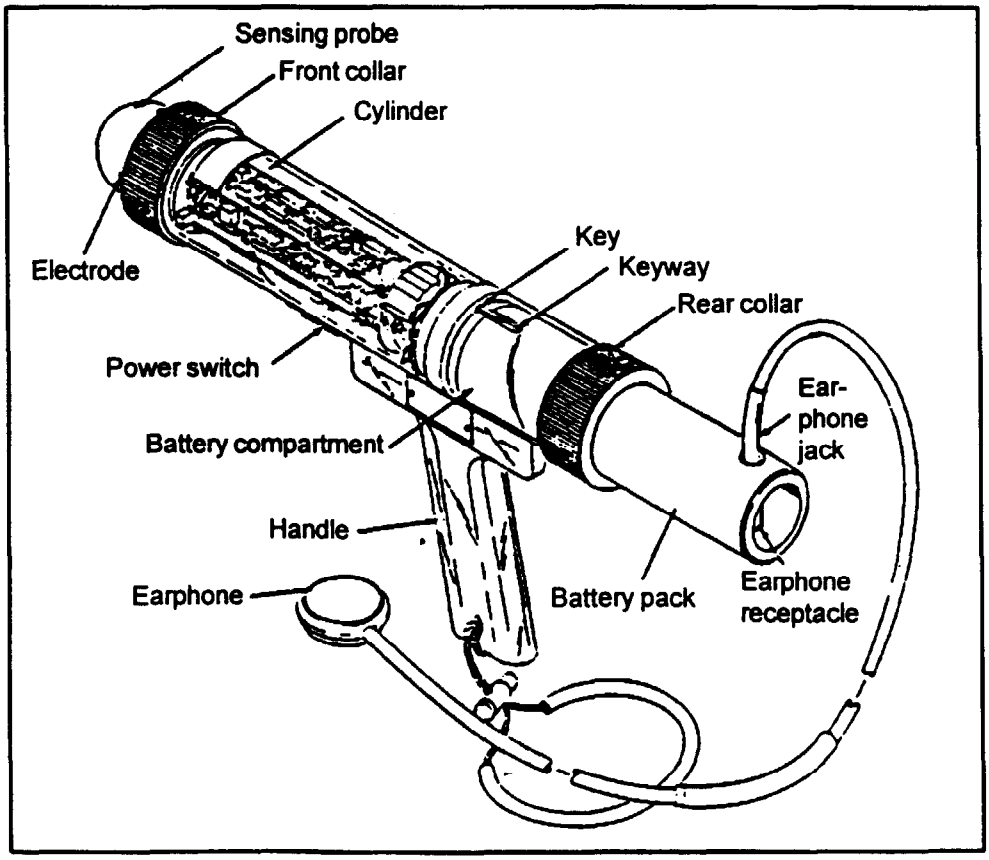



Figure 2-11. Underwater electric field detector.

The unit is calibrated to detect and warn the diver of a weak field and a strong field as follows:

- Weak field signal (0.1 V/ft) will warn the diver that an electric field is present and to proceed with caution.

- Strong field signal (0.2 V/ft) will warn the diver he is swimming into a dangerous electric field whereupon he should swim away or get out of the water. A field strength of 0.2 V/ft is not fatal but will be physically perceptible and may be uncomfortable.

### 2.2.6 Stud Driver

The stud driver shown in Figure 2-12 is a power velocity tool which drives fasteners using a 38-caliber cartridge. Factory pre-loaded, waterproof barrels are used to drive fasteners. Both threaded (stud) and headed (nail) fasteners are available. The tool can be used to attach padeyes, zincs, patches, and anchoring points to metal and concrete.

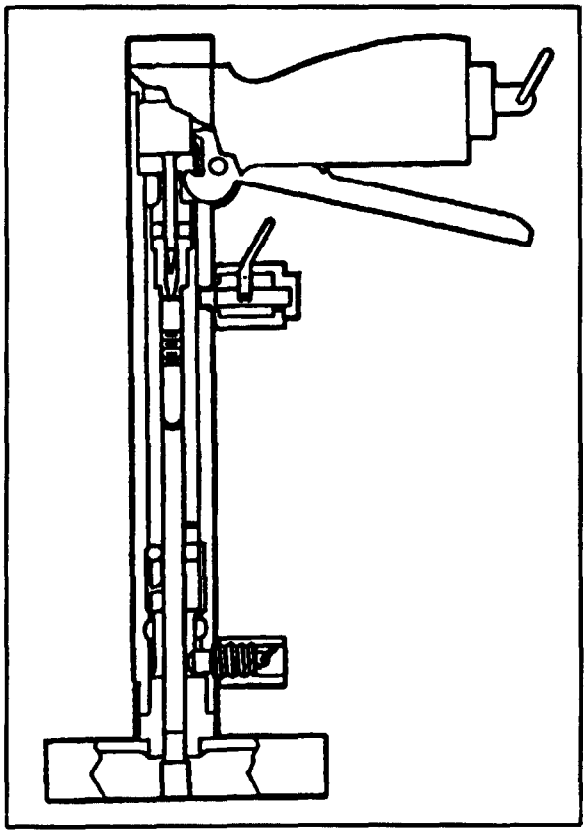


Figure 2-12
Underwater version of the Ranset stud driver currently approved for Navy use.

The underwater version of the stud driver is on the Navy ANU list and is capable of driving fasteners into steel up to 1 inch thick or concrete to any thickness. Fasteners are color coded to provide different load levels. Because of the potential for injury to personnel, NAVSEA OOC requires operator training and certification prior to tool use.

**WARNING**
**An operator's certification card must be obtained before operating the tool.**

**WARNING**
**Never fire into hard or brittle materials such as cast iron, tile, glass, or rock. These materials can shatter causing sharp fragments and/or the fastener to fly freely.**

**2.2.6.1 Concrete.** Table 2-5 provides some examples of the holding power of fasteners in concrete materials. As a fastener is driven into concrete, it displaces its embedded volume and compresses the area of concrete directly surrounding the fastener shank. In addition, sufficient heat is generated during the driving process to cause fusion of small masonry particles with the fastener shank. The bond developed by the compressed concrete and fusion creates the fastener's holding power.

Table 2-5. Allowable Working Values for Low Velocity Fasteners in Stone Aggregate Concrete (lb)

| Catalog Number Series | Shank Diam (in.) | Pene-tration (in.) | Min. Edge Distance (in.) | Min. Spacing (in.) | Concrete Compressive Strength (psi) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2,000 | | 3,000 | | 4,000 | |
| | | | | | Tension | Shear | Tension | Shear | Tension | Shear |
| 3300 Series Drive Pins | 0.170 | 1-1/4 | 3 | 4 | 165 | 225 | 185 | 255 | 210 | 280 |
| | | 1-1/2 | 3 | 4 | 220 | 330 | 225 | 315 | 225 | 300 |
| 9100 Series Treaded Studs | 0.205 | 13/16 | 3 | 5 | 80 | 125 | 90 | 145 | 105 | 170 |
| | | 1-1/16 | 3 | 5 | 115 | 265 | 150 | 250 | 190 | 230 |
| | | 1-1/4 | 3 | 5 | 165 | 315 | 230 | 330 | 295 | 350 |
| | | 1-1/2 | 3 | 5 | 300 | 375 | 310 | 420 | 320 | 460 |

1. Except as noted, values reflect an 8 to 1 safety factor.
2. Job-site testing may be required to determine actual job-site values.

**WARNING**

- **Do not fasten closer than 3 inches from edge of concrete. Otherwise the concrete may crack allowing the fastener to ricochet and cause serious injury.**
- **Minimum recommended spacing between fasteners in concrete is 6 inches to prevent cracking and ricocheting.**
- **Concrete should be at least three times as thick as the fastener penetration (Table 2-6).**

**2.2.6.2 Steel.** A fastener driven into steel displaces the steel radially away from its shank. Elastic properties of the steel cause it to spring back and apply a high compressive load on the fastener that provides the holding power. Some examples of holding power of driven fasteners are provided in Table 2-7.

Increasing the shank diameter will increase the fastener's holding power as long as the steel thickness is sufficient to accept the fastener. The **general rule of thumb is: minimum steel thickness = fastener shank diameter.**

**WARNING**

- **Do not install fasteners closer than 5/8 inch from edge of steel because the steel may break allowing the fastener to ricochet and cause serious injury.**
- **The recommended minimum distance between fastenings is 2-1/4 inches.**
- **Do not fasten into steel material which is thinner than the fastener shank diameter.**

Table 2-6. Fastener Penetration

| Material | Penetration Depth |
|---|---|
| 2- to 3-ksi concrete | 9 to 10 times shank diameter |
| 3- to 4-ksi concrete | 7 to 8 times shank diameter |
| 4.5- to 6-ksi concrete | 5 to 6 times shank diameter |

Note: Concrete should be at least three times as thick as fastener penetration.

Table 2-7
Allowable Working Values for Low Velocity Fasteners in Steel (lb)

| Catalog Number Series | Shank Diam (in.) | Type of Shank | Min. Edge Distance (in.) | Min. Spacing (in.) | Steel Thickness (in.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 3/16 | | 1/4 | | 3/8 | |
| | | | | | Tension | Shear | Tension | Shear | Tension | Shear |
| 3300 Series Drive Pins | 0.170 | Smooth | 5/8 | 1-1/8 | 85 | 820 | 180 | 895 | 330 | 900 |
| 9140K Treaded Studs | 0.205 | Knurled | 3/4 | 1-3/8 | NA | NA | 480 | 1,565 | 550 | 1,950 |

Notes: 1. Holding values shown are for fastenings that have the entire pointed end of the fastener driven through the steel plate.
2. Holding values shown incorporate a 10 to 1 safety factor for tension and a 5 to 1 safety factor for shear. Wood or steel connecting members must be investigated separately.

### 2.2.7 Mechanical Cutting

The Stanley Model CS-11 hydraulic chain saw (Figure 2-13) is used for cutting timber piles, particularly in relatively shallow water, and other timber members. As with all power tools, great care must be exercised in their use.

Also available is the Stanley Model DS-11, which is equipped with diamond impregnated cutters for cutting reinforced concrete.

The hydraulic band saw (Figure 2-14) is primarily for cutting cable but can also be used for cutting pipe and angle iron if sufficient access is available.

The diver-operated hydraulic pile cutter shown in Figure 2-15 is an oil hydraulic-powered liner shear cutter designed to cut up to 13-inch-diameter timber piles. The shears are capable of cutting piles off at the mudline or in the water column. Total cutting time for a single pile is less than 1 minute. A flotation buoy is required to compensate for the pile cutter's 600-pound in-water weight. Because of its size and weight, it is difficult to operate the pile cutter in heavy currents. Operating the pile cutter in shallow water less than 8 feet deep requires that it be supported from the surface. In some locations where surface access to the piling (barge or pier deck) is readily available, it may be more efficient to use the pile cutter supported from a crane instead of maneuvering with lift bags.

### 2.2.8 Metal Locator

The Buried Pipe and Chain Locator (BP&CL) can be used for locating and tracking buried metallic pipe, chain, armored cables, and miscellaneous ferrous objects. It can be used underwater or on dry land.

The BP&CL is a modified commercially available magnetometer, with the batteries and electronics and controls enclosed in a submersible housing (operational down to a 190-foot depth). It can be operated in two modes: as a diver or person carried tool (Figure 2-16), or in a dipping (or towed) mode operated from a surface vessel. When operated in the dipping mode (Figure 2-17), a 150-foot-long electrical umbilical separates the magnetometer from the controls. The **BP&CL consists of** the:

- Control electronics housing
- Probe
- Battery pack
- Ear phone
- Extension handle

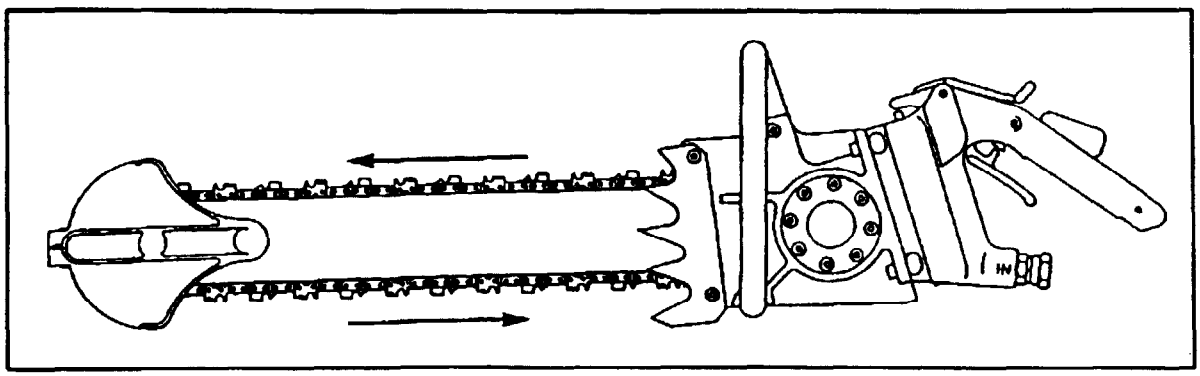


Figure 2-13
Underwater wood cutting chain saw, Stanley Model CS-11. Also available in the Stanley Model DS-11, which is designed for cutting steel-reinforced concrete.

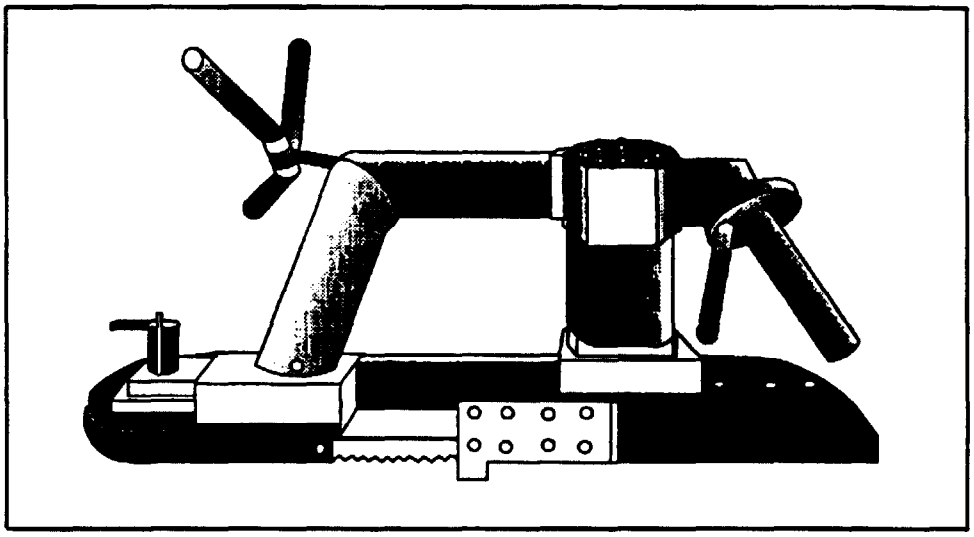


Figure 2-14
Hydraulic band saw.

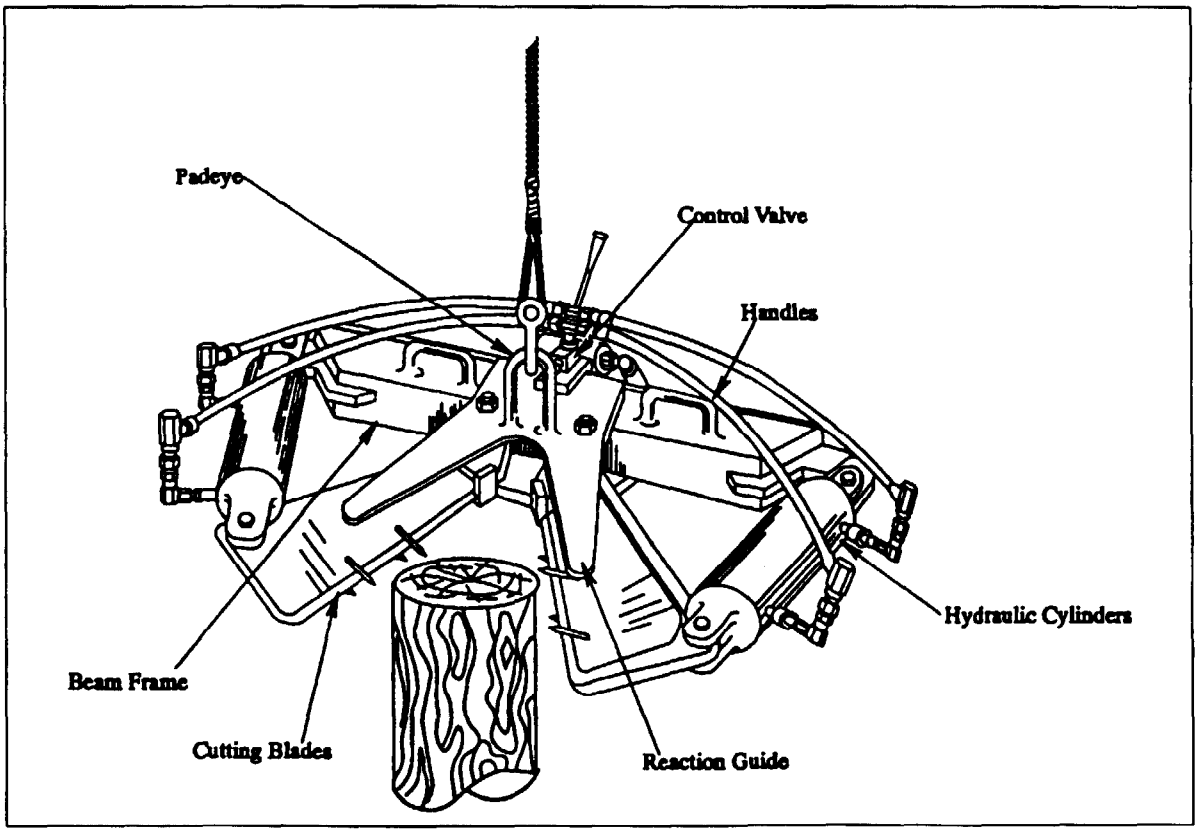



Figure 2-15
Hydraulic pile cutter for severing wood piles up to 13 inches in diameter.

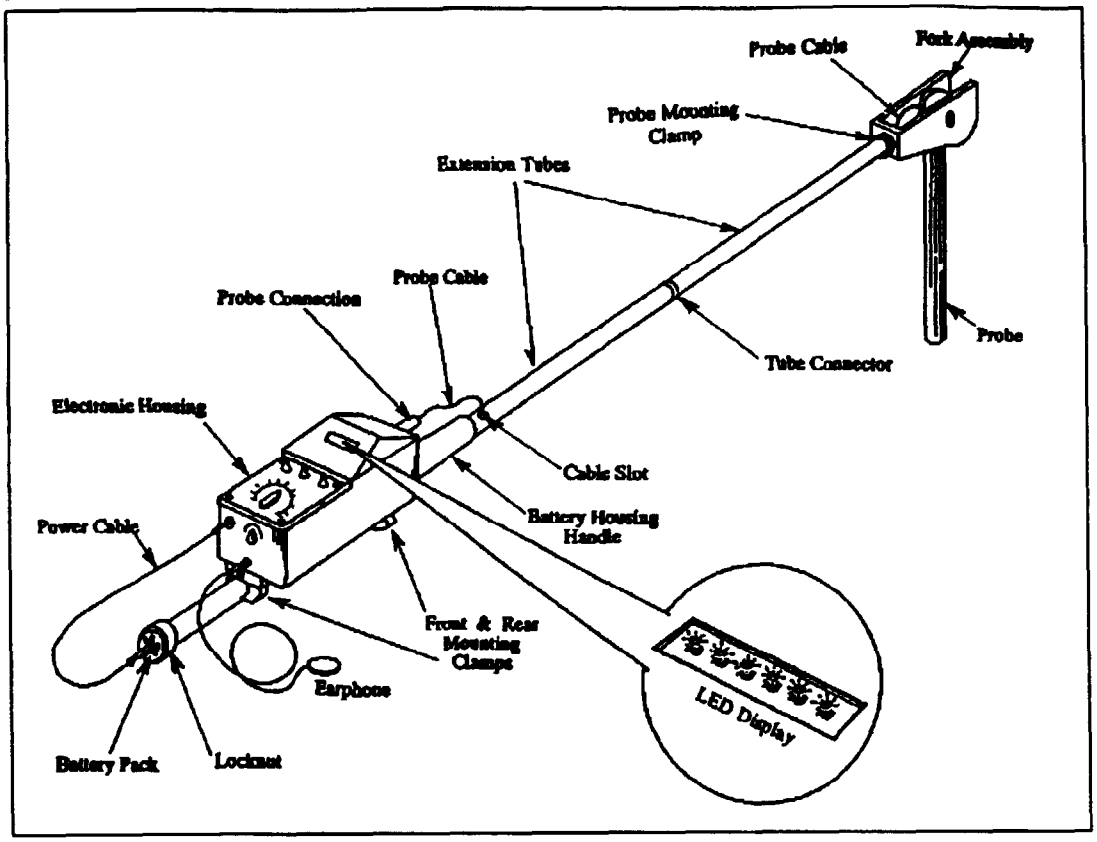



Figure 2-16. BP&CL magnetometer in diver mode.

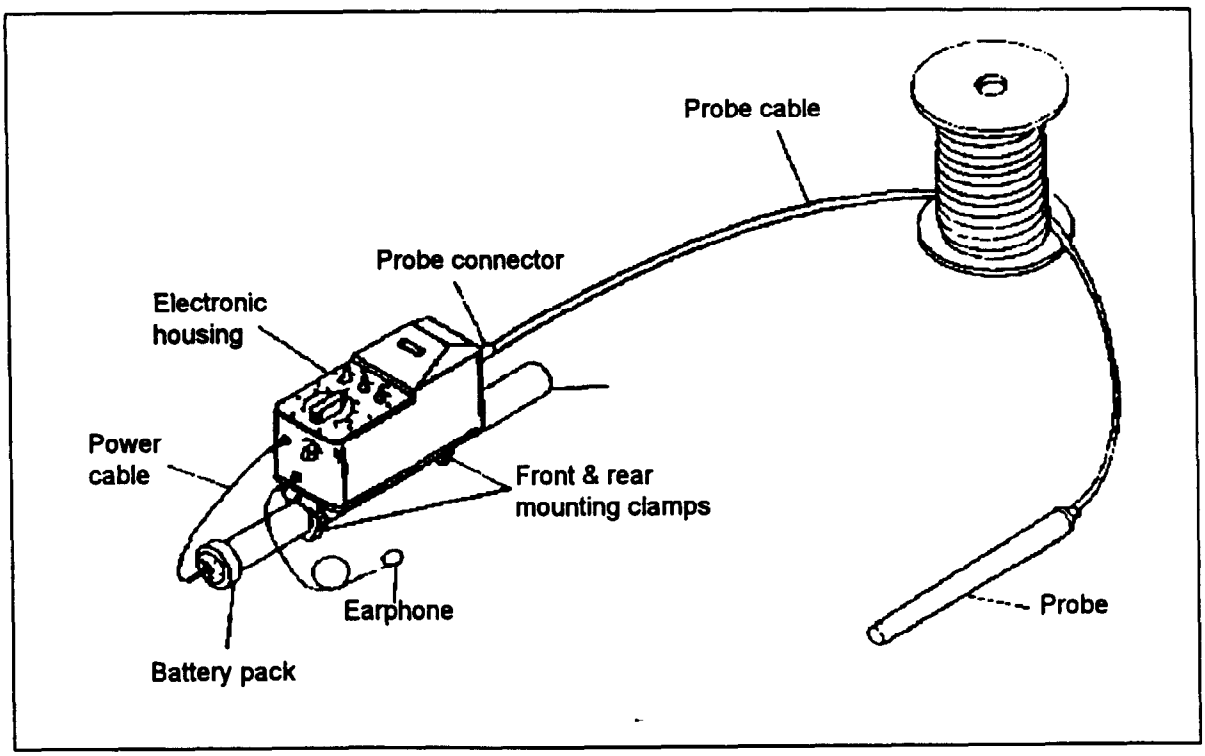



Figure 2-17. BP&CL magnetometer in dipping model.

The probe contains two magnetometer flux gates that sense the earth's magnetic field. The extension handle provides a separation between the diver and the probe. This separation minimizes interference in the earth's magnetic field sensed by the probe from the divers' tanks and gear.

A row of 11 LEDs on the electronics housing (Figure 2-18) displays the output of the system. An earphone provides variable frequency audible signal. The center LED shows that power is on. The five LEDs on either side of the power indicator light progressively, either left or right, according to the magnetic signal strength and polarity.

Detection range and display readings will vary depending on the size, shape, and proximity of the ferrous object and interference from nearby ferrous material. Thus, there are a **few different signal characteristics which might be displayed as the probe passes over a ferrous object**:

- Detection may occur with the signal increasing to a maximum level and then decreasing.
- The signal may increase to a maximum level and then reverse polarity.
- The signal may increase to a maximum level and then reverse polarity twice.

> **NOTE**
> **Practice on land with ferrous metal targets buried at various depths before deploying to the field.**

**Follow these procedures when searching**:

- Set the operating mode switch to the appropriate level (1- is least damping and most sensitivity).

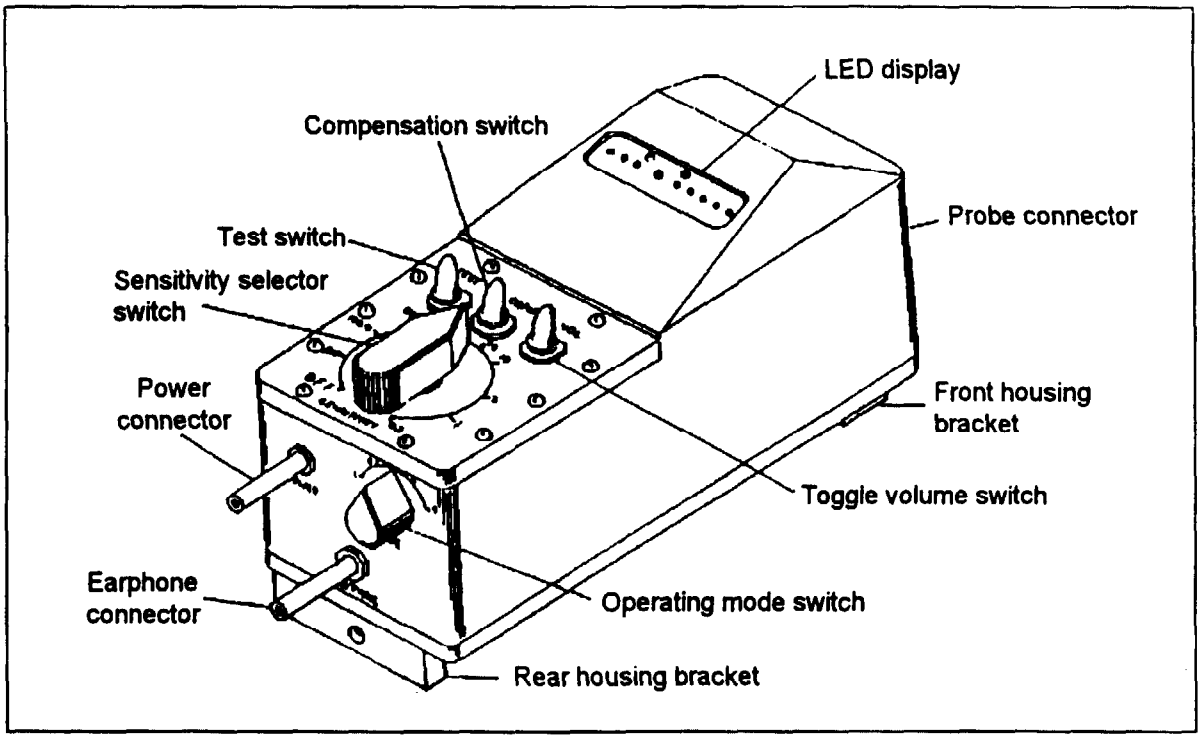



Figure 2-18. BP&CL electronics housing.

- Turn the tool on by rotating the sensitivity selector to the most sensitive position.

- Adjust the volume control to provide a comfortable level.

- Set the LED bar to zero using the compensation switch.

- Begin the search at the greatest sensitivity setting. If local magnetic interference causes the display to always display maximum, use the next lowest sensitivity level. Reduce sensitivity until only two LEDs are lit. The setting is different for every site.

- Hold the unit so the probe is perpendicular to the ocean floor.

- Sweep the probe to the left and right while moving forward.

- Move in the direction of increasing signal. Decrease the sensitivity setting as the display shows maximum intensity.

- Find the area where the greatest signal intensity occurs at the lowest sensitivity level.

## 2.3 REMOVING MARINE GROWTH

Virtually all inspection, maintenance, and repair operations on marine structures require some degree of marine growth removal. An underwater structure provides an ideal substrate for colonies of marine organisms. This marine growth, particularly if evident in large numbers, can have significant negative effects on the integrity of the structure. The presence of marine growth increases the size and mass of the structure, which causes the structure to undergo greater wave and current forces, perhaps to the point of causing structural failure. The presence of marine growth can also cause accelerated deterioration of paint, steel, and concrete. However, in most cases, the organisms cause less damage than the process of removing them. Unless required for inspection, maintenance, repair, or reduction in weight or drag, the organisms should be left in place and not removed. Some typical growths found on underwater structures include kelp, seaweed, mussels, anemones, sponges, and barnacles.

There are **several methods to clear structures of marine growth**, generally divided into two groups: **hand tools** and **power tools**. Hand tools include such items as wire brushes and scrapers. Hand tools are good for general marine growth removal and are especially effective when a diver must be highly mobile, such as in the inspection of fleet moorings. They are generally not used when large areas of growth must be removed, such as in nondestructive testing (ultrasonic thickness measurement and magnetic particle inspection) or for maintenance and repair operations. Hand tools have an extra advantage -- they are highly portable and involve minimum hazards in their use.

Power tools are useful for removing marine growth because they are faster and usually more effective than hand tools. The following types of Navy-approved, commercially available **devices are recommended for cleaning underwater structures**:

1. A reactionless water jet with variable flow rates and pressures for heavily fouled concrete and steel structures.

2. A rotary abrading device on concrete structures.

3. A hydraulic or pneumatic chipping hammer.

These devices are:

• **Reactionless High-Pressure Water Jet,** shown in Figure 2-19, is available with a number of fan nozzles varying in orifice size and fan angle. The retrojet is surrounded by a diffuser shroud with slots that force the exiting high-pressure water out the side holes to prevent injury from inadvertently passing the tool in front of the operator. The system operates within a wide range of flows and pressures limited only by the pump capabilities and includes a topside, foot-operated control valve that permits surface personnel to quickly shut off flow to the tool in case of emergencies or equipment malfunction. This device can effectively remove heavy marine growth and corrosion for most situations and satisfies most cleaning criteria and requirements.



Figure 2-19
Reactionless high-pressure waterjet.

• **"Barnacle Buster"** or "Whirl Away" tool, shown in Figure 2-20, is a rotary abrading attachment that fits a standard hydraulic drill, sander, or grinder. Seven sets of hardened steel cutters rotate on their axles while the shaft of the tool attached to the hydraulic motor rotates in the opposite direction. Water displaced from the rotary motion creates a low-pressure area on the cutter side of the tool. This effect causes the tool to be pushed against the work surface but still allows movement in any direction under the operator's guidance. The Barnacle Buster is the most effective tool for removing fouling from concrete surfaces and is the safest cleaning device to operate because it does not require high-pressure water.




Figure 2-20
"Barnacle Buster" tool.

• **Water Jet Cleaning System** - This system was developed by the NFESC and is available for the routine cleaning of structures, particularly in limited access areas. The system, shown in Figure 2-21, includes a:

- Small hand-held water jet pistol
- Interchangeable cavitating fan and straight jet nozzles
- Diver-operated trigger valve with automatic safety lock
- Flexible, small diameter, high-pressure supply hose
- Foot-activated shutoff valve
- High-pressure swivel

The power source, which delivers up to 5 gpm at 12,000 psi, is driven by a diesel engine. The power unit operates on either freshwater or seawater. The system also provides 12-gpm, 3,000-psi oil for powering oil-hydraulic diver tools.

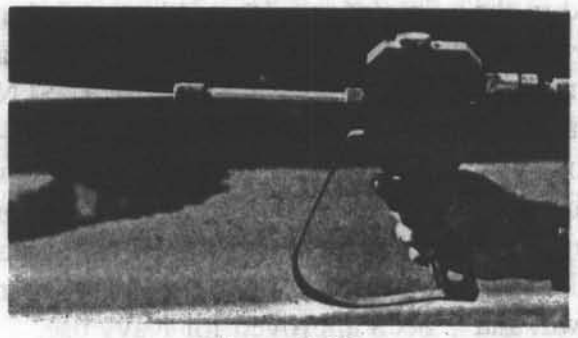


Figure 2-21a
High-pressure waterjet cleaning nozzle.



Figure 2-21b
NFESC waterjet cleaning power source.

• **Noncavitating High-Pressure Water Jet**-This device, without retrojet for surface-subsurface cleaning, is commonly used by the UCTs. This device, illustrated in Figure 2-22, develops more than 40 pounds of back thrust and may be equipped with a shoulder stock to provide support during operation. It operates at up to 10 gpm and 10,000 psi and is available with a number of standard and fan nozzles.

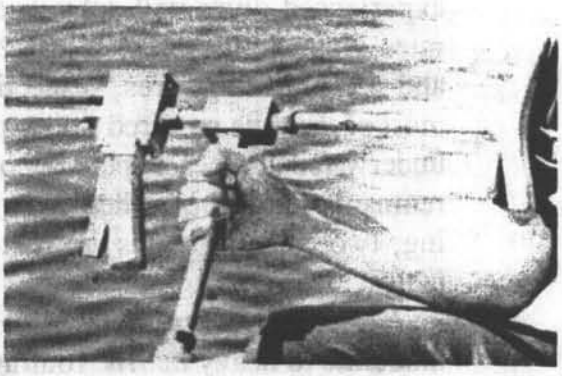


Figure 2-22
Noncavitating high-pressure waterjet without retrofit.

Many different commercial high-pressure water jet systems are available. Also commercially available are high-pressure water jet systems with abrasives injected into the fluid stream. These systems are primarily designed for abovewater use for cutting material and are especially hazardous to use both underwater and on land.

**CAUTION**

**Exercise extreme care while using any high-pressure cleaning systems. The water jet is capable of cutting skin and bones. Never point the jet at anyone, even underwater.**

The best operating technique for all high-pressure jets includes a standoff distance of 1/2 to 3 inches, an impingement angle of 50 to 90 degrees, and quick and agitated translation. Each tool has an optimum operating technique that should be established prior to any actual cleaning.

Cleaning rates for the various cleaning methods differ. In addition, the cleaning rate depends on the type of structural material, fouling amount and type, water visibility, temperature and surface condition, size of area to be cleaned, operating pressure and flow rate, and operator experience. Assuming good working conditions, an average experienced diver will achieve the cleaning rates given in Tables 2-8 and 2-9 for steel and concrete structures, respectively. Since most of the time required to completely clean underwater surfaces is spent removing the last remnants of stubborn shell growth and fouling, two cleaning times are indicated in the tables.

A **"preliminary cleaning"** to remove moderate to heavy marine fouling consisting of weed growth, algae, rust, and loose barnacles or tubeworms is sufficient for most routine inspection and maintenance operations. A **"final cleaning"** to remove all heavy fouling including stubborn shell growth and any protective coating is required for other situations. A diver should not be expected to work longer than the time indicated in the table; fatigue could render the diver unsafe.

## 2.4 THERMAL CUTTING/WELDING

There are two general categories of underwater cutting techniques: mechanical and thermal. The equipment used for mechanical cutting includes hydraulically-powered chain saws, band saws, and shears. Thermal cutting techniques employ the use of a thermal arc with and without oxygen.

### 2.4.1 Thermal Cutting

A brief description of thermal cutting methods is contained below and a full discussion can be found in the **U.S. Navy Underwater Cutting and Welding Manual, NAVSEA S0300-BB-MAN-010.**

All underwater thermal cutting methods are potentially hazardous to personnel. Divers performing underwater cutting and welding must have greater skill and stamina than those doing the same work topside. The use of the correct techniques and equipment becomes extremely important underwater. Diving apparel, depth, currents, low temperature, poor visibility, and suitable footing are all factors that make underwater cutting and welding difficult.

Only personnel trained and qualified in underwater welding may be assigned to those jobs. Dives must be carried out in conformance with the U.S. Navy Diving Manual (NAVSEA 0994-LP-001-9010). Cutting and welding must be carried out in accordance with the procedures described in the Underwater Cutting and Welding Manual using equipment that has been approved for Navy use.

**WARNING**

**Serious injury or death may result when adequate precautions are not followed during underwater cutting and welding operations. Supervisors shall ensure that all personnel are trained and qualified in underwater cutting and welding and are thoroughly familiar with the safety precautions covered in the U.S. Navy Underwater Cutting and Welding Manual.**

Table 2-8
Marine Growth Removal from Steel Structures

| Method | Production Rate ($ft^2$/min) | | Safe Work Duration (hr) |
|---|---|---|---|
| | Preliminary Cleaning | Final Cleaning | |
| Hand Scraper | 0.3 | --- | 2 |
| Reactionless Jet | 4.1 | 4.0 | 2 |
| Barnacle Buster | --- | 2.4 | 1 |
| NFESC System | 3.4 | 2.7 | 2 |
| Reaction Jet | 1.7 | 0.7 | 1 |

Table 2-9
Marine Growth Removal from Concrete Structures

| Method | Production Rate ($ft^2$/min) | | Safe Work Duration (hr) |
|---|---|---|---|
| | Preliminary Cleaning | Final Cleaning | |
| Hand Scraper | 0.2 | --- | 2 |
| Reactionless Jet | 2.3 | 0.8 | 2 |
| Barnacle Buster | --- | 0.6 | 1 |
| NFESC System | 3.0 | 0.7 | 2 |
| Reaction Jet | 3.7 | 1.1 | 1 |

There are **two underwater thermal cutting processes currently approved for underwater use**. They are:

- Shielded metal-arc cutting
- Oxygen-arc cutting with exothermic electrodes, steel-tubular electrodes, and Keri Cable

The shielded metal-arc underwater cutting process uses the intense heat of the arc to do the cutting. No oxygen is needed. It is the preferred method when cutting metal of 1/4 inch or less in thickness or when cutting nonferrous or corrosion-resistant metals of any thickness. The heat melts a localized area of metal forming a small molten pool. The pool will not flow enough to produce a good cut due to the rapid cooling from the quenching effect of the surrounding water. Therefore, the tip of the electrode must be manipulated to push the molten metal out of the kerf.

With oxygen-arc cutting the cutting action depends on the oxidation of a metal, such as steel, which oxidizes readily. Heat is applied with an electrode to a spot on the metal surface on the intended line of cut. When the metal is heated to a "kindling" temperature, a high-velocity jet of pure oxygen is directed at the heated spot and the metal oxidizes or burns rapidly, a process which takes place instantly. The high-velocity jet performs two necessary functions: (1) It produces additional heat by oxidizing the preheated metal, and (2) it blows the molten oxidized metal away.

The tip of the electrode, which is exposed to the effects of heat and oxidation, is consumed rapidly and must be replaced frequently.

Two types of electrodes are used for underwater oxygen-arc cutting: the exothermic and the steel-tubular electrode as illustrated in Figure 2-23. The BROCO ultrathermic cutting electrode is composed of seven small rods inside a steel tube. One of the seven rods is a special alloy that will burn independently once an arc is struck and oxygen is flowing through the tube. The remaining six rods are made of steel. The electrode, which is insulated with electrical tape, is 18 inches long and is available in both 3/8- and 1/4-inch diameters. The 3/8-inch-diameter rod is also available in 36-inch lengths.

The Arcair Sea-Jet cutting electrode consists of a thin mild steel tube enclosed in a spiral, mild steel spring-like wrapping, which is encased in a larger metal tube (see Figure 2-24). The electrode is coated with waterproofing and insulating material. Like the Ultrathermic, the Sea-Jet will burn ferrous and nonferrous mate-

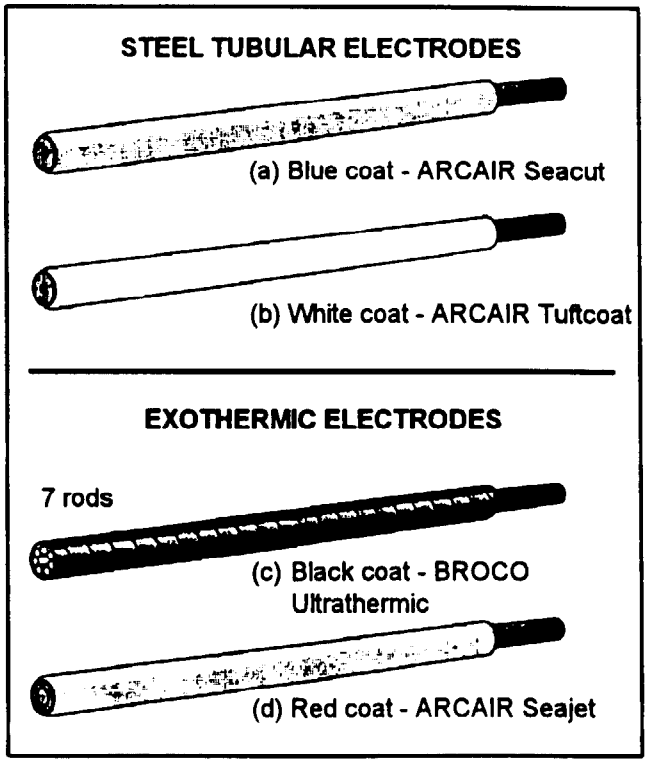



Figure 2-23
Underwater oxygen-arc cutting electrodes.

rials such as concrete, rock, barnacles, and other sea growth. The electrode is 3/8 inch in diameter and 18 inches long. It will also fit the Arcair, BROCO, and the Craftsweld Torch.

The steel-tubular cutting electrode consists of a steel tube with a waterproofed flux covering. It is 14 inches long with a 5/16-inch outer diameter and a bore diameter slightly under 1/8 inch.

A similar exothermic cutting method is the Clucas Thermic-Arc System (Kerie Cable). Unlike a rigid electrode, the consumable electrode is a long flexible spiral cable with the center strand pulled out to allow for oxygen to pass. The cable consists of six bundles of high tensile steel wire, which is encased in a plastic sheath. The Kerie Cable is applicable to all metal thicknesses and has a longer burn time than tubular electrodes. There is no electrical hazard after ignition.

For using the Kerie Cable, Table 2-10 provides oxygen pressure requirements; Table 2-11 gives cable size for metal thicknesses; and Table 2-12 provides estimated consumption rates for both cable and oxygen. The major disadvantages of using Kerie Cable are that it requires more oxygen than the other methods and it cannot be used to cut concrete or rock.

**WARNING**
**The Kerie Cable WILL NOT cut rock or concrete either above or below water. To attempt to do so may create an explosion causing injury or death.**

**NOTE**
**The Keri Cable has been removed from the UCT TOA.**

**WARNING**
**The Kerie Cable should not be used to cut nonferrous metals underwater since they do not oxidize and have to be melted. Experience has shown that this can result in a violent explosion which could be fatal.**

For UCT operations, exothermic electrodes are preferred because they continue to burn after the current is switched off without loss in efficiency. They can also be used for cutting nonferrous metals and some nonmetals.

The exothermic electrode is held in a cutting torch as illustrated in Figure 2-25. Additional required equipment includes:

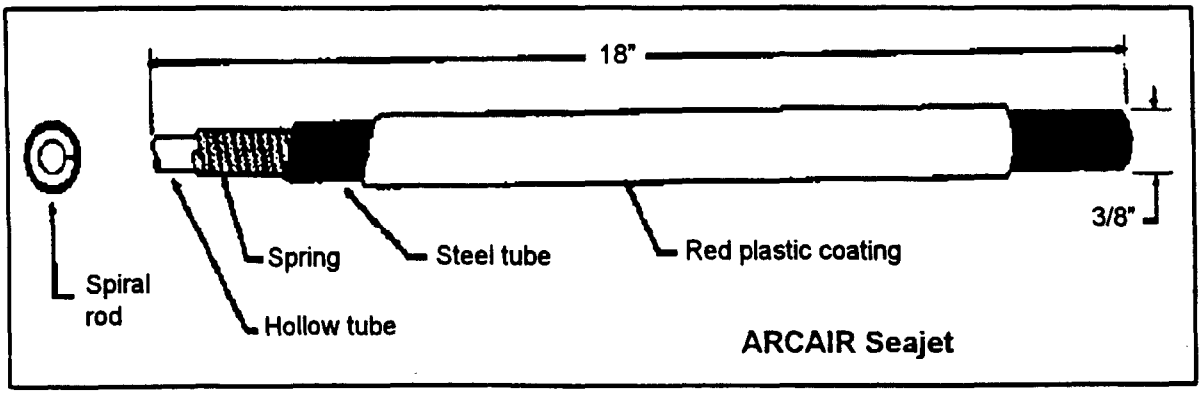



Figure 2-24
Underwater oxygen-arc electrode designs.

Table 2-10
Oxygen Regulator Settings for Kerie Cable Cutting

| Cable Size | Overbottom (OB) Pressure Formula (psi) |
|---|---|
| 0.24 in. (6 mm) | D + (250 to 300 psi) = OB* |
| 0.36 in. (9 mm) | D + (300 to 340 psi) = OB* |
| 0.48 in. (12 mm) | D + (340 to 380 psi) = OB* |

*A 40- to 50-psi range is allowed for diver preference.
D = Seawater depth, in feet.

Table 2-11
Kerie Cable Size/Metal to be Cut*

| Cable Size | Metal Thickness (in.) |
|---|---|
| 0.24 in. (6 mm) | up to 1 |
| 0.36 in. (9 mm) | 1 to 2-1/2 |
| 0.48 in. (12 mm) | over 2-1/2 |

*Based on manufacturer's data.

Table 2-12
Kerie Cable Oxygen and Cable Consumption Ratio

| Cable Size | Average Cable Consumed (ft/min) | Average Oxygen Consumed (psi/min) |
|---|---|---|
| 0.24 in. (6 mm) | 2.1 | 13.9 |
| 0.36 in. (9 mm) | 2.2 | 35.5 |
| 0.48 in. (12 mm) | 2.4 | 40.6 |

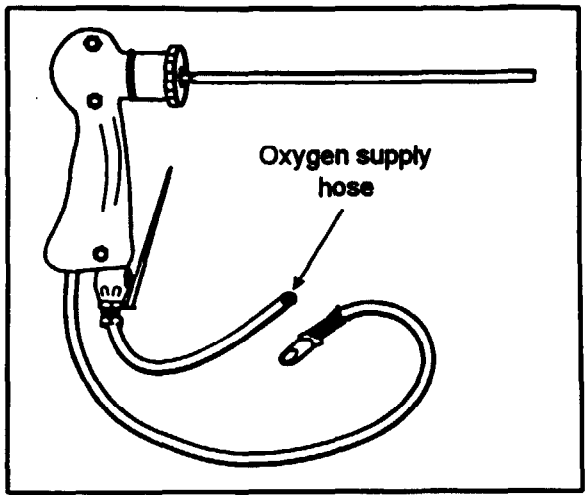



Figure 2-25. BROCO exothermic cutting torch.

- High-volume oxygen regulator
- Oxygen cylinders (obtained at the site)
- Single-pole, 400-ampere, direct current (DC) safety switch
- Underwater C-type grounding clamp
- 200-ampere minimum DC welding machine
- 12-volt battery (can be used as the ignition source)
- 1/0 welding cables for torch and ground clamp
- 3/8-inch-ID oxygen supply hose from regulator to torch
- Two-way, diver-topside communication system

Before starting cutting operations, clean the metallic surfaces well to facilitate striking of the initial arc and to restart the arc as necessary during the cutting process. The first step is to clean a spot for the ground clamp.

**NOTE**
**For diver safety, use only C-type clamps for grounding during both cutting and welding.**

The clamp must be firmly secured to the work piece for the arc-striker plate when cutting nonconducting materials. The diver may elect to lightly tack weld the clamp in place where there is a possibility that it may work loose.

When cutting or melting nonconductive materials, such as concrete, rock, coral, mastic, rope, or marine growth, a striker plate is necessary to strike an arc. This metal plate is connected to the ground cable and placed next to the material to be cut. If the rod ignition is lost, the rod is relit from the striker plate by repeating the ignition procedure. Each subsequent rod must be lit from the striker plate in the same manner.

The BROCO 1/4-inch ultrathermic rod may be used for steel up to 1/2 inch thick for maximum cutting economy. The 1/4-inch rod leaves a narrow kerf and is preferred for line cutting. However, in bad visibility or for heavier steels, the 3/8-inch rod will give higher production. For materials 1/2 inch thick and over, the 3/8-inch rod is preferred. For materials several inches thick, saw and wedge cutting (analogous to chopping a tree with an axe) may be necessary to make entry space for the cutting process.

**"Rule-of-thumb"** estimates for rod diameter versus plate thickness and length of cut per rod for an experienced operator are given in Table 2-13.

The oxygen flow rate is determined by the regulator pressure, bottom depth, and pressure losses in the lines. While oxygen

flow rate is usually not critical for successful cutting, it is more critical for thicker materials. Thus, a higher psi is required to ensure the molten slag is blown away, otherwise the rod will be snuffed out as the rod is pushed into the cut. Satisfactory cutting can be performed within a fairly wide range of oxygen flow. However, a low flow rate (low pressure) may slow down the operation and require more diver attention, tiring the diver. A high flow rate (high pressure) may needlessly tire the diver by creating excessive reaction force at the nozzle. Recommended pressure settings for the oxygen regulator are listed in Table 2-14.

Based on a standard oxygen cylinder of 244 $ft^3$ at a pressure of 2,200 psi, one cylinder will be consumed for each 15 to 20 3/8-inch-diameter (18-inch-long) rods consumed.

The ultrathermic electrode will melt cast iron, stainless steel, and nonferrous metals. For these materials the length of cut per rod is reduced from that given in Table 2-13. When cutting these materials, the tip must be firmly buried in the work.

Table 2-13
Length of Cut for BROCO Ultrathermic Electrodes

| Rod Diameter (in.) | Plate Thickness (in.) | Length of Cut Per Rod (in.)* |
|---|---|---|
| 1/4 | 1/4<br>1/2 | 20 to 25<br>10 to 15 |
| 3/8 | 1/2<br>1<br>1-1/2 | 12 to 20<br>9 to 14<br>8 to 12 |

*The length of cut per electrode represents cuts with and without power. The higher number is cutting power on.

Table 2-14
Oxygen Regulator Settings for Ultrathermic Electrodes

| Plate Thickness (in.) | Overbottom Pressure (psi) |
|---|---|
| 1/4 | 75 |
| 3/8 | 80 |
| 1/2 | 80 |
| 3/4 | 85 |
| 1 | 90 |
| 1-1/4 | 95 |
| 1-1/2 | 95 |

Saw and wedge cutting may be necessary. Alternatively, maximum cutting efficiency may be achieved by burning a series of holes through the piece prior to cutting across it.

When cutting concrete and rock, a 3/8-inch rod should be used, remembering that it is necessary to ignite the rod on a striker plate. The rod tip must be pressed into the material to create a molten pool. As the material is melted, the tip pressure is periodically released slightly to allow the oxygen to blow the molten material away.

### 2.4.2 Underwater Welding

Underwater welding is not covered here in detail except for a few brief comments.

> **NOTE**
> **Underwater welding is described in detail in the U.S. Navy Underwater Cutting and Welding Manual. Before proceeding, the welder must be thoroughly familiar with applicable safety precautions and methods contained in the manual.**

When welding is required for critical applications such as permanent welds or for welding on ship hulls, specifications are contained in **ANSI/AWS D3.6-93, Specifications for Underwater Welding**, published by the American Welding Society.

Although underwater welding does not have as many applications as underwater cutting, it is a useful process. The overall advantage is that underwater welding can significantly reduce the time spent on making repairs, both temporary and permanent, over those using other methods. In underwater construction and repair, it can be effectively used to attach patches to pipes, and for providing lifting or attaching points to steel H-piles and sheet pile.

A major disadvantage of welding is that it requires considerable practice to achieve a consistently good standard of welding. The problem is that the ocean acts as a large heat sink that draws heat off the electrode, which can cause holes in the welded material and possible loss of strength of the metal.

The **two types of welding** are discussed in the Navy Underwater Cutting and Welding Manual. They are:

- Wet welding where the diver is completely submerged.

- Dry welding at the "splash zone" where the welder is in a dry box or cofferdam at atmospheric pressure. It is essentially conventional welding. Details to exclude water from the weld area are provided in the Underwater Cutting and Welding Manual.

Shielded metal-arc welding is the most widely used process for wet welding. Specific welding procedures for underwater maintenance work on ships is addressed in the **Underwater Ship Husbandry Manual (NAVSEA S0600-AA-PRO-010)** and the **Naval Ships' Technical Manual, Chapter 074 (NAVSEA S9086-CH-STM-010)**.

As with underwater cutting, serious injury or death can result when adequate precautions are not followed during underwater welding.

> **NOTE**
> **Supervisors shall ensure that all personnel are thoroughly familiar with the specific precautions covered in the Underwater Cutting and Welding Manual. Only personnel trained and qualified may be assigned to conduct underwater welding.**

## 2.5 LIFT BAGS

In conducting underwater work, it is sometimes necessary to move heavy and bulky objects, such as instrument arrays, support towers, anchors, pallets of construction materials, construction tools and equipment, and similar objects. It may also be necessary to safely float equipment, materials, and assembled construction products on the surface of the water (e.g., armored cable assemblies). This can be achieved underwater by the diver using lift bags and float balloons, and from the surface using cranes and winches.

There are several **lift bag systems that can be used in underwater operations.** They are:

- Open- and closed-bottom commercial lift bags
- 8.4-ton salvage pontoons
- Variable-buoyancy zipper lift bags
- Fixed-displacement Kevlar lift bags

### 2.5.1 Open-Bottom Lift Bags

**WARNING**

**The ascent and descent rates of all lift bags can rapidly exceed allowable levels for divers. Operators must ensure that all divers are clear of the path before deploying the bag.**

The buoyancy of open-bottom lift bags is increased by admitting air into the bottom opening of the bag and decreased by exhausting air through a top-mounted, manually-operated, air exhaust valve or by venting air through a vertical zipper as discussed in Section 2.5.3. The buoyancy of these lift bags is difficult to accurately control because of the on-off nature of the exhaust valves and the change in gas volume (buoyancy change) with depth. A slight ascent of the bag allows the air to expand and buoyancy to increase, which can cause the lift bag and its attached load to accelerate toward the surface. Conversely, a descent compresses the air, causing a loss of buoyancy.

Open-bottom lift bags have been used the most by the UCTs because of their availability and simplicity. These bags are typically used for moving relatively light loads around underwater. However, controlling a 10-ton load would pose considerable difficulty due to the size and mass of the load. There is a high potential to lose air out the bottom of the bag as it breaches the surface. The bag may then lose buoyancy and drop the load back to the bottom. These lift bags, as illustrated in Figure 2-26, are available in sizes from 50 to 12,000 pounds. Reliability of open-bottom lift bags is generally good. The PMS requirements are simple, requiring only cleaning and exhaust

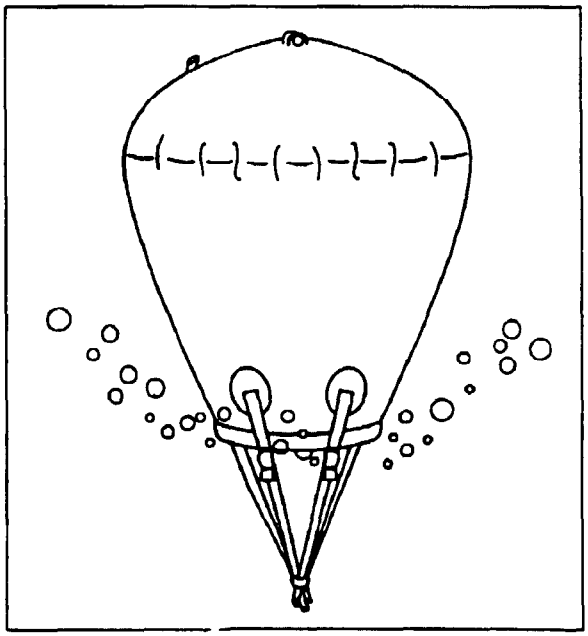


Figure 2-26. Open-bottom lift bag.

valve lubrication. Leaky exhaust valves are easily replaced. They are also easily transported and stored because of their compactness.

### 2.5.2 Closed-Bottom Lift Bags

Closed-bottom lift bags are generally used for lifting objects from the seafloor to the surface and not the reverse.

Commercial closed-bottom lift bags come in a variety of sizes and shapes as illustrated in Figure 2-27. They are used for many different applications including salvage, cable laying, surface floats, and general underwater construction support. Some closed-bottom lift bags, such as the heavy duty pillow-shaped bags, can be used for assisting in land construction: for example, an appropriately sized deflated boulder bag placed under an object makes it suitable for lifting vehicles, pontoons, etc.

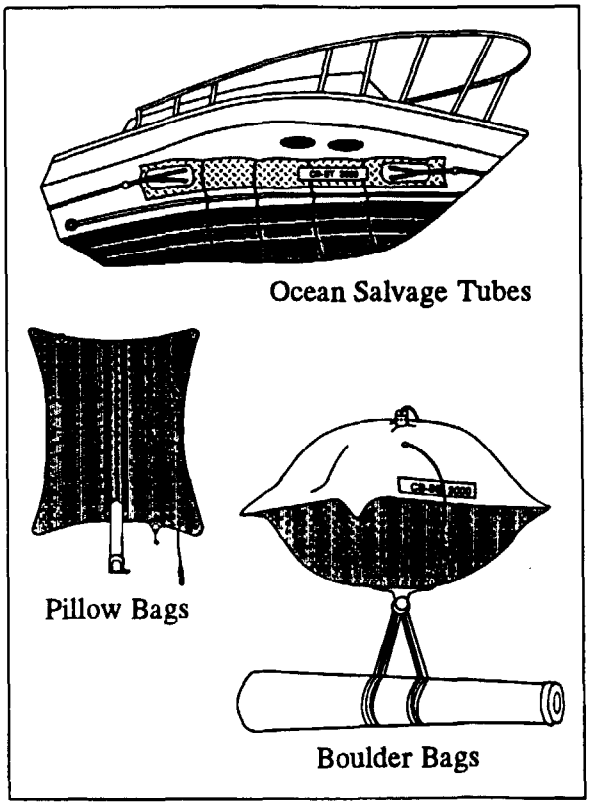



Figure 2-27. Closed-bottom lift bags.

Closed-bottom lift bags are commercially available in sizes from 200 to 20,000 pounds (possibly larger ones are available). The totally enclosed design helps prevent the loss of air when the assembly is bobbing at the surface.

Because the bags are totally enclosed, they are equipped with overpressure vent valves that dump the expanding air as the bag rises to the surface. The rate of ascent of the bag will be determined by the dump valve capacity and the excess buoyancy of the bag during ascent.

Bag manufacturers design the dump valves to provide adequate venting from the bag as it rises through the water column provided that the load being lifted is as least 80 percent of the bag's rated lift capacity. **Avoid excessive buoyancy**. Too light a load can result in:

- The lift rising too rapidly.
- Inability of the dump valve to exhaust the expanding gas.
- Excessive internal pressure.
- Potential rupture of the bag whereby the load will fall back to the seafloor.

> **WARNING**
> **For safety reasons, select closed-bottom lift bags so that the underwater weight of the lifted object is at least 80 percent of the bag's lift capacity.**

The totally enclosed, tear-shaped salvage lift bags are ideally suited for lifting a load from depth and holding it on the surface. The tear-drop shape and single lift point provide a stable configuration through the water column. The CANFLEX Model DLE10 shown in Figure 2-28 is available

from the ESSM Pool. It has a 22,000-pound lift capacity, weighs 210 pounds, and has an ascent rate of 66 ft/min when the underwater load is at least 80 percent (at least 17,000 pounds) of the bag capacity. The bag measures 8.5 feet in diameter by 8.5 feet long when inflated.

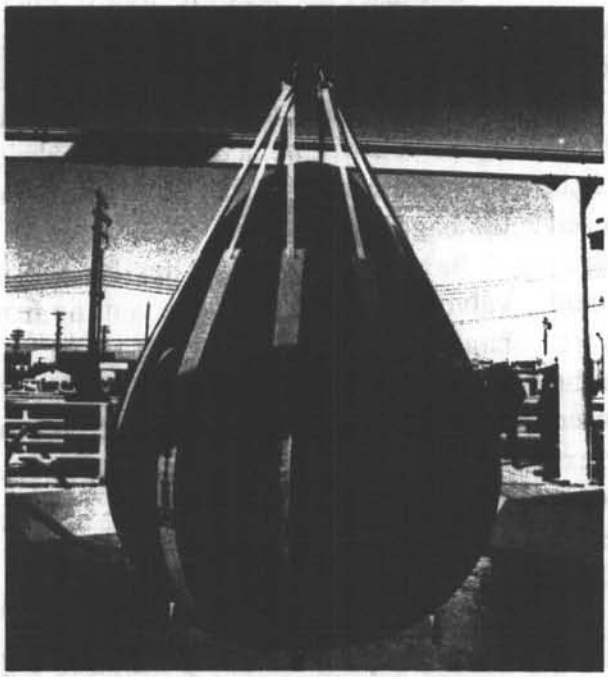


Figure 2-28
CANFLEX salvage lift bag.

Pontoon (horizontal cylindrical-shaped) lift bags such as those shown in Figure 2-29 are best suited for shallow water lift. There is a general concern for the stability of the bags as they are being filled. If they fill unevenly, excessive side loading can be put on the straps causing uneven lifting and possibly tearing the lift bag loose from the straps.

Pontoon lift bags can be effectively used for **REDUCING** the weight of underwater objects to supplement controlled lifting from other means such as winches.

**WARNING**
**Pontoon lift bags are not recommended for use in an excess buoyancy mode.**

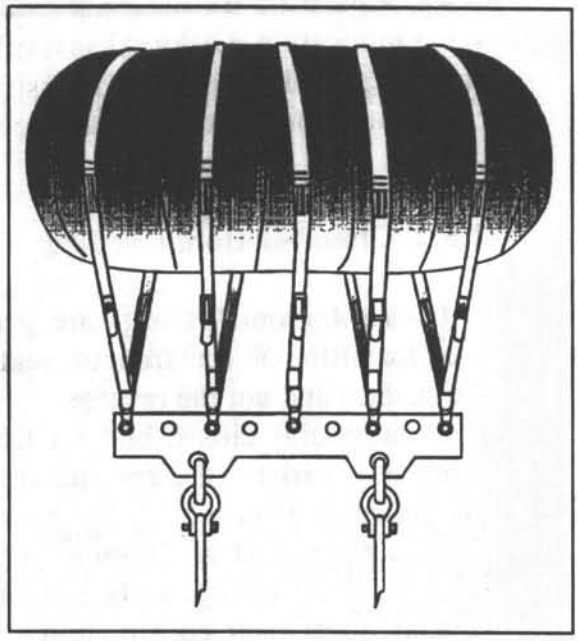


Figure 2-29. Pontoon lift bag.

Pumpkin Floats, Figure 2-30, are available in the TOA. Their primary UCT application is for floating shore cables during their installation. The floats, which have a 250-pound buoyancy, are tied to the cable as the cable is payed out from the cable vessel or shore. Once the cable is landed, the float lines are cut by swimmers or from a small boat to deploy the cable. It is very important that the float be properly tied to the cable to prevent slipping or loosening during deployment. The recommended procedure is demonstrated in Figure 2-31.

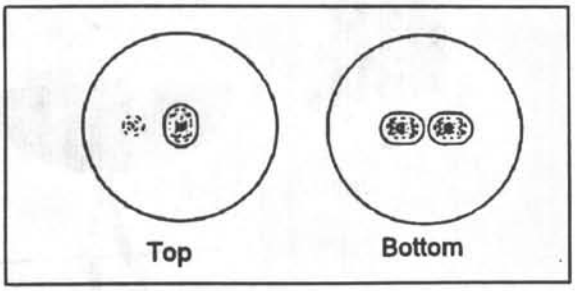



Figure 2-30. Pumpkin floats.

### 2.5.3 Variable-Buoyancy Lift Bags

The Diver Lift System provides three different sizes of open-bottom, variable-buoyancy lift bags with the following lift capacities: 220 to 500 pounds, 500 to 1,250 pounds, and 1,000 to 3,000 pounds. Because the bags are not rigid and open bottom, air must be continually added during descent to the seafloor.

Each lift bag (Figure 2-32) has features permitting buoyancy adjustment and fine trimming to accommodate maneuvering loads. The lift bridle includes internal rigging, which allows the load to be lifted in or out of the water from the top of the bag. This is a feature that is not available in most underwater lift bags.

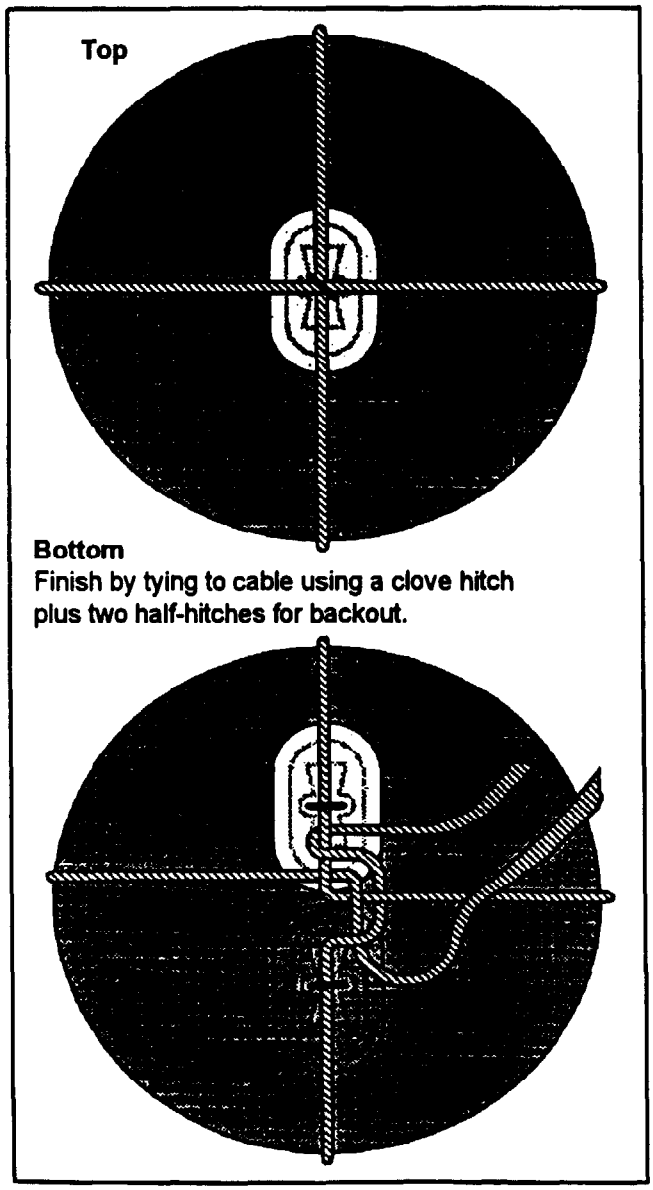



Figure 2-31. Method for tying pumpkin float to cables.

The in-water weight capacity of each bag is adjusted by setting the position of the leakproof zipper. Excess air from filling or expansion during ascent is vented through the zipper opening. The maximum lift is attained with the zipper fully closed.

Ascent/descent rate and hovering of the bag are controlled by the diver. A lanyard operated iris-type diaphragm valve is mounted on the top of each bag to accommodate regulated release of air. The lift system contains a fill valve assembly that is attached via a hose to an air supply (compressor or scuba) tanks.

Detailed procedures for operating the diver lift system are included in the Diver Lift System O&M manual. Training in use of the lift bag is highly recommended. The training should include in-water experience with ascent, descent, hovering, and load transfer in and out of the water.

**NOTE**
**Inexperienced operators should not operate lift bags.**

**WARNING**
**All lift bags and rigging shall be thoroughly inspected before use. Failure could result in serious injury to the diver.**

### 2.5.4 Surface Lift

For large lifting operations, there are many devices that are controlled

and operated from the deck of a surface vessel and powered by pneumatic, hydraulic, and electric means. **Powered lifting devices available through the OCEI** include:

- Cable reel stands
- Utility winches
- Puller-tensioner winches
- Mooring winches

These devices can be mounted on an **ocean construction support platform**, such as:

- Modular Construction Platform
- LARCs
- LCMs
- Warping tugs
- Work boats
- Barges

The lifting cable may be rigged over an end of a vessel (such as in a pipe-pulling operation) or over some type of A-frame rigging system.

Wire ropes have been conventionally used as lift lines in the past. An optional replacement line is a Kevlar (aramid) line. A wide variety of rope sizes and constructions are available in the commercial market. For a given strength, Kevlar line has the same diameter as the wire rope. Therefore, it is compatible with the existing winch and sheaves. Kevlar lines do not surge or snap back like nylon or polyester lines. The Kevlar line can be easily terminated by an eye splice like a wire rope. The cost of a Kevlar line is much higher than a wire rope, however, the higher cost may be justified by the ease in handling both on deck and underwater by the divers.

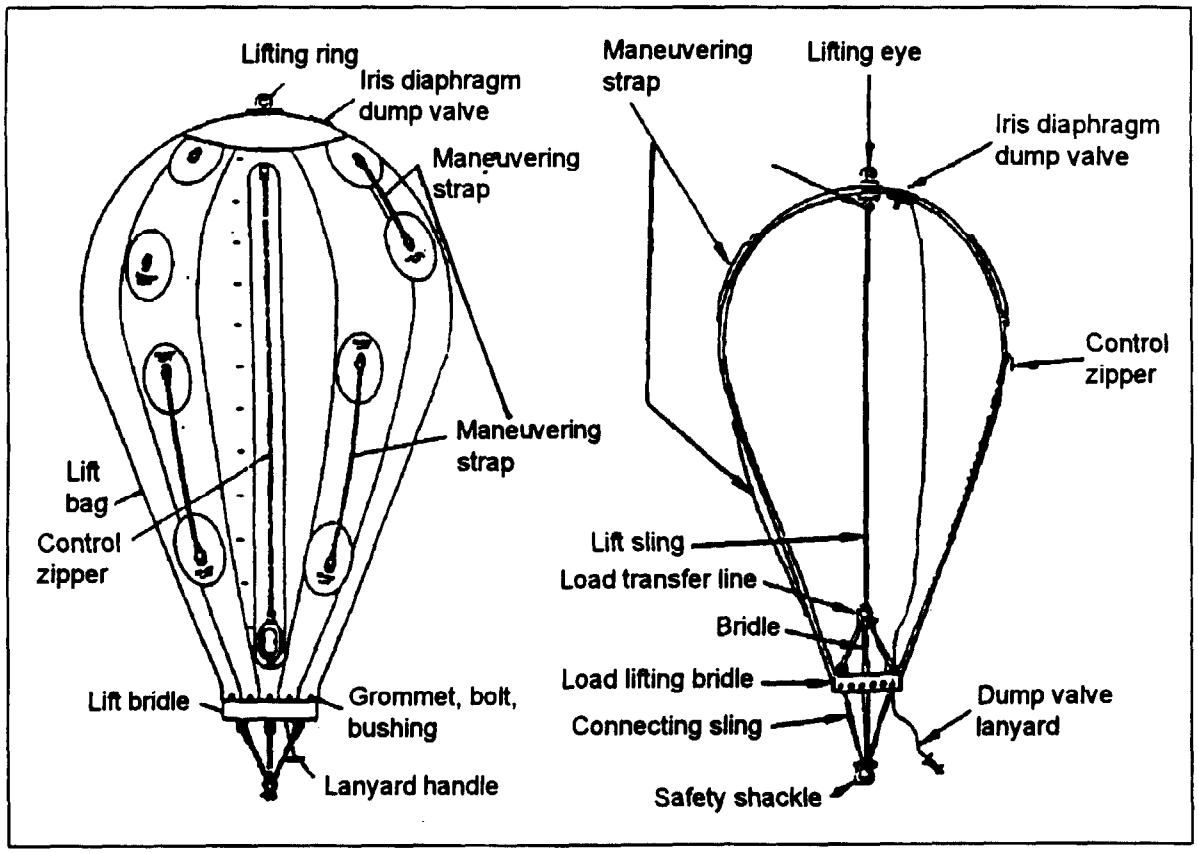



Figure 2-32
Diver lift system - bags available in three sizes: up to 500, 1,200, and 3,000 pounds.

Since surface-powered lifting devices are normally used when heavy weights or large tension forces are involved, an in-line, end-of-line, or running line dynamometer is used. This allows support personnel to monitor the tension forces in the lift lines and to watch for impending danger due to overload. Particular care must be exercised when heavy objects break the water surface as loads increase when the buoyancy effect of the water is lost. UCT personnel using surface-controlled lifting devices should be aware of the hazards involved and should have a thorough working knowledge of rigging procedures. All pulling/lifting cables should be run through fairlead sheaves at appropriate intervals to prevent a line from moving beyond the control of the operators.

**WARNING**
**Personnel should stand clear of heaving lines when lifting is in progress.**

For heavy lift operations in relatively high sea states, provision should be made to compensate for ship heave motion, which is detrimental to lifting safety. A ram tensioner ship heave motion compensator is available through OCEI. It is capable of supporting up to 25,000 pounds. The unit consists of a pneumatic/hydraulic cylinder and a set of sheaves. This compensator unit should be placed between the deck winch and the outboarding sheave (Figure 2-33). It acts like a giant shock absorber and compensates for the effect of ship heave by paying out additional lift line as the ship heaves up and by taking in the line when the ship dips down. An air compressor or a set of compressed air cylinders is required to charge the unit initially. The unit can also be used during cable laying or pipe pulling operations to maintain steady line tension.

### 2.5.5 Underwater Running Rigging System

Underwater running lines are sometimes required to move bottom sitting weights with winches located either on a surface platform or on shore. These lines are often used with fairlead or multiple sheave blocks to direct the proper tension force to the weight. The conventional running rigging system consists of either a 3/4-inch-diameter 6 x 37 wire rope, or a 1-inch-diameter polyester rope. The wire rope system can handle a load up to 10,000 pounds whereas the polyester line can hoist a maximum load of 5,000 pounds. A 3/4-inch-diameter braided aramid fiber (Kevlar)

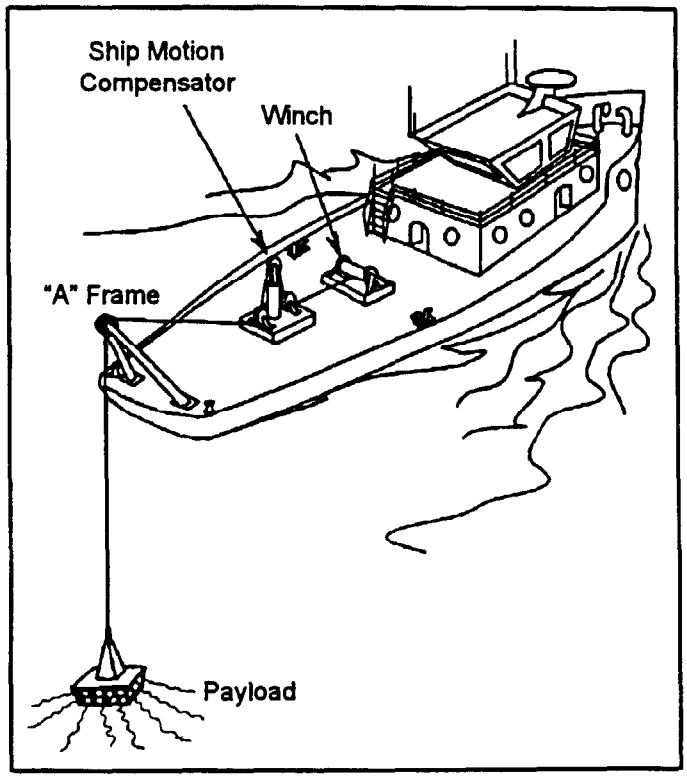



Figure 2-33
Fantail rigging for ship motion compensator.

line with a braided polyester outer jacket is available commercially to replace the stiff, heavy, and greasy wire rope as the primary running rigging system. The cost of the aramid rope is much higher than the wire rope. Lightweight blocks consisting of nylon sheaves are also commercially available for underwater weight handling. Although such lightweight hardware is costly, it does reduce the diver's strenuous activities underwater, increases work efficiency, and enhances the safety of the operation.

## 2.6 EXCAVATION

There are several different methods of excavating seabed material. The methods most suitable for typical UCT operations include:

- Air lifting
- Jetting
- Suction dredging
- Controlled blasting

Commercial divers sometimes use diesel/gasoline-driven solids handling pumps and submersible electric-driven solids handling pumps as shown in Figure 2-34. The best method for any particular situation depends on a number of factors including:

- The nature of the seabed material to be excavated: soft or hard, fine grained or coarse grained, maximum size of particle.

- Water depth.

- The horizontal distance the excavated material must be moved.

- The vertical distance the excavated material must be lifted.

- The quantity of material to be excavated and the nature of the excavation (i.e., trench for cable or pipeline burial, excavation around the base of existing piles, general excavation, etc.).

- The nature of local currents and wave action.

- The type of topside equipment and the size of construction platform available.

- Limitations on shipping space and weight for the excavation equipment.

Table 2-15 provides some general guidance on the suitability of the various excavation methods for particular circumstances. Of course, not all situations are included, and sound judgment must be exercised in the selection of the optimum method for any particular situation.

A description of each of the excavation methods is provided.

### 2.6.1 Air Lifting

An air lift can be used underwater to provide the controlled removal of seabed material. The air lift works on a differential density principle. Air is introduced into the lower end of a partially submerged pipe. When air bubbles combine with the water in the pipe, a mixture that is less dense (lighter) than the water outside the pipe forms. The lower density mixture in the pipe rises, causing a suction at the inlet. The amount of material lifted will depend upon the size of the air lift, submerged depth of the pipe, air pressure and volume used, and the discharge head.

The air lift (Figure 2-35) consists of a discharge pipe and a foot piece or air chamber. The size of the discharge pipe can range from 3 to 12 inches in diameter, depending on the work to be done (see Table 2-16). The air chamber should

be located 20 to 30 inches from the intake end of the pipe and should be fitted with a control valve that cannot be opened or closed accidentally. A handle attached to the lower end will make it easier for the diver to use. It is sometimes necessary to add weight to the lower end to help keep the intake on the bottom.

**NOTE**
**When diving with an air lift, communication between diver and topside supervisor is necessary.**

Operating the air lift involves turning on the air compressor and control valve

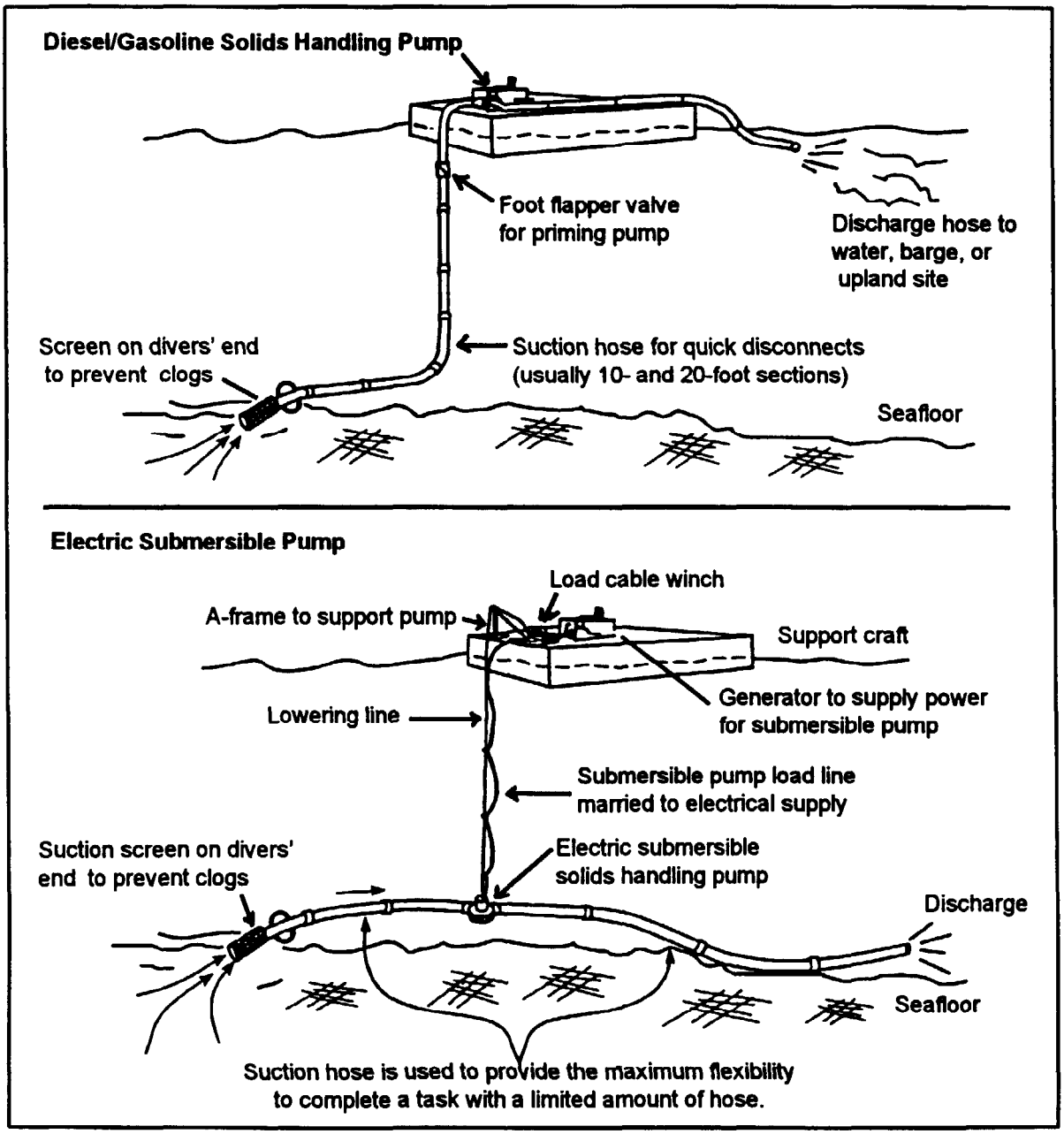



Figure 2-34. Excavation by solids handling pump.

Table 2-15
Suitability of Underwater Excavation Methods

| Excavation Factor | Excavation Method | | | |
|---|---|---|---|---|
| | Air Lift | Jet | Dredge | Blasting |
| Type of seabed material | Mud, sand, silt, clay, cobbles | Mud, sand silt, clay | Mud, sand silt, clay | Coral, rock |
| Water depth | 30 to 75 ft | Unlimited | Unlimited | Unlimited |
| Horizontal distance material moved | Short | Short | Short to long | Short |
| Quantity of material excavated | Small to large | Small to medium | Small to medium | Small to large |
| Topside equipment required | Compressor | Pump | Pump | Hydraulic power unit |
| Shipping space/weight | Large | Small | Medium | Large |

Table 2-16
Selection Guide for Air Lift Discharge Pipe and Air Line

| Diameter of Discharge Pipe (in.) | Diameter of Compressed Air Supply Line (in.) | Discharge Rate (gpm) | Air (cfm) |
|---|---|---|---|
| 3 | 0.50 | 50 - 75 | 15 - 40 |
| 4 | 0.75 | 90 - 150 | 20 - 65 |
| 6 | 1.25 | 210 - 450 | 50 - 200 |
| 10 | 2.00 | 600 - 900 | 150 - 400 |
| 12 | 2.00 | 900 - 1,000 | 200 - 250 |

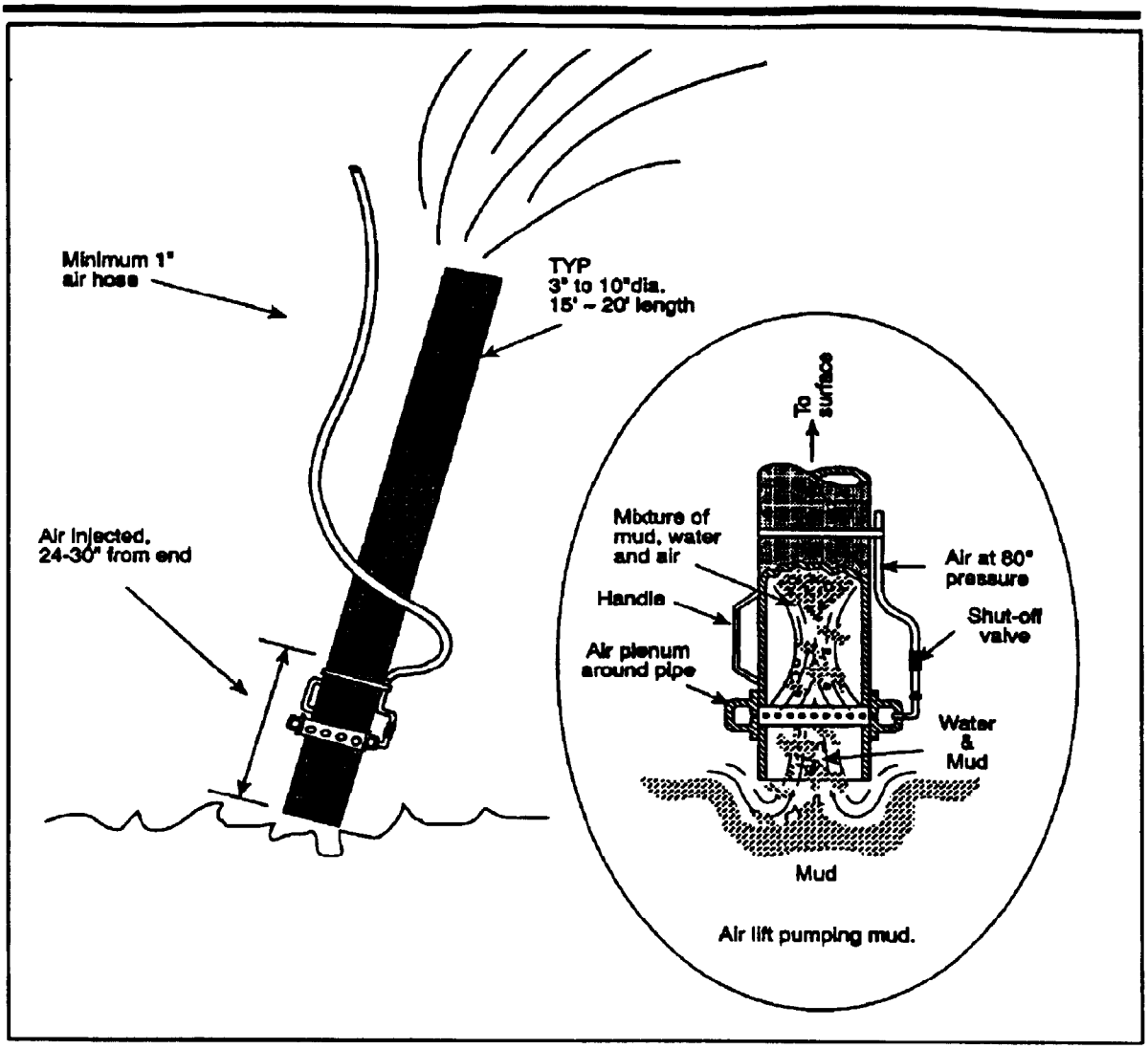



Figure 2-35. Sample air lift pumping mud. Pipe will buck at start up and if inlet is plugged, diver requires communication with surface.

and then submerging the intake end (foot piece) into the seabed material. The seabed material starts to lift almost as soon as the low-density fluid in the discharge pipe rises. Experimentation is usually required to determine the volume of air necessary for maximum efficiency. The air pressure supplied is relatively unimportant, but it must be at least greater than the pressure at the depth of water in which the excavation is being performed.

The air lift can be from 10 to 70 feet long, but it is inefficient in lengths of less than 30 feet. Although it can be used in shallow waters, it is better to use the underwater dredge, described in Section 2.6.3, in water depths less than 16 to 18 feet. The discharge end of the air lift should be kept as close to the surface as possible to avoid reducing efficiency.

The air lift has the disadvantage of discharging the lifted material relatively close to the intake point. This may result in some of the material settling back into the excavated area. The discharge should be positioned down current to allow the prevailing currents to carry the material away.

**CAUTION**

**Divers operating the air lift should use caution around the inlet to avoid the effect of suction and stay clear of the area under the discharge end where heavy objects are ejected.**

### 2.6.2 Jetting

Jetting is useful for moving seabed soils for the burial of cables and pipelines and for installing instrument tubes and structural piles. Jetting is done by supplying pressurized water from a pump mounted on a surface-support platform. A variety of jetting mandrels and nozzles can be used, depending on the work to be done and the flow characteristics desired, such as width of jet and jet velocity.

In the simplest form of jetting, vast quantities of mud, sand, or silt can be moved by directing a high-velocity water stream, through a jet nozzle, at the material to be moved. The diver using the jet will have to provide resistance to the back thrust from the jet nozzle. Commercial nozzles are available that have balancing jets that reduce or eliminate the back thrust (Figure 2-36). A pump with a flow rate of about 100 gpm and a discharge pressure of between 50 and 150 psi over bottom pressure is adequate for this type of jetting operation.

When there is a large mound of material to be moved, the diver should start at the top of the mound and wash it away, rather than starting at the base and digging a hole into it. A good procedure is to play the jet on to the objective in short, sharp bursts, in between raising the jet above the work area and directing it horizontally. In this way the disturbed material will be moved away from the area by water from the nozzle and the visibility will remain quite good in the work area. This type of jetting is efficient if there is a fairly strong current to carry the disturbed material away from the excavation area. The diver should be positioned upstream of the current.

**2.6.2.1 Cable and Pipeline Burial.** Cable or pipeline burial by jetting can be done by two quite different techniques:

- The first technique involves using large jets to erode and displace the seabed soil to leave an open trench. This method works well in many slightly or moderately consolidated cohesive soils (mud) as well as in some noncohesive (sandy) materials. The cable or pipeline to be buried is laid on the seafloor along the planned route. The jetted trench is then excavated either beneath or beside the cable or pipeline. The cable then either settles into place or is placed in the bottom of the trench.

- The second jetting method, called fluidization, is used for sandy soils (noncohe-

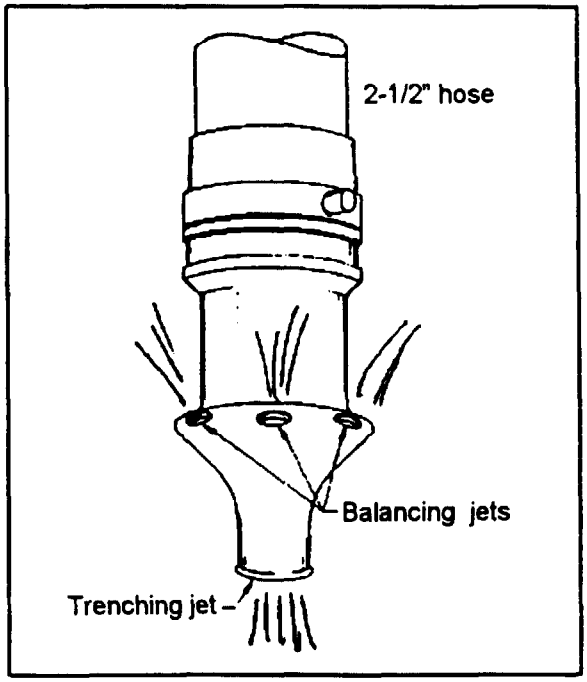



Figure 2-36. Jetting nozzle.

sive) that have a flat natural slope (angle of repose). These conditions ordinarily would require removing large volumes of material. Many small jets are mounted on the leading edge of a plow-like stinger. The small jets erode and suspend the sand in front of the stinger. The cable to be buried is fed into the jetting area by a guide chute. The reduced density of the sandy soil allows the cable or pipeline to fall and become buried. The pump used for the fluidization jetting operation should have a flow rate of at least 500 gpm at a pressure of about 100 to 150 psi. See **Sections 5.2 and 5.3 for more discussion of burial by jetting.**

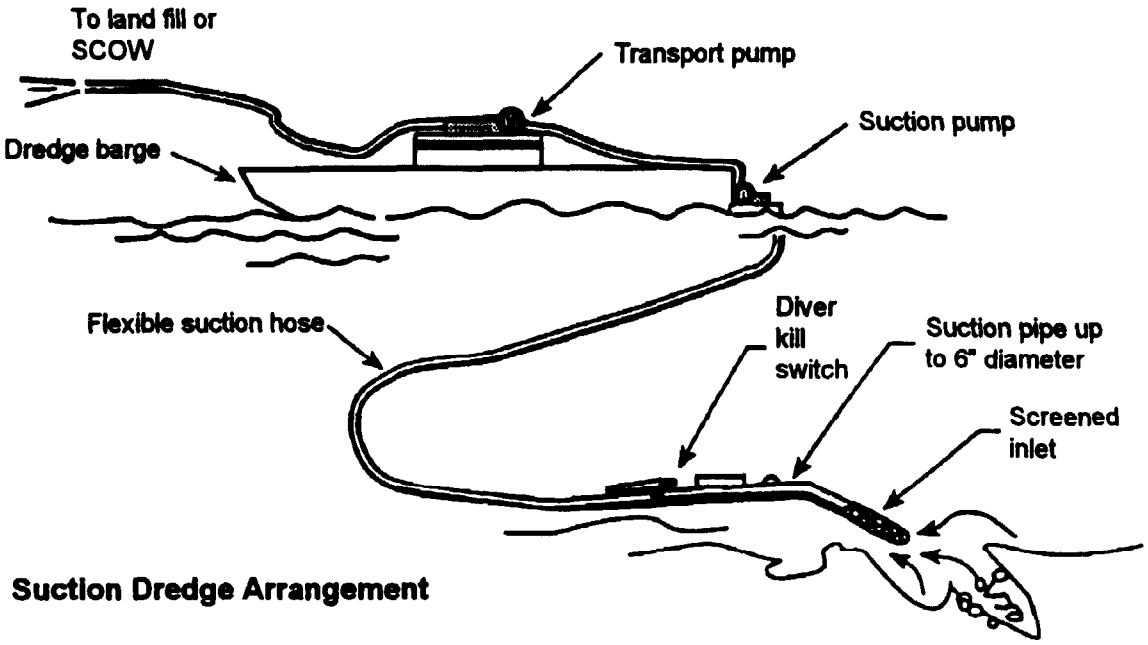
**2.6.2.2 Vertical Instrument Tube Installation.** Jetting can be used for installing vertical or near vertical instrument tubes, such as those required in shallow water arrays. To maintain the required orientation, instrument tubes are typically installed using a jetting stand. The jetting stand is placed over the location, and the instrument tube, with the jetting mandrel placed inside, is lowered by crane. The installation is directed by divers using two-way communication. With the mandrel in place, the water jet is turned on and the soil under the instrument tube is displaced. This allows the tube to fall. When the tube reaches the desired depth, the water jet is turned off. The jetting mandrel is removed and the stand is moved to the next location.

**2.6.2.3 Structural Pile Installation.** Jetting can be used for installing structural piles. Reinforced concrete piles may have a jet pipe built into the center of the pile. The water pump hose is connected to the top of the pile and the opening at the bottom of the pile tip serves as the nozzle. For all types of piles, a jet pipe is placed alongside the pile, with the tip of the pipe slightly below the bottom of the pile. The pile and jet pipe are lowered together as the jet displaces the soil below the pile. Usually the jet is removed before the pile reaches the specified penetration, and a hammer is used to drive the pile the final 5 feet or so to ensure that it has adequate bearing capacity. This method of pile installation is only effective in noncohesive (sandy) soils.

### 2.6.3 Dredging

Underwater dredging is a useful technique for moving large quantities of soft seabed material where the water is too shallow for an air lift to be effective and where the material does not have to be lifted too far above the intake point. Figure 2-37 illustrates two underwater dredge arrangements. One system uses an eductor tube or pipe with a 30-degree bend near the intake end. At the center of the bend a water jet is connected. The water jet is aimed toward the discharge along the centerline of the main pipe. The jet moves the water in the pipe and creates a suction at the intake. The nozzle suction is created by the venturi principle and the height of the lift attained depends on the size of the pipe and the output of the pump. A 200-gpm pump with a 6-inch pipe will lift as high as 60 feet above the seabed. When operating only a few feet above the seabed this same system can move as much as 10 $yd^3$ of loose gravel, mud, and sand per hour. Table 2-17 lists typical suction pipe, jet pipe, and pump sizes. Commercial eductor nozzles such as the gold dredge are listed in Appendix A.

It is preferable for the suction pipe to be lightweight for ease of handling, and plastic or aluminum pipe is recommended. A diver can hold the suction end in place and reposition it simply by swimming to a new position. Reaction forces are low and buoyancy is not normally required. A screened




**Suction Dredge Arrangement**

**Underwater Gold (Eductor) Dredge Arrangement**

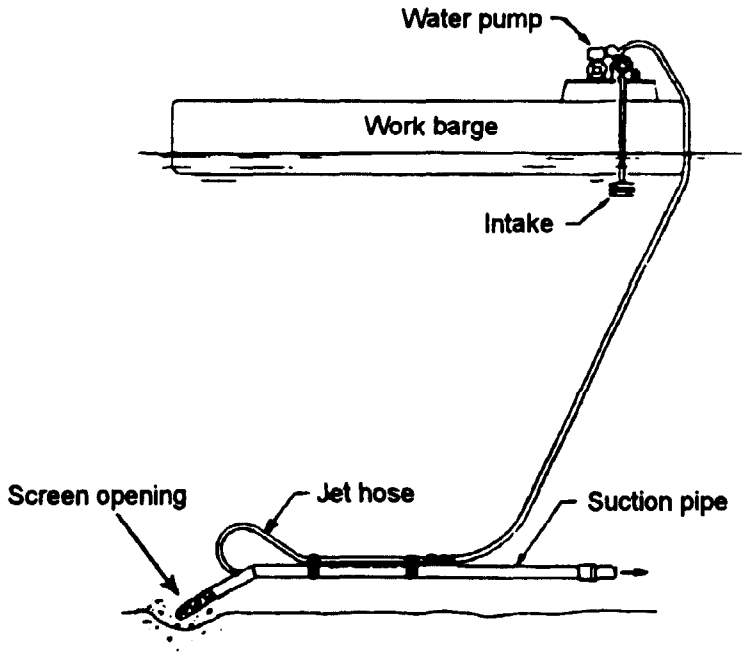



Figure 2-37
Underwater suction dredge and gold (eductor) dredge arrangements.

Table 2-17
Selection Guide for Underwater Dredge Suction Pipe, Jet Pipe, and Pump

| Diameter of Suction Pipe (in.) | Diameter of Jet Hose (in.) | Minimum Pump Output (gpm) |
|---|---|---|
| 2 | 1 | 55 |
| 3 | 1 | 100 |
| 4 | 1-1/2 | 125 |
| 6 | 1-1/2 | 300 |
| 8 | 3 | 500 |

standoff should be provided at the suction opening to prevent the diver's body from stopping the suction flow.

**WARNING**
**Positive two-way surface communication between diver and topside diver is required while dredging.**

The second suction dredge method uses a flexible suction hose connected to a dredge pump. A nozzle or suction pipe is attached to the other end of the suction hose and equipped with two handles to provide positive diver control. A kill switch should be provided on the suction nozzle to allow the diver to shut the system down. Suction dredge nozzles and hose up to 6 inches in diameter have been used. The nozzle must be equipped with a screened standoff to prevent the diver's hand or body from shutting down the suction flow. Some **specific operational recommendations are**:

- Use a screened standoff with open areas in the screen not exceeding 3 inches to eliminate the potential for portions of the diver's body or umbilical to shut off the flow.
- Use surface-supported diving gear with positive two-way communications.
- Equip the suction head with handles to provide two-handed diver control of nozzle.
- Install a diver-operated kill switch.
- Include provisions in the dive plan for routine inspection of nozzle safety screen, kill switch, and diver communications.
- Establish standard operating procedures for throttle up and diver GPM-comfort level during initial startup and diver familiarization evaluation.

## 2.7 CONTROLLED BLASTING

The information provided in this section will provide an introduction to planning and implementing underwater blasting operations. A number of factors that contribute to conducting a successful blasting operation are discussed below. However, **underwater blasting must be conducted in accordance with the procedures discussed in the following technical publications**:

- NAVSEA SW061-AA-MMA-010, Technical Manual for Use of Explosives in Underwater Salvage
- NAVSEA OP 5, Vol 1, Rev A, Ammunition and Explosives Ashore: Safety Regulations for Handling, Storing, Production, Renovation, and Shipping
- NAVSEA SW060-AA-MMA-010, Demolition Materials

**UCT blasting operations can be classified** into one of the following categories:

• ***Obstacle removal: steel, concrete, wood*** - Removing obstacles such as coral and rock outcroppings may be required for cable or pipeline installations.

• ***Trenching*** - Trenching can be used for burying pipeline and cables when other methods are impractical.

• ***Ramping*** - Ramping involves removing a cliff to provide a smoother transition for the cable or pipeline.

• ***Demolition*** - Demolition includes cutting and removing bridge piers, pilings, and various underwater foundations.

• ***Excavation*** - Excavations might include deepening or widening shipping channels.

### 2.7.1 Planning

Underwater or surface blasting is planned and executed only by properly trained UCT personnel.

> **NOTE**
> **Personnel must have successfully completed the Salvage/Construction Demolition Course and be assigned the proper blasting Navy Enlisted Classification (NEC) 5375. Personnel must complete the Explosives Handling Personnel Qualification and Certification Program at the local command in accordance with OPNAVINST 8023.2.**

An Underwater Explosives Operation Plan must be prepared before a blasting operation can be conducted. The plan is prepared after a detailed site survey has been done. **The plan should contain:**

• Description of what is to be done.

• Schedule.

• Site specific information:

- Location
- Local restrictions
- Charts (depth/profile)
- Bottom materials (samples)
- Tidal information
- Current conditions
- Weather expected
- Wave conditions
- Water temperature
- Ice conditions
- Thickness and character of overburden
- Permafrost

• Location/frequency of ship/submarine traffic.

• Description/location of underwater structures, cables, ranges, and pipelines.

• Description of affected adjacent land structures.

• List of permits/authorizations required.

• Environmental concerns:

- Marine life
- Park/Recreational areas
- Fisheries
- Natural oil/gas seepage

• Debris management.

NAVSEA SW061-AA-MMA-010 provides discussion items to consider when planning underwater blasting operations. Consideration must be given to adjacent and nearby structures, ships, and facilities, both on land and on or under the water.

Ideally, the energy released from the explosives should all be directed at doing the specific job. However, a large amount of energy will be released into the environment and must be taken into consideration to prevent damage to local facilities and ships. Consider the following when planning the blasting operation:

- Released energy tends to follow the path of least resistance.

- Released energy concerns are: air shock waves, water shock waves, and ground motion.

  - All can rattle and break windows.
  - Ground motion and water shock waves can severely damage ships, underwater structures, and buildings.

- Charges detonated inside structures and buildings can reduce air/water shock waves but increase ground waves.

One underwater explosive technique that is effective in containing the shock wave is bubble screening, sometimes called the "air curtain." This simple technique of creating a "wall of air" around the blast will reflect the shock wave back in the direction it came from. The air screen pattern is constructed using standard 2-inch galvanized piping that can be assembled in any geometric shape. A standard air hose fitting is attached at each end. The pipe is then perforated at regular intervals with holes not larger than 1/4 inch in diameter. The assembled pipe is lowered and positioned around the blast area. When a large volume air compressor (250 scfm or greater) is used to pump air into the pipe, the air escapes through the perforations and rises through the water column to create an "air curtain."

### 2.7.2 Permits and Authorizations

**Review Section 1.4.4.** All underwater detonations require prior approval due to military, environmental, or legal reasons. Federal, State, and local agencies must be contacted. The highest Navy authority has mandated that all Navy activities comply with environmental regulations:

- Navy Fleet Commanders have issued amplifying instructions for underwater detonation requirements.

- Obstruction or alteration of U.S. navigable water requires authorization via the Army Corps of Engineers.

- Local and State officials have their own specific requirements that must be adhered to, contact:

  - State Oil and Gas Commission
  - State Land Commission County Board of Supervisors
  - City Police
  - Fire Marshal
  - City Engineer

- Environmental concerns include disruption/destruction of marine life and all forms of pollution. An environmental impact statement is required for any operation that could adversely effect the environment (see Section 1.4.4).

- Contact Fish and Game Commission.

### 2.7.3 Equipment

In addition to equipment required for the actual demolition work, other types of equipment are required for underwater operations. Equipment lists are provided in

NAVSEA SW061-AA-MMA-010, Chapter 8. These include:

- Demolition equipment
- Salvage accessories
- Salvage equipment

### 2.7.4 Technique

All factors must be considered when selecting the best explosives for a particular job. Inspection dives are needed to accurately determine site conditions that relate to technique selection. NAVSEA SW061-AA-MMA-010 lists characteristics of most conventional military explosives as well as selection criteria to be used in Chapter 4 (see Table 4-2). Examples of techniques for most applications used by the UCTs are also described in Chapters 11 through 16 of the NAVSEA document. Yet, another good source for underwater demolition techniques is the **Army Field Manual FM 5-250, Chapters 3 and 4.**

As a general rule in planning explosives operations such as cutting steel, wood, and timber, test shots should be done in advance of the operation to determine the best methods and techniques to do the task. The test shots will also serve to identify potential hazards that could be encountered during the operation, such as the size of the ground or water shock wave and how it effects surrounding structures, barges, boats, etc.

**NOTE**

**Always plan on doing test shots. Start with small shots and gradually increase, checking the results after each shot. Factors to consider include size, number, location, and delay patterns of charges.**

### 2.7.5 Standard Operating Procedures (SOPs)

SOPs are required for all detonations involving bulk charges by NAVSEA OP 5, Vol 1, Rev 5, Chapter 2. All personnel involved must be familiar with the SOP and their specific responsibilities and duties. The SOP will include:

- Description of duties for all involved personnel.
- Description of team organization.
- Safety analysis.
- Operating procedures.
- Identification of medical facilities, emergency access routes, representatives, and responsibilities.
- Emergency procedures, telephone numbers, and contacts.
- Casualty procedures.
- Area security.
- Prefire procedures.
- Misfire procedures.

#### 2.7.5.1 Incident Reporting.

**NOTE**

**Commanding Officers are required to conduct investigations and report all explosive mishaps within their commands. The mishaps will be reviewed by NSWC Crane, Indiana.**

Procedures and format for reporting mishaps are covered in OPNAVINST 5102.1C Appendix B. The following apply:

- ***Explosive mishaps***: Unplanned or unexpected event causing injury, illness, or death, damage, or loss of material. Unplanned explosions.

- ***Explosive accident***: Accidental explosion or fire involving demolition or incendiary materials, including the inadvertent actuation, jettisoning, or release of materials which result in fire or damage.

- ***Explosive incident***: Any demolition occurrence which creates a potentially hazardous situation including errors in processing, assembling or using explosives, loss or abandonment of explosives, misuse or unauthorized alteration of materials.

**2.7.5.2 Transporting Explosives.** Regulations for transportation of explosives are contained in NAVSEA 2239, NAVSEA OP 2165, and OPNAVINST 5330.13A. Vehicles and drivers must meet requirements specified in the explosive drivers handbook. Most demolition materials fall into a security classification category II requiring an armed guard during transportation.

### 2.7.6 Explosive Cutting Techniques

There are many commercially available explosives that are approved for use. Blasting personnel should be thoroughly familiar with the explosive before using it. Whatever explosive is used, care must be taken to ensure that it has a water resistance that stays in place and is not moved by currents or surge.

A list of the more common explosives and initiation systems. Information on their use can be found in manufacturers' literature as well as from the Naval Weapons Support Center, Crane, Indiana. They are:

- C-4/TNT
- Flexible Linear Charges
- Explosive Cutting Tape
- Novel/Primadet Initiation Systems

Explosive Cutting Tape (ECT) is a flexible linear-shaped charge with a copper liner and can be used to cut all types of metal targets such as steel "H" pile and the like. It is available in various sizes, such as:

| | |
|---|---|
| MK 142 | 300 gr/ft |
| MK 143 | 600 gr/ft |
| MK 144 | 1,200 gr/ft |
| MK 145 | 2,400 gr/ft |
| MK 149 | 5,400 gr/ft |

Primadet is a versatile reliable nonelectrical detonator for blasting and demolition. It has replaced blasting caps for most blast initiations. It is much easier to use and more reliable than electric detonators. The shock tube cannot be initiated by radio frequency energy, static or stray electrical energy, flame, friction, or impact. When installed, the shock tube sends a low energy signal at approximately 6,500 feet per second. With its shipping plug in place, it will not initiate nearby explosives should it be accidentally initiated.

Figure 2-38 provides an example of how to use Primadet with ECT to cut through steel "H" piles. The explosives must be held securely against the pile. A plywood standoff helps keep the tape up against the web. Duct tape wrapped around the periphery holds the cutting tape in place.

### 2.7.7 Explosive Excavation Techniques

There are various explosive excavation techniques that UCT personnel should be

familiar with: contact blasting, snakeholing, blockholing, drilled charges, and shaped charges. These techniques are shown in Figure 2-39.

• ***Contact blasting*** is an external charge method where the explosive charges are placed on and in intimate contact with the material to be excavated. As the explosive detonates, it imparts a violent shock to the material, causing it to shatter or crack.

• ***Snakeholing*** is a blasting method used where boulders or formations are buried or partially buried in the bottom. This technique consists of drilling a hole immediately under the obstruction to be removed, placing a charge in the hole, and detonating.

• ***Blockholing*** is an internal charge method based on drilling and loading one or more holes in a rock or ledge, and is used primarily for obstacle removal. This technique is efficient because the charge is contained and will always explode outward, causing cracking in all directions.

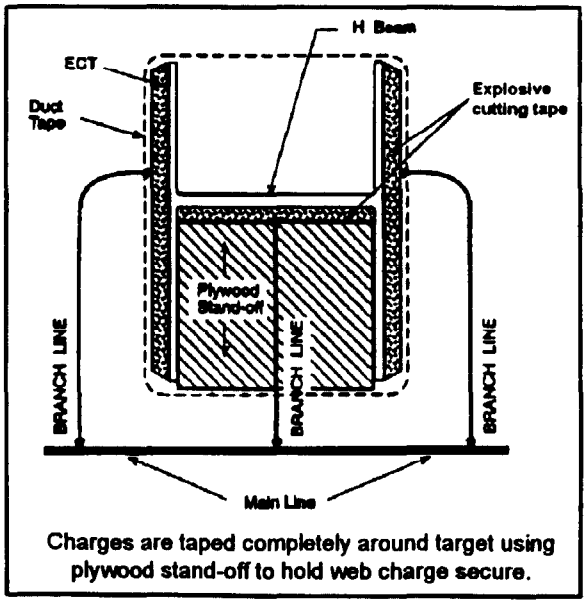



Figure 2-38. How Primadet, with ECT, cuts through steel "H" piles.

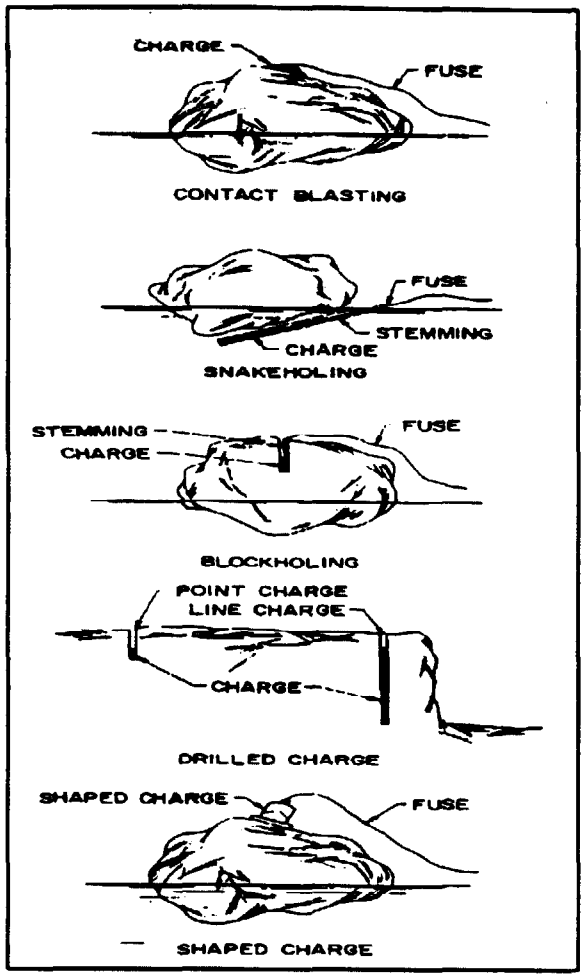



Figure 2-39. Explosive excavation techniques.

• ***Drilled charge*** is a highly accurate method where large areas can be excavated by detonating blasting charges located in drilled boreholes in a calculated sequence. Drilled charges can be either point charges or line charges. A charge that is very short (less than two or three borehole diameters in length) is considered a point charge. A charge that is long in comparison with its borehole is considered a line charge. The difference between the blasting effects of these two types is that the shock waves from the point charge radiate spherically outward, while the shock waves from the line charge radiate radially from the line.

All charges placed in a borehole require proper stemming. Ten feet of water above

the borehole is considered adequate. Filling the borehole with sand also helps to confine the explosion and improve the efficiency.

- ***Shaped charge*** is an external charge method that is widely used. This technique provides deeper penetration than conventional contact techniques for the same amount of explosive, and has the same advantage of easy charge placement associated with contact blasting. Although the term "shaped charge" is commonly used, and is used in this manual, the type of charge referred to herein is technically a "linear shape charge." A linear shape charge is a shaped charge that is configured to stand off from the surface on which it is placed. This standoff creates an air pocket that allows the formation of a gas jet.

## 2.8 ANCHORING

Anchoring is integral to many UCT operations both on land and offshore. Often, there is no one anchor choice that is the best for any application. Many anchors and anchor types will work acceptably if used correctly and with a little creativity. This section discusses the various anchor types, their limitations, and their strengths to allow the UCTs to solve most of the anchoring problems typical of nearshore operations.

Anchors are classified as:

- Drag embedment
- Deadweight
- Direct embedment

Drag embedment anchors rely on dragging to embed the anchor to achieve holding capacity. Deadweight anchors rely on weight to counteract uplift loading and to develop capacity through friction or adhesion with the seabed. Direct embedment anchors are anchors embedded deeply into the seafloor by various means and they rely on the strength of the overlying soil to develop capacity.

### 2.8.1 Drag Embedment Anchors

**2.8.1.1 Anchor Selection.** Common types of drag embedment anchors are shown in Figure 2-40. They include:

- Plowshare (CQR and Bruce)
- Hooking anchors like the Northill and grapnel
- Lightweight (Danforth, LWT, Fortress)
- Navmoor 100 pound
- Stato 200 pound
- Stockless anchors

The seafloor conditions where these anchors work best are listed in Table 2-18. Approximate holding capacity to weight ratios (efficiency) are listed in Table 2-19.

Sharp-fluked anchors like the CQR, Lightweights, Northill, and Navmoor are suitable for hard sand and clay seafloors. Broader fluked anchors like the Bruce, Stato, and Stockless anchors have difficulty biting into and penetrating harder soils; thus, they are better suited to less dense sands and clays.

Bruce, CQR, Stato, and Navmoor anchors are stable and do not tend to roll out of the seafloor when they are dragged. Deep burying anchors with pointed flukes and small crowns (lightweight types), and Stockless anchors can roll out of the seafloor when they are overloaded and may not re-engage with further pull.

Lightweight anchors are built from steel and aluminum. The capacities of similar size steel and aluminum anchors are roughly equal, even though the aluminum anchors

weigh half as much as the steel anchors. The greater efficiency of the aluminum anchors must be balanced against their higher cost. These anchors can penetrate deeply into the seafloor and generally produce the highest capacities of the anchor types. However, because of their tendency to roll (be unstable), it is advisable to be a little more conservative in their sizing. Very lightweight (aluminum) anchors have had problems in soft mud, because anchor crown size is insufficient to cause the flukes to rotate and to trip into the soil during drag. The new Fortress anchor design seems to have overcome this deficiency. Deep burial of these streamlined anchors can cause problems with anchor recovery, particularly in mud. These anchors are not recommended for free swinging moorings because the shanks have a tendency to bend when loading direction changes.

The small Navmoor and Stato anchors are unlike most small anchors, because they are configured just like the much larger fleet mooring size anchors. They are included here because they are available, provide similar performance in most seafloors, and are less likely to be damaged (bent flukes or shank) during use than streamlined small boat anchors.

Hooking anchors are effective in coral and rock seafloors. The Navmoor 100 has also worked effectively in rock. It is designed like its full-size counterparts and is capable of tolerating very high loads on the fluke tips. Lightweight anchors cannot tolerate loads on the fluke tops, thus they are not recommended for rocky conditions.

Table 2-18
Where Common Anchors Are Effective

| Anchor | Sand/Clay | Mud | Gravel | Coral/Rock | Weeds |
|---|---|---|---|---|---|
| Bruce | X | | X | | |
| CQR Plow | X | X | | | X |
| LWT | X | | | | |
| Danforth | X | X | | | |
| Fortress | X | X | | | |
| Stockless | X | | | | |
| Stato 200 | X | X | | | |
| Navmoor 100 | X | X | | | |
| Northill | X | | X | X | X |
| Grapnel | | | | X | |

Table 2-19
Average Anchor Efficiency[a] for Small (<200-lb) Anchors

| Anchor Type | Mud/Soft Clay | Sand/Stiff Clay |
|---|---|---|
| Bruce | 6 | 30 |
| CQR Plow | 10 | 40 |
| LWT | 2 - 10 | 40 |
| Danforth | 20 - 40 | 50 - 100 |
| Fortress (Aluminum) | 35; 50 (@ 45[b] degrees) | 100 - 180 |
| Stockless | 2 - 3 | 5; 10 (@ 35 degrees) |
| Stato 200 | 25 | 20; 30 (@ 28 degrees) |
| Navmoor 100 | 25 | 40 - 50 |

[a]Anchor capability = anchor efficiency x anchor weight.
[b]Angles refer to fluke angle settings.

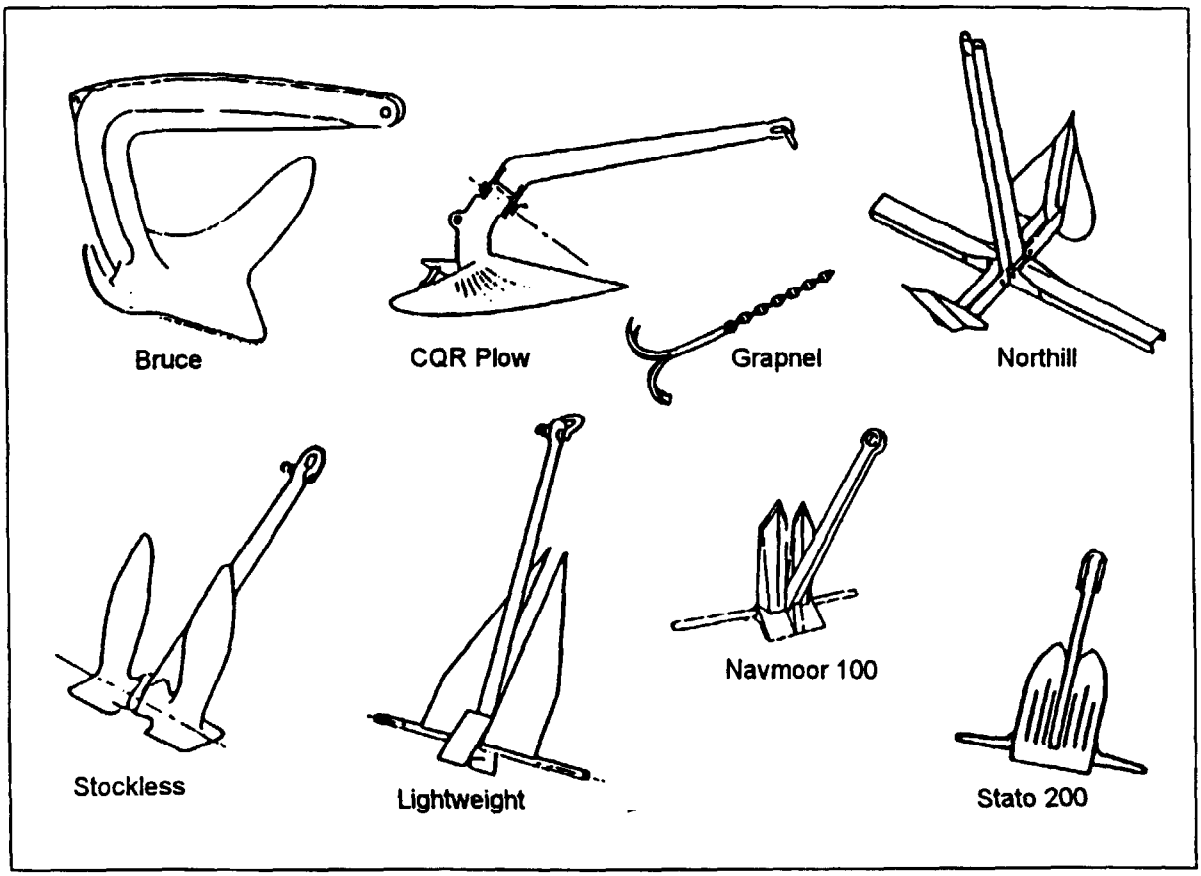



Figure 2-40. Small drag embedment anchors -- less than 200-pound weight

**2.8.1.2 Ways to Improve Capacity and Troubleshooting Anchor Problems.** An anchor can fail to hold because it is improperly set, is inappropriate for the seafloor or load conditions, or the scope is too small for proper anchor performance. Some typical problems and solutions are listed in Table 2-20.

The minimum scope required depends on the expected load and the characteristics of the anchor rode. Scope can vary from 5 (ratio of line length to water depth) for chain to 10 or more for wire or synthetic line. The scope must be adequate to ensure that the line angle at the anchor is less than about 6 degrees at the mooring design load. Scope can be reduced by the addition of line clumps which depress the line and reduce the line angle at the seafloor. Line clumps can be preinstalled on permanent moorings or they can be added during emergencies when small boat anchors fail to hold.

Table 2-20
Common Anchor Problem Tests

| Problem | Solution |
|---|---|
| Sand/Hard Soils | |
| Anchor not embedding | Reduce fluke angle<br>Sharpen anchor flukes<br>Add piggyback<br>Use larger or heavier anchor or more chain<br>Use diver to help set flukes with jet or airlift<br>Add scope or add kellet to the chain<br>Change to a hooking anchor |
| Mud | |
| Anchor not embedding | Fix the flukes in the open position and place anchor on seafloor<br>Change points down to plow-type anchor or anchor with large tripping palms |
| Sand/Hard Soils/Mud | |
| Anchor unstable | Add or extend stabilizers<br>Change to more stable anchor |
| Anchor not holding | Use larger anchor<br>Add piggyback<br>Increase scope/add kellet<br>Check anchor for fouling |

The first option when a small boat anchor drags is to increase scope. Continued dragging may require use of engine power to augment the anchor. Another option, illustrated by Figure 2-41, is to slide a line clump down the anchor rode to depress the line. The weight is called a "kellet" and it can be constructed from materials on hand. The best position of the kellet is about midway along the rode, but it may have to be adjusted if there is too much bounce in the line.

Another method to increase holding capacity is to use multiple anchors, in tandem (piggyback) or side-by-side (Figure 2-42). Tandem anchors can hold 20 to 30 percent more than two anchors pulled individually provided that the correct anchors are used in tandem. The piggyback is also useful in helping the leading anchor penetrate harder soils. The simplest connection for the piggyback anchor is directly from the piggyback's shank to the crown end of the leading anchor. For this to be effective, the leading anchor must be of a stable design, like the Bruce, plow, or Navmoor. Lightweight anchors become unstable when loaded by the piggyback method and roll out of the seafloor. The preferred connection for lightweight anchors is to the leading anchors' shackle; although, this complicates installation. Side-by-side and tandem anchors should be separated longitudinally by a distance equal to at least two anchor lengths to avoid interference.

### 2.8.2 Deadweight Anchors

Deadweight anchors can vary from sophisticated (concrete/steel anchors with cutting skirts) to engine blocks, railroad wheels, concrete clumps, etc. Some options are shown in Figure 2-43. Although inexpensive to fabricate, they are cumbersome to handle; thus, they are seldom used. Deadweights can be constructed from concrete or steel. The material has an important effect on capacity because concrete loses 43 percent of its weight in water compared to 15 percent for steel, and holding capacity is related to the submerged anchor weight.

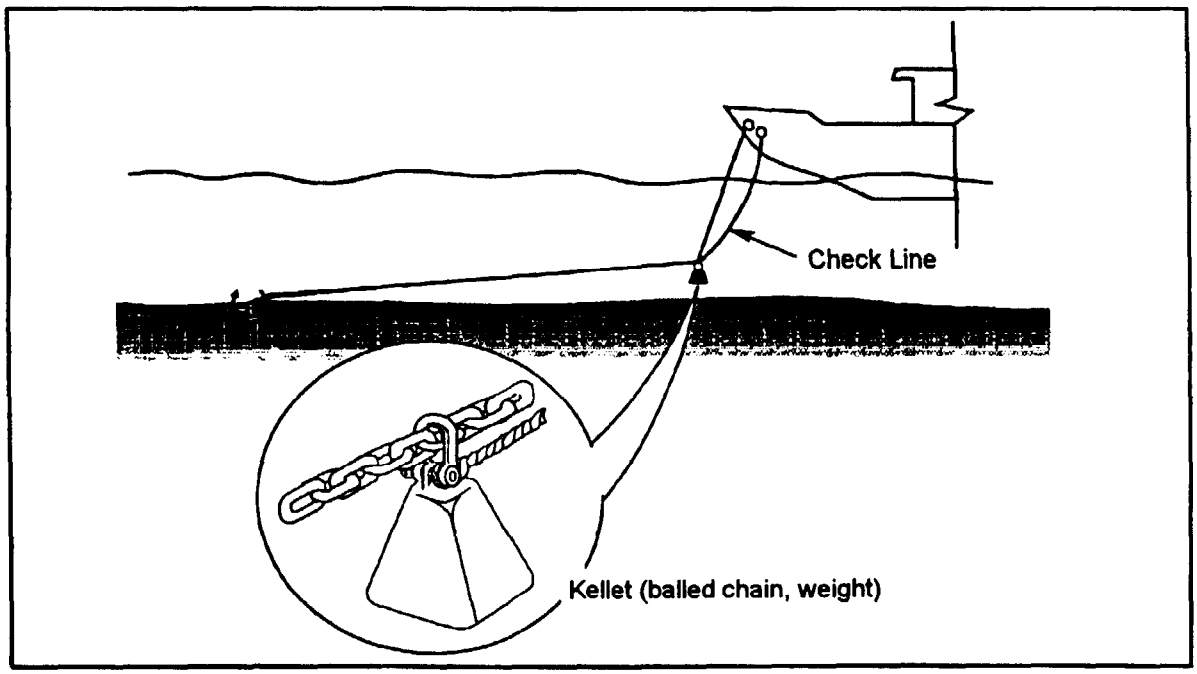



Figure 2-41. Use of a kellet to improve anchoring.

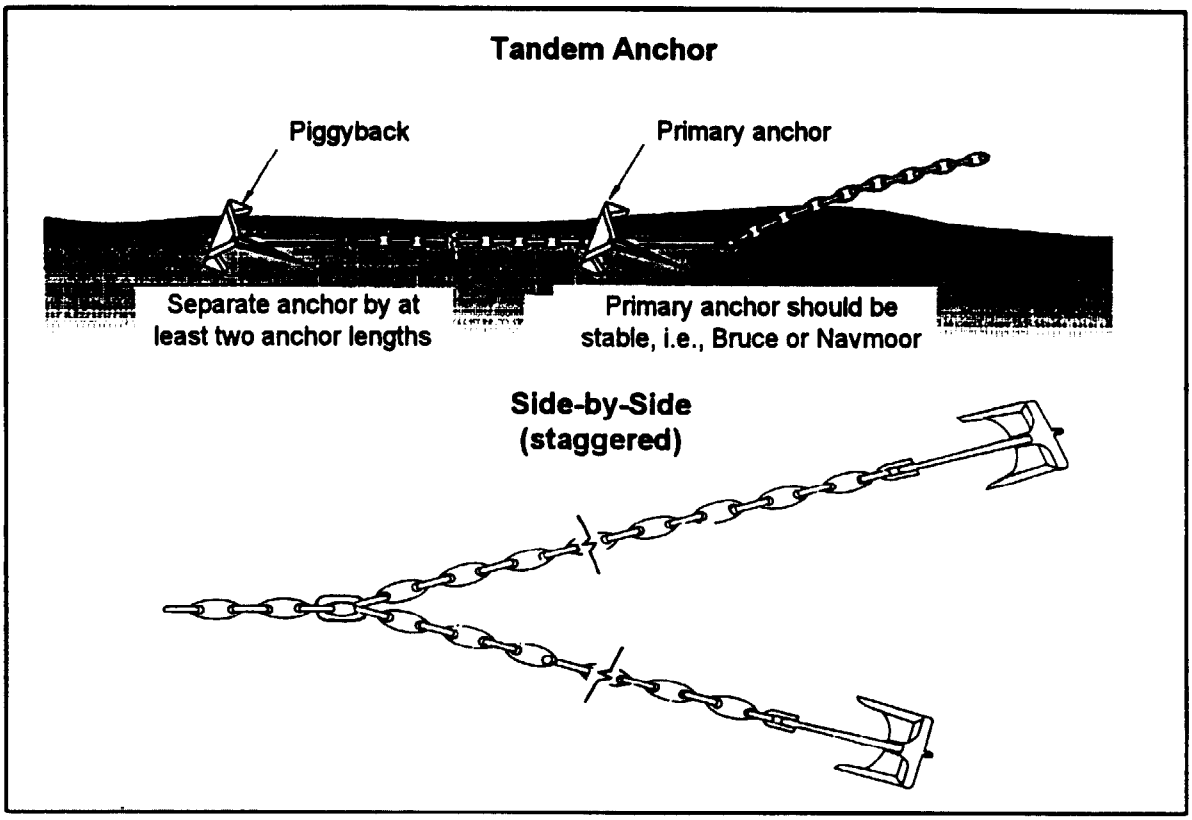



Figure 2-42. Use of multiple anchors to improve anchoring.

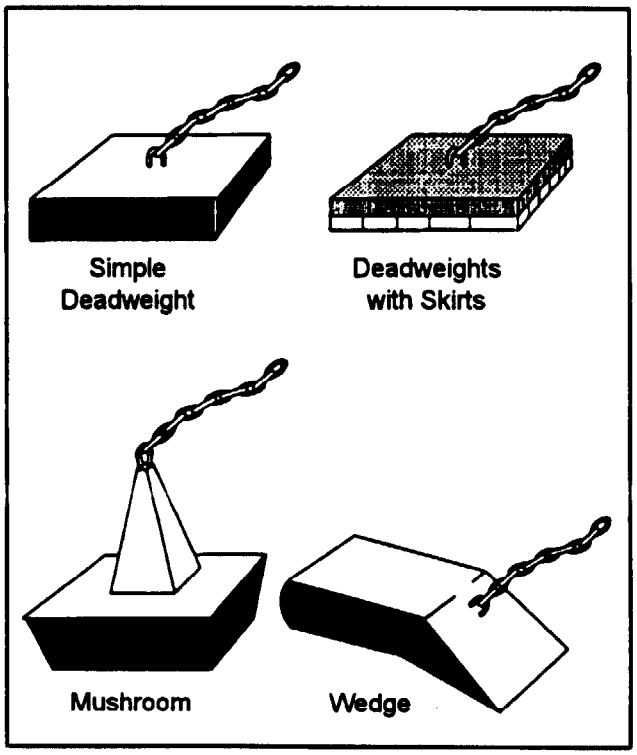



Figure 2-43. Deadweight anchors.

**2.8.2.1 Simple Deadweights.** The capacity of a simple deadweight anchor in mud will increase with time as it becomes silted in and as the soil strengthens due to the anchor weight; eventually achieving a capacity of about 50 percent of the anchor's net submerged weight. The initial horizontal capacity for deadweights in mud or clay can be as little as 20 percent of their net weight, and they have been known to slide on slopes of as little as 5 degrees.

Holding capacity of deadweights in mud can be increased by the addition of skirts at the base of the anchor. The skirts should be vented to allow the water and soil to escape during embedment. The anchor's concrete or steel body embeds roughly the same for plain and skirted anchors, but the skirts are sized to penetrate to deeper, stronger

soil. This results in a significant increase in anchor capacity. The horizontal holding capacity of a simple deadweight on sand is roughly 70 percent of the net submerged weight. Adding skirts for sand is useful in preventing scour at the base but has little effect on anchor capacity. Procedures for optimizing deadweight anchor design are given in the NCEL Geotechnical Engineering Handbook (Rocker, 1985) or from the NFESC Seafloor Engineering Division.

The idealized simple deadweight resists horizontal load by static friction and the vertical load by a portion of the submerged anchor weight. Any vertical load reduces the anchor's net weight and, thus, the capability of the anchor to resist horizontal loads. Simple deadweight anchor capacity can be estimated by the following equation:

$$F_h = K * W - F_v$$

where:

$F_h$ = horizontal load

K = 0.5 (mud); 0.7 (sand)

W = net weight of anchor

$F_v$ = vertical load

**2.8.2.2 Mushroom and Wedge Anchors.** These anchors are more efficient forms of deadweight anchors when they are not subjected to significant vertical loading. For horizontal loading, these anchors will develop a holding capacity in mud equal to their weight in air; and a holding capacity in sand equal to 2-1/2 times their weight in air. The wedge anchor can be used on hard clays, coral, and rock seafloors with the addition of a steel digging plate at the front face.

Methods for improving the capacity of wedge anchors are being developed at NFESC.

### 2.8.3 Direct Embedment Anchors

Direct embedment anchors installable with equipment available to the UCTs are shown in Figure 2-44. They include driven, jetted, and screw anchors procured commercially or sized and built according to simple guidance provided in this manual. These anchors can be used alone for low capacity applications or used in multiples to satisfy high holding capacity requirements.

**2.8.3.1 Driven Anchors.** This type of anchor is installed by using a small hydraulic or pneumatic driver. The drive rod should have sufficient length to achieve a depth of embedment after anchor setting in sand and clay soils of at least five times the anchor's minimum dimension. For soft seafloors or for higher capacity, multiple extension drive rods are used to achieve deeper embedment. The user should be aware that extraction of deeply embedded drive rods can be difficult, particularly in sand. After driving, the drive rod is extracted and the anchor is available for setting if verification of final capacity is needed. For example, anchors used to restrain a pipeline must be set to prevent slack from occurring while the anchors are in use. During setting, the anchor rotates or keys to a position perpendicular to the direction of loading. A typical setting load is 50 percent of the anchor's rated capacity.

NFESC testing showed that simple plates or Manta Ray anchors can be installed on the beach to depths of 6 to 10 feet in a few minutes with a lightweight powered driver. Poinjar and Cobra pneumatic and Stanley hydraulic drivers were equally effective on

the beach. The NFESC hydraulic rock drill was an effective driver during offshore testing.

The Arrowhead (triangular) anchor is available in sizes of 2 to 17 inches; installers report difficulty in driving anchors larger than 10 inches in harder soils. In harder soils, the Arrowhead frequently pulls out without setting. To avoid this, the hole should be backfilled and tamped prior to setting. This also is a manufacturer-recommended procedure for Manta Ray Duckbill anchors in hard soils.

The plate anchor shown in Figure 2-45 can be built from mild steel and sized to the application (NFESC can provide design guidance). The plate anchor sets (keys) more rapidly than the other anchors because of the eccentric wire connection, and can be fabricated from readily available steel sections. Small plate anchors (about 30-in.$^2$ area) driven to depths of about 10 feet at the shoreline have shown extraordinary capacities of over 20,000 pounds. This simply suggests the potential of small driven anchors for satisfying many UCT needs.

**2.8.3.2 Jetted Anchors.** Piles, deadweights, mushroom, and simplified cone anchors can be jetted into the seafloor. Jetting is applicable to sand and mud soils, but is not suitable for clays. Tests at NFESC of the simplified cone anchor show that these diver-emplaced anchors are suitable for low to moderate uplift loads (2 to 10 kips). The following applies to jetting of simple pipe and cone anchors that can be accomplished with equipment available to the UCTs.

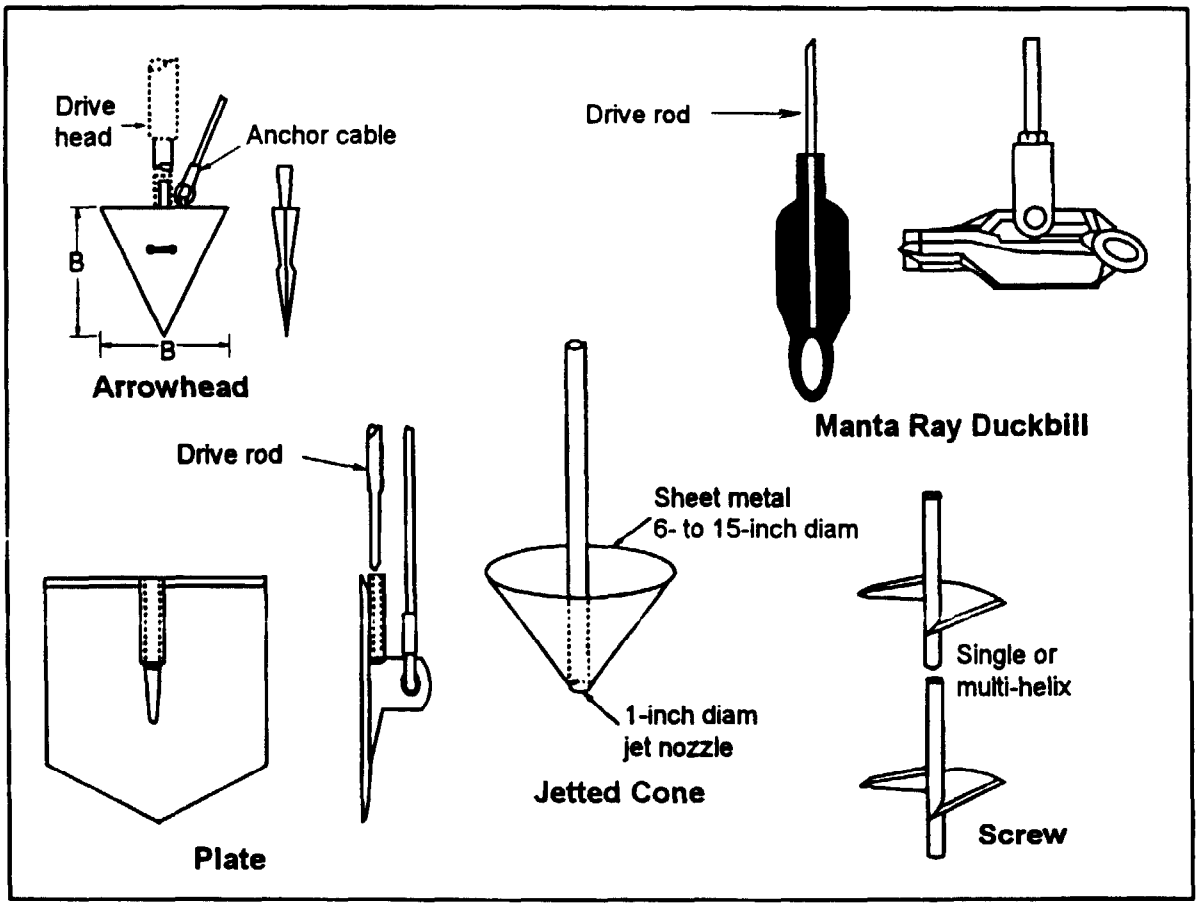



Figure 2-44. Direct embedment anchors.

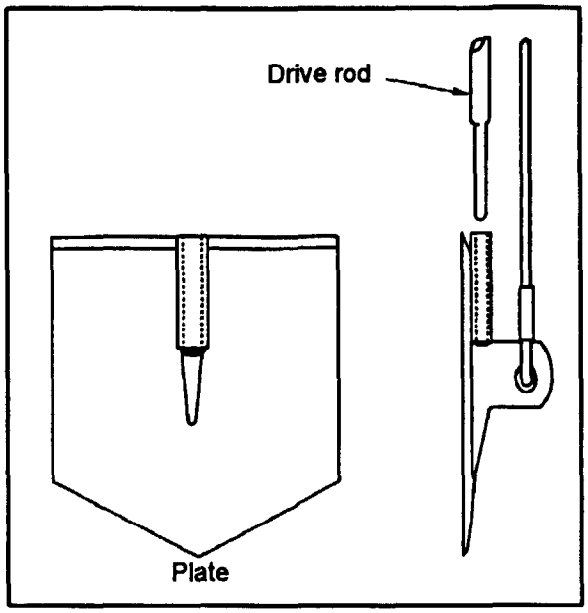



Figure 2-45
Simple fabricated plate anchor. (Note: The length should be 1 to 1-1/2 times the width.)

Water is pumped into the upper end of the pipe and discharged at the bottom, thereby dislodging soil and permitting the cone and pipe to settle into the liquefied soil. The soil should be tamped thoroughly after jetting to redensify the soil and increase anchor capacity. Another method of increasing capacity is to pump grout through the pipe to fill any voids, enlarge the effective area of the cone shape, and to further compact the soil. If there are gravel or clay layers in the seabed, the cone should be eliminated from the assembly to simplify installation. Then, grout can be pumped to create a small bulb of grout at the base of the pipe to increase capacity. Studs can be located on the pipe to enhance grout-to-pipe bonding.

**2.8.3.3 Screw Anchors.** This anchor comes in single and multi-helix configurations. High capacity screw anchors are installed on land easily with truck- or jeep-mounted equipment, while lower capacity anchors are installed by hand or with a power digger. Small 4-, 6-, and 8-inch anchors are usually installed by hand by placing a bar through the shaft eye. Anchoring capacity depends on soil type, number and spacing of helixes, torsional strength of the shaft, and depth of anchor embedment. For safety, it is recommended that only the lower helix of a multi-helix screw anchor be considered when calculating anchor capacity.

Due to difficulties associated with torque resistance during installation, screw anchors are better suited to onshore anchoring applications. Use of screw anchors underwater is more difficult because of the need to resist the applied torque. To eliminate this problem for pipeline anchoring, a counter-rotating twin-screw anchor system that is surface controlled was developed by Anchoring Incorporated of Houston, Texas, to clamp the pipeline to the seafloor.

**2.8.3.4 Plate Anchor Holding Capacity.** There is a significant amount of data on the capacity of the various anchor types that is often conflicting and difficult to interpret. The following methods for estimating plate anchor capacity, $F_a$, in sands and clays are based on NFESC testing and are suitable for routine anchoring applications. These equations are valid for anchors embedded to at least five times the minimum anchor dimension after setting:

*Sand*

$F_a = 15 * D * A$ --- Offshore anchors and beach anchors below water table.

$F_a = 25 * D * A$ --- Beach anchors above water table.

**Note:** For jetted anchors in sand, reduce $F_a$ by 50 percent to account for soil disturbance during jetting. For horizontal loading in sand, increase $F_a$ by 25 percent.

***Mud and Clay***

$$F_a = 12 * C * A$$

where:

$F_a$ = anchor holding capacity (pounds)

D = anchor depth of embedment after setting (feet); for driven anchors, use driven depth minus one anchor length.

A = anchor area (square inches)

C = soil undrained shear strength (psi); this can be determined with the vane shear device provided in the geotechnical tool kit.

## 2.9 REMOTELY-OPERATED VEHICLES

Remotely-operated vehicles (ROVs) are robots that can be used to support inspection, survey, and light work tasks underwater. They provide deep and long duration dive capabilities in hazardous water conditions with minimal risk to personnel. ROVs can also supplement manned diving operations by performing support tasks before, during, and after the divers are deployed. Overall ROV operations require less personnel and support equipment than do manned diving operations.

Performance capabilities and designs of ROVs vary widely and, except for vehicles originating from the same manufacturer, there is little similarity from vehicle to vehicle. Available ROVs range from lightweight, "eyeball" or inspection only, to 10-ton heavy work systems that are capable of diving to 20,000-foot depths.

The **four basic types of ROVs** are:

- Tethered, Free-Swimming
- Tethered, Bottom-Crawling
- Towed
- Untethered

A wide assortment of instruments and tools can be attached to ROVs. The number and type of auxiliary hardware that a vehicle can accommodate depends on the payload (size and weight), power, and spare wires available in the umbilical.

The UCTs have two tethered, free-swimming type ROV systems available for mission support. Both can be further classified as professional inspection and light work systems. These are:

- MiniROVER® MKII, Figure 2-46 (Benthos)
- PHANTOM DHD2+2, Figure 2-47 (Deep Ocean Engineering)

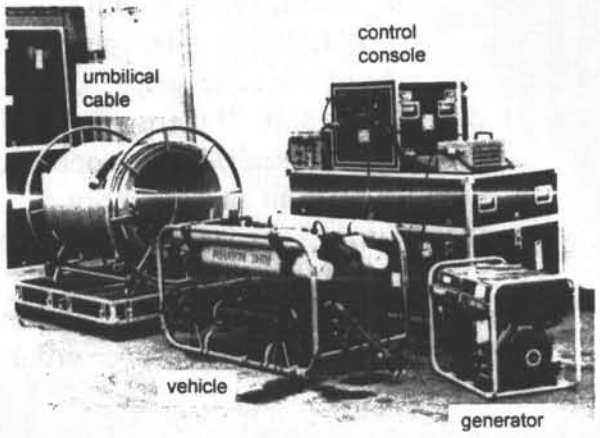
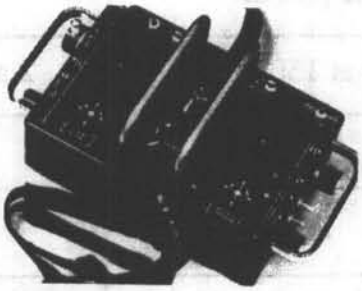


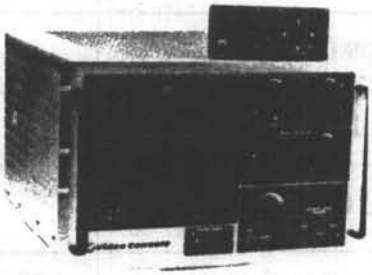

Figure 2-47. Phantom DHD2 vehicle system's primary components. (Printed with permission from Deep Ocean Engineering.)



MiniROVER® MKII Vehicle



Control Console



Remote Hand Controller

Figure 2-46. MiniROVER® MKII system components. (Printed with permission from Benthos.)

### 2.9.1 Description and Comparison of UCT ROV Systems

Table 2-21 summarizes specifications for the UCT MiniROVER® and PHANTOM vehicle systems. Table 2-22 provides a summary of the shipping requirements for the vehicles.

Both vehicles are capable of supporting tasks in temperate, tropic, and arctic environments. The basic system consists of:

- Vehicle with camera, lamps, thrusters, fluxgate compass, depth gauge, and ballast/flotation
- Control console
- Viewing monitor
- Power transformer
- Generator
- Umbilical cable

Optional equipment can include a:

- Hand-powered umbilical winch with electrical slipring
- Video recorder
- Manipulator
- On-screen depth and heading display computer
- Umbilical junction box
- Various mission specific auxiliary hardware.

Table 2-21
UCT ROV System Specifications

| Item | MiniROVER® MKII | PHANTOM DHD2+2 |
|---|---|---|
| Vehicle<br>Maximum Depth (ft)<br>Size (in.)<br>Air Weight (lb) | <br>600<br>34 x 19 x 16<br>75 | <br>2,000<br>60 x 30 x 30<br>250 - 325 |
| Forward Thrust (lb)<br>Thrust | 22<br>Horizontal, lateral, vertical | 100 - 200<br>Horizontal, lateral, vertical |
| Manipulator Functions | One | Three |
| Payload (lb) | 12 | 75 - 100 |
| Camera | Color pan/tilt | Color tilt |
| Lamps (watts) | 2 at 150 | 2 at 150 plus camera |
| Umbilical Length (ft) | 500 | 500 - 2,000 |
| Spare Conductors | 2 | 8 |
| Power Requirements | 120/208 VAC, 50/60 Hz,<br>1.5 kW | 120/240 VAC, 50/60 Hz<br>4.5 kW |
| Recommended Crew | 2 - 3 persons | 3 - 4 persons |

Table 2-22
Shipping Requirement Comparison

| Vehicle | No. of Boxes | Shipping Weight (lb) | Ship Cube (cu ft) |
|---|---|---|---|
| MiniROVER® | 4 | 875 | 77[a] |
| PHANTOM Minimum | 6 | 1,220 | 116[b] |
| Complete PHANTOM | 11 | 2,600 | 212[b] |

[a]Does not include surface or subsurface navigation system.
[b]Assumed on-site power available, no generator shipped, and 500-foot umbilical.

The MiniROVER® MKII is suitable for operating to 130-foot water depths where water currents of less than 1 knot are present. With no current, the vehicle can effectively be used to depths of approximately 500 feet.

The MiniROVER® MKII is not equipped with electrical safety circuits and is not approved for diver in-water interaction.

**CAUTION**
**Divers must maintain a minimum distance of 5 feet from the MiniROVER® MKII while in the water.**

The PHANTOM DHD2+2 vehicle is suitable for operating in water depths to 2,000 feet when water currents of less than 3.5 knots are present. The PHANTOM DHD2+2 system is equipped with electrical safety equipment NOT approved for Navy use for diver in-water interaction.

The PHANTOM DHD2+2 vehicle is much more powerful and versatile than the MiniROVER® MKII and therefore can operate with a larger payload capacity and in higher water currents. The MiniROVER® MKII is easier to transport, handle, and maneuver in small working areas.

### 2.9.2 Training Requirements

ROVs are complicated systems that are not foolproof. They require technical decision making and troubleshooting during setup and use. Ideally, ROV operations should be conducted by full-time operators. Since this is not practical for UCT operations, successful completion of the missions will depend heavily on the experience of the operating crew and on the condition of the vehicle.

Operators should be trained in both ROV maintenance and operation. Training should include formal instruction which includes maintenance, operation, and troubleshooting. There is no substitute for hands-on vehicle training conducted at an in-water site with sufficient space to accommodate maneuvering in currents, umbilical handling, and navigation.

In addition to formal training, it is highly recommended that operator crews train with the vehicle prior to deployment. Specific work functions required on the job should be practiced. At the conclusion of this training, the vehicle should be thoroughly checked out before being shipped to the deployment location.

### 2.9.3 Vehicle Deployment and Recovery

Typical support platforms suitable for ROV operations include:

- Dock
- Dam
- Vessel/barge (30-foot length and greater)
- Ice
- Small boat (18- to 30-foot length)
- Pier
- Beach

The MiniROVER® MKII can be deployed and recovered by hand (no additional overboarding hardware needed) with one or two persons. This depends on sea conditions and weather during operations. However, if at all possible, it is best to plan to overboard either system with the use of a davit, small crane, articulated boom, or some other device that can lift the vehicle and extend it away from the side of the platform. Tag lines are required to control vehicle movement during lifting, and overboarding procedures should be carefully planned and practiced.

For through-ice deployment and recovery, a small tripod can be used to support either of the vehicles.

Beach and small boat operations are special cases (Figure 2-48). Beach deployment can be done where surf is not excessive: ***Common sense prevails!*** Essentially the vehicle is carried out to a water depth of 3 to 4 feet (enough to provide maneuvering). It may be necessary to add floats to the umbilical as longer lengths of umbilical are payed out.

CAUTION

**For safety reasons, recommend that power not be supplied to the vehicle until it is released by the vehicle handlers.**

Two people are needed to carry the MiniROVER® MKII vehicle, and a minimum of four people are needed to carry the PHANTOM DHD2+2.

Operations from small boats such as inflatables provide several challenging problems including deployment of the vehicle and protection of the electrical controls and equipment. Neither system has splash-proof controls and monitors as standard equipment, so small boat operations are usually limited to very calm water.

### 2.9.4 Umbilical Handling and Management

Umbilical management is important to the success of the dive. Too much umbilical in the water can result in tangling and excessive drag. Maintain only the length of umbilical that is needed in the water.

Care must be taken to reduce the possibility of umbilical damage from propellers and tangling with objects in the water column and on the seafloor. As the operation progresses, it is advisable to construct a rough map of the area being inspected, including any obstructions or entanglements encountered. The map can then be referred to as an additional navigation aid during the remainder of the dive. Always maintain good communications between the vehicle operator and the umbilical crew.

When swimming the vehicle within structures or around moorings, it is important for the operator to keep track of the umbilical. Tide shifts and accompanying current reversal can result in the umbilical becoming wrapped around objects.

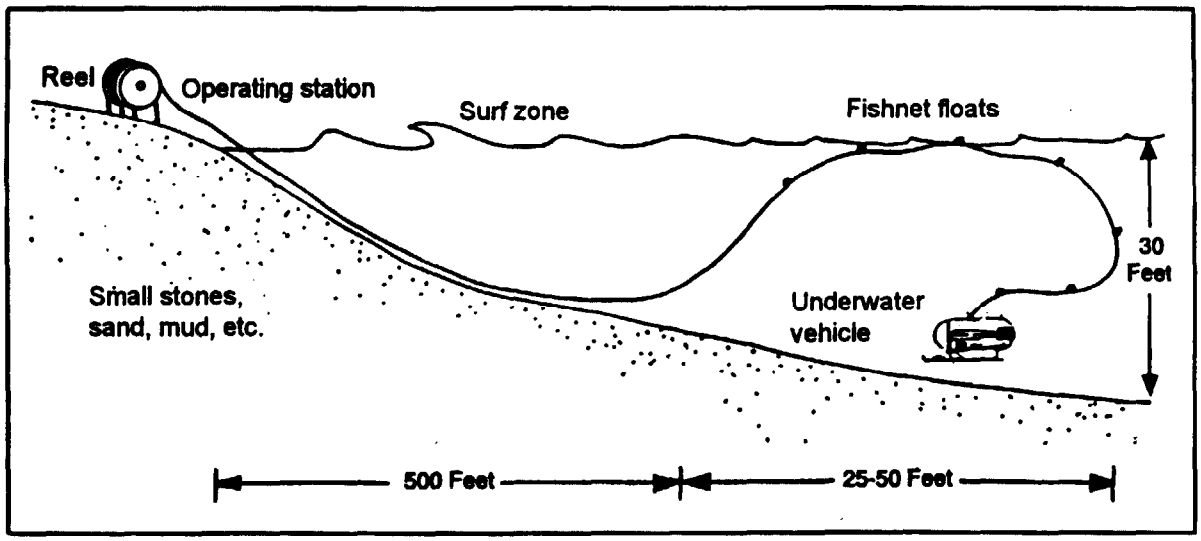



Figure 2-48. Beach and surf zone configuration

### 2.9.5 Typical ROV Operational Configurations

Figure 2-49 shows the general configuration for shallow water ROV operations performed from an anchored vessel or fixed structure (such as a dam or pier), where very little water current exists in the operation area.

For ROV operations in areas where water currents impede the maneuverability of the vehicle, a depressor weight should be used. This is especially true when conducting live boat operations. Figure 2-50 shows the general rigging and configuration of the umbilical for dives requiring a depressor weight. Larger weights may be required with long umbilicals and high currents.

### 2.9.6 Navigation and Tracking

The navigation and tracking support required to complete a task depends on the task, water depth, water visibility, the horizontal distance from the support platform, and the site distance away from shore.

Table 2-23 lists the navigation and tracking instruments available for use with the UCT ROV systems, and a brief discussion of applications. A technical description of navigation systems is found in Chapter 4.

### 2.9.7 Cold Weather Operations

Operation of the vehicles in conditions where the air temperature is below freezing (such as the Arctic) must be conducted from a warmed shelter. Neither the Mini-ROVER® MKII nor the PHANTOM DHD2+2 is designed to operate at below freezing temperatures.

Placing a cold soaked vehicle in the relatively warm seawater (28°F and lower) will result in ice forming on the vehicle. Expansion of the ice and contraction of vehicle components will almost certainly result in seal failures or damage to components and is therefore not recommended.

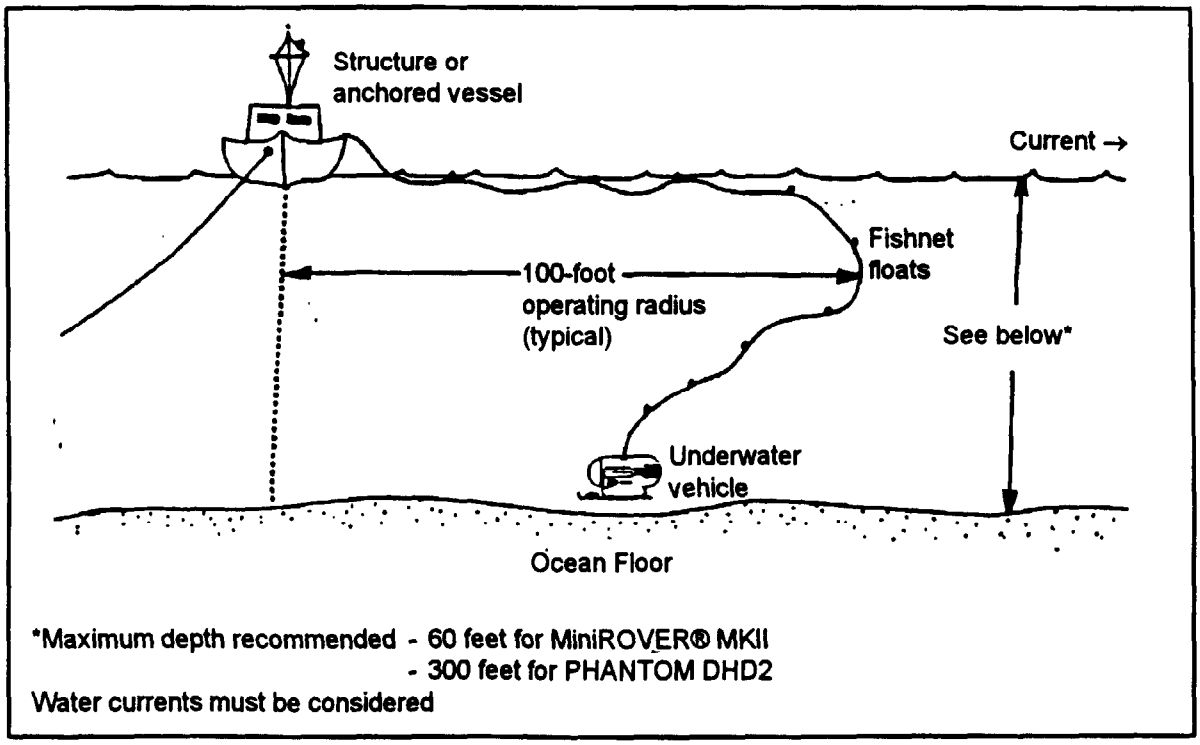



Figure 2-49. Shallow water configuration.

### 2.9.8 Diver Safety

The MiniROVER® MKII and PHANTOM DHD2+2 vehicle systems can supplement manned diving operations by performing support tasks. The systems can also be used to observe, document, and provide additional illumination for the working divers. However, because of electrical safety reasons, neither can interface directly with divers in the water.

The diver and ROV umbilical can become entangled. Also, ROVs can injure divers, through collision, with thrusters, or with tools on the vehicle such as a manipulator jaw. The following are **guidelines for operations with divers and ROVs working in the same vicinity**:

- ROV operators come under control of dive supervisor when diving is in progress.
- All personnel should be briefed on ROV operations and safety concerns.
- Maintain a direct communication link between the dive supervisor and ROV operator.
- MiniROVER® and PHANTOM DHD 2+2 are not equipped with fully-approved ground fault detection circuits, so a minimum standoff distance of 5 feet must be maintained.
- Use only trained and experienced ROV operators.

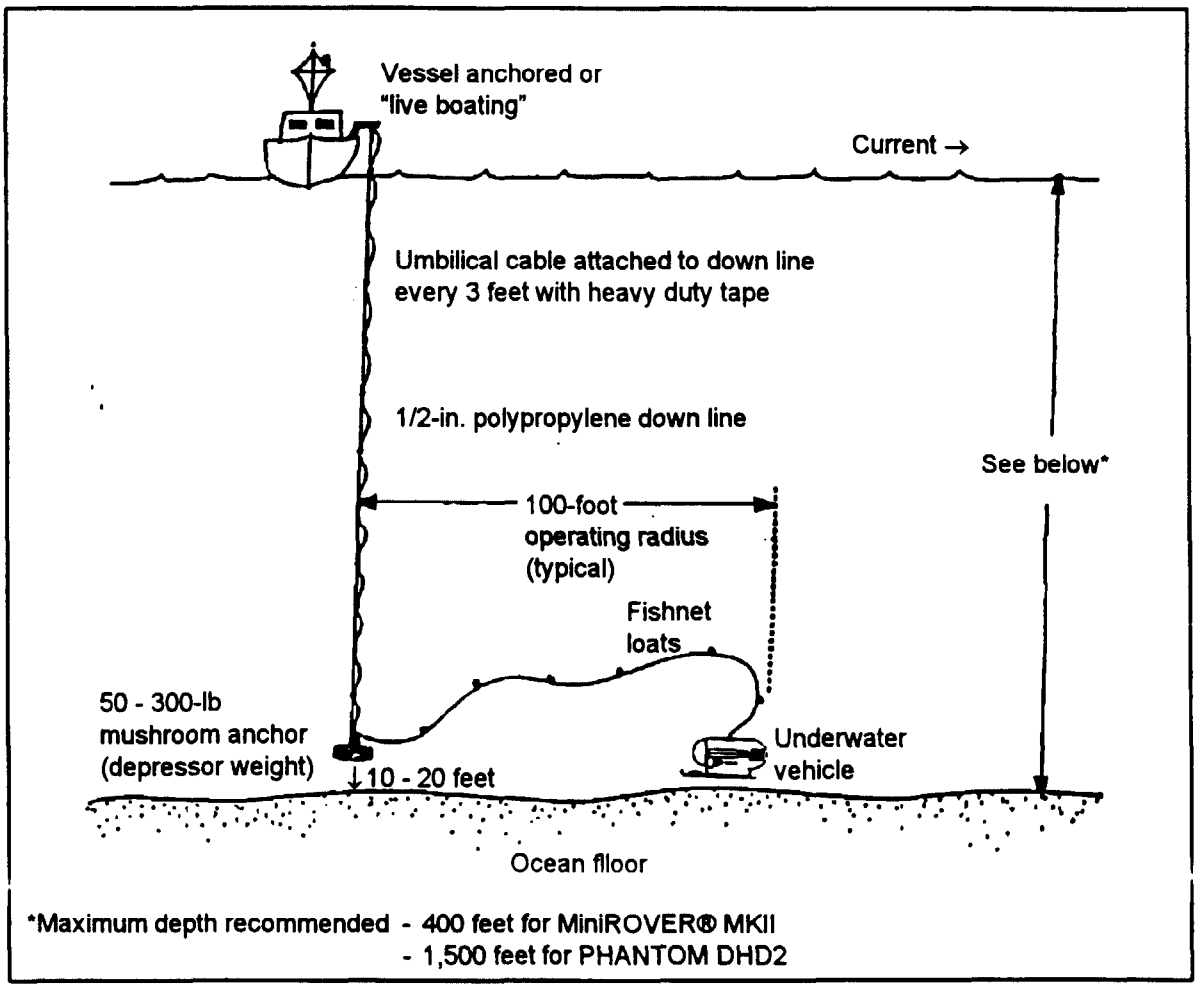



Figure 2-50. Deep water configuration.

Table 2-23
Navigation Summary

| Type | Instrument | When Used | Comments |
|---|---|---|---|
| **Subsurface** | | | |
| Visual | ROV Video Camera | Clear, shallow water. Reference points in water or on bottom. | Vehicle location not tracked. |
| Bearing | Vehicle Compass | Transit to known position and for orientation. | Vehicle location not tracked. Affected by water current (drift). |
| Acoustic | Ultra-Shore Baseline (USBL) | Long distance, deep water, or where precise positioning is needed. | Vehicle and object locations tracked. Uses remote sound sources. |
| | Sonar | Target location, medium range (a few hundred feet navigation). | Can use on ROV surface platform to track ROV. |
| **Surface** | | | |
| Optical | Theodolites, EDM, Sextant | Nearshore, high accuracy. Need good visibility at site. | Shore personnel required, many calculations to plot, highly portable. |
| Radio/ Microwave | Loran C, Del Norte, Motorola - MINIRANGER | Good accuracy for high frequency systems. Ranges from 1/2 to 22 nm. | Shore stations required to be set up for Del Norte and MINIRANGER. |
| Satellite | GPS, DGPS | Open ocean navigation. Accuracy ± 100 m for GPS, ± 5 m for DGPS. | Shore station required to be set up for DGPS. |

• ROV/diver emergency procedures should be worked out before commencing operations.

• Separate the ROV umbilical on the surface platform as far from the diver hoses as possible.

• Deploy the ROV before diving commences and recover after divers leave the water.

• Operate thrusters at low level to prevent sudden ROV movements.

• Do not use auto depth or auto heading when operating with divers.

• The ROV should not approach divers without the dive supervisor's permission.

• In the event of diver/ROV emergencies such as umbilical entanglement, the dive supervisor takes charge.

### 2.9.9 ROV Applications

ROVs can be used in a variety of ways to support UCT tasking. Their use can span from installation of sensors to inspection of moorings. In some cases, the ROV can replace the diver while in others the ROV can assist and monitor the diver's work. The ROV can be particularly useful where the dive site is in contaminated water or where other hazardous conditions exist. **Examples of potential ROV tasks are:**

• **Data collection** (in-situ temperature, salinity, conductivity, speed of sound, dissolved oxygen, PH, and other data, versus depth). Probe(s) can be attached to a vehicle and data is either transferred to a surface computer via a spare wire in the ROV umbilical, or data is stored in the probe(s) and transferred after vehicle recovery. The PHANTOM DHD2+2 vehicle has the designed in payload and thrust to carry probes and maneuver with probes.

• **Cable and pipeline tracking and inspection.** Visual tracking, inspection, and documentation can be performed using the vehicle video camera. If the cable or pipeline is buried, the cable tracker or pipe and chain locator can be attached to the PHANTOM vehicle. A spare umbilical wire can be used to transfer signals to displays on the surface platform. An ROV technician will be needed to set up and checkout the vehicle for this type of operation.

• **Video search** (expanding box and circle searches). A subsea acoustic tracking system is desirable for these tasks. For the expanding box search pattern, an acoustic beacon is dropped to the seafloor at the last known or suspected position, or a waypoint is input on the tracking system screen for the start search position. After descending to the start position, operators follow the pattern shown on Figure 2-51. A beacon on the vehicle is tracked by the acoustic system during the search.

The search leg length "a" varies depending on water visibility, or the range of the sonar (if used). A 10 percent overlap of search pattern is recommended. For example, if the visibility is 50 feet, "a" would be 45 feet.

Detected targets are investigated using the vehicle video. If the target is not the sought object, then the vehicle is returned to the position it was prior to leaving the search pattern.

A circle search is performed in the same general manner, except the vehicle is driven in concentric circles around the starting point (similar to diver circle search).

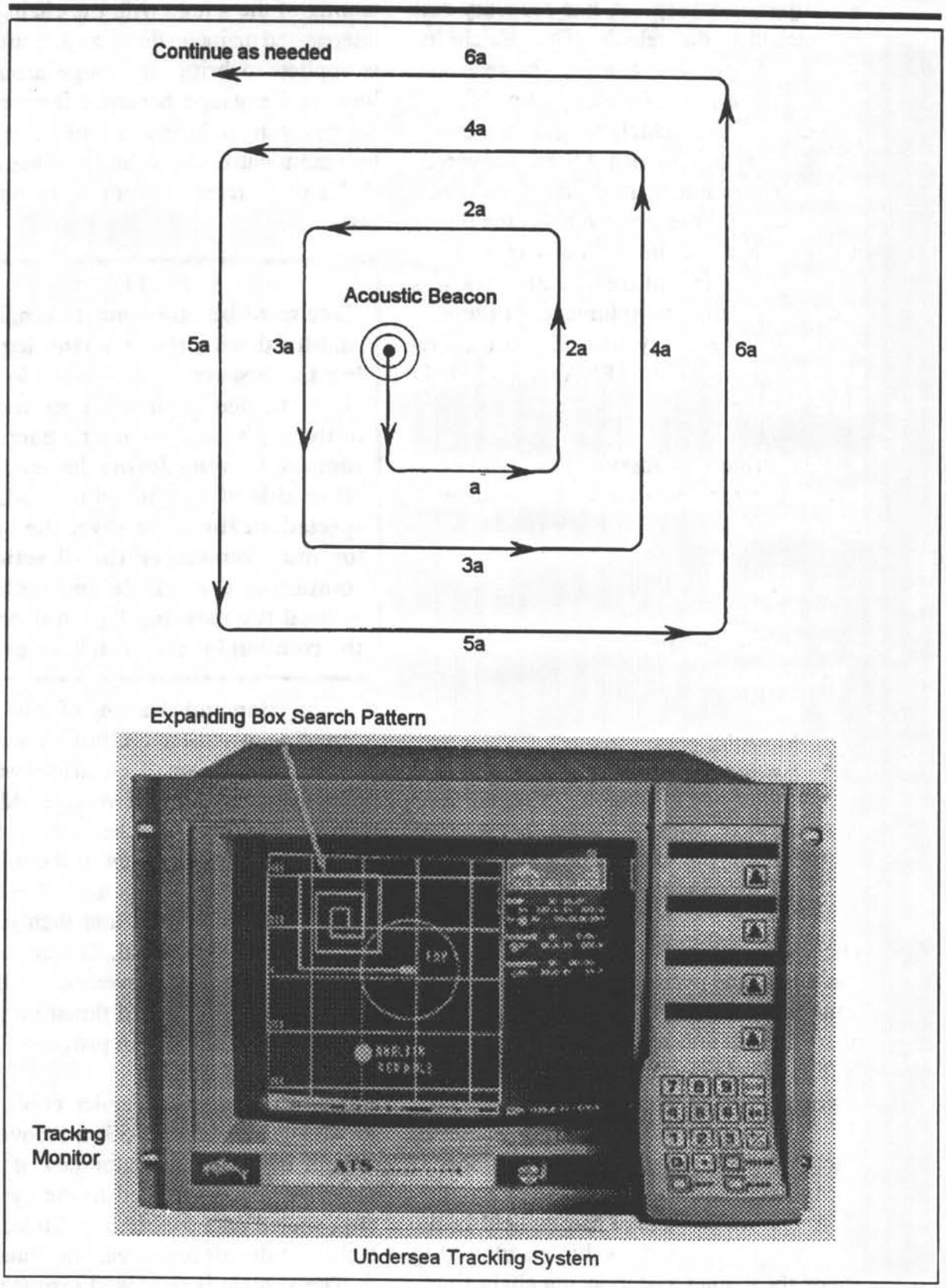



Figure 2-51. Example of a visual search pattern shown in an expanding box where "a" is a distance picked with regard to visibility (camera only search) or range of sonar. Tracking monitor is also shown.

• **Object recovery.** A line recovery reel is attached to the vehicle. The vehicle locates the object and attaches the recovery line to it with a self-locking clip. Line is payed-out as the vehicle returns to the surface. Once the vehicle has been recovered, the end of the line is transferred to a winch or capstan for object recovery. If the line is used for marking only, a buoy is attached to the surface end of the line after slack is taken out of the line (plumbed). Figure 2-52 shows a recovery line clip in the manipulator jaws of the PHANTOM DHD 2+2 vehicle.

• **Inspection and observation.** ROVs can be used for a variety of **underwater inspections** such as:

- Dams
- Drydocks
- Sewer outfalls
- Seafloor
- Buoys
- Moorings
- Anchor and chains
- Under- ice formations and conditions
- Salvage work
- Identifying hazards to the divers before commencing dive operations

The ROV can also be used to monitor equipment and personnel conducting operations to provide engineering documentation of conditions and repairs.

The vehicle can be maneuvered along the leg of a mooring while video-documenting the condition of the hardware including lines, connections, chains, and anchors if not buried.

A "go-no go" gauge can be held in the manipulator jaw of the vehicle and used to check the diameter of mooring chain links. Vehicle propulsion is used to maneuver the mating of the gauge with the chain link of interest and maintain depth as forward thrust is applied to bring the gauge around the link. If the gauge becomes jammed with the mooring link and cannot be removed by manipulator and vehicle maneuvering, the gauge is released from the manipulator jaw.

**NOTE**

**Care must be taken not to tangle the umbilical with the mooring leg during the inspection. The vehicle must be controlled to descend on one side of the leg by maintaining a particular compass heading during descent. If the other side of the mooring is also inspected on the same dive, the operator must remember the direction of rotation of the vehicle and umbilical around the mooring leg, and reverse the rotation before vehicle recovery.**

• **Inspection and cleaning of mud, sand, or marine growth accretion on underwater surfaces.** A small electrical water jet pump is mounted on the vehicle and a hose with jet nozzle is attached to the vehicle manipulator. Spare wires in the umbilical are used to power the pump. The vehicle is controlled to inspect and then jet away the accretion of material. Direction of the jet is controlled by movement of the manipulator. Some forward thrust may be required when jetting is in progress.

• **Deployment of under-ice cable spans.** As shown in Figure 2-53, a recovery clip is held in the manipulator jaw of the vehicle. A line is attached to the eye of the clip, routed underneath the vehicle, and attached to the aft lower vehicle frame.

The vehicle is deployed through an ice hole in the ROV shelter and can maneuver

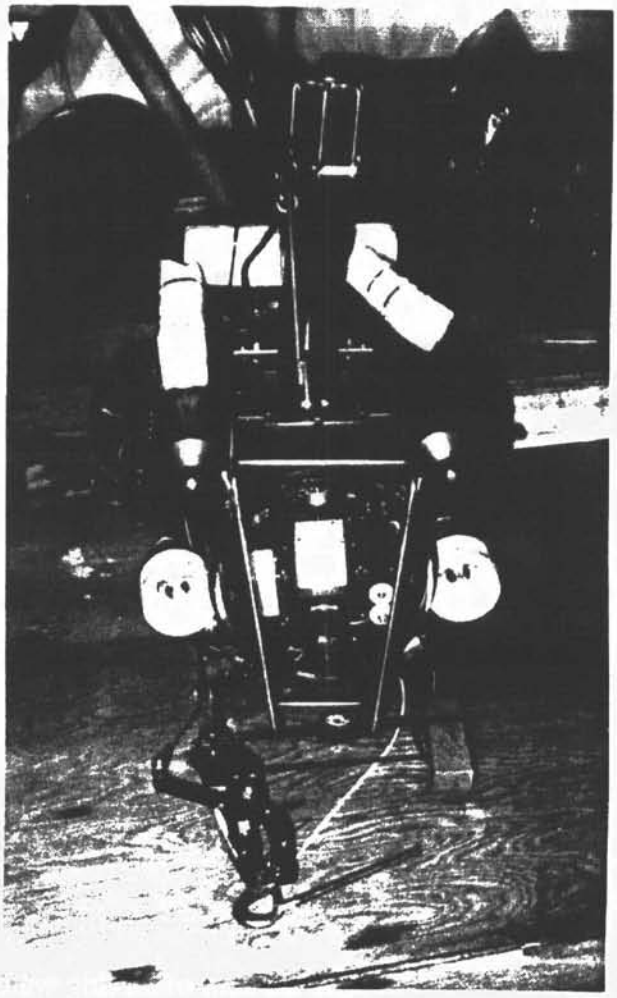


Figure 2-52
Recovery line clip in vehicle jaw.

to a target hole up to 1,500 feet away (depending pon the length of the umbilical used with the ROV system).

A ring is lowered from the target hole. The vehicle operator locates the ring, connects it to the recovery clip, and releases the clip from the manipulator. Once released, the hook will drop below the vehicle (attached at the aft frame).

The vehicle is then maneuvered back to the deployment hole as messenger line is deployed from the target hole. Many combinations are possible to achieve longer distances. For example, a run in the opposite direction can be made and the two messenger lines connected to double the distance of the span.

• **Cable/line cutting.** For small diameter cables (0.1 inch or less in diameter) and lines (0.25 inch or less in diameter), blades are attached to the manipulator jaws of the vehicle for cutting. For larger diameter cables and lines, a cable/line cutting device is attached to the vehicle manipulator arm or a support frame on the vehicle. Spare conductors in the umbilical can be used to transmit the signal to activate the device.

• **Moving and placing** (water column and on seafloor). Moving, placing, and recovering objects can be done. However, the vehicle umbilical should not be used to lift the vehicle with loads heavier than 50 pounds. Instead, a line delivered from a recovery reel should be used. Lightweight (less than 50 pounds) or neutrally buoyant objects can be recovered or placed using vehicle propulsion. The vehicle manipulator jaws or release mechanisms attached to the vehicle are used to implement pickup and release.

A heavier object can be fitted with a flotation device to provide neutral buoyancy. Once the ROV delivers the object, the flotation device is released or deflated.

• **Diver assistance.** ROVs can be used in conjunction with diver operations to provide useful functions including:

- Video observation of the diver/ work area for safety and work quality documentation
- llumination of the work site
- Delivery of messenger lines and small tools
- Backup communication via video/ slate

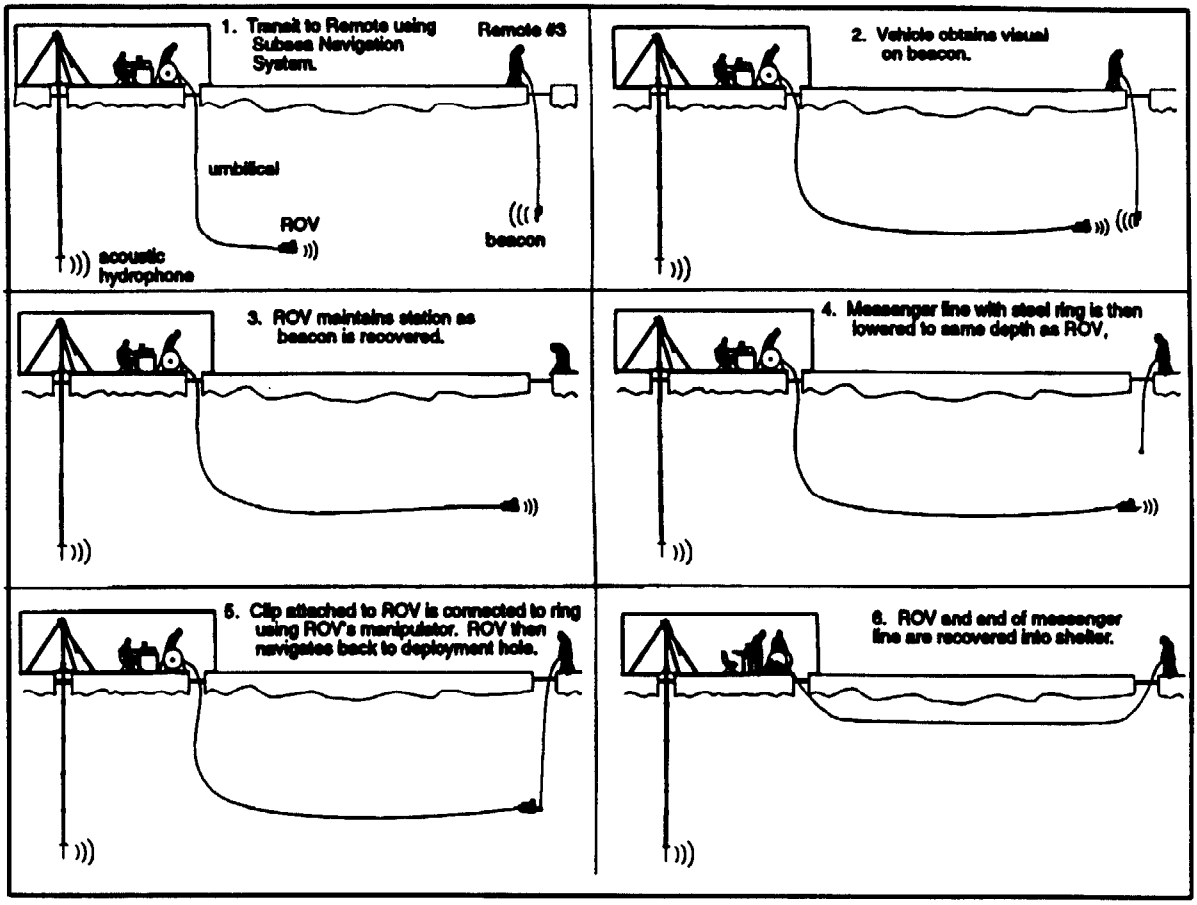



Figure 2-53. Deployment of under-ice cable span.

## 2.10 CONCRETING

Concrete placed underwater is the most widely used repair method in marine applications. The concrete mix should be designed in accordance with ACI 211.1-91, Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete. Naval Facilities Engineering Command Guide Specification NFGS-03300G, Cast-in-Place Concrete, provides a number of concrete mix examples that are helpful in initial selection of trial mixes. The mix must have good workability and, thus, should meet the following conditions:

- The mixture must incorporate the proper proportions of sand and gravel in a rich paste of portland cement and freshwater.
- The total amount of mixing water should not exceed a water/cement ratio (w/c) of 0.44, i.e., 0.44 pounds of water for each pound of cement (this is the equivalent of 5.0 gallons of water per bag of cement). (A bag of cement weighs 94 pounds in the United States.) The "added" water is the net water to be included in the mixture after adjustments are made for the wetness or dryness of the aggregates. If the aggregates have free moisture (e.g., sand frequently has 5 to 6 percent by weight of free water), this becomes part of the mixing water so that less added water is needed. On the other hand, if the aggregate particles are surface dry and not saturated, they will absorb some of the gross mixing water (e.g., up to 1 percent or so of aggregate weight as is often the case with coarse aggregates); therefore, extra mixing water must be added.

• The mixture should contain not less than 7 bags and not more than 10 bags of cement per cubic yard of concrete. The cement should be ASTM Type II with a tricalcium aluminate content greater than 5 percent and less than 10 percent. Pozzolans (fly ash) conforming to ASTM C618 are a good addition to the mix. Fly ash can have the beneficial effects of improving the durability of the concrete, increasing corrosion protection to the reinforcing steel, and improving workability of the mix. The amount of fly ash used typically replaces about 15 to 20 percent of the weight of cement in the mix. The total weight of the cement and fly ash is considered the cementitious content of the mix.

• The concrete should incorporate a water-reducing admixture or a high-range water reducing admixture (superplasticizer). Superplasticizers allow concrete to have high workability and, at the same time, low water content. Do not exceed the recommended manufacturer's dosage as segregation may occur.

Concrete to be used in the intertidal zone and the marine atmosphere that will be subjected to subfreezing temperatures should be air-entrained with an air-entraining admixture in accordance with:

• CEL CR 81.009, Survey of Techniques for Underwater Maintenance/Repair of Waterfront Structures (and Amendment P00001)

• NCEL TN-1624, Underwater Inspection of Waterfront Facilities: Inspection Requirements Analysis and Nondestructive Testing Technique Assessment

• PCA, Design and Control of Concrete Mixtures, of the American Concrete Institute

• The admixture manufacturer's instructions

A relatively new type of admixture is being marketed called an anti-washout admixture. Anti-washout admixtures are intended for use in concrete placed underwater. The admixture increases the viscosity of the concrete mix, which improves the resistance to water dilution and washing away of cement fines in the surface exposed to water. High-range water reducers and anti-washout admixtures are usually used together. However, not all commercially available admixtures are compatible with all brands of cement and air-entraining admixtures. Therefore, if possible, all admixtures should be from the same manufacturer and their compatibility with the cement being used should be confirmed. The quantities used should be in accordance with the manufacturer's instructions. Admixtures are usually dissolved in the mixing water before it enters the concrete mixer. Admixtures should be used in accordance with ACI 212.3R-91, Chemical Admixtures for Concrete, and ACI 212.4R-93, Guide for Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete.

• The sand and gravel should be physically sound. Great care should be exercised in selecting aggregates at locations where sound material is not readily available, particularly coral and limestone islands. Concrete made with coral or limestone may not be durable. If coral or limestone must be used, thoroughly washed it with freshwater to remove all organic and clay-like fine material. For reinforced concrete, wash the aggregate with freshwater to remove all salts.

• The formwork in which the concrete is placed must be secure, carefully fitted (so

that there are no leaks at joints and corners), and designed so that no underwater currents can pass through it. Provision must be made for the seawater displaced by the concrete to escape from within the form.

• Low temperatures during mixing and curing of concrete (i.e., below 50°F) can delay strength development. Chemical admixtures, without chlorides or hot water, can be used in the concrete to accelerate early strength gain. In reinforced concrete, calcium chloride should not be used as an accelerator; however, for unreinforced concrete, calcium chloride is acceptable.

• An enclosed chute or "trunk" should be used and the end of the chute should be kept embedded in the newly deposited concrete so that there is no washing away of cement fines or mixing with water during placement.

Concrete placed underwater is typically placed in a form. Forms used in UCT operations include cut plywood forms that are fabricated on site, flexible fabric forms that are secured underwater, cylindrical fiberglass forms, rigid fiberboard forms, cut metal pipe, as well as others.

When calculating the quantity of concrete needed, always be liberal to ensure that a sufficient amount is available to complete the job. Unplanned interruptions of an underwater concrete placement operation can have disastrous effects on the quality of the completed work. A complete description of working with concrete forms is given in Chapter 5, Underwater Maintenance and Repair Procedures.

Concrete is placed underwater by four methods: pumping, tremie, prepacked, and sacked. By far the most common method used by the UCTs is pumping. When a concrete pump is not available, the tremie method is used as a substitute. For special circumstances where the pumped or tremie method is not suitable, the prepacked method may be used. Sacked concrete may be used to build underwater walls, protect slopes from underwater wave and current wash, and cover cables and pipelines. Each of these methods is described below.

### 2.10.1 Pumped Concrete

Pumping freshly mixed concrete is the most expeditious means of placing concrete underwater in spaces of limited accessibility. It is generally preferred over the tremie method, however, the following considerations should be accounted for:

• Pumped concrete should be used to fill the forms from the bottom upward, displacing the seawater as additional concrete is forced in at the bottom. (Recently, new admixtures have been developed that enable concrete to be dropped without a tremie.)

• High quality concrete is required, because the mixture must be both workable and cohesive, so as to pass through the pump without blockage.

• Workable mixtures containing relatively small coarse aggregate particles tend to provide an easily placed concrete.

• The slump must be carefully controlled to prevent segregation, as excessively wet mixtures will sometimes segregate and cause blockage in the hose or pipeline. (High-range water reducers used as an admixture in the concrete can provide the high workability and eliminate segregation.)

• Coarse aggregate should consist of rounded particles, as crushed stone mixtures are comparatively difficult to pump because

the angular particles tend to increase friction in the pipeline.

- If it is necessary to use crushed rock, the maximum coarse aggregate size should not be greater than one-third the smallest inside diameter of the hose or pipe.

- The properties of the fine aggregate (sand) are more important than those of the coarse aggregate. In particular, the sand should have a relatively high proportion of the finer sizes (i.e., 15 to 30 percent should pass the no. 50 sieve, and 5 to 10 percent should pass the no. 100 sieve).

- Porous aggregates (e.g., expanded clay, foamed slag, pumice, and many coralline materials) should be avoided unless denser aggregates are not available. If porous aggregates are used for pumped concrete, they should be presoaked as described in ACI 304.2R-91, Placing Concrete by Pumping Methods.

- Inserting a pig between mixes is usually a good idea. Care must be taken with long vertical drops with the pump hose. With no backpressure, i.e., break seal or disconnect, the concrete wants to siphon and collapse hose, creating an instant plug.

The pumping method offers several advantages:

- Concrete can be transferred from a barge directly into the forms.

- The process is less subject to operator error than the tremie concrete process.

- Pumped concrete is more easily placed in awkward situations and locations with difficult access, such as under piers.

- The pressurization process consolidates the repair material, providing for full encapsulation of exposed reinforcing steel.

The concrete pump most often used by the UCTs is a direct-flow, reciprocating piston pump with a pumping rate of about 25 $yd^3$/hr, a hopper capacity of 6 $ft^3$, and a maximum pumping distance of about 400 feet. The pump, illustrated in Figure 2-54, is normally fitted with a 2-inch-diameter hose but can be fitted with a 2-1/2-inch-diameter hose for mixes that are hard to pump. It requires concrete with 3/8-inch maximum size aggregate, graded as indicated in Table 2-24. A recommended concrete mix design for pumped concrete that has proved successful in the past is given in Table 2-25. While this is suitable for placement in areas of limited accessibility, larger aggregate sizes and corresponding pump sizes should be used for large pours.

Carefully planning the location of the pump and hose routing before starting an operation can save subsequent moves throughout the project. The pipeline should be either horizontal or vertical rather than inclined, wherever possible. With an inclined pipeline, any water bleeding from the freshly mixed concrete within the pipeline will collect above the concrete and run down the inside of the pipe.

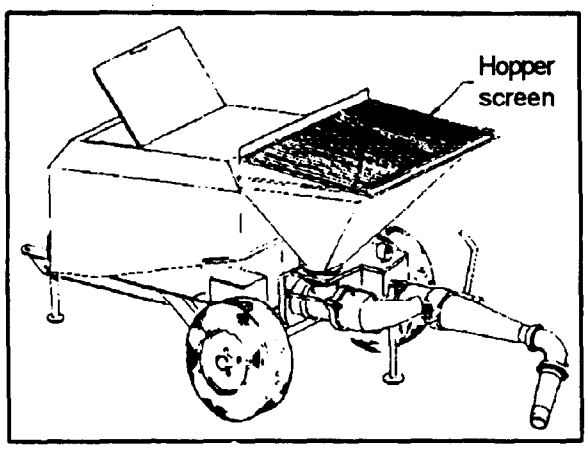



Figure 2-54. Typical concrete pump.

Table 2-24
Gradation of Aggregates for Pumped Concrete

| Aggregate | U.S. Standard Sieve | Percent Passing (by weight) |
|---|---|---|
| Gravel | 1/2 in. | 100 |
| | 3/8 in. | 85 to 100 |
| | No. 4 | 10 to 30 |
| | No. 8 | 0 to 10 |
| | No. 16 | 0 to 5 |
| Sand | 3/8 in. | 100 |
| | No. 4 | 95 to 100 |
| | No. 8 | 80 to 100 |
| | No. 16 | 50 to 85 |
| | No. 30 | 25 to 60 |
| | No. 50 | 15 to 30 |
| | No. 100 | 5 to 10 |

Table 2-25
Design Mix for Pumped Concrete for Underwater Use
[Quantities indicated are per cubic yard of concrete.]

| Item | Quantity |
|---|---|
| Cement (Type II) | 640 pounds (8 sacks) |
| Fly Ash | 112 pounds |
| Sand | 2,100 pounds |
| Gravel (3/8-inch maximum) | 800 pounds |
| Water | 40 gallons |
| Admixture - Water Reducer | In accordance with manufactuer's recommendations |
| Slump | 6 inches |
| Strength | 4,000 psi |

When placing pumped concrete, surfaces that might trap air are trimmed, or vent pipes are provided in the formwork. (A rough profile on the concrete substrate resulting from surface preparation of existing concrete prior to a repair will not entrap air.) The formwork is designed to accommodate the weight and pressure of the concrete. The minimum design pressure is 14 psi. The maximum pressure occurs when the formwork cavity is full and pressurized. The pump hose is attached to the formwork with flanged plumbing fittings and ball valves, or the pump line is attached using hand-held friction fit insertion followed by wooden plugs.

The pumping sequence is from bottom to top. Large repairs may require bulkheads to separate placements into manageable areas. Pumping continues until the concrete flows out of the top of the form or through a vent. Once the form is full, pump pressure is exerted on the concrete, causing it to consolidate and make intimate contact with the form, or existing substrate in the case of a repair.

Before concrete is discharged into the hopper, 3 to 4 gallons of water should be sprayed into the hopper followed by about 5 gallons of a creamy cement and water slurry (1/2 bag of cement to 5 gallons of water). This procedure lubricates the hose and prevents separation and blockages. Delays as long as 1-1/2 hours can generally be tolerated if the mixture is moved several feet at least every 5 minutes (while in the hose or pipeline) until continuous pumping is resumed. If the concrete becomes excessively stiff because of a long delay, the concrete should **not** be retempered by adding water but should be discarded and a fresh batch mixed. If the concrete contains a high range water reducer (superplasticizer), the slump can decrease substantially after 3/4 to 1 hour. Concrete in the mixer can have additional plasticizers added to increase the slump one time. Concrete in the pipeline should be removed before the slump decreases. When concreting is completed, all parts of the pump and pipeline should be thoroughly cleaned.

The concrete should be pumped as near to its final underwater position as possible. The diver who has control of the discharge end should not permit lateral flow within the open-top form of more than 2 or 3 feet. The discharge end of the line must always be kept buried in the mass of fresh concrete; otherwise, washout will occur at the point where the concrete comes out. Aluminum pipe should not be used because an adverse chemical reaction with the concrete may occur. The pipeline should be protected from any excessive heat (solar included).

**CAUTION**

**Use extreme caution when a hose blockage requires opening a coupling due to the pressure from the concrete column.**

### 2.10.2 Tremie Concrete

One method of placing concrete underwater, especially at easily accessible locations, involves a tremie -- a steel tube with a hopper for filling at its upper end. A plug, consisting of either a rubber ball or a wad of burlap that fits snugly inside the tremie, is inserted below the loading hopper. The freshly mixed concrete, introduced at the hopper, forces the plug down and displaces the seawater. The tremie is continually replenished with concrete while the lower end is kept embedded in the newly deposited concrete. Compaction by vibration is not permitted, as it generally results in excessive laitance. Tremie concrete must be quite workable so that it flows readily into place.

Fine aggregate contents of 45 to 55 percent by volume of total aggregate, and air contents of 4 to 5 percent, are generally desirable. A typical aggregate gradation is indicated in Table 2-26. A typical mix design for tremie concrete is given in Table 2-27. The size of the coarse aggregate should be restricted as follows:

- Very large pours: 1.5 inch maximum
- Normal pours: 0.75 inch maximum
- Restricted access pours: 0.375 inch maximum

It is general practice to use a steel tremie, but a rigid rubber hose could be substituted. Joints in the tremie must be well-gasketed and sealed, otherwise the water could leach the cement from the concrete. An aluminum alloy tremie should not be used because an adverse chemical reaction could occur, producing inferior concrete. For deep placements, the tremie should be fabricated in sections, with joints that allow the upper sections to be removed as the placement progresses.

The size of the tremie depends on the maximum size of gravel and on the quantity of concrete to be placed; the usual range in diameter is from 4 to 10 inches, and should be at least eight times the maximum coarse aggregate size. The slump of tremie concrete should be maintained between 6 and 9 inches.

The quality of tremie concrete is greatly dependent on proper mix design and placement. Reinforcing should be designed to minimize segregation due to a screening effect. The largest size bars possible should be used, and they should be spaced a minimum of three to four times the aggregate size. Admixtures are used to improve the flowability of the concrete. Otherwise, much laitance, due to washing out of cement, and gravel pockets, due to lifting of the tremie pipe to facilitate placement, can result. Water reducing retarders in combination with an air entraining agent, and/or superplasticizers, are used to provide increased flowability at low water cement ratios. This increased flowability permits wider spacing of the tremie pipes, longer pipe lengths, wider pipes, and longer placing times.

The tremie method of pumping concrete is best suited for footings. The tremie is difficult to handle and will often hang up in spacers typically used in the encasement of piles.

### 2.10.3 Prepacked Concrete

Prepacked concrete is used on large underwater repair jobs where placement of regular concrete would be either difficult or impossible, and/or where minimization of shrinkage is a requirement. It is most economical for isolated locations, where pumping distances are excessive.

Prepacked concrete involves placing coarse aggregate in a form and then filling the voids in the aggregate mass with grout, as shown in Figure 2-55.

The preplaced aggregate concrete components should meet the requirements specified in Chapter 7 of ACI 304.2R-91. Form materials are essentially the same as for regular cast-in-place concrete, except that they must be sufficiently tight to prevent leakage.

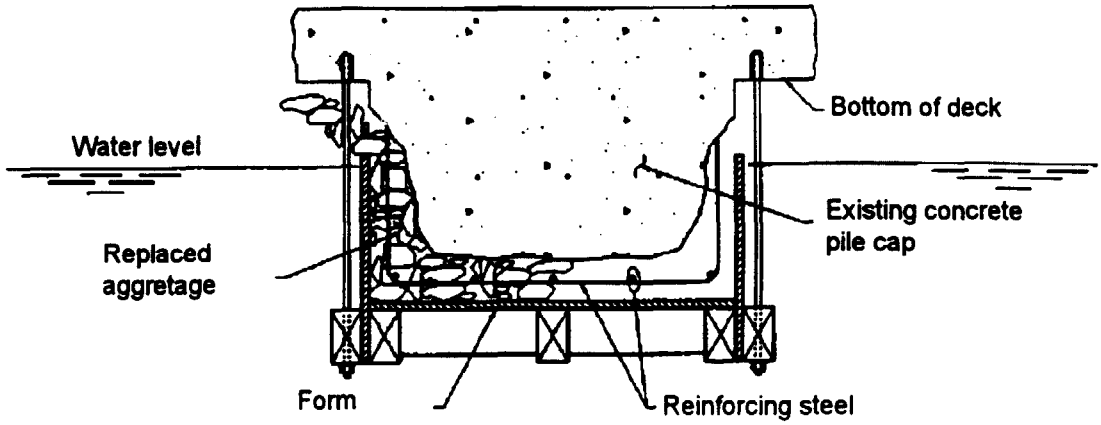
The cement, aggregates, and water for preplaced aggregate concrete are also similar to those for regular cast-in-place concrete, however, the concrete mix contains a higher percentage of coarse aggregate. Aggregate gradation is in accordance with Table 7.2 of ACI 304.2R-91. A typical gradation is indicated in Table 2-28. For repair depths exceeding 12 inches, gradations with larger size aggregates are used. The

Table 2-26
Gradation of Aggregates for Tremie Concrete

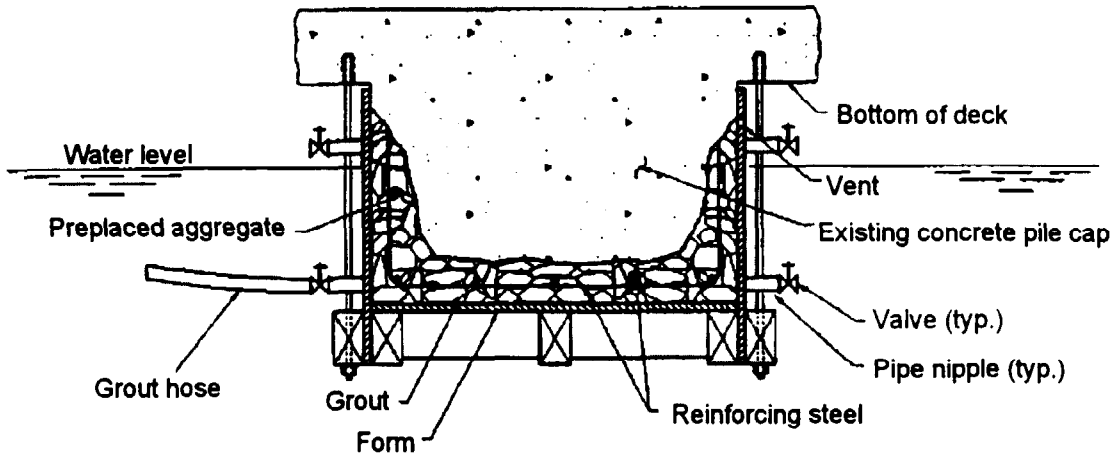
| Aggregate | U.S. Standard Sieve | Percent Passing (by weight) |
|---|---|---|
| Gravel | 1/2 in. | 100 |
| | 3/4 in. | 90 to 100 |
| | 3/8 in. | 20 to 55 |
| | No. 4 | 0 to 10 |
| | No. 8 | 0 to 5 |
| Sand | 3/8 in. | 100 |
| | No. 4 | 95 to 100 |
| | No. 8 | 80 to 100 |
| | No. 16 | 50 to 85 |
| | No. 30 | 25 to 60 |
| | No. 50 | 10 to 30 |
| | No. 100 | 2 to 10 |

Table 2-27
Design Mix for Pumped Concrete for Underwater Use
[Quantities indicated are per cubic yard of concrete.]

| Item | Quantity |
|---|---|
| Cement (Type II) | 640 pounds (8 sacks) |
| Fly Ash | 112 pounds |
| Sand | 1,300 pounds |
| Gravel (3/8-inch maximum) | 1,800 pounds |
| Water | 40 gallons |
| Admixture - Water Reducer | In accordance with manufactuer's recommendations |
| Slump | 6 inches |
| Strength | 4,000 psi |




**Step 1. Aggregate placed into form.**




**Step 2. Form completed and grout being placed.**

Figure 2-55
Steps for placing prepacked concrete into form.

diameter ratios of the smallest particles of coarse aggregates to the largest particles of sand should not be less than 4 to 1.

The void content of the coarse aggregate is as low as possible, which can usually be attained by grading it uniformly from the smallest aggregate size to the largest aggregate size. The gradation shown in Table 2-28 is recommended to minimize the void content. Gap grading sometimes provides a lower void content than uniform grading. The void ratio of the cavity after the aggregate is placed is usually 35 to 40 percent.

The grout is proportioned in accordance with the requirements of ASTM C938, Standard Practice for Proportioning Grout Mixtures for Preplaced-Aggregate Concrete. Its consistency is determined in accordance with ASTM C939, Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method). The consistency, which is measured as an efflux time, should be on the order of 22 $\pm$2 seconds. The grout con-

sists of Portland cement, sand, and Class F fly ash of Class N pozzolan. Whether fly ash or pozzolan is used will largely depend on the Contractor's previous experience and/or the results of trial tests. Generally, the mix that provides the best workability, highest strength, and least shrinkage should be recommended for repairs.

Class F fly ash is normally produced from burning anthracite or bituminous coal, while Class N pozzolan is a raw or calcined natural material containing silica or aluminum in a finely divided reactive form. The fly ash and pozzolan are used to improve pumpability of the grout, extend its handling time, and provide increased impermeability and erosion resistance.

The fly ash and pozzolan must conform to the requirements of ASTM C618, Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete. The proportion of portland cement to pozzolan is in the range of 2.5:1 to 3.5:1, by weight, as discussed in ACI 304.2R-91. The ratio of cementitious material (i.e., portland cement plus pozzolan or fly ash) to sand is approximately 1:1, while the water to cementitious material ratio ranges from 0.42 to 0.50.

In addition, a grout fluidifier, meeting the requirements of ASTM C937, Standard Specification for Grout Fluidifier for Preplaced-Aggregate Concrete, is used to offset the effects of bleeding, reduce the water/cement ratio, and retard stiffening. The dosage of fluidifier is approximately 1 percent of cementitious material by weight. The amount of bleeding in the grout should be less than the amount of expansion, as determined in accordance with ASTM C940, Standard Test Method for Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory.

Table 2-28
Gradation of Aggregates for Prepacked Concrete

| Aggregate | U.S. Standard Sieve | Percent Passing (by weight) |
|---|---|---|
| Gravel[a] | 2 in. | 100 |
| | 1-1/2 in. | 90 to 100 |
| | 1 in. | 20 to 55 |
| | 3/4 in. | 0 to 15 |
| | 3/8 in. | 0 |
| Sand[b] | No. 8 | 100 |
| | No. 16 | 95 to 100 |
| | No. 30 | 55 to 80 |
| | No. 50 | 30 to 55 |
| | No. 100 | 10 to 30 |
| | No. 200 | 0 to 10 |

[a]Placed separately before intrusion of grout.
[b]Used in the grout

The forms are constructed in two steps, as shown in Figure 2-55. At the completion of the first step, there must be sufficient openings to place the coarse aggregate. After washing and screening the coarse aggregate so that it is free of fines and bond inhibiting materials, it is placed in the forms using a flexible elephant trunk or rubber-lined chute to avoid segregation and breakage. The forms must be strong enough to permit the aggregate to be tamped with vibrators or tampers in order to minimize the void content. When coarse aggregate is to be placed in restricted areas of forms, the aggregate particles are frequently moved by hand. Movement can alternatively be accomplished by the use of an air lance, utilizing a short length of 3/8-inch pipe.

Once the aggregate is in place, the formwork is completed, as shown in Step 2 of Figure 2-55. The forms are built sufficiently tight to prevent grout leakage. The aggregate is kept wet until the grout is placed to facilitate the grout's smooth flow. This requires caulking of all small openings and sealing adjacent form panels with tape.

The grout pipes are installed, generally before aggregate placement, and often are fixed to the form or to a reinforcing cage. The pipes range from 3/4 inch to 1 inch in diameter, and are spaced at 5 to 6 feet on center. After the aggregate is placed, a highly flowable structural grout is pumped into the bottom of the form and flows upward, displacing the water.

The grout makes contact with the existing concrete surface as the cavity is filled, providing intimate contact and bonding. A unique advantage of this method is the point-to-point contact between the coarse aggregate, resulting in a drying shrinkage of approximately one-half that of regular cast-in-place concrete. The aggregate contact restricts the volume change of the cement grout as drying shrinkage occurs. Densities of preplaced aggregate concrete are generally slightly higher than those of normal concrete. Bond strengths of prepacked to regular concrete are between 70 to 100 percent of that attainable in regular concrete. This makes it possible to restore deteriorated concrete members to near their original strengths or to enlarge existing members to take additional loads.

When repairing existing components, weakened material should be removed to expose sound concrete, and the surfaces of sound concrete should be roughened by either chipping or water blasting before repair. Space must be provided for at least 3 to 4 inches of new prepacked concrete. Grouting should begin immediately after the forms are completed to avoid contamination of the aggregate. Grout placement always starts from the lowest point in the forms. After grout flows from adjacent ports, the grout hose is disconnected from the port being pumped and reconnected to the port showing new flow, while the previous port is sealed. The process continues until the cavity is full and pressurized. When the forms are filled, a closing pressure of approximately 10 psi is held for up to 1 hour to drive out all air and water through a vent at the highest point. The forms may be removed 1 or 2 days later.

**When handling prepacked concrete**, it is important to:

- Prevent fines from collecting in the coarse aggregate because they tend to impede the flow of the grout. These fines, which could result from abrasion of the coarse aggregate during handling, collect on the bottom of the conveying barges or trucks.

- Deposit the aggregate in a clean place that is free of mud, silt, slurry, or other contamination.

- Pump the grout promptly after aggregate placement.

- Protect the aggregate from contamination between the times of placement and grout intrusion.

### 2.10.4 Sacked Concrete

Slope protection, scour protection around structures, and cover for underwater cables and pipelines can sometimes be done by using sacked or bagged concrete. Three methods are used:

- In one method burlap sacks are half-filled with dry mix. The sacks are lowered underwater on pallets, then placed by a diver. Water penetrates the burlap and concrete to imitate hydration of the cement. This method has one advantage in that the time of handling and placing is not critical, but the sacks can be dislocated by waves or other water movement before the concrete sets. The bond between adjacent sacks may or may not be thorough, and the cement may not be uniformly distributed through the mix. The concrete mix used should be similar to that used for tremie concrete, but with the water and admixtures omitted.

- Another method is to use a wet mix in burlap or jute sacks. The mix should be low-slump. Bags of 1-$ft^3$ capacity are filled to about two-thirds full, securely tied, then promptly lowered into position and placed. Good bond can be obtained and the general quality of the mix can be verified. Bags can be placed in stretcher-and-header courses so as to interlock. The concrete mix used should be similar to that used for tremie concrete, but with less water.

- The preferred method is to fill the sacks underwater. Fabric forms of nylon can be placed over the surface to be protected and pumped full of concrete. The fabric is porous and acts as a combined filter and protective lay. The concrete mix used should be similar to that used for pumped concrete.

## 2.11 GROUTING

### 2.11.1 Materials

Grouts for underwater use can be generally classified as either a hydraulic cement or an epoxy. Several variations of both the hydraulic cement and the epoxy are commercially available for use in different applications.

A hydraulic cement is a single-component cement that is capable of setting and hardening underwater because of the interaction of water and the constituents of the cement. Admixtures are available from hydraulic cement manufacturers for obtaining specific performance goals (i.e., accelerate or slow down the reaction rate).

Epoxy grouts are used for bonding different surfaces or for filling thin voids. All epoxy grouts have at least two components: a resin component and a hardener component. Some epoxy grouts also have additions of fillers or aggregates to "extend" or increase the usable volume of the grout or to modify the characteristics of the grout. Epoxy grouts without additions or fillers are called "neat" grouts. Epoxy grouts are commercially available in different formulations, each having a specific performance or physical characteristic (i.e., strength, mixing ration, pot life, moisture sensitivity, etc.).

Table 2-29 lists the materials for the grouting applications described in Sections 2.11.2 through 2.11.5.

Table 2-29
Grouting Applications and Materials

| Procedure | Material |
|---|---|
| Securing U-bolts or rock anchors to seabed | • Hydraulic cement grout<br>• Neat epoxy resin grout |
| Repairing deteriorated concrete surfaces | • Epoxy resin/oven-dried aggregate grout<br>• Hydraulic cement grout |
| Repairing cracks in concrete | • Neat epoxy resin grout |
| Installing anchor bolts in concrete | • Prepackaged epoxy grout<br>• Hydraulic cement grout<br>• Neat epoxy resin grout |

### 2.11.2 Securing U-Bolts or Rock Anchors to Seabed

Grouted-in-place U-bolts or other types of anchor bolts provide an excellent anchoring technique for pipelines or for split-pipe cable protection systems in soft rock or coral seabeds. Either hydraulic cements or neat epoxies are used for grouting these anchor bolts.

The first step in securing the U-bolt or rock anchor is to drill a hole of the required dimensions (usually 1 to 1-1/2 inches in diameter, 12 to 16 inches deep) at the desired anchoring location. See to Section 2.2.3 for a discussion of drilling equipment and techniques. In some locations, drifting sand can be expected to fill the drilled hole before the grout can be inserted. In this case, compressed air should be used to blow the hole free of sand just prior to inserting the grout. If compressed air is not available, the hole can be temporarily plugged by placing a pipe into the hole immediately after drilling. The diameter of the pipe should be slightly smaller than the diameter of the hole and the upper end of the pipe should extend 6 inches to 1 foot above the seabed to keep the sand out.

**2.11.2.1 Hydraulic Cement.** Hydraulic cement is placed by either of two methods. In the surface mix method, the cement-sand mixture and water are poured into a 4- to 5-foot length of flexible plastic tube, about 5 inches in diameter and 6 mils thick, with a knot in the lower end. The mixture is shaken and kneaded on the surface, the tube is carried to the bottom by a diver, and the contents are squeezed into the drilled hole. This procedure has often proved to be unsatisfactory because the mixture tends to harden too rapidly. A better solution, referred to as the toothpaste-tube method, is to pour the cement-sand mixture into a tied-off tube, twist and hold the tube at the center, pour in the freshwater, and then tie off the top of the tube. The tube is then lowered to the diver in a tool bag, who releases the twist in the tube and mixes the grout on the bottom. This will allow sufficient time to squeeze the grout into the hole before the mixture hardens.

When working with hydraulic cement it is prudent for the diver to have voice communications (COMS) with the surface. Using COMS, the diver can inform the tenders when to lower tubes of cement to the worksite.

**2.11.2.2 Epoxy Resin.** When selecting an epoxy resin material, the water temperature at the work site as well as the manufacturer's packaging and application technique should be considered. Generally, for applications where the water temperature is greater than 60 degrees, a polyester resin approved for marine use may be used. However, for temperatures between 23 and 60°F, a vinylester resin (or other specially formulated resin) should be used. The vinylester resin can also be used for warmer areas.

Generally, epoxies consist of two components (resin and catalyst) that may come in a variety of different mixing ratios. One manufacturer's product (HILTI) comes packaged in a self-contained glass vial that is inserted into a hole (made by a rock drill) and then mixed by rotating a threaded fastener down into the glass vial. The hammering/rotary action applied by the drill breaks the glass vial and mixes the components of the capsule together. The advantage of this particular system is that the mixing technique minimizes the amount of handling. However, because the mixing takes place in the fastener hole, it is important that the hole fully contain the epoxy during the mixing process. For this reason, the use of glass vial products is not recommended in coral seafloors (where the epoxy may not be well contained during the mixing process).

For applications requiring flexibility in the amount of grout dispensed, the epoxy is placed by using either a caulking gun or the NFESC grout dispenser. Both of these techniques have been used in coral seafloors, where it has been shown that increased fastener holding strength can be achieved by completely filling all of the void spaces in a fastener hole with epoxy (effectively strengthening the foundation material).

Pneumatically-operated caulking guns (60 to 100 psi) that dispense epoxy grouts from disposable plastic cartridges are commercially available.

The grout is usually premixed in buckets on the surface, poured into the cartridges, and then relayed to the divers at the work site. The divers then systematically load and dispense the contents of each cartridge. Since most epoxy grouts have a relatively short pot life (30 minutes or less), successful application using this technique requires quick execution and teamwork.

The NFESC grout dispenser, shown in Figure 2-56, is a pneumatically-powered diver tool. The grout dispenser simultaneously mixes and dispenses neat epoxy (1:1 mixing ratio) from two 20-fluid ounce disposable plastic car-

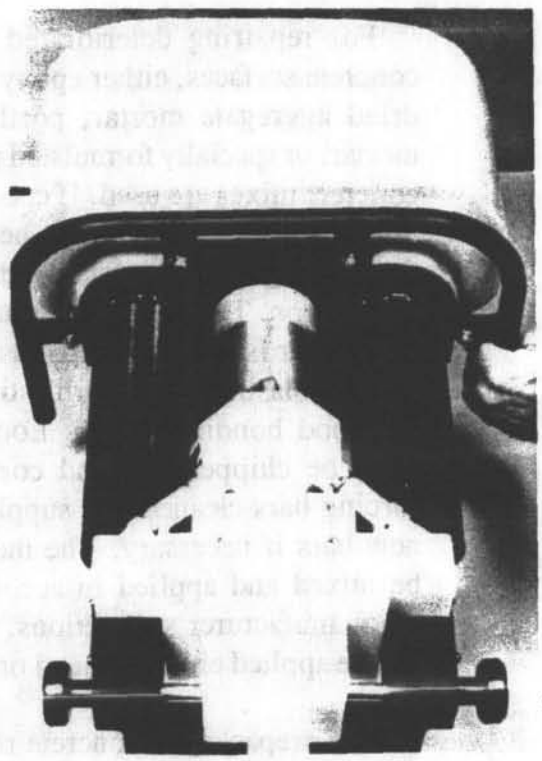


Figure 2-56
Diver-operated epoxy grout dispenser.

tridges. The tool can be reloaded underwater with full cartridges of epoxy and can dispense epoxies at a repetitive rate of 1,000 fl oz/min. In addition, the tool incorporates a "blow-out" system for cleaning residual epoxy from the mixing mechanism. This helps prevent epoxy from hardening inside the tool. The tool weighs approximately 35 pounds dry and 8 pounds submerged. In comparison with other underwater grouting techniques, this method delivers larger quantities of grout in shorter periods of time, employs air pressure rather than muscle to mix and dispense epoxy, and eliminates errors in mixing.

Also, if desired, the epoxy components can be preassembled (by the epoxy manufacturer, cartridge manufacturer, or a contractor), thereby minimizing exposure or contact with dive personnel and equipment.

### 2.11.3 Repairing Deteriorated Concrete Surfaces

For repairing deteriorated underwater concrete surfaces, either epoxy resin/oven-dried aggregate mortar, portland cement mortar, or specially formulated prepackaged concrete mixes are used. If epoxy mortar is used, the epoxy resin must be formulated for beading to wet surfaces and underwater application. The concrete surfaces to which the mortar is to be applied must be cleaned by sandblasting or waterblasting to allow for good bonding action. Loose concrete must be chipped out and corroded reinforcing bars cleaned and supplemented by new bars if necessary. The mortar should be mixed and applied in accordance with the manufacturer's directions. The mortar can be applied either by hand or tool smearing.

The prepackaged concrete mixes can be either hand applied or pumped. Surface preparation is as described above for the mortar. The special formulation provides dimensional stability underwater with minimal washout.

### 2.11.4 Repairing Cracks in Concrete

The best method for repairing small to medium cracks in concrete piles or structures is pressure injection of neat epoxy resin. This method can generally be used for cracks up to 1/4-inch wide. The epoxy selected should be a low-viscosity formulation suitable for wet surfaces and underwater application. In choosing the appropriate resin, it is important to confer with the manufacturer to ensure that the resin is compatible with the crack size and depth, temperature variations, characteristics of the concrete, and the equipment to be used to apply the resin. Holes should be drilled into the bottom of the crack every 6 inches to 3 feet along its length, and small tubes, or one-way polyethylene valves, should be installed. The area around the tube or valve and the entire surface of the crack should be sealed with a quick-setting epoxy paste adhesive. Fiberglass tape can be used in conjunction with the paste as described later in Section 5.7.2. The low-viscosity epoxy resin is then injected into the lowest valve until it reaches the level of the next valve. The lower valve is closed. The epoxy is then injected in the upper valve and the procedure repeated until the crack is filled. In the event of unanticipated leakage from previously undetected cracks, hydraulic cement is used as a sealer.

### 2.11.5 Installing Anchor Bolts in Concrete Structures

Using prepackaged epoxy grout in glass tubes is an extremely efficient method of installing anchor bolts in existing concrete structures. The action of screwing the an-

chor into the tube breaks the glass, which then acts as a coarse aggregate, and mixes the resin to start the setting action. This type of grouting system is very cost effective for small projects.

Alternatively, portland cement mortar or epoxy resin can be used. With these materials the grout is squeezed or injected into the drilled and cleaned hole so that the hole is almost full. The anchor bolt is then inserted into the hole, forcing some of the grout out and ensuring that the hole is completely filled.

## 2.12 PROTECTIVE COATING APPLICATION

The life of marine structures can be extended when proper measures are taken to protect surfaces in contact with seawater. Applying protective coatings is the conventionally accepted method of protecting steel marine structures from corrosion attack. Since marine structures are subject to salt, air, or water exposure, the coating systems used are much more sophisticated than ordinary systems for inland steel structures.

Many references are available for applying marine structure protective coatings above the water line. Two excellent references are:

- NAVFAC MO-104 - Maintenance of Waterfront Facilities (scheduled for revision in 1997)

- NAVFAC MO-110 - Paints and Protective Coatings

The following discussion is concerned only with the application of protective coatings below the high water line.

### 2.12.1 Types of Protective Coatings

Several underwater-curing, epoxy-polyamide mastic coatings are available on the market. The suitability of these coatings for a particular application may be affected by factors such as seawater temperature and salinity, surface preparation, and electrical charge on steel surfaces (as from a cathodic protection system). Therefore, it is desirable to test the proposed coating on a small section of the surface to be coated to confirm that it will adhere properly.

The available underwater coatings fall into two general categories: brush/roller applied and hand applied. The hand-applied coatings are generally more suitable for UCT operations. They consist of two separate packages, each with a different color pigmentation. The viscous liquid epoxy resin in one package reacts with the viscous polyamide resin in the second package to form a hardened mass.

Apply a three-coat system with a total dry film thickness of 9 mils (0.009 inch) consisting of one coat of MIL-P-24441 formula 150 (0.003-inch minimum thickness), one coat of MIL-P-24441 formula 151 (0.003-inch minimum thickness), and one coat of MIL-P-24441 formula 152 (0.003-inch minimum thickness).

Coal tar epoxy polyamide is also used but has toxicity problems, primarily during application. The recommended coating of this type is Steel Structures Painting Council Paint #16.

All coatings should be mixed and applied following the manufacturer's instructions. It cannot be stressed too strongly that the manufacturer's instructions must be followed to obtain a long system service life. Shortcuts can reduce service life.

### 2.12.2 Surface Preparation

To prepare the surfaces to receive the underwater coating, all dirt, oil, grease, loose paint, rust, rotted and spalling concrete, rotted wood, marine growth, and other interference materials must be removed. Adhesion of the coating will only be as good as the cleanliness and soundness of the substrate. Sandblasting to a near white metal is the preferred cleaning method but high-pressure waterblasting may be acceptable. Scraping and other manual means of surface preparation are time consuming and of limited benefit.

In many cases, local environmental restrictions require that the abrasive blast media and paint be collected and not fall into the water. Abrasive blasting and the application of some paints may also be locally regulated. Particular care should be taken when removing lead-based paint. When removing lead-based paint, the worksite generally needs to be enclosed and all of the paint that is removed needs to be treated as hazardous waste. In addition, special precautions must be taken to prevent contact with or inhalation of the old paint or contaminated blast media.

Metal surfaces should be coated as soon as possible after cleaning to minimize the formation of new corrosion products. If the surface is not coated within about 4 hours, it should be cleaned again.

Field experience has shown that successful application of underwater coatings on steel surfaces requires that the steel have a positive or neutral charge. A negative charge on a steel surface will repel the negatively charged epoxy coating. An underwater voltmeter should be used to check the charge on the surface. If the structure has a cathodic protection system, it can be neutralized either by turning off the system, as in the case of an impressed current system, or by removing remnants of a sacrificial anode system.

### 2.12.3 Mixing

The two differently colored components of the underwater coating should be thoroughly mixed (preferably in 1-quart quantities) by hand to produce a uniform color. The preparation and method of mixing depend on the particular product being used; therefore, the manufacturer's instructions should be carefully followed.

**CAUTION**

**Since some people may be sensitive to epoxy or polyamide resins, wear protective gloves.**

Most underwater coatings have a work time, or pot life, ranging from 15 to 45 minutes at 70°F. The pot life is usually reduced by 50 percent at temperatures above 80°F. Some preplanning, therefore, must be given to the quantity of material that can be used in the span of the pot life. Material may still be workable after the pot life has passed, but it will not adhere properly.

### 2.12.4 Application

Epoxy coatings are best applied by hand. A ball of the thoroughly mixed coating should be picked up with wet gloved hands and pressed against the area to be coated. It should be forced from the center to the outside to give a thickness of 1/8 to 1/4 inch and then smoothed and feathered at the edges. Epoxies are best applied at temperatures above 60°F. An average experienced diver can apply the coating at a rate of about 1/2 $ft^2$/min. Based on a pot life of 15 minutes, not more than 1/2 gallon should be prepared at one time for each diver.

Regarding paints for potable water tanks, yes, potable water tanks can be painted. Specific paints are approved by each State for use in potable water tanks. Most approved paints are epoxies. The National Sanitation Foundation has several approved systems.

### 2.12.5 Coverage

The coverage of underwater coatings varies with each specific material and the applied thickness. For a 3/16-inch thickness, theoretical coverage is 8.5 $ft^2$/gallon, practical coverage is about 6 $ft^2$/gallon.

# Chapter 3

# UNDERWATER INSPECTION PROCEDURES

## 3.1 SCOPE

A major portion of the UCT's activity is directly related to the underwater inspection of a wide variety of waterfront structures and other marine facilities. UCT underwater inspections are primarily visual observations of the facility being inspected. Quantitative measurements, such as underwater voltmeter readings on metal structures and thickness measurements on mooring chain and steel piling, are often taken.

Before making the observation, it is usually necessary to clean the structure of marine growth and fouling. Several techniques are used to accomplish this cleaning, ranging from hand cleaning with scrapers and wire brushes to the use of waterblasting jets and hydraulically-powered mechanical abrasive tools. These techniques are discussed in Section 2.3.

This chapter has been arranged to present a general description of:

- Waterfront facilities (Section 3.2)
- General inspection procedures (Section 3.3)

and detailed descriptions of the procedures to be used for:

- Inspecting steel structures (Section 3.4)
- Fleet moorings (Section 3.5)
- Concrete structures (Section 3.6)
- Timber structures (Section 3.7)
- Stone masonry structures (Section 3.8)
- Coastal protection structures (Section 3.9)
- Graving drydocks (Section 3.10)

Each of these sections also includes a description of the causes of deterioration of the relevant type of structural material.

In addition to the facilities listed above, the UCTs often are required to carry out inspections of undersea cables, wire rope, pipelines, and instrument arrays. However, these inspections are often performed in conjunction with repair or installation operations and, consequently, are discussed in Chapters 5 and 6.

## 3.2 INTRODUCTION TO WATERFRONT FACILITIES

An important part of the UCT's work is related to the underwater inspection of a wide variety marine facilities. The following discussion provides a very brief introduction to the types of waterfront facilities that UCT personnel may encounter. More detailed information is provided in other sections in this manual as well as in specific official Government handbooks. Other marine facilities such as moorings and cable/pipeline systems are discussed in in-

dividual sections. The following handbooks provide useful information and should be a part of the OIC reference library:

MIL-HDBK-1025/1 - Piers and Wharves

MIL-HDBK-1025/6 - General Criteria for Waterfront Construction

MO-104.1 - Maintenance of Fender Systems and Camels

MO-104.2 - Specialized Underwater Waterfront Facilities Inspections

MO-306 - Maintenance and Operation of Cathodic Protection Systems

DM-26.1 - Harbors

DM-26.5 - Fleet Moorings

Marine facilities of interest to the UCTs include:

- Berthing facilities
- Drydocks
- Coastal protection structures
- Components of waterfront structures: fender systems, piling, and dolphins
- Fleet moorings
- Underwater cables and pipelines

### 3.2.1 Berthing Facilities

Berthing facilities provide space for: mooring, shore utilities, hotel services, loading and unloading of cargo, personnel, ordnance, and fuel, and maintenance, repair, and fitting out. Piers are also used to support specific functions such as magnetic silencing facilities for submarines. Some typical configurations of piers and wharves are shown in Figure 3-1.

**3.2.1.1 Piers.** Piers are docks that extend outward from the shore into the water. There are basically four types of pier structures with distinct differences in configuration: open, closed, combination, and floating. These piers are :

(a) **Open piers** (Figure 3-2) are pile-supported platform structures which allow water to flow underneath. Conventionally open piers are single deck structures although some are double deck (Figure 3-3).

(b) **Closed piers** (Figure 3-4) are constructed so that water is prevented from flowing underneath. The solid fill pier is surrounded along the perimeter by a bulkhead that holds back the fill.

(c) **Floating piers** (Figure 3-5) can be constructed of steel or concrete and are connected to the shore with access ramps. Guide piles or anchor systems prevent lateral movement. Floating piers may be either single or double deck.

**3.2.1.2 Piling.** Piling is a common element found on piers, wharves, and some fender systems. Inspection and repair of piling forms an important part of UCT tasking. Figure 3-6 provides some typical pile cross sections for steel wood and concrete piles with dimensions typically found in marine structures.

The basic types of piling are:

(a) Vertical bearing piles are used to support the dead weight of the pier as well as the live loads on the pier.

(b) Batter piles primarily provide lateral and longitudinal stability but do provide limited load carrying capacity.

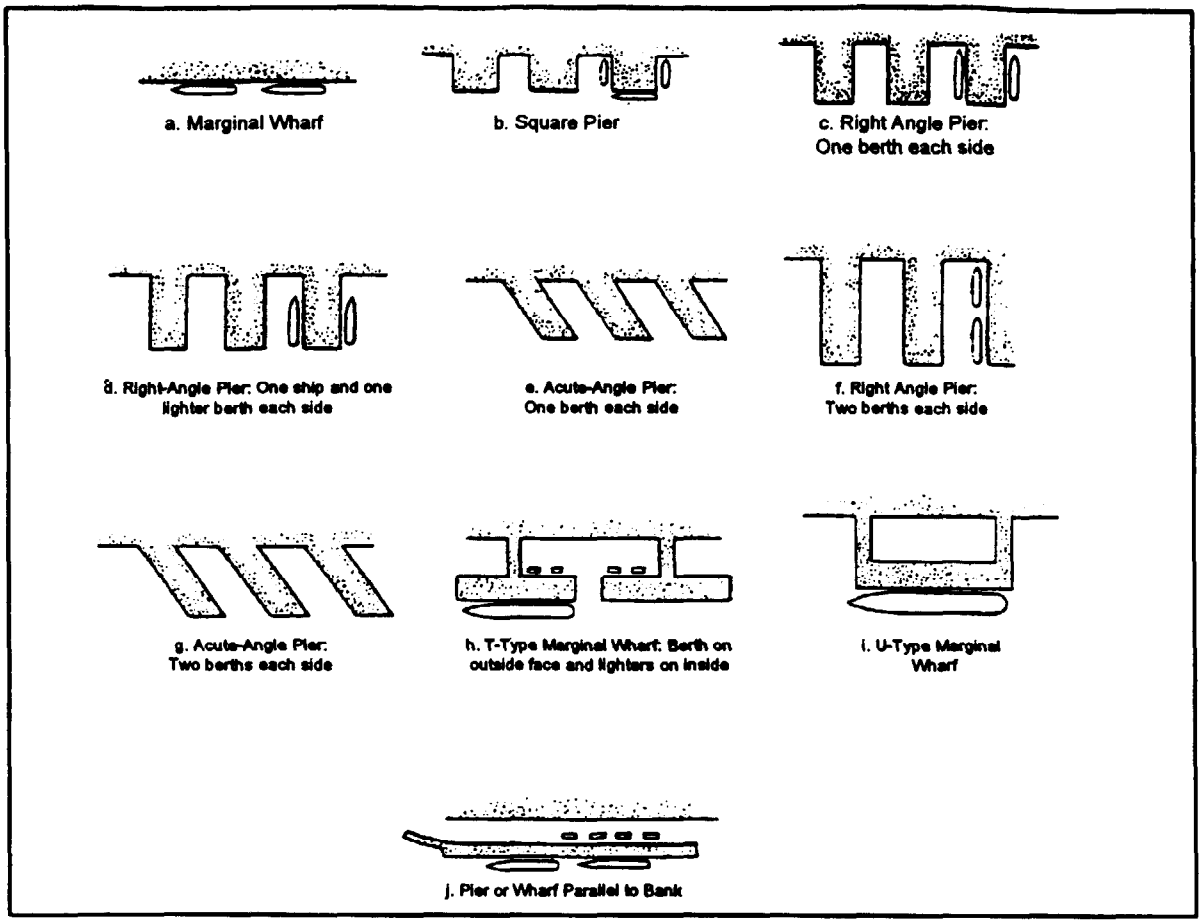



Figure 3-1. Basic configuration of piers and wharves.

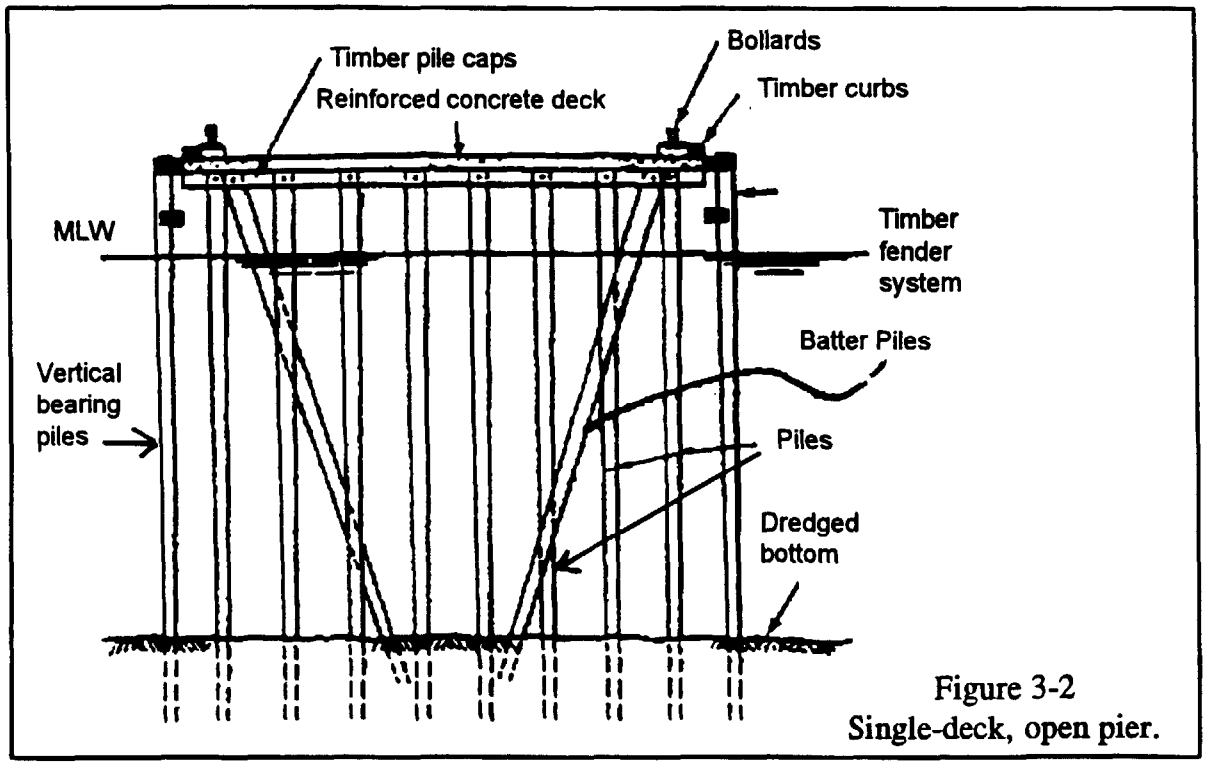



Figure 3-2
Single-deck, open pier.

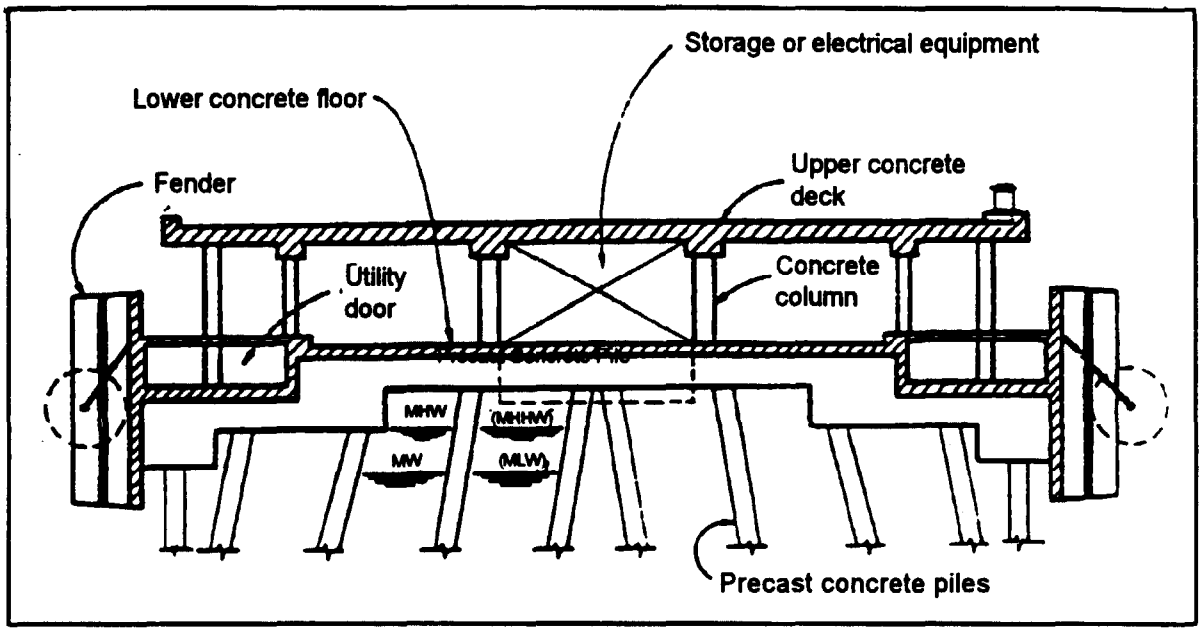



Figure 3-3. Double-deck pier.

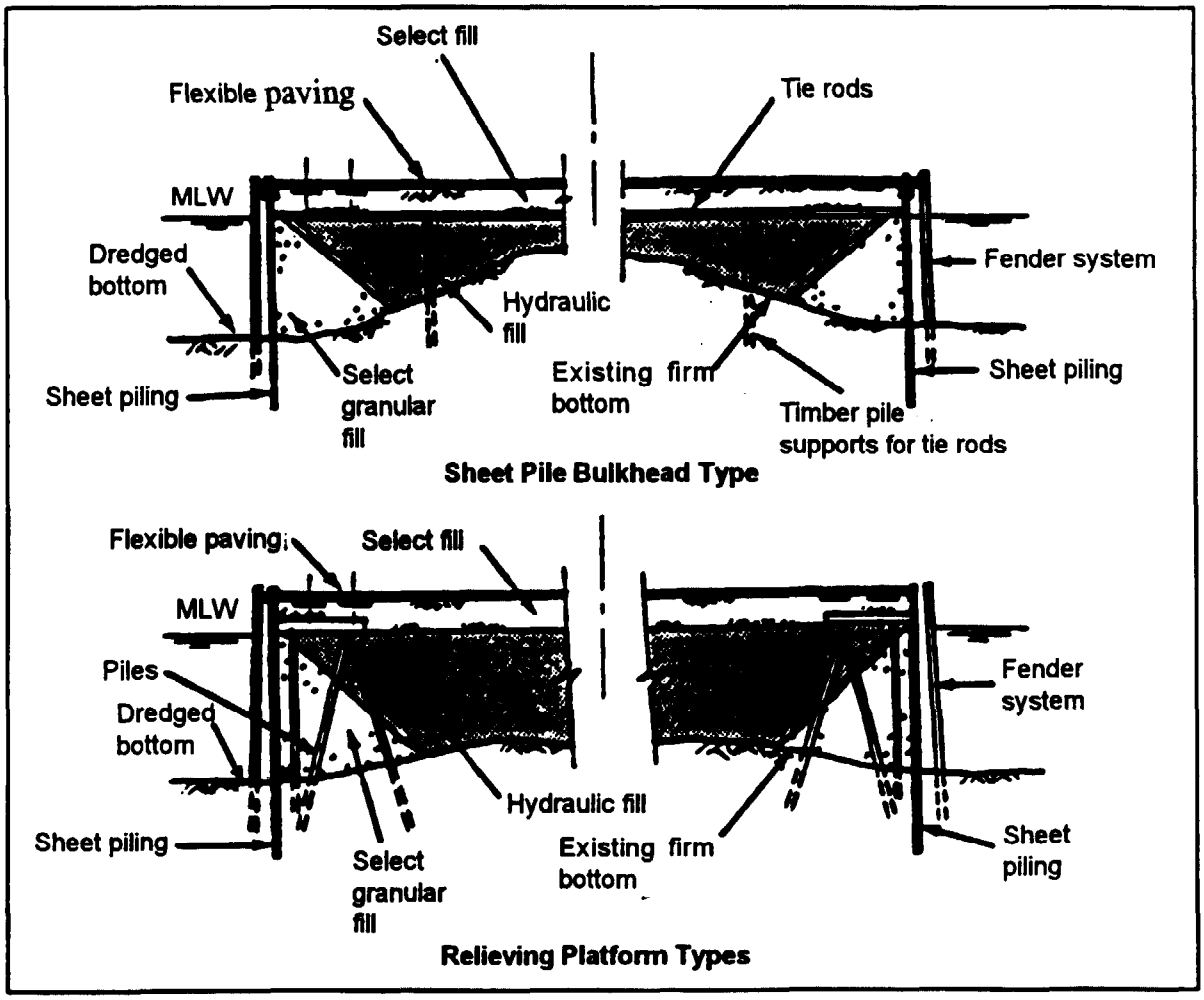



Figure 3-4. Solid fill pier.

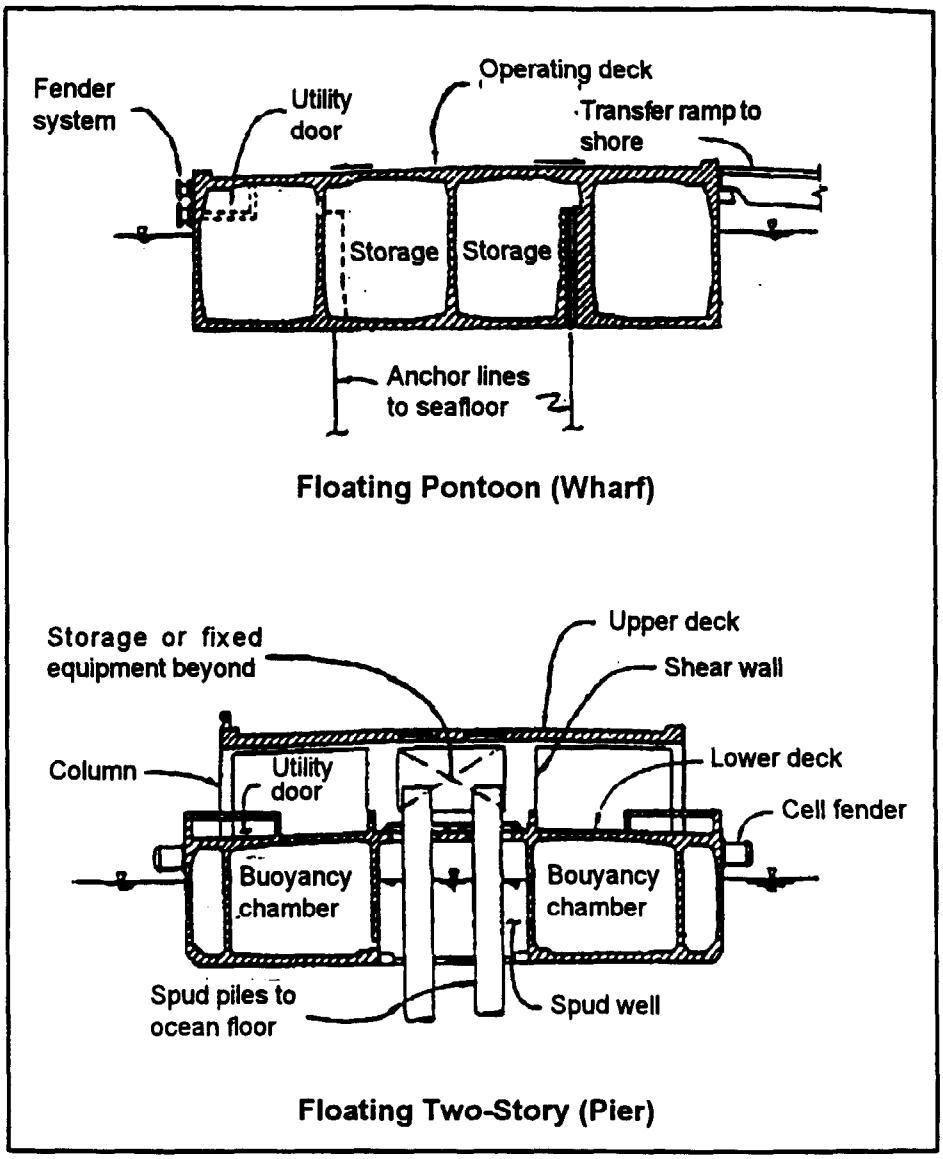



Figure 3-5. Floating pier.

(c) Fender piles absorb the impact of berthing ships.

(d) Sheet piling is used with various waterfront facilities to retain fill.

**3.2.1.3 Wharves and Quaywalls.** Wharves are docks which are oriented approximately parallel to the shore and are connected to shore along their entire length. The retaining structure used to contain the backfill is commonly referred to as the quaywall or bulkhead. Several types of these structures are shown in Figure 3-7.

**3.2.1.4 Fender Systems.** Fender systems are used on piers to protect the ship and the pier during berthing operations and while the ship is moored. On relatively inflexible piers and wharves the fender acts as a buffer in absorbing or dissipating the impact energy of the ship without damaging the ship. Where ships are berthed against pile-supported structures, protection of the struc-

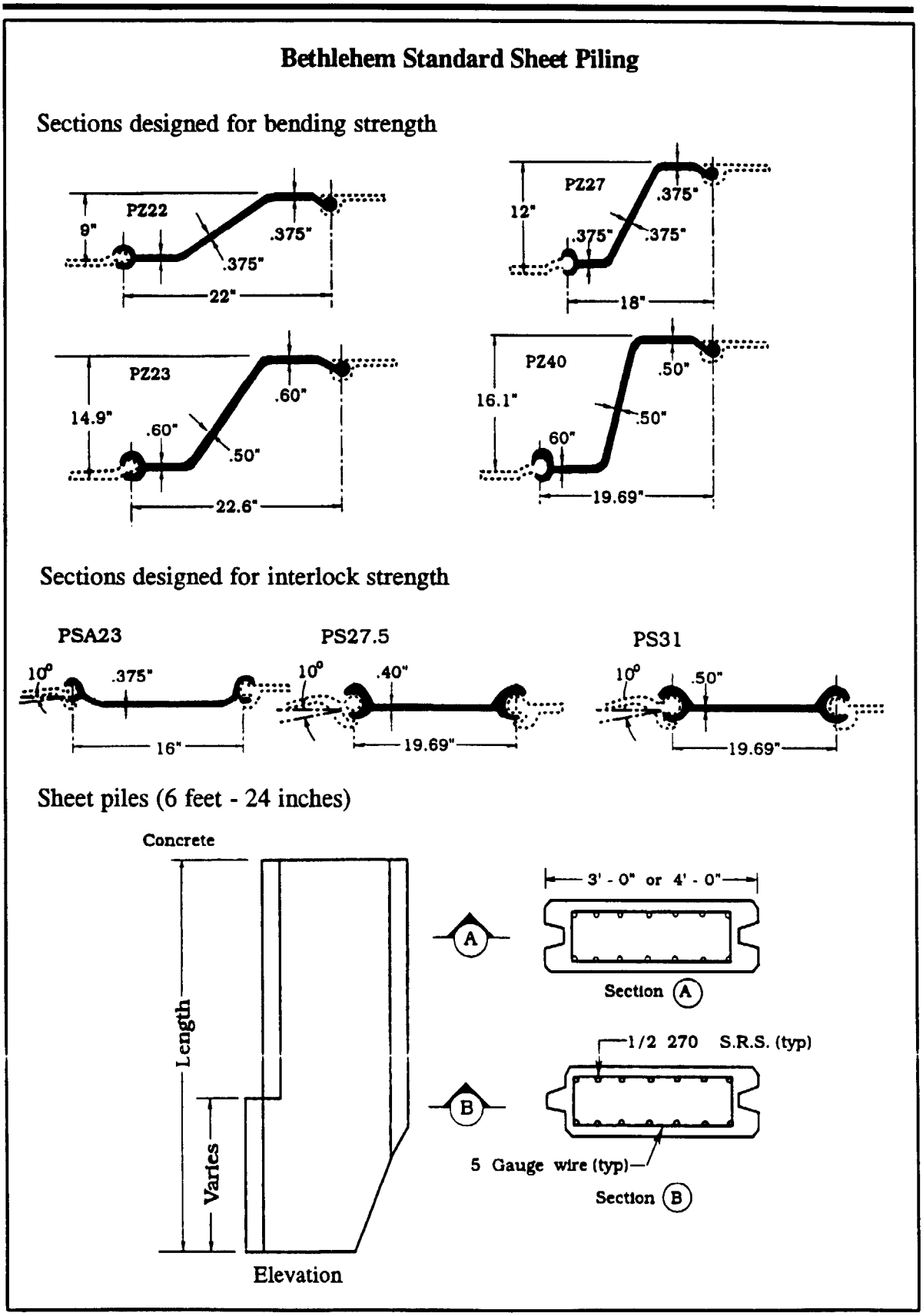



Figure 3-6
Examples of steel, wood, and concrete piling.

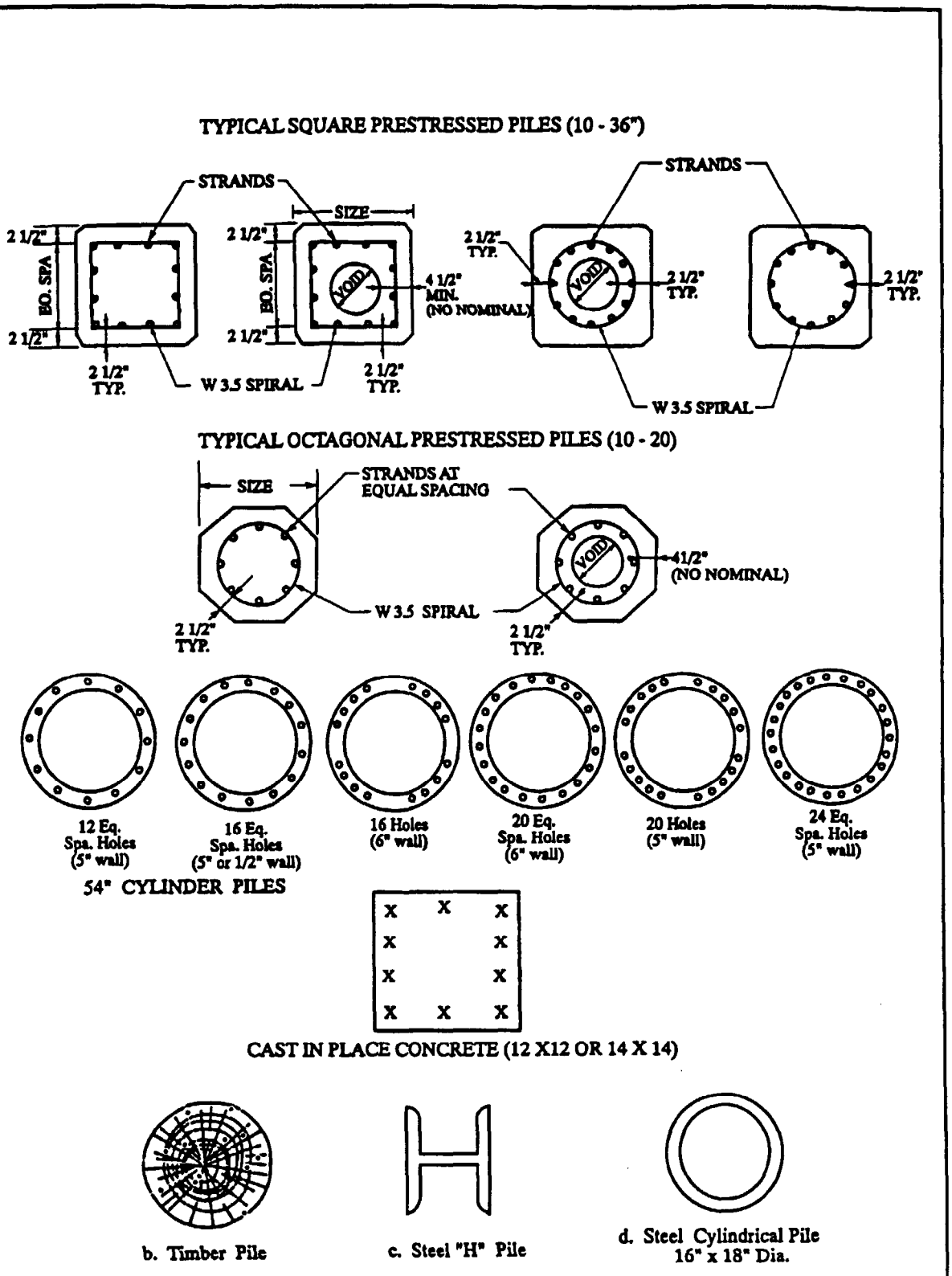



Figure 3-6
Examples of steel, wood, and concrete piling (continued).

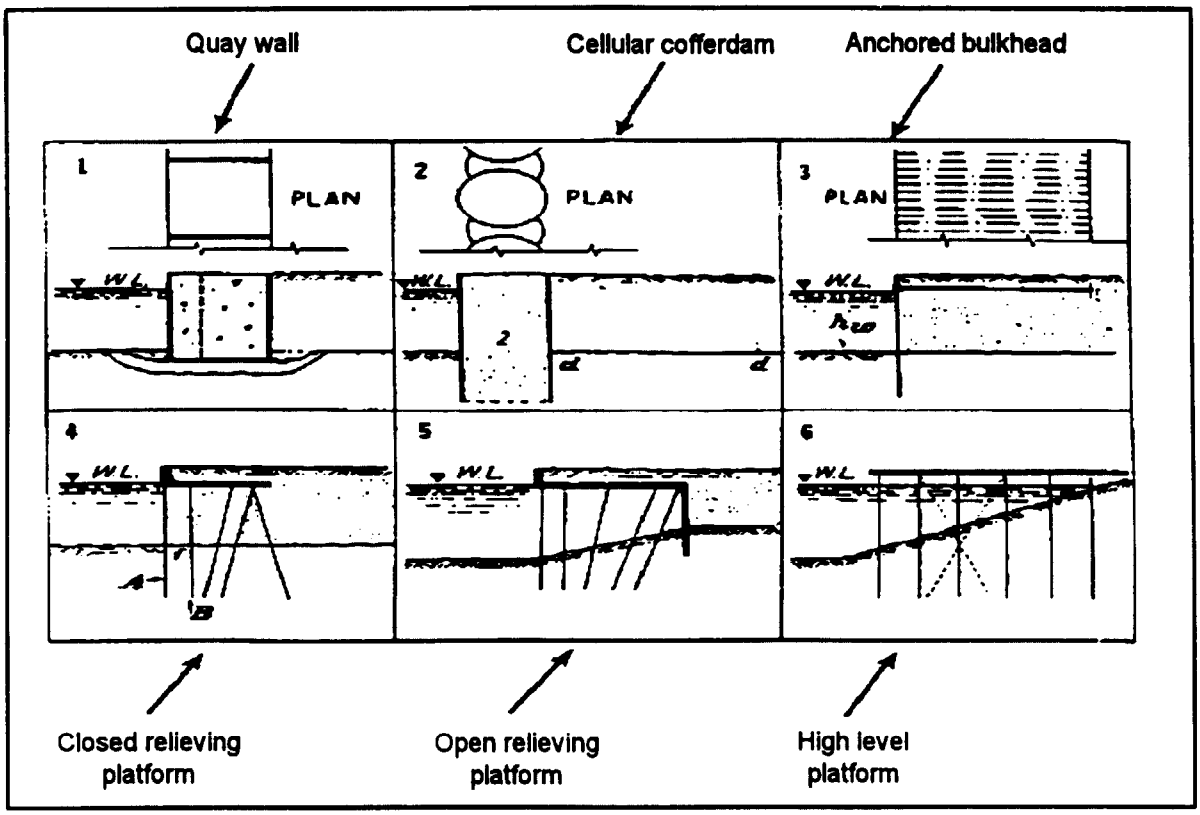



Figure 3-7. Types of wharves and quaywalls.

ture is of more serious concern. The main type of fenders and components that are found on older and smaller piers are fender pile systems. For modern larger piers, various types of fenders are attached to the pier, and they include:

- Rubber units in compression or shear (various shapes: cylindrical, rectangular, trapezoidal, wing, etc.).
- Buckling column (various shapes).
- Pneumatic (air filled) shapes.
- Foam filled (typically cylindrical shape).

**3.2.1.5 Dolphins.** Dolphins (Figure 3-8) are groups of piles placed near piers and wharves or in turning basins and ship channels. These structures are used to guide vessels into their moorings, to mark underwater structures, to moor vessels to, to berth vessels against, and to support navigational aids.

**3.2.1.6 Drydocking Facilities.** Drydocking facilities are used for construction and maintenance of ships and barges. The different types of drydocks include:

(a) **Graving drydocks** are fixed basins adjacent to the water's edge and are constructed of stone masonry, concrete, or sheet pile cells. They can be closed off from the waterway by a movable water barrier (usually called a caisson). After closing the caisson, the basin is pumped dry allowing the vessel to settle on the blocking. The caisson and drydock seals and sealing surfaces need to be inspected and serviced (this topic is discussed in Section 3.10).

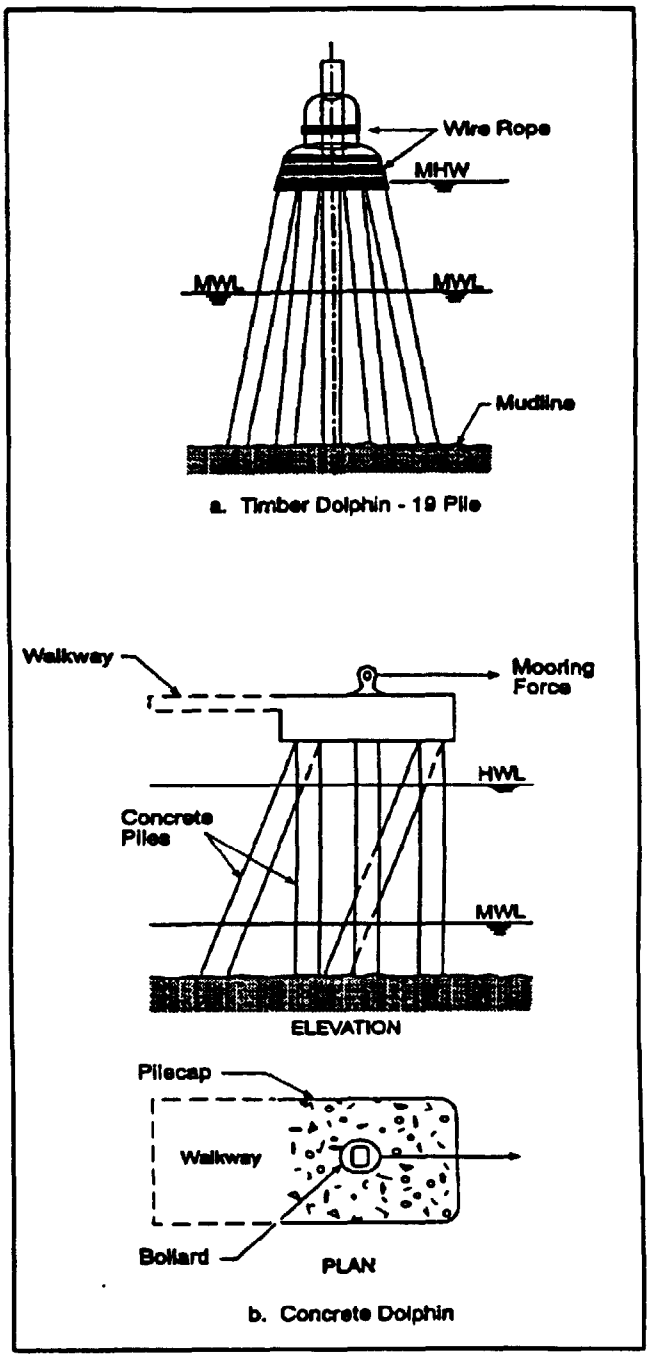



Figure 3-8. Mooring dolphins.

(b) **Floating drydocks** are ship or U-shaped structures that are submerged by flooding. After flooding, the vessel enters. The dock is then pumped dry which raises the vessel out of the water for maintenance or repair.

### 3.2.2 Coastal Protection Structures

Coastal protection structures are designed to reduce the effects of wave action, so as to protect harbors and reduce the formation of sandbars. They can be fabricated out of a variety of materials including concrete, rock rubble, granite masonry, and reinforced precast concrete armor units as shown in Figure 3-9. Typical coastal structures include seawalls, groins, jetties, and breakwaters. These structures are:

(a) **Seawalls** are massive coastal structures built along the shoreline. Their primary function is to protect areas from erosion caused by waves or flooding.

(b) **Groins** (Figure 3-10) are designed to minimize coastal erosion by controlling the rate of shifting sand by influencing offshore currents and waves. Groins project outward, perpendicular to the shoreline.

(c) **Jetties** extend outward from shore to prevent the formation of sandbars and direct the flow of water from currents, tides, and waves.

(d) **Breakwaters** are generally located outside the entrance of a harbor, anchorage, or coastline. They are designed primarily to protect the inner waters and shoreline from the effects of heavy seas. Breakwaters may be connected or detached from the shore.

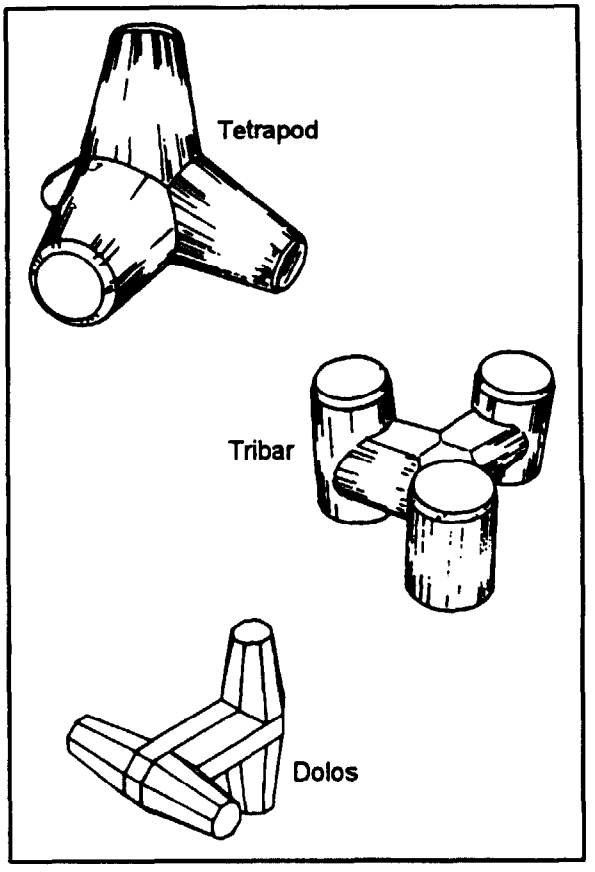



Figure 3-9. Precast concrete armor units used in jetty breakwaters and groins.

## 3.3 GENERAL INSPECTION PROCEDURES

The purpose of any inspection is to provide the information necessary to assess the condition (capacity, safety, and rate of deterioration) of a structure. The usefulness of an inspection depends, therefore, on the suitability and recording of the data (observations) obtained for use in later engineering evaluations. An underwater inspection is a condition survey; therefore, the diver should make and report observations and measurements that can be used by an engineer to make the engineering assessments. A part of the engineering assessment will be to determine the cause of the failure or damage; thus, it is important to detail and document the inspection.

For example, the diver should observe, measure, and report that a sheet pile wall has a hole measuring 2 feet by 3 feet, at a depth of 2 feet below mean low water (MLW), and that behind the hole is a 6-

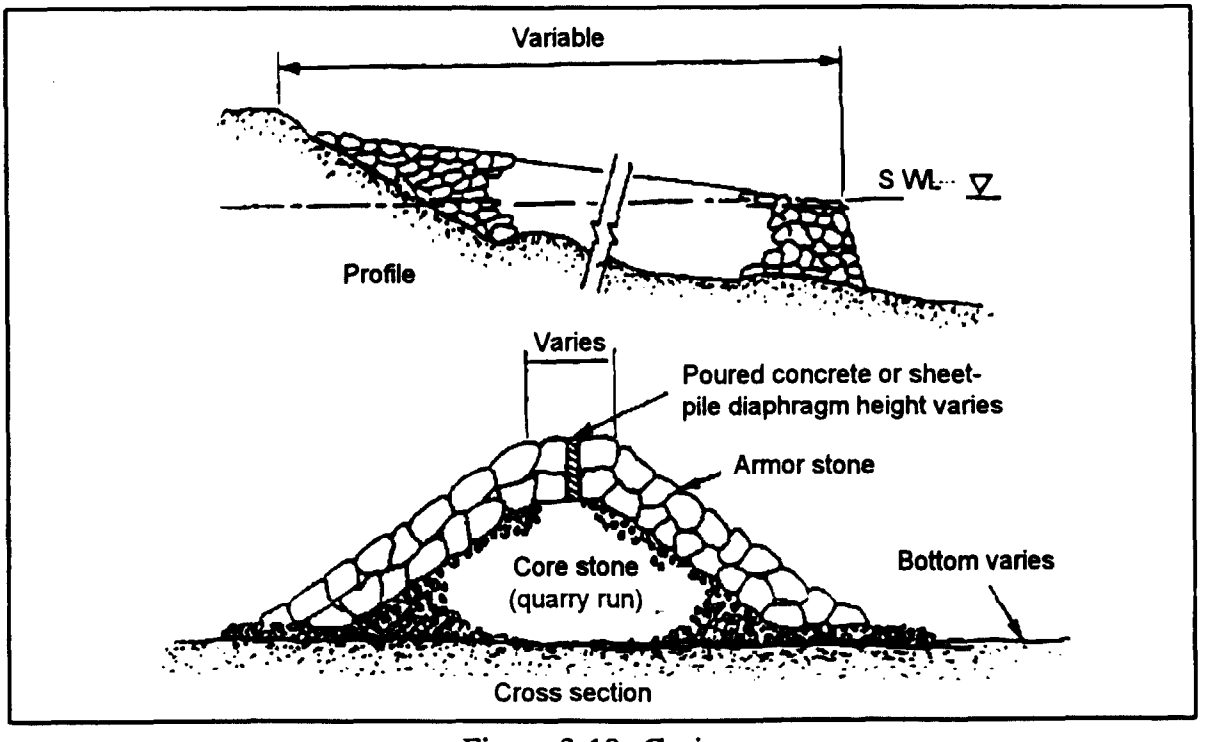



Figure 3-10. Groins.

foot deep cavity. These data may be supplemented by the diver's opinion regarding the structural adequacy of the wall if the nature of its condition is obvious. But a final conclusion can only be reached after an analysis of the structure's existing condition has been carried out.

Since divers' observations and measurements are often the only data available for the topside to make an engineering assessment, the reliability of such data is critically important. Therefore, the quality control of the measurements becomes an important issue. At least 10 percent of all measurements and observations must be rechecked by a second diver to ensure accuracy. If there is any discrepancy, all measurements and observations must be rechecked.

An important part of any inspection operation is the recording of the diver's observations. Observations, both qualitative and quantitative, can be recorded underwater on a Plexiglas slate with a grease pencil. However, direct hardwire communication between the diver and topside is much more efficient. In addition, use a video recording system, a photographic camera, and a voice recorder whenever possible. The dive supervisor or detachment leader should debrief the working diver as soon after the dive as possible. This valuable information should be recorded for later reference.

### 3.3.1 Levels of Inspection

Three basic types or levels of inspection are used for inspecting marine facilities. They are distinguished by the resources and preparation needed to do the work and the type of damage/defect that is detectable, as:

- **Level I - General Visual Inspection.** The Level I effort can confirm as-built structural plans and detect obvious major damage or deterioration due to overstress (collisions, ice), severe corrosion, or extensive biological growth and attack.

  This type of inspection does not involve cleaning of any structural elements and can therefore be conducted much more rapidly than the other types of inspections. The Level I effort is essentially a general inspection "swim-by" overview. It does not involve cleaning of structural elements, which allows the inspection to be conducted rapidly. The underwater inspector relies primarily on visual and/or tactile observations (depending on water clarity) to make condition assessments. These observations are made over the specified exterior surface area of the underwater structure, whether it is a quaywall, bulkhead, seawall, pile, or mooring. Although this is an overview, close attention should be given to confirming or providing information to update available facility drawings and condition evaluations.

- **Level II - Close-Up Visual Inspection.** Level II efforts are complete, detailed investigations of selected components or subcomponents, or critical areas of the structure, directed toward detecting and describing damaged or deteriorated areas that may be hidden by surface biofouling. Limited deterioration measurements are obtained. These data are sufficient for gross estimates of facility load capability. This type of inspection will generally involve prior or concurrent cleaning of part of the structural elements. Since cleaning is time consuming, it is generally restricted to areas that are critical or that may be typical of the entire structure. Simple instruments such

as calipers and measuring scales are commonly used to take physical measurements. Subjective judgments of structural integrity are occasionally made by probing wood with ice picks and by pounding concrete with hammers.

• **Level III - Highly Detailed Inspection.** This level of inspection is primarily designed to provide data that can be used to perform a structural assessment and will often require the use of Nondestructive Testing (NDT) techniques. The procedures are conducted to detect hidden or imminent damage. The training, cleaning, and testing requirements will vary depending on the type of damage/defect that is to be investigated and the type of inspection equipment to be used. In some cases, Level III inspections will require the use of partially destructive techniques such as sample coring in wood or concrete, material sampling, and in-situ surface hardness. The use of Level III inspection techniques is usually limited to key structural areas that may be suspect, or to structural areas that may be representative of the overall structure.

On steel H-piles, pipe piles, and sheet piles, metal thickness measurements are made with ultrasonic thickness equipment (Section 3.6.4.3). In addition, electrical potential measurements, using a half cell, are taken to verify the performance of the cathode protection system for steel structures. Concrete surfaces can be evaluated for hardness using the rebound hammer described in Section 3.6.4.2. A magnetic rebar locator (Section 3.6.4.1) can be used to establish the location and depth of rebar. There are few underwater instruments currently available for assessment of the interior of wood structures. Wood is inspected using calipers, ice picks, and hammers, and in some cases an incremental borer is used to obtain a core sample.

Table 3-1 summarizes the type of damage that is detectable with the three types of inspection. The level of inspection to be used for a particular task is usually decided early in the planning phase. However, depending upon visibility, marine growth, and extent of deterioration, this may be adjusted as the inspection proceeds. Often, the requirements of the local Public Works office Staff Civil Engineer or other authority will dictate the level of inspection.

The time and effort required to carry out the three different levels of inspection are quite different, and the time required for any particular level will depend on a number of factors, including visibility, currents, wave action, water depth, severity of marine growth, and the skill and experience of the diver.

Table 3-2 provides a guide for estimating the time required to conduct Level I and Level II inspections. This information is based on:

(1) a water depth of 30 to 40 feet
(2) visibility of 4 to 6 feet
(3) warm, calm water
(4) moderate marine growth (about 2 inches thick)
(5) an experienced diver of average skill

For the Level II inspection it has been assumed that 3 feet of the structural element in the splash zone, 1 foot at mid-depth, and 1 foot at the bottom will be completely cleaned of marine growth. It has also been assumed that the most efficient method of removing marine growth will be used (refer to Section 2.3).

Level III inspections depend on the extent of existing damage, the type of inspection techniques, the equipment used (ultra-

Table 3-1
Level of Inspection Versus Detectable Damage to Waterfront Structures

| Level | Purpose | Detectable Defects | | |
|---|---|---|---|---|
| | | Steel | Concrete | Wood |
| I | General visual to confirm as-built condition and detect severe damage | Extensive corrosion<br><br>Severe mechanical damage | Major spalling and cracking<br><br>Severe reinforcement corrosion<br><br>Broken piles | Major losses of wood<br><br>Broken piles and bracings<br><br>Severe abrasion or marine borer attack |
| II | Detect surface defects normally obscured by marine growth | Moderate mechanidal damage<br><br>Major corrosion pitting | Surface cracking and crumbling<br><br>Rust staining<br><br>Exposed rebar and/ or prestressing strands | External pile damage due to marine borers<br><br>Splintered piles<br><br>Loss of bolts and and fasteners<br><br>Early borer and insect infestation |
| III | Detect hidden and imminent damage | Thickness of material | Location of rebar<br><br>Beginning of corrosion of rebar<br><br>Internal voids<br><br>Change in material strength | Internal damage due to marine borers (internal voids)<br><br>Decrease in material strength |

Table 3-2
Production Rate for Surface and Underwater Inspection of Structural Elements

| Structural Element | Inspection Time Per Structural Element (min) | | | |
|---|---|---|---|---|
| | Level I | | Level II | |
| | Surface | U/W | Surface | U/W |
| 12-in. steel H-pile | 2 | 5 | 15 | 30 |
| 12-in. wide strip of steel sheet pile | 1 | 3 | 8 | 15 |
| 12-in. square concrete pile | 2 | 4 | 12 | 25 |
| 12-in. wide strip of concrete sheet pile | 1 | 3 | 8 | 15 |
| 12-in. diameter timber pile | 2 | 4 | 10 | 20 |
| 12-in. wide strip of timber sheet pile | 1 | 3 | 7 | 15 |

sonic thickness measurements, increment borings, caliper measurements, etc.), and the degree of cleaning required. Therefore, estimates of time for Level III inspections are not included in Table 3-2.

### 3.3.2 Planning for Inspection

Before starting a facility inspection, all available information about the facility should be obtained. As described in Section 1.4, this will usually require a preliminary visit to the facility by the UCT OIC. The OIC should meet with the local Public Works personnel and obtain copies of the facility drawings and general background about the existing condition of the facility. Any unique features or special problems that may be encountered should be noted. **Local information** that should be obtained include:

- Atmospheric temperature range.
- Water temperature range.
- Tidal range.
- Water depths.
- Water visibility.
- Currents.
- Any condition that could have a direct impact on the time needed to perform an inspection, such as amount of biofouling growth on piles or any other condition that would inhibit the performance of an inspection such as ice or seasonal flooding.
- Ship traffic and facility berthing requirements.

The Public Works Officer can provide information about the local support, equipment, and utilities that can be made available to the UCT.

Once the information about the facility has been collected, an inspection plan should be developed. Of critical importance

to the effectiveness of each survey is the proper and adequate selection of the areas to be examined. It is important to select a sufficient number of inspection areas to provide representative information on the overall structure. Making this selection requires an understanding of the facility structural behavior to determine which areas are subjected to maximum stress, fatigue, and impact forces. A knowledge of deterioration and damage theory is also useful. Consequently, the inspection plan must be prepared in cooperation with qualified engineers familiar with the structure. The inspection plan should include the identification of the inspection equipment most appropriate to the specific tasks.

For older facilities where little or no data, including drawings, is available, the inspection plan should allot time for developing and/or confirming the structural layout, and confirming whether previously identified repairs have been made.

### 3.3.3 Inspection Frequency

The frequency of inspection will be dependent upon whether the inspection is surface or underwater, and the expected rate of deterioration and damage. A typical example requiring more frequent inspection is an area experiencing damage by ships berthing that results in advanced deterioration to both fender and structural piling. The frequency and level of inspection should, therefore, be closely tied to the historical deterioration rate of the facility. Recommended frequencies are listed in Volume 4 of NAVFAC MO-322, Inspection of Shore Facilities.

- All superstructure and piling/sheet piling above the waterline, including the splash and tidal zones (Figure 3-11), should be inspected annually.
- All concrete and steel structural members should be inspected at least every 6 years. Timber members should be inspected at least every 3 years. In areas with known active marine bores, the frequency for inspection of timber may warrant an underwater inspection in as little as every year.

### 3.3.4 Documentation of Inspection

For the results of the inspection to be useful, they must be documented in a clear and concise manner and in accordance with generally understood terminology. Inspection forms and reports should be completed as soon as possible after the inspection has been completed. Standard forms and report formats greatly facilitate the documentation procedure and are essential for comparing the results of the present inspection with past and future inspections. Figure 3-12 is a standard form for reporting the condition

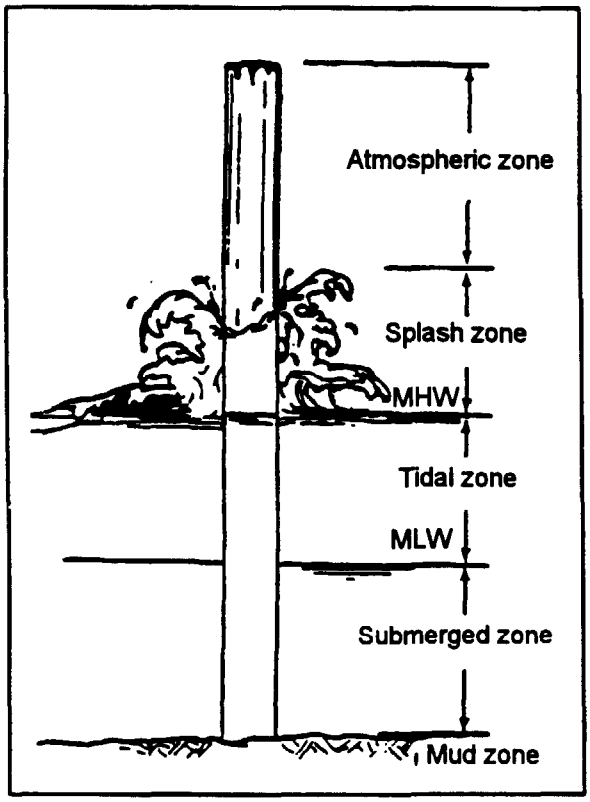



Figure 3-11. Exposure zones on piling.

## PILE INSPECTION RECORD

| LOCATION | DATE | DIVERS |
|---|---|---|

| PIER NAME/NO. | PILE TYPE<br>☐ BEARING ☐ FENDER ☐ SHEET | PILE MATERIAL<br>☐ TIMBER ☐ STEEL ☐ REINFORCED CONCRETE |
|---|---|---|

| WATER DEPTH | TIME OF DAY | TIDE | DEPTH OF DAMAGE FROM DATUM = GUAGE DEPTH - TIDE |
|---|---|---|---|

| BENT NO. | PILE NO. | NI | PILE CONDITION | | | | | TYPE DAMAGE | | | GAUGE DEPTH DAMAGE | DIMENSIONS OF DAMAGE | | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ND | MN | MD | MJ | SV | MECH. | BIO | FUNC. | | HGT | WIDTH | PENETR | |
| | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | |

Figure 3-12. Standard pile inspection report form. (See Figures 3-13 snd 3-14 for explanation of Ratings.)

of piles; Figure 3-13 is an explanation of the condition ratings for concrete piles used on the form; and Figure 3-14 is an explanation of the condition ratings for timber piles. Steel pile inspection results are usually recorded in terms of remaining metal thickness. It should be noted, however, that the categorization of a defect, i.e., moderate, major, etc., will depend on the water depth. Piles in deeper water, with a long unsupported length, are susceptible to buckling, and loss in strength becomes more critical.

Whenever appropriate, damaged areas should be documented with still photography and closed-circuit television. Still photography provides the necessary high definition required for detailed analysis, while video, though having a less sharp image, provides a continuous view of events that can be monitored by surface engineers and recorded for later study. All photographs should be numbered, dated, and labeled with a brief description of the subject. A slate or other designation indicating the subject should appear in the photograph. When color photography is used, a color chart should be attached to the slate to indicate color distortions. Video tapes should be provided with a title and lead-in, describing what is on the tape. The description should include the method of inspection used, the nature and size of the structure being inspected, and any other pertinent information.

A debriefing with the activity personnel, with slides or photographs, should be conducted before leaving the site, and all questions should be resolved.

## 3.4 STEEL STRUCTURES

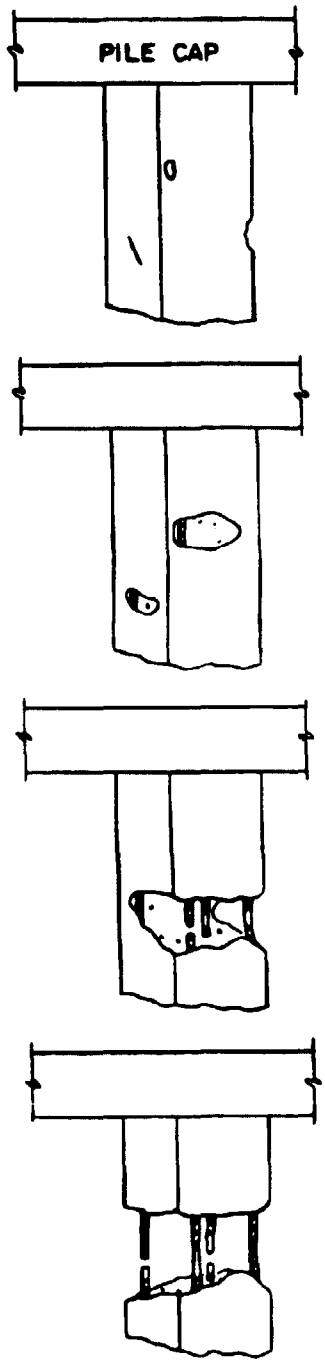
### 3.4.1 Types of Steel Structures

Structural steel is used in most metal waterfront structures because it is strong, readily available, easily fabricated into any shape, and not excessively costly. In marine applications, steel has many uses as a construction material. Steel piles, either H-piles or pipe piles, are used as support members for open piers, wharves, and other waterfront structures and facilities. Steel sheet piling is used primarily as a retaining wall structure for bulkheads used in the support of piers, wharves, drydocks, and quaywalls as well as near-water, earth-retaining structures. Fabricated structural steel members, whether tubular, plate, or other shapes, are used to construct undersea support towers for testing ranges, instrument arrays, and operation support platforms.

### 3.4.2 Deterioration of Steel Structures

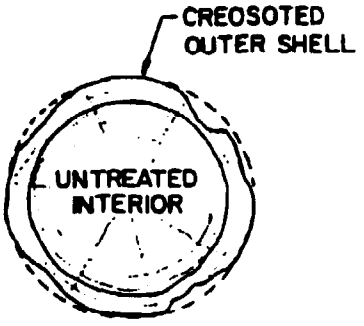
There are six major types and causes of steel structure deterioration in the marine environment:

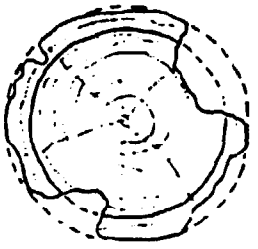
- Corrosion
- Abrasion
- Loosening of structural connections
- Fatigue
- Overloading
- Loss of foundation material

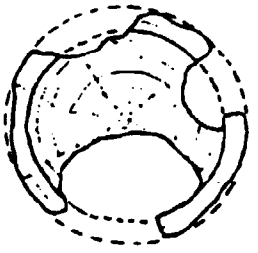


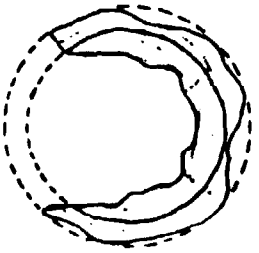

| Concrete Pile Condition Rating | Explanation |
|---|---|
| NI | Not inspected, inaccessible or passed by |
| ND | No defects:<br>- fine cracks<br>- good original surface, hard material, sound |
| MN | Minor Defects:<br>- good original section<br>- minor cracks or pits<br>- surface spalling that exposes course aggregate<br>- small chips or popouts due to impact<br>- slight rust stains<br>- no exposed rebar<br>- hard material, sound |
| MD | Moderate Defects:<br>- spalling of concrete<br>- minor corrosion of exposed rebar<br>- rust stains along rebar with or without visible cracking<br>- softening of concrete due to chemical attack<br>- surface disintegration to 1 inch due to weathering or abrasion<br>- reinforcing steel ties exposed<br>- popouts or impact damage |
| MJ | Major Defects:<br>- loss of concrete (40 to 50%)<br>- one or two rebars badly corroded<br>- one or two ties badly corroded<br>- large spalls 6 inches or more in width or length<br>- deep wide cracks along rebard<br>- dummy areas full wide of face |
| SV | Severe Defects<br>- two or three rebars completely corroded<br>- no remaining structural strength<br>- significant deformation |

Figure 3-13
Explanation of pile condition ratings for concrete piles.







| Timber Pile Condition Rating | Explanation |
|---|---|
| NI | Not inspected, inaccessible or passed by |
| ND | No defects:<br>- less than 5% lost material<br>- sound surface material<br>- no evidence of borer damage |
| MN | Minor Defects:<br>- 5 to 10% lost material<br>- sound surface material<br>- no evidence of borer damage<br>- minor abrasion damage |
| MD | Moderate Defects:<br>- 15 to 45% lost material<br>- significant loss of outer shell material<br>- evidence of borer damage<br>- significant abrasion damage |
| MJ | Major Defects:<br>- 45 to 75% lost material<br>- significant loss of outer shell and interior material<br>- evidence of severe borer damage<br>- severe abrasion damage |
| SV | Severe Defects<br>- more than 75% lost material<br>- no remaining structural strength<br>- severe borer damage |

Figure 3-14.
Explanation of pile condition ratings for timber piles.

**3.4.2.1 Corrosion.** Corrosion is the principal cause of deterioration of steel waterfront structures. Corrosion of steel is an electrochemical process that converts the steel into iron oxides. These iron oxides are easily recognized by their reddish-brown color and are commonly called rust. The rust may remain in place in the form of an encrustation or may naturally fall away or be removed by wave action or abrasion. The corroded surfaces are usually irregular and in some cases the attack in localized areas will be much greater than in other areas resulting in pitting. Over a period of time, unchecked corrosion will reduce the structural integrity of steel components of waterfront structures.

On bare unprotected steel pilings, corrosion is often most severe just above the high tide line, with another zone of severe attack just below the low tide line, as shown in Figure 3-15. Figures 3-16 and 3-17 illustrate typical corrosion on steel H-piling and sheet piling.

Submerged steel is also subject to galvanic corrosion. Galvanic corrosion occurs when two dissimilar metals are in electrical contact and both are submerged. An electrical current then flows between the two metals causing one of them to corrode rapidly. The speed of the attack is governed by the composition of the metals, the exposed area, and the electrical conductivity of the liquid. Salt water is an excellent electrical conductor, and galvanic corrosion resulting from dissimilar metals in contact is a significant problem on waterfront structures. The possibility of galvanic corrosion must be considered whenever dissimilar metals are used in marine structures.

An effect similar to galvanic corrosion can occur when there is a difference in environment between different areas on a single metal. When oxygen levels are reduced by limitation in free access of freshly oxygenated water, such as in the threads of a bolt or between structural members, the difference in oxygen content can cause an

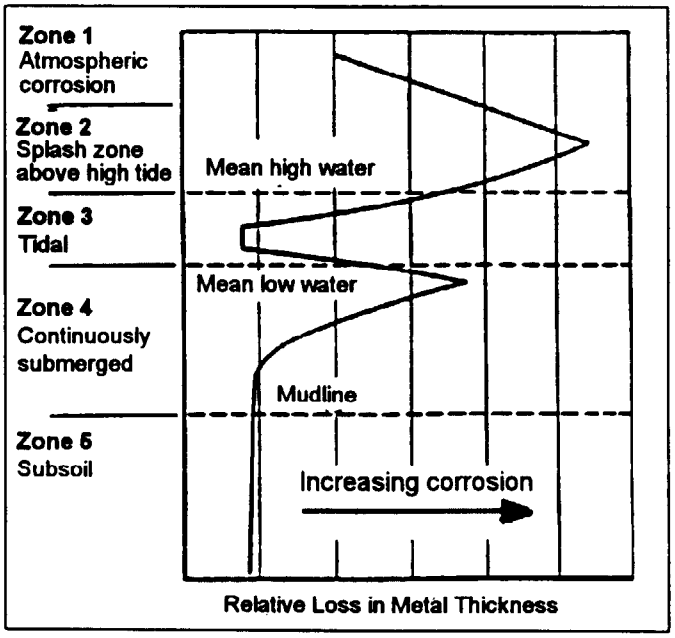



Figure 3-15. Corrosion of steel in various zones on waterfront structures.

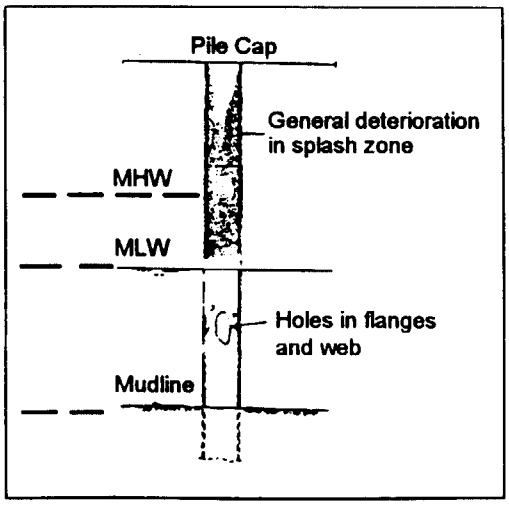



Figure 3-16. Corrosion of steel H-pile.

electrical current to flow between the areas of high and low oxygen content with the result of accelerated corrosion. This effect is particularly severe on stainless steels and aluminum alloys. A difference in environment with resulting accelerated corrosion can also be created when a surface is partially covered by an electrically conductive material such as concrete.

Corrosion can also be accelerated by the action of bacteria. In the absence of oxygen, sulfate-reducing bacteria can grow, and the sulfides they produce can cause rapid attack on steel. Areas such as the inside of pipe piles that are not filled with concrete can become depleted in oxygen and are frequently the site of sulfate-reducing bacteria attack. Some bottom sediments are oxygen deficient and sulfate-reducing bacterial attack can occur on buried steel in such sediments. Sulfate-reducing bacteria attack is more likely to occur in polluted harbors but can occur whenever oxygen is depleted. The presence of sulfate-reducing bacteria can often be detected by the odor of rotten eggs produced by the bacteria. As sulfate-reducing bacteria attack usually occurs on the inside of pipe piles or below the mudline, it is especially difficult to locate and repair open end pipe piles which are not concrete filled and typically used on offshore and waterfront structures, and experience indicates that the insides are generally not subject to corrosion.

Finally, corrosion can be initiated by the presence of stray currents, e.g., from nearby electrical power lines.

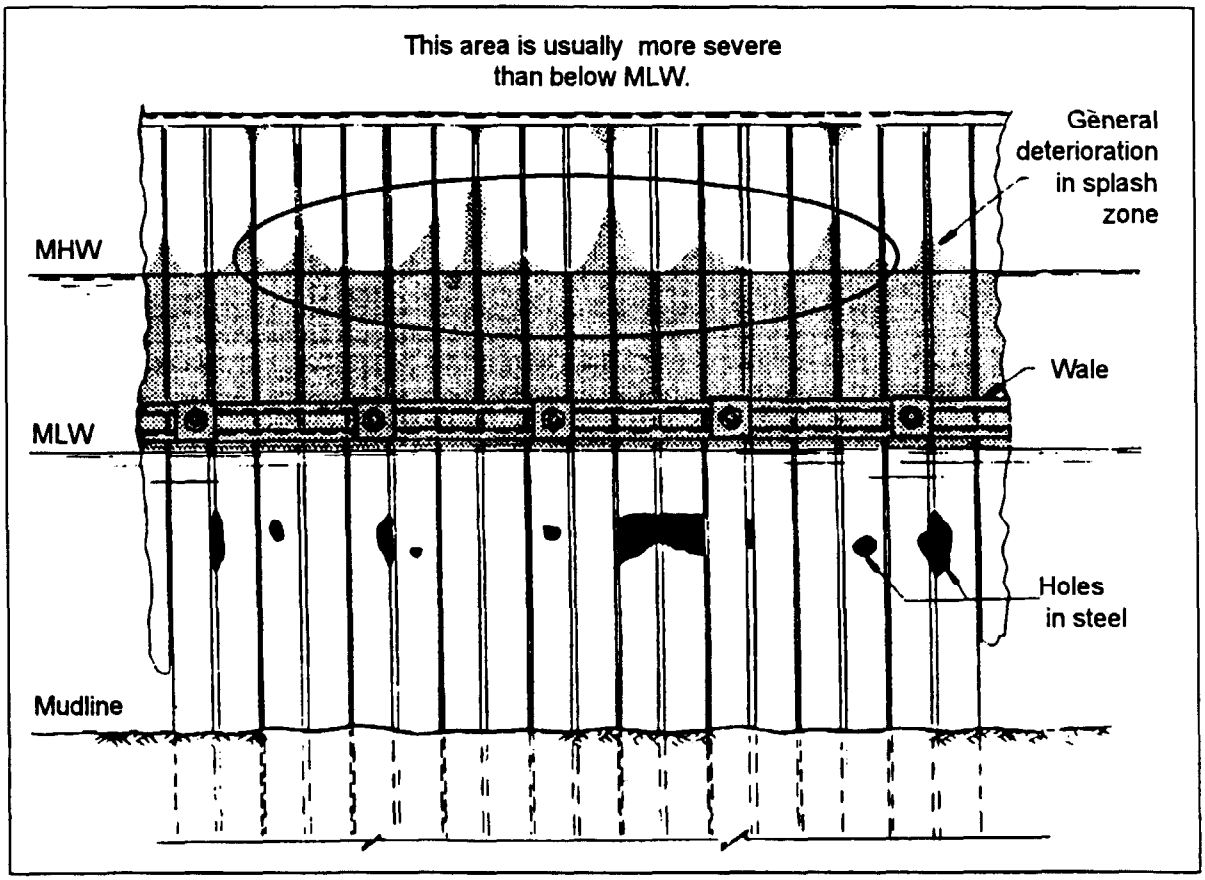



Figure 3-17. Corrosion of steel sheet piles.

**3.4.2.2 Abrasion.** Abrasion of steel structures can generally be recognized by a worn, smooth, polished appearance of the surface. Abrasion is caused by continual rubbing of adjacent moving steel surfaces, or by the exposure of structural components to wave action in areas of sandy bottom. Steel sheet piling and pile-supported structures are particularly susceptible to sand abrasion in exposed locations. Abrasion of steel structures is a problem because it removes both protective coatings and protective layers of corrosion products, thus accelerating corrosion.

**3.4.2.3 Structural Connection Loosening.** Structural connections joined together by rivets or bolts have a tendency to work loose over an extended period of time. Connection loosening can result from impact loadings of the type imparted by a vessel striking a pier or wharf fender system. Wave action and reciprocating machinery mounted on or below pier or wharf decks are other sources of possible connection loosening. Corrosion of bolts, rivets, nuts, washers, and holes can also contribute to connection loosening. Loosening of connections will tend to produce misalignment in mating surfaces, which, in turn, can result in distortion and stress concentrations in framing members.

**3.4.2.4 Fatigue Failure.** Fatigue failure results in the fracture of structural members as a consequence of repeated high loadings. Fatigue distress can be recognized by a series of small hairline fractures perpendicular to the line of stress in the member. Tubular connections of offshore platforms are particularly susceptible to fatigue failure. Fatigue cracks are difficult to locate. Since fatigue cracks represent an extremely dangerous condition in steel marine structures, extreme care must undertaken when inspecting structural members subjected to repetitive loadings, particularly high wave loading. Figure 3-18 illustrates the typical location of fatigue cracks.

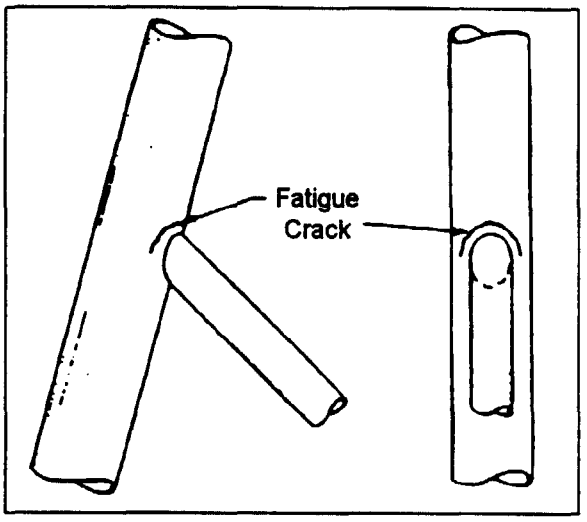



Figure 3-18. Location of fatigue cracks in offshore platform.

**3.4.2.5 Overloading.** Steel structural elements are sensitive to impact damage from berthing vessels and other types of accidental overloading. Impact or collision damage can generally be recognized by the appearance of local distortion (deformation) of the damaged member. This damage is generally characterized by a sharp crimp or a warped surface as illustrated in Figure 3-19. Compression overloading damage of a steel pile is illustrated in Figure 3-20.

**3.4.2.6 Foundation Deterioration.** Loss of foundation material from around steel piles leads to accelerated corrosion and loss of column strength of the piles. The loss of foundation material is usually caused by the scouring of material from around the piles, as illustrated in Figure 3-21. Scouring can be caused by an increase in the velocity of the water passing by the piles or a change in the current's direction. If the piles thus exposed are not protected, eventual collapse

of the structure is possible. A loss of foundation material in front of a sheet pile bulkhead may cause kick-out of the toe of the wall and result in total failure.

### 3.4.3 Typical Inspection Procedure

Inspection of a steel waterfront structure should proceed as outlined in Table 3-3.

### 3.4.4 Steel Structures Offshore

When steel is used as a structural member in support towers and other ocean platforms, members are usually welded together. These welded connections must be carefully inspected as they are highly susceptible to electrochemical corrosion and fatigue cracking. Clean these welded connections of all marine growth and, depending on visibility, inspect visually or by touch. Again, record all information immediately in the inspection log.

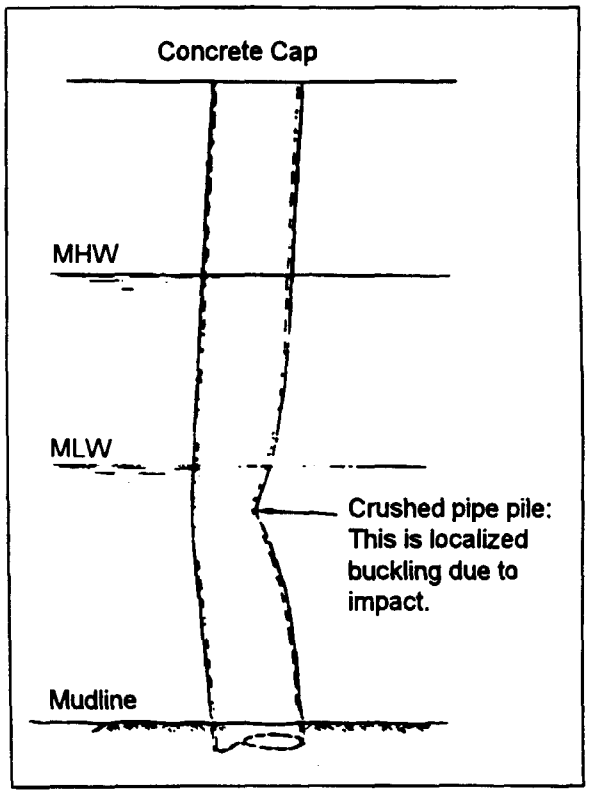



Figure 3-19. Bending overloading of steel pile.

Note: Crushing is usually the result of impact, leading to localized distortions; however, maximum bending moment is at the cap and/or below the mudline, depending on the support conditions and distribution of corrosion.

### 3.4.5 Equipment and Tools Required

To ensure a thorough inspection, the area must be cleared of all marine growth. This can be done by various means, depending on surface support. A high-pressure water jet is the most effective method for clearing marine growth sufficiently for visual inspection. Hand tools, such as wire brushes and scrapers are sufficient for smaller jobs.

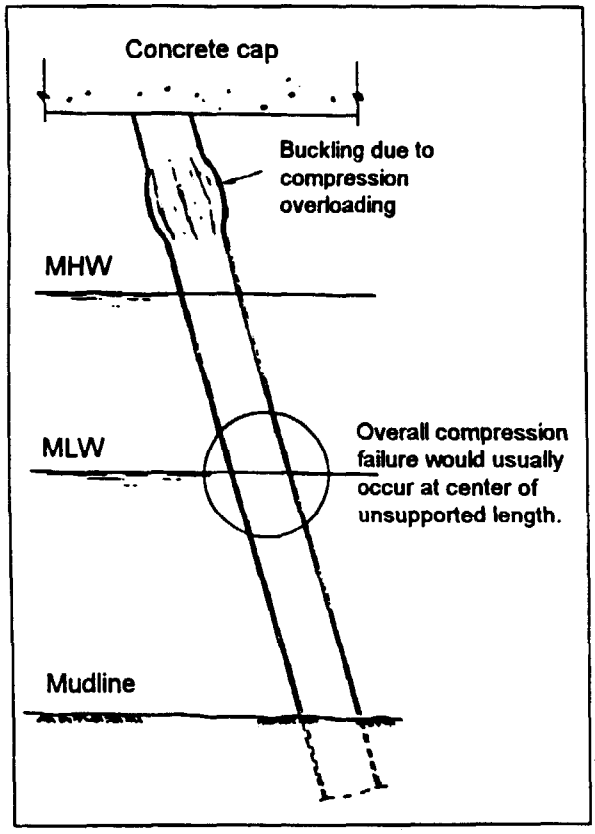



Figure 3-20. Overloading of steel pile.

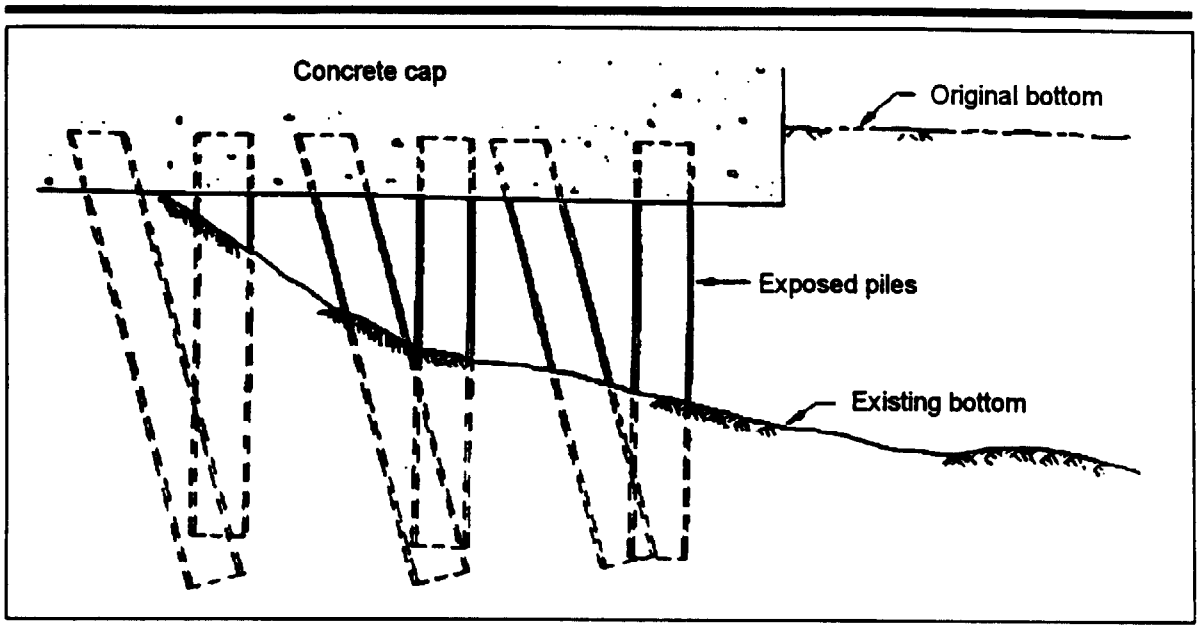



Figure 3-21. Foundation loss around steel piles.

Refer to Section 2.3 for information on marine growth removal. Sounding of the structure can be done with a small hammer or pickax. Inspection of the structure requires some type of underwater data recording device, such as a grease pencil/slate, or hardwire communications with topside personnel. Calipers and scales are used to determine thicknesses of steel flanges, webs, and plates. A portable reference electrode (Figure 3-22) or an underwater voltmeter (Figure 3-23) is used to determine the effectiveness of cathodic protection on steel structures. Table 3-4 gives voltages measured by the underwater voltmeter for steel structures. Visual documentation may be desirable for illustrating problem areas to others who did not physically make the inspection dive. This can be done by using an underwater camera or television system.

**3.4.5.1 Ultrasonic Inspection.** Ultrasonic thickness measurement equipment is available for inspecting steel structures. Thickness measurements are obtained because certain types of ultrasonic waves travel at a constant speed through a material, because they travel in straight lines, and because a portion of the wave is reflected when it meets an interface. The difference in time between the detection of the front surface and back surface echoes is correlated to the thickness of the material. Figure 3-24 illustrates a digital readout device for underwater ultrasonic thickness measurement. Ultrasonic thickness measurements require a thorough removal of marine growth and scale and can be unreliable if the surface on which the instrument is placed is heavily pitted. Adequate training and experience are required to obtain readings and to evaluate the measurements made with this equipment.

**3.4.5.2 Underwater Magnetic Particle Testing.** Underwater magnetic particle testing (UWMT) is a nondestructive method for locating and defining surface discontinuities (such as cracks) in magnetic materials underwater. Its principle of operation is that magnetic particles are attracted to flux leakages at the surface of magnetized materials and form indications of discontinuities located either at or just below the surface.

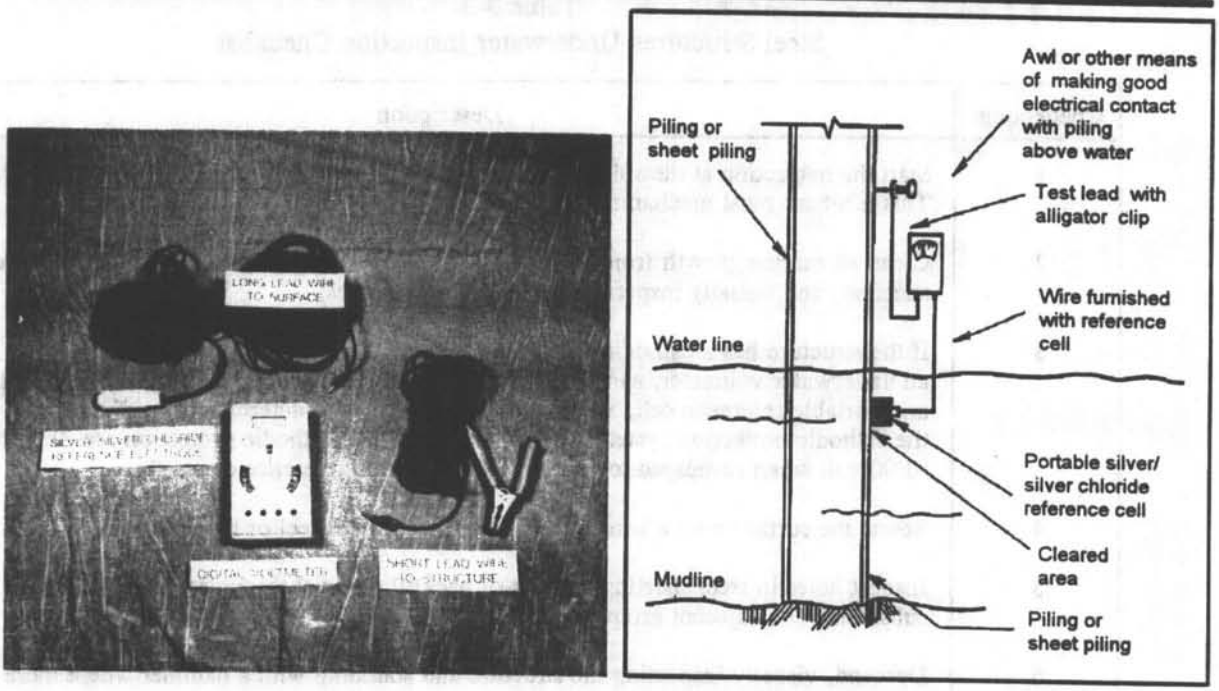



Figure 3-22. Do a cathodic protection system check using a portable voltmeter and portable reference electrode.

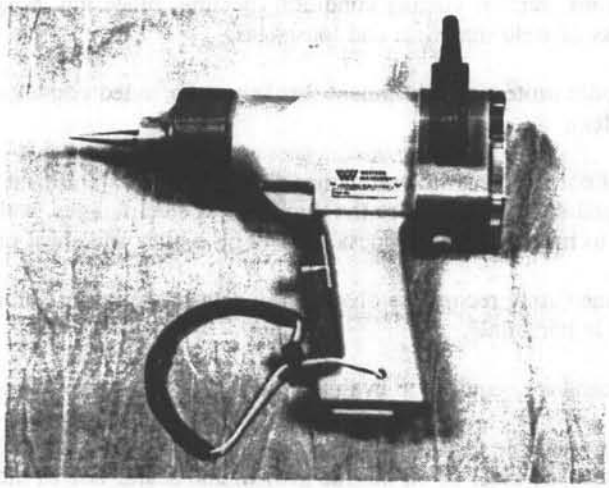


Figure 3-23. Underwater volt meter.

In operation, the magnetic material or item of interest is magnetized using an electromagnetic yoke specially designed for underwater use. Wherever surface discon-tinuities exist within the yoke's field of influence, magnetic flux will "leak" from the surface of the part. A slurry of magnetic particles are attracted to, and aligned with, the leaking magnetic flux. The particles are brightly colored and form a visible indication corresponding to the location of discontinuities at or very near the part's surface.

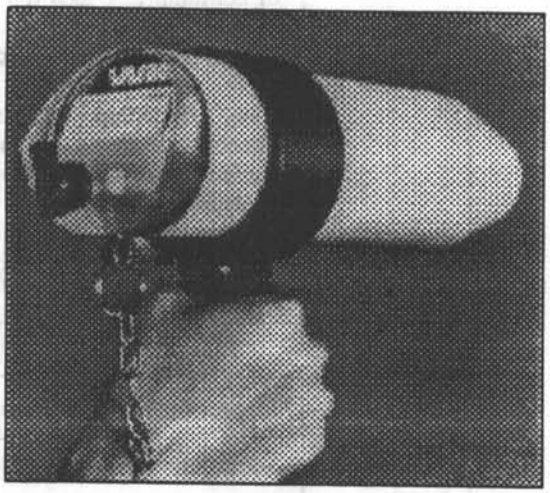


Figure 3-24. Underwater ultrasonic thickness indicator.

Table 3-3
Steel Structures Underwater Inspection Checklist

| Checkpoint | Description |
|---|---|
| 1 | Start the inspection at the splash/tidal zones and proceed to about 3 feet below the MLW. This is where most mechanical and corrosion damage is normally found. |
| 2 | Clean all marine growth from a 1-foot square section of pile (a larger areas, if inspecting sheeting) and visually inspect for rust, scale, and holes. |
| 3 | If the structure has a cathodic protection system, check the cleared underwater area with an underwater voltmeter, as shown in Figure 3-22, or use a portable reference electrode and portable reference cell, as shown in Figure 3-23, to determine the effectiveness of the cathodic protection system. Acceptance levels for cathodic protection are -0.80 to -0.90 volt when compared to a silver/silver chloride reference electrode. |
| 4 | Sound the surface with a hammer to detect any scaled steel or hollow areas. |
| 5 | Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacent ground surface. |
| 6 | Descend, visually inspecting the structure and sounding with a hammer where there is minimal marine growth. |
| 7 | At the bottom, record the water depth, using a wrist gauge, on a Plexiglass slate with a grease pencil, or communicate the information to topside personnel. |
| 8 | Record other visual ovservations, such as coating condition (peeling, blistering, erosion). Closely inspect splices for loss of weld materials and looseness. |
| 9 | Record the condition of cathodic protection equipment (broken or corroded conduits, loose wires, consumed or lost anodes). |
| 10 | Record the extent and type of corrosion, structural damage, or any other significant observations, using calipers and scales to measure the thickness of steel flanges, webs, and plates, and ultrasonic meters to measure the thickness of steel pipe piles and sheet piling. |
| 11 | Return to the surface and immediately record the observation data in the inspection log, or communicate data to topside personnel. |
| 12 | Where more sophisticated means are required to evaluate the condition of steel piling:<br>• Ultrasonic inspection is available for thickness measurements. Pay particular attention to ensure that the areas are clear of all marine growth and scale. Use of ultrasonic equipment in areas with corrosion pitting can result in erroneous thickness measurements.<br>• Magnetic particle inspection may be used, particularly on welded connections, to detect cracks and small defects. |
| Exposed Area Under Pier or Along Wharf | |
| 1 | Inspect for structural damage, rust, scale, and holes. |
| 2 | Sound the surface with a hammer to detect any scaled steel or hollow areas. |
| 3 | Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacemtn ground surface. |

Table 3-4
Underwater Voltmeter Values for Steel Structures

| Voltage Measured (V) | Description |
|---|---|
| 0.0 to -0.7 | Steel is cathodically unprotected. The rate of corrosion depends on the effectiveness of paint or tar coatings, marine growth, and local water chemistry and water currents. On some structures, the hard layer of marine growth may provide some protection. The closer to 0 volts the more active is the corrosion potential. **Note:** -0.6 volt is the potential of bare, unprotected steel in seawater. |
| -0.7 to -0.82 | The steel is partially protected. |
| -0.83 to -1.1 | The steel is adequately protected. Cathodic protection systems are working effectively. |
| -1.1 or higher negative values | The steel is "overprotected." **Note:** Under some circumstances, the metal surface can be made more brittle when overprotected. Surface coatings may be damaged or "lifted off" by the excess formation of hydrogen bubbles. |

• **UWMT Applications** - Underwater magnetic particle testing is used primarily as a quality assurance tool to support underwater welding on ship structures. It can also be used to inspect hulls or other magnetic components for surface discontinuities such as cracks and lack of fusion in welds. UWMT can be used to define the true length (and locate the true ends) of discontinuities detected visually and to help determine where corrective measures (e.g., stop drilling) should be applied.

• **UWMT Limitations** - As with any inspection method, UWMT has some limitations. These include:

1. Underwater magnetic particle testing has limited subsurface capability. For use on U.S. Navy applications, it is considered to be strictly a method for detecting and measuring surface discontinuities. It is not an approved method for detection of subsurface discontinuities.

2. The adequacy of inspection with UWMT (as with most nondestructive test methods) is largely a function of the operator's knowledge and skill. Inspections with UWMT are to be performed only by personnel trained and specifically certified in UWMT.

3. UWMT is limited to ferromagnetic materials, which include most steels. For most applications, a simple check with a magnet is sufficient to determine suitability for UWMT.

• **Certification Requirements for UWMT** - Personnel performing UWMT require certification in UWMT. Certification can only be obtained by training and examination.

Divers may be trained either by a certified UWMT examiner or by NAVSEA's agent. Training can be done at either the diver's activity or at the agent's facility, as determined by NAVSEA.

• **Specific Preparation Requirements for UWMT** - Preparation for conducting UWMT entails assembling all necessary material and personnel required to safely satisfy the plan requirements. Divers must determine that the water current will not affect the application of magnetic particles where UWMT is to be conducted. Water currents greater than 1 knot make it difficult to perform UWMT. Divers must also determine that the underwater visibility is adequate for the interpretation of the test results.

The following paragraphs describe inspection equipment required to conduct UWMT. Inspection equipment specific to UWMT, along with general surface preparation and recording equipment are:

- **Inspection Equipment**

  Electronic yoke with power cable
  Ground fault interrupter (GFI)
  White light source
  U/W-1 magnetic particles with applicator
  Magnetic field indicator

- **Surface Preparation and Restoring Equipment**

  Diver staging (optional)
  Hydraulic or pneumatic hand-held grinder or high-pressure water jet
  Anti-corrosion coating (epoxy)

- **Recording Equipment**

  Stereo and/or still camera (optional)
  Video and monitor system (optional)
  Measuring devices (tape or rule)
  Plexiglas writing slate, grease pencil, arrow punch

For fleet users, the equipment for UWMT is specified in NAVSEA drawing number 6653063. This equipment meets the requirements of MIL-STD-271F. Only this equipment may be used. UWMT equipment includes:

• **Electromagnetic Yoke** - An electromagnetic yoke (Figure 3-25), which meets the specifications of MIL-STD-271F and is listed in NAVSEAINST 10560.2C, is used to induce a magnetic field in the material. The articulation of the yoke's legs allows any pole spacing between 2 inches and 8 inches, and the yoke can accommodate plate offsets of up to 6 inches and joint angles from about 45 degrees to 270 degrees. To minimize the risk of electric shock, there are no controls on the yoke. A topside operator energizes the yoke.

• **Power Cable** - A two-conductor power cable with a braided external ground and a protective jacket (Figure 3-26), listed in NAVSEAINST 10560.2C, delivers power to the electromagnetic yoke. Typical cables are 250 feet long to permit operation in the majority of locations accessible by a surface-supported diver. The external ground braid generates a ground fault whenever the cable is cut; the power conductors cannot be reached except by first penetrating the ground braid.

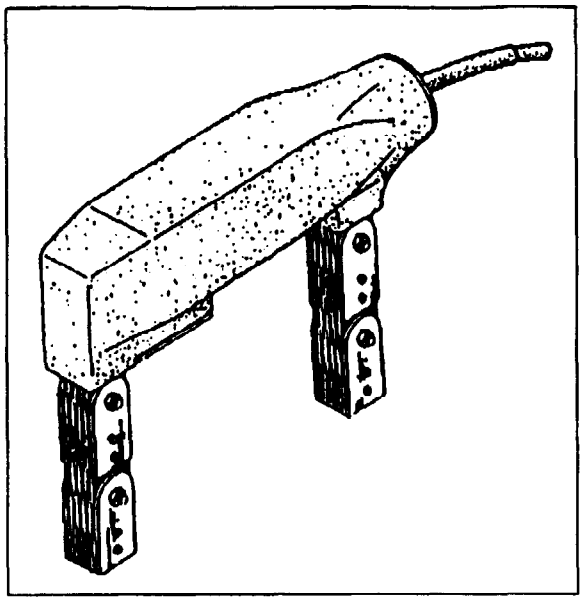


Figure 3-25. Electromagnetic yoke.

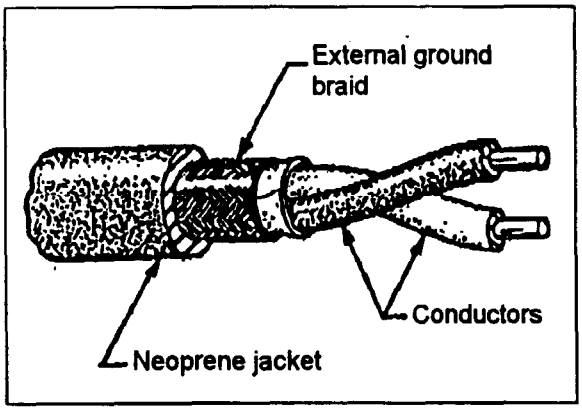



Figure 3-26. Two-conductor power cable with braided external ground and neoprene jacket.

• **Ground Fault Interrupter (GFI)** - The diver's primary protection from electric shock is an approved isolation transformer/ GFI device (Figure 3-27), listed in NAVSEAINST 10560.2C. The GFI interrupts power when it senses a drop in the resistance between the isolated system power leg and the power supply ground.

• **White Light Source** - The primary illumination source is a Remote Ocean Systems model TUBE-LIGHT, listed in NAVSEAINST 10560.2C.

• **Magnetic Particles** - Magnetic particles are finely divided ferromagnetic particles having a low magnetic retentivity and a high permeability. The magnetic particles used for UWMT must meet the specifications of MIL-STD-271F. They are dyed pink to be visible under normal lighting. The particles are mixed with wetting agents and corrosion inhibitors to enhance their underwater performance.

• **Magnetic Particle Applicator** - The magnetic particle applicator is a reservoir of magnetic particles and water that the diver uses to deliver magnetic particles to the surface of the inspection area. A simple and effective magnetic particle applicator is a plastic squeeze bottle that contains a marble-sized object to aid in mixing.

• **Magnetic Field Indicator** - The magnetic field indicator is a small device with crack-like discontinuities on its face. The indicator is used to determine if the inspection site has adequate magnetic flux. The diver places the indicator at the inspection site, topside energizes the yoke, and the diver delivers the particles. A clearly visible accumulation of particles (indications) should then form along the crack-like discontinuities on the pie-shaped magnetic field indicator (Figure 3-28). In the pie-shaped gauge, the crack-like discontinuities are furnace-brazed joints between adjacent steel wedges. Though a simple test to measure the magnetic field strength inside the material being inspected is unknown, it is assumed that an adequate field just outside the material signifies an adequate field inside as well.

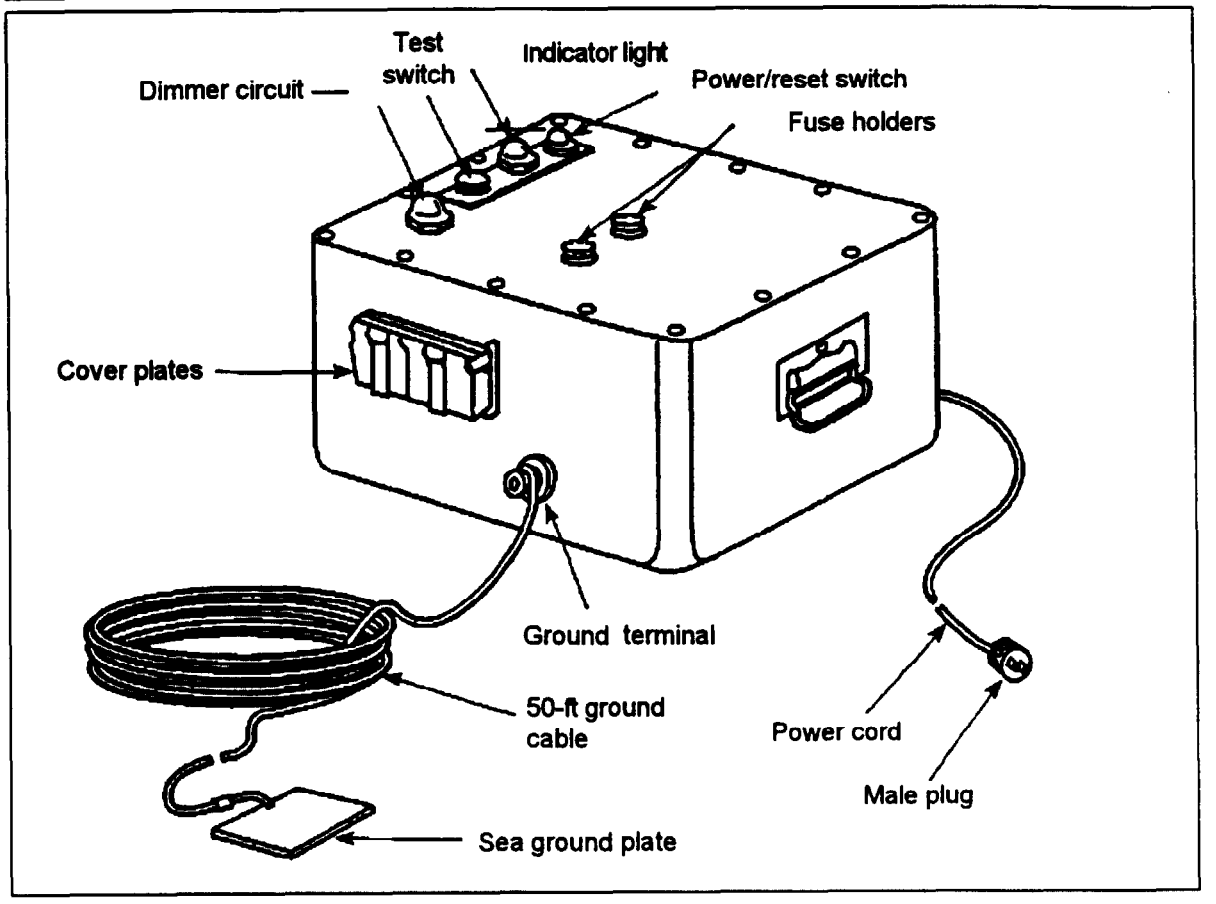



Figure 3-27. Ground fault interrupter.

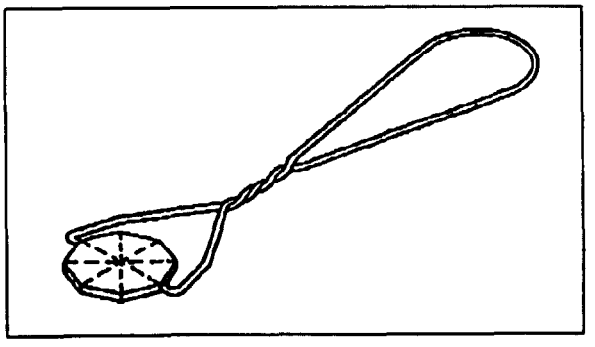


Figure 3-28. Magnetic field indicator.

## 3.5 FLEET MOORINGS

### 3.5.1 Types of Fleet Moorings

Fleet moorings allow ships to maintain either a fixed or semi-fixed position. A fleet mooring in common use is the riser free-swinging mooring as shown in Figure 3-29. This type of mooring achieves its holding power through anchors embedded in the seafloor. These anchors are connected to ground leg chains that meet at the ground ring which, in turn, is connected to a riser-type buoy by a riser chain.

Another fleet mooring is the nonriser free-swinging mooring (previously called telephone), illustrated in Figure 3-30. This configuration uses anchors embedded in the seafloor that are individually connected to a telephone buoy. Both riser and nonriser moorings require a good deal of unobstructed water surface to allow the ship to rotate around the mooring according to changes in wind and current direction.

Figure 3-31 illustrates a spread mooring with three mooring buoys. A spread mooring eliminates the tendency for the buoy to rotate. This type of mooring uses

two or more mooring buoys, usually in conjunction with the ship's anchors, to hold the ship in a fixed position.

The most commonly used types of buoys are illustrated in Figure 3-32 and fleet mooring hardware components are illustrated in Figure 3-33.

### 3.5.2 Fleet Mooring Anchors

The most common types of anchors used in Navy fleet moorings are illustrated in Figure 3-34. They are:

• **Drag Embedment Anchors**. Common drag embedment anchor types found in Navy moorings are shown in Figure 3-35. Of these anchor types, the NAVMOOR anchor is typically found in high capacity moorings (Class C - 100,000 pounds and above); while the stabilized Stockless anchor is used in moderate to low capacity moorings (Class C or below). Stockless anchor flukes will be fixed in the fully-opened position for mud soil applications.

When mooring load in a ground leg exceeds the capacity of a single anchor, multiple anchors are used side by side or in tandem (piggyback). The ground leg options are shown in Figure 3-36. In mud seafloors, the piggyback and connecting chain will be buried. However, in hard clay and sand seafloors, the connecting chain and hardware will be exposed and available for inspection.

• **Wedge Anchor** (Pearl Harbor Anchor). This inexpensive anchor may be found in low capacity and short-scope moorings in single and multiple anchor ground legs. Both primary and tandem chain connections and tandem chain often are exposed on the bottom and thus are available for inspection. For rock seafloors, this anchor may be fitted with steel digging plates on the front anchor face, which may be worn or damaged and should be inspected.

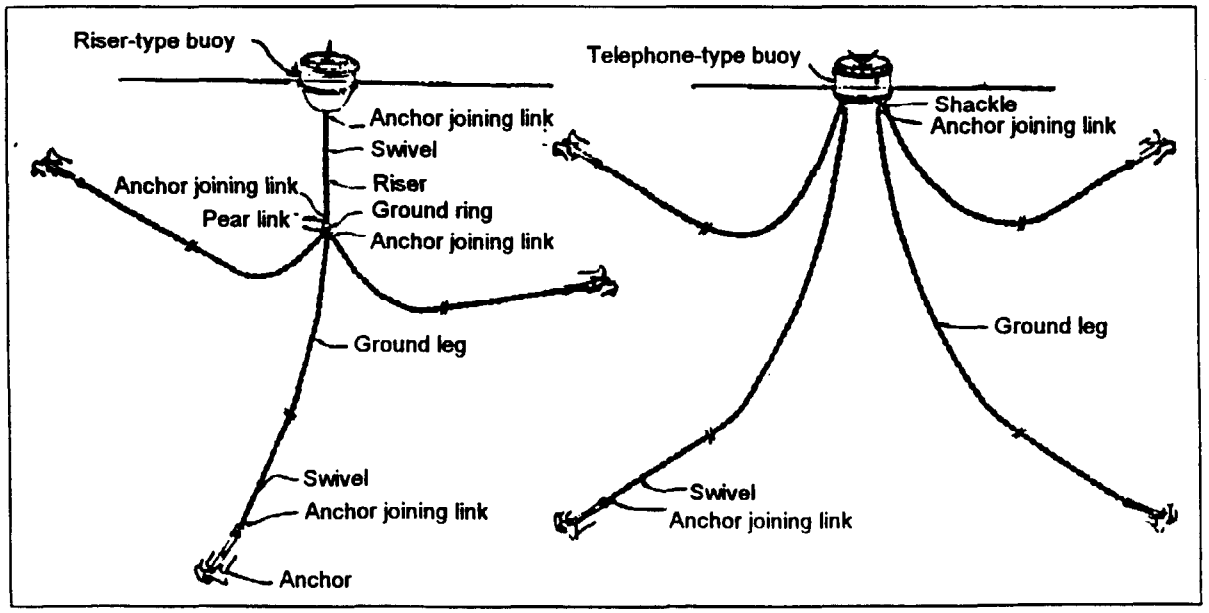



Figure 3-29
Riser free-swing fleet mooring.




Figure 3-30
Nonriser free-swinging fleet mooring.

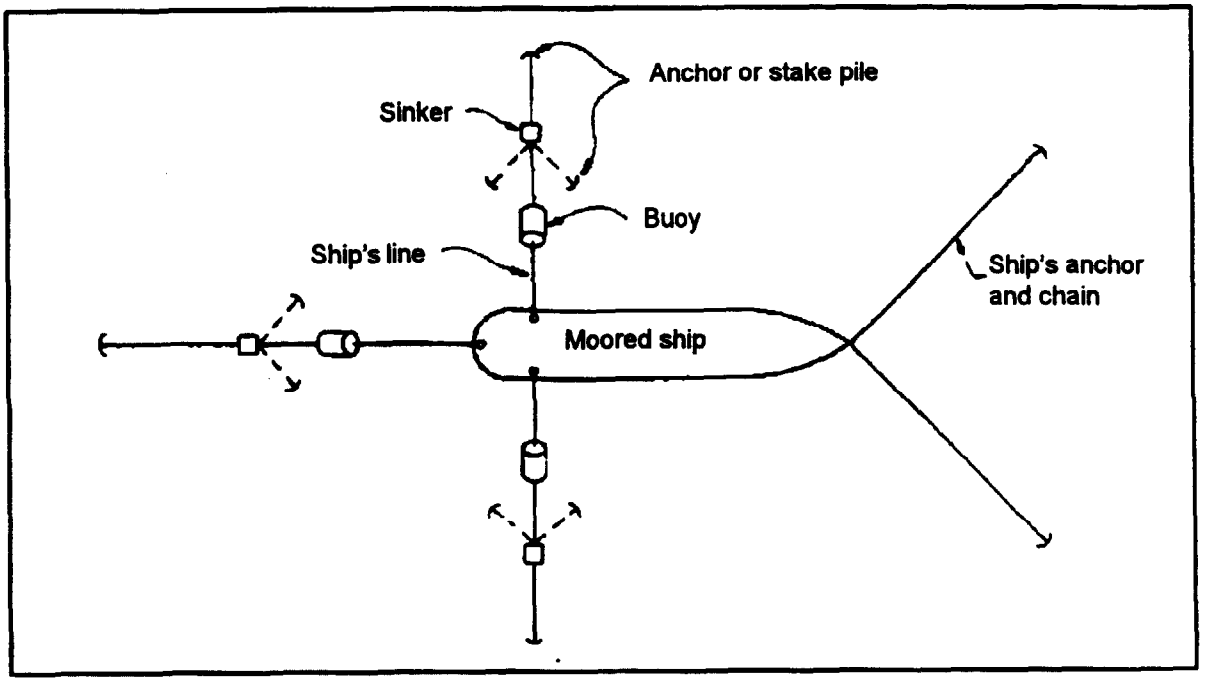



Figure 3-31. Typical spread mooring.

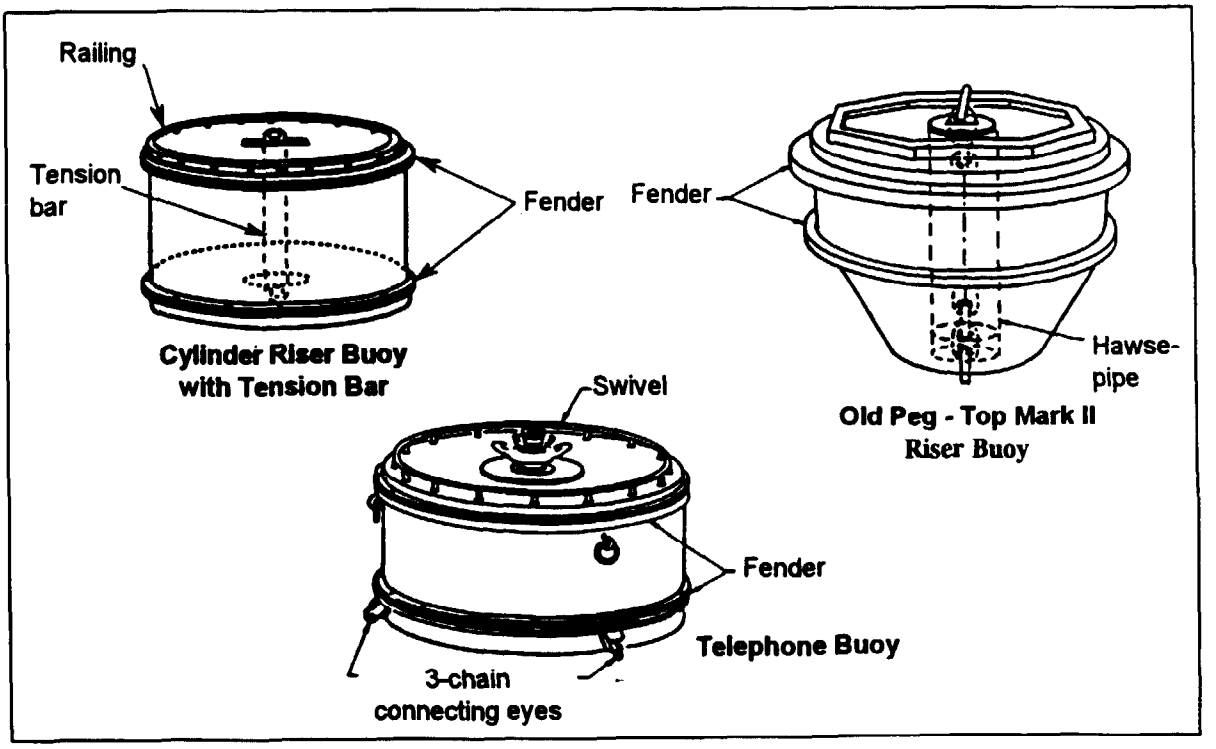



Figure 3-32. Commonly used mooring buoys.

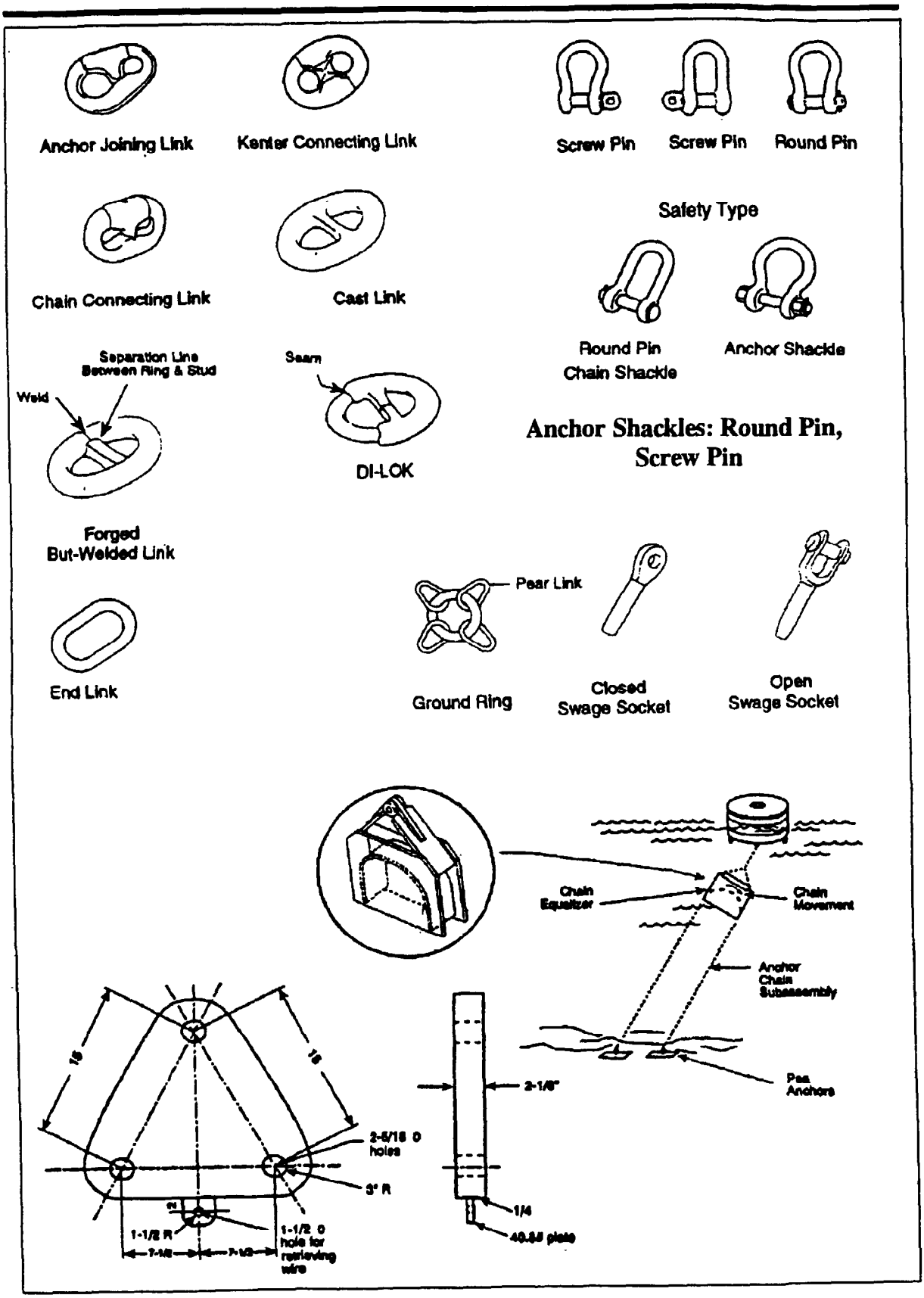



Figure 3-33. Fleet mooring hardware components.

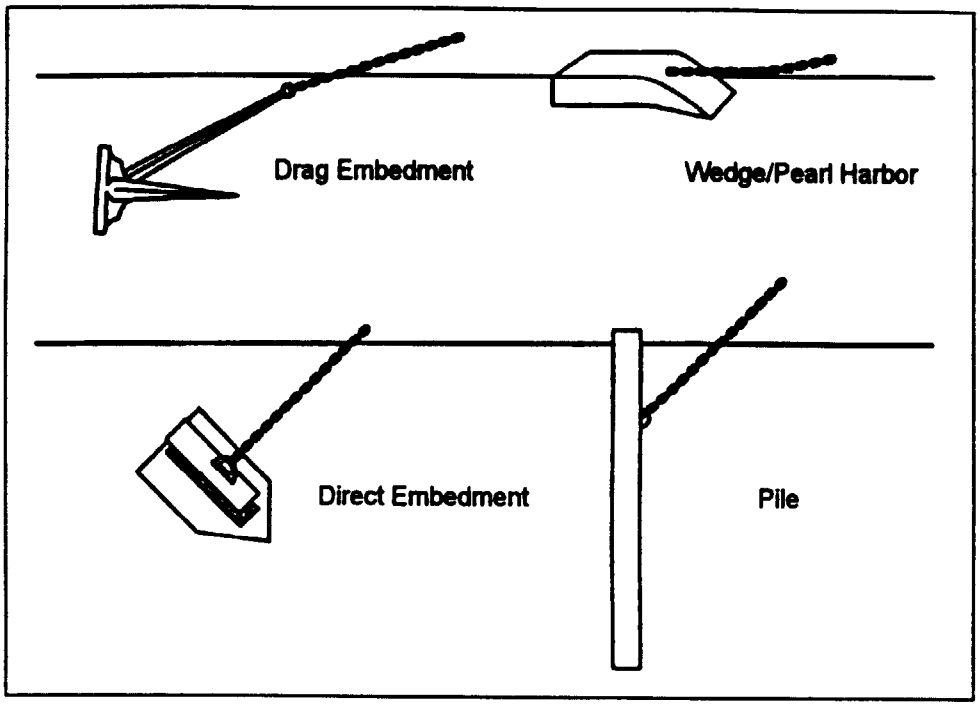



Figure 3-34. Fleet mooring anchors.

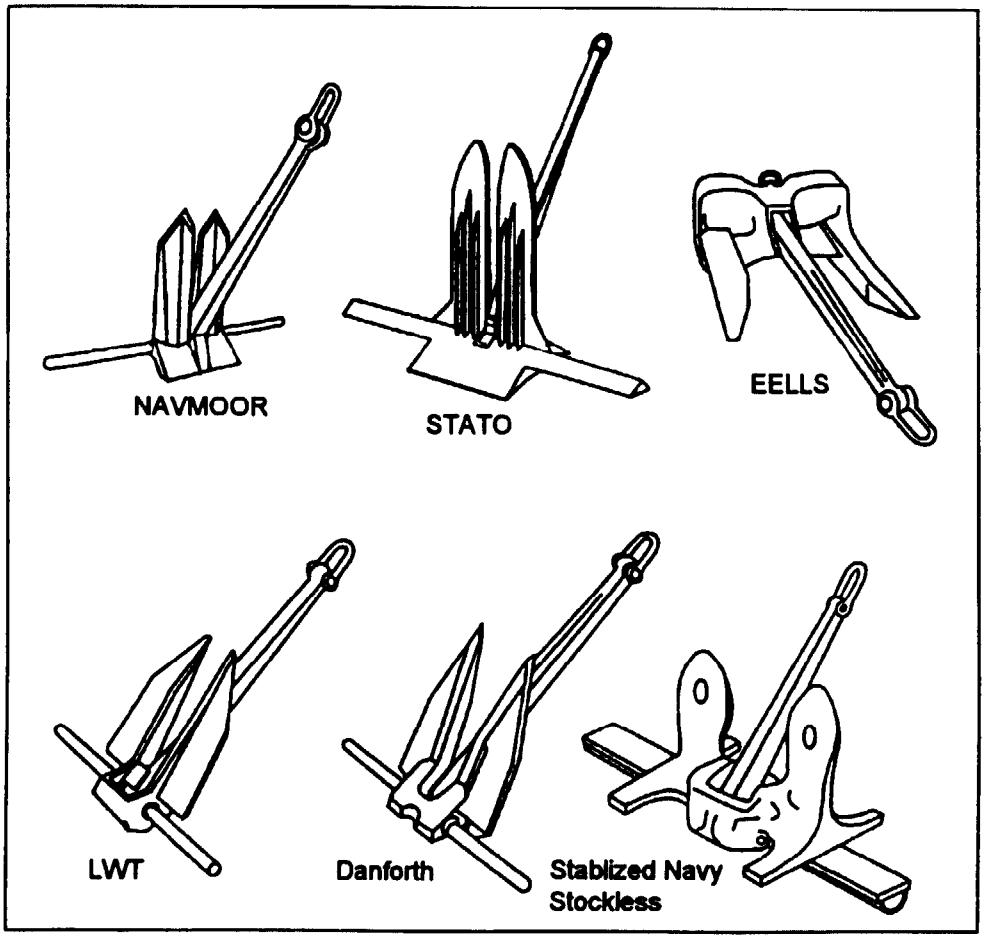



Figure 3-35. Drag embedment anchors.

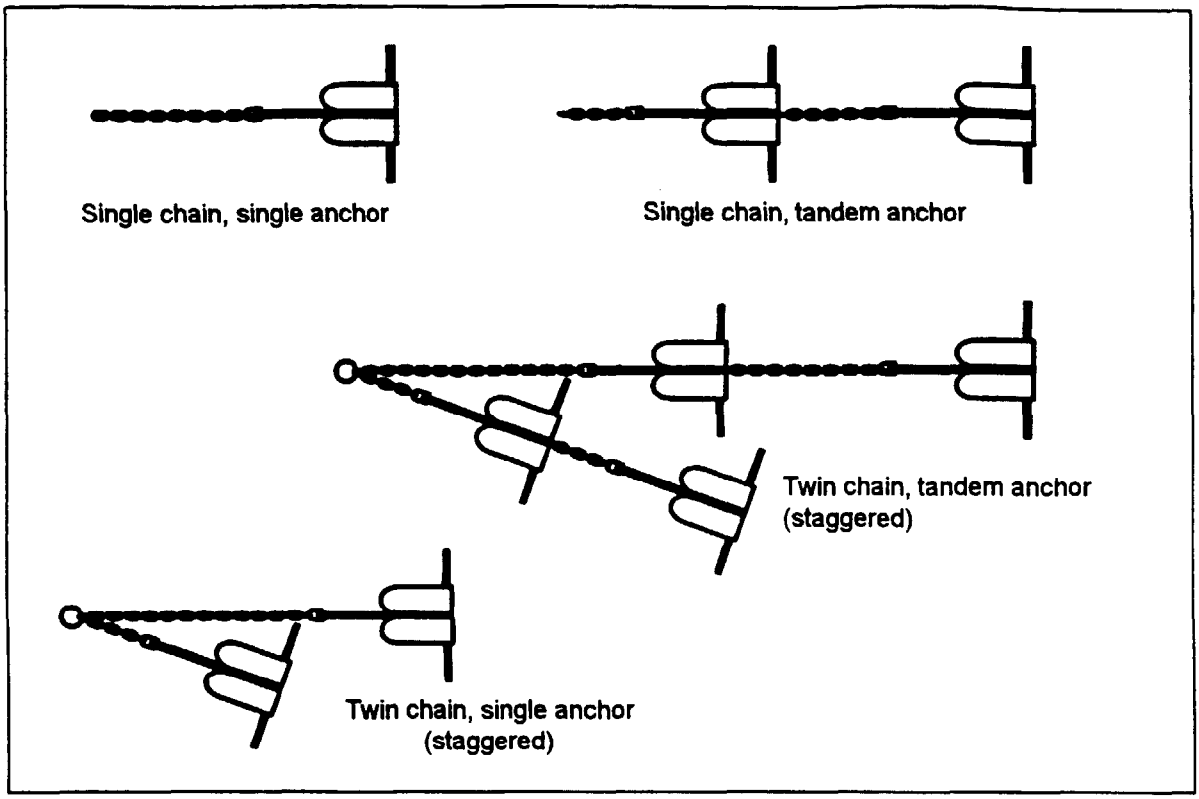



Figure 3-36. Fleet mooring ground leg options.

• **Direct Embedment Anchors**. Two direct embedment anchor types, which are characterized by their method of installation, are used in Navy fleet moorings. They are the propellant-embedded anchor (PEA) (Figure 3-37) and the pile-driven plate anchor (PDP) (Figure 3-38). The PEA with a wire downhaul cable is fired into the seafloor from a gun (harpoon-like). The wire cable is particularly susceptible to wear at the soil, coral, or rock interface. The PDP is driven into the seafloor by a pile driver and follower assembly. A chain or chain and wire combination can be used with the PDP, but the chain segment always occurs at the soil or coral interface to reduce wear potential. The seafloor interface segment of wire or chain connected to all direct embedment anchors should be inspected.

• **Pile Anchors**. This anchor is used often with bow ground legs of Mediterranean moorings. Its use should be limited in the future due to expanded use of driven plate anchors. The pile anchor to chain connection is usually located below the mudline. Inspection of this connection can be accomplished using a suction dredge to uncover the connection. Inspection is only necessary if there is indication of severe chain wear/corrosion at the mudline.

### 3.5.3 Deterioration of Fleet Moorings

Deterioration of fleet moorings is primarily due to corrosion and wear losses on the mooring chains, fittings, and anchors. Fleet moorings are affected by loss of buoyancy due to accumulations of fouling organisms. Fleet moorings are also affected by both electrochemical corrosion and a form of corrosion known as fretting. Fretting is the combined effect of corrosion and ordinary wear. Fretting and ordinary wear

is caused by the relative movement between interconnecting links and fittings under the influence of waves, currents, tidal variations and action from the motion of the buoys. Corrosion and wear of metal components is observed as pitting, holes, cracks, fissures, loose or missing bolts or rivets, and reduction of chain wire diameter. Reduction of chain wire diameter is often greatest at interlink connections.

**3.5.3.1 Chain-Link Measurements.** One significant parameters used to evaluate the condition of a mooring is the chain wire diameter. A selective sampling of wire diameter of chain links and connecting hardware is taken to determine the amount of deterioration due to corrosion and wear.

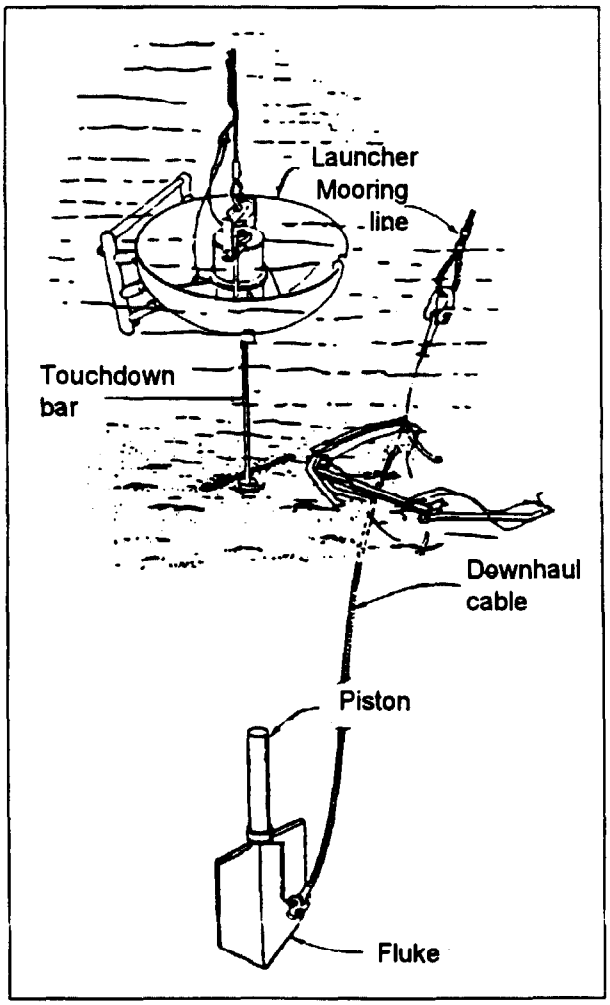



Figure 3-37. Propellant-embedment anchor.

- "Single-link" measurements are taken where chain is slack.

- "Double-link" measurements are taken where two links connect under tension.

Figure 3-39 shows where chain-link measurements are made. Chain links and other chain components that measure greater than 90 percent of original wire diameter are considered to be in "good" condition. Measurement between 80 and 90 percent of original diameter is considered "fair" condition and is cause for the mooring to be downgraded in classification. Measurement less than 80 percent is considered an indication of "poor" condition and is cause for the mooring to be declared unsatisfactory for fleet use.

### 3.5.4 Typical Inspection Procedure

Inspecting a fleet mooring should be performed after contacting the fleet mooring inspection agency (NFESC Code ESC55) and in accordance with the following checklist. The information should be recorded on a standard fleet mooring underwater inspection report, as illustrated in Figure 3-40.

#### 3.5.4.1 Inspection Checklist

**1. BUOY UPPER PORTION**

***a. Overall Condition***

- Record buoy type (drum, peg top, etc.).

- Measure and record buoy diameter and freeboard (waterline to top of buoy).

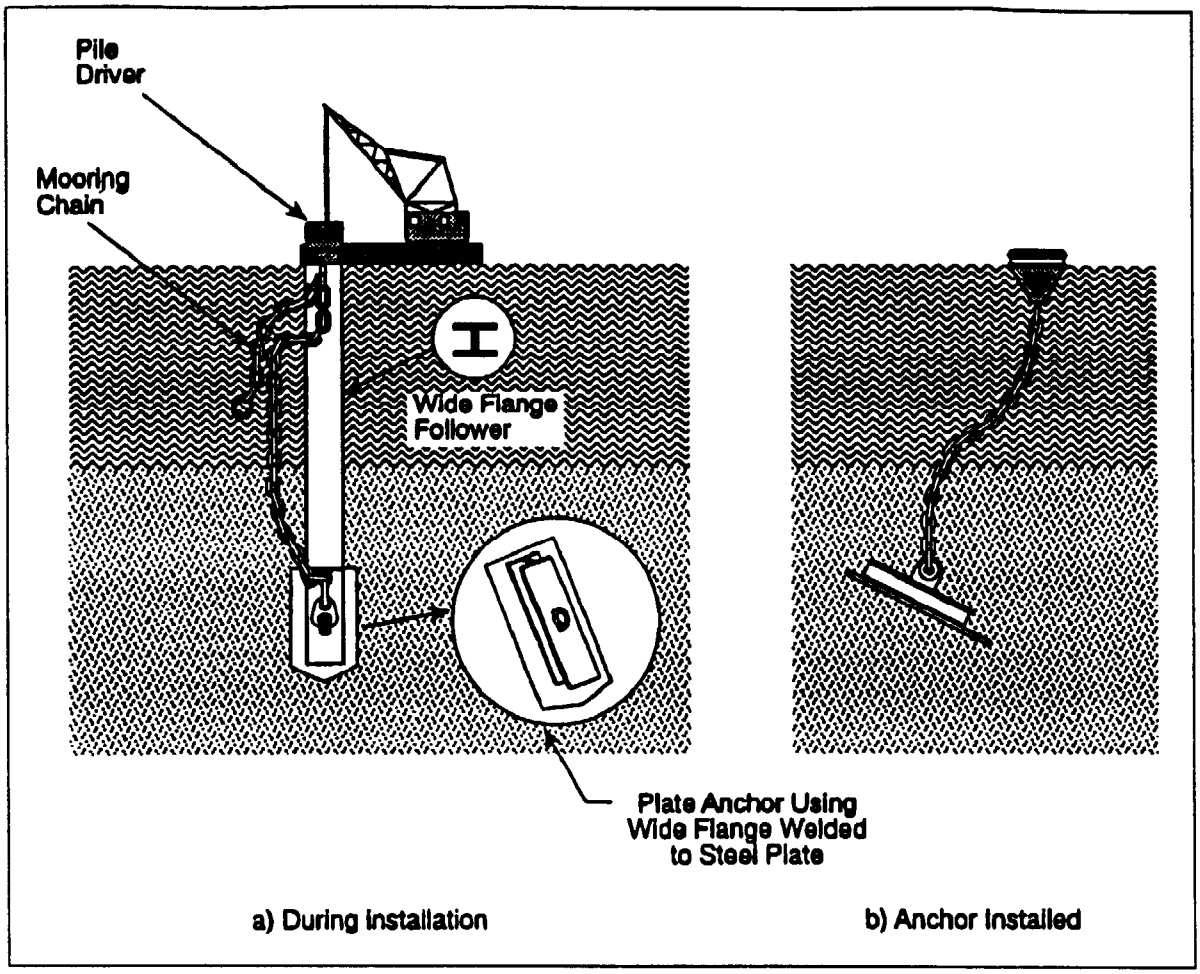



Figure 3-38. Pile driven plate anchor.

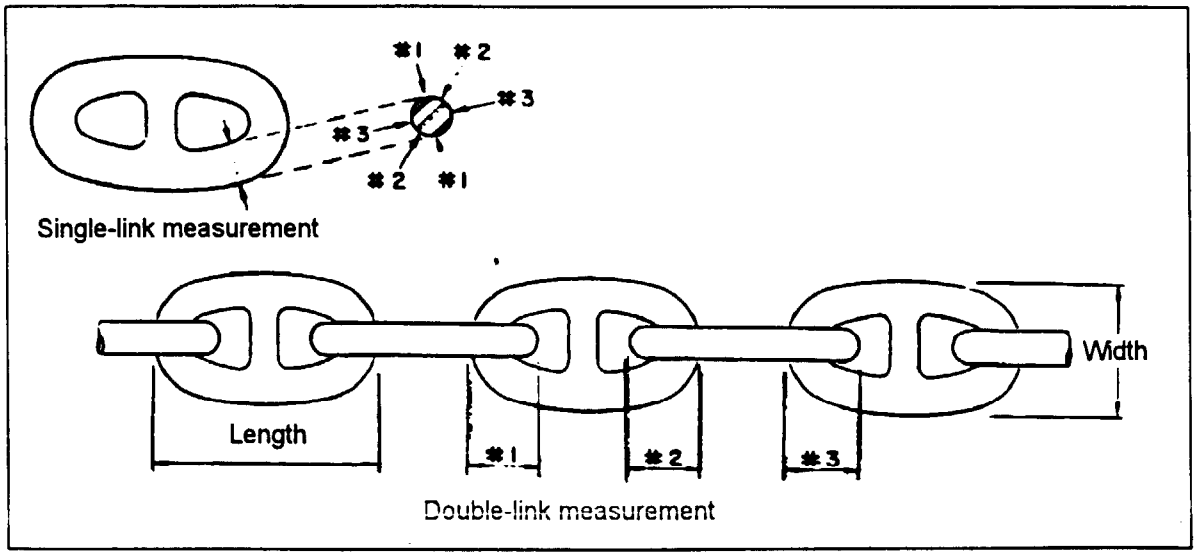



Figure 3-39. Locations for taking chain-link measurements.

- Buoy overall condition: report any visible damage or listing. If the buoy is listing, determine which inner compartment has water in it.

- Report the color and markings. Ensure that the identification number on the buoy is the same as that depicted on navigation charts; if not, report it.

*b. Fiberglass Coating*

- Report hull dents or separation of the fiberglass from the buoy. The metal could be indented and the fiberglass could look undamaged.

- Report peeling or loose seams or edges. Fiberglass will often fail there first.

- Report any rust bleeding. This indicates trapped moisture between the fiberglass and the buoy's hull.

- Report blisters, bubbles, cracks, checking, or glazing that may be hidden under paint.

*c. Painted Surfaces*

- Report spalling, cracking, peeling, and blisters.

- Report lack of full paint coverage of the buoy or paint discoloration due to chemical reactions or rust bleeding.

*d. Top Jewelry*

- Identify each component and prepare a sketch depicting the location of each within the top jewelry.

- Report any wear or corrosion of jewelry components.

*e. Fenders/Chafing Strips*

- Record the number and location of each.

- Record the method of fender/chafing strip attachment.

- Check for and report any loose, rusted, or broken attachments or bolts.

- Check the welds securing the fender/chafing strip mounting brackets to the buoy hull and report any cracks or separation of the welding material from the parent metal.

- Ensure that drainage holes through the chafing strips are open and not clogged with debris.

**(1) Timber**

- Report any splintering, dry rot, worm/borer holes, or broken sections.

- Record paint type and condition.

**(2) Rubber**

- Check for and report any rubber brittleness or cracking.

- Record any tears, rips, or missing sections.

**(3) Steel Pipe Chafing Rail**

- Record pipe rail diameter and height above the deck.

- Check for rust and a secure attachment at the base of the stanchions and rust on the underside of each horizontal rail.

- Record any damage, i.e, dents, fractures, or loose parts on which a line may foul.

MOORING NO. _____ CLASS. _____ LOCATION _____ LAT. _____ LONG. _____

ANCHOR TYPES/SIZE: _____ BUOY TYPE: _____ BUOY DIAM: _____ BUOY COLOR/MARKINGS: _____

BOTTOM TYPE: ☐ SAND ☐ MUD ☐ CLAY ☐ CORAL ☐ ROCK VISIBILITY _____ D = DEPTH NI = NOT INSPECTED, INACCESSIBLE

| COMPONENTS | | NI | NEW | CONDITION | | | | | | D | COMMENT/DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SINGLE LINK (%) | | | DOUBLE LINK (%) | | | | |
| | | | | 90+ | 80+ | 80- | 90+ | 80+ | 80- | | |
| **Chain Measurements** | | | | | | | | | | | |
| Riser | Near Buoy | | | | | | | | | | |
| | Middle | | | | | | | | | | |
| | Near Grd Rg | | | | | | | | | | |
| **Ground Ring** | | | | | | | | | | | |
| Ground Leg No. A | Upper End | | | | | | | | | | |
| | Middle | | | | | | | | | | |
| | Enters Bottom | | | | | | | | | | |
| Ground Leg No. B | Upper End | | | | | | | | | | |
| | Middle | | | | | | | | | | |
| | Enters Bottom | | | | | | | | | | |
| Ground Leg No. C | Upper End | | | | | | | | | | |
| | Middle | | | | | | | | | | |
| | Enters Bottom | | | | | | | | | | |
| Ground Leg No. D | Upper End | | | | | | | | | | |
| | Middle | | | | | | | | | | |
| | Enters Bottom | | | | | | | | | | |

| Component | Condition | Comments/Description |
|---|---|---|
| Overall Buoy Condition | | |
| Buoy Fiberglass Coatings | | |
| Paint Condition | | |

Date: _____ Engineer in Charge: _____ Divers: _____

Figure 3-40. Standard mooring inspection report form.

(Continued on back)

| Component | Condition | Comments/Description |
|---|---|---|
| Hull Condition | | |
| Top Jewlery | | |
| Top Fenders/Chaffing Strips | | |
| Top Manhole | | |
| Top Tension Bar | | |
| Top Hawsepipe | | |
| Lower Fender | | |
| Lower Hull | | |
| Lower Hawsepipe | | |
| Bottom Jewlery | | |
| Buoy Cathodic Protection | | |
| Bottom Tension Bar | | |
| Joining Hardware | | |
| Swivel | | |
| Top Riser Joint Hardware | | |
| Bottom Riser Joint Hardware | | |
| Ground Ring | | |
| Ground Leg A Joint Hardware | | |
| Ground Leg B Joint Hardware | | |
| Ground Leg C Joint Hardware | | |
| Ground Leg D Joint Hardware | | |
| Ground Leg Swivels | | |
| Chain Anodes | | |
| Visible Anchors | | |
| Anchor Hardware | | |

Figure 3-40. Standard mooring inspection report form (continued).

*f. Manhole Covers*

- Report the number, size, and location of each manhole.

- Report rusting of the covers or bolts. The edges of the covers may show a "delamination" of the steel.

- Check for and report any loose or missing bolts.

- On fiberglass-coated buoys, report whether the manhole covers are fiberglassed or not.

*g. Tension Bar*

- Check eye for wear and measure its diameter with calipers.

- Measure steel bar thickness.

- Check base plate for cracks, warping, or other damage.

- Record plate thickness.

*h. Hawsepipe*

- Measure and record wire diameter and condition of chain held in place by the retaining plate.

- Check for and report bell mouth rusting or wear.

## 2. BUOY LOWER PORTION (UNDERWATER)

*a. Lower Fender*

- Record fender material.

- If timber, report any splintering or broken/missing sections.

- If rubber, report any tears, rips, or missing sections.

- If visible, record fender attachment method.

- Check for and report any rusted, loose, or broken attachments or bolts.

*b. Buoy Bottom*

- Record marine growth thickness.

- If there is no appreciable marine growth, check and record the type and condition of the protective coating (paint or fiberglass).

- Report any dents or other bottom hull damage.

*c. Tension Bar*

- Check lower tension bar eye for wear and measure its wire diameter with calipers.

- Check retaining plate and report any observed wear or warping.

*d. Hawsepipe*

- Measure and record chain wire diameter at the bottom of the hawsepipe.

- Check and report rubbing casting wear. If the rubbing casting is missing, then check for rusting and wear of the bell mouth.

- Ensure that chain is securely attached to rubbing casting.

*e. Bottom Jewelry*

- Identify and report each type of chain component between lower tension bar eye and riser chain.

- Measure and record component length and wire diameter.

- Report any observed wear or corrosion.

*f. Cathodic Protection System on Buoy*

- Record number, size, and location of installed anodes.

- Ensure that each anode is securely attached to buoy.

- Use an underwater voltmeter or portable voltmeter and silver/silver chloride reference electrode as described in Section 3.4.5, measure the potential of the bottom of the buoy in at least three locations and record the potentials. The guidelines for interpretation of the potentials given in Table 3-4 also apply to steel buoy bottoms.

**3. RISER CHAIN SUBASSEMBLY**

*a. Links*

- Record chain type (cast, forged, Dilok).

- Using appropriate tools, clean the following components for measurements:

(1) First three links below bottom jewelry.

(2) Three links just above ground ring.

(3) Three links about halfway in between these two areas.

(4) If the riser contains more than one shot of chain, clean links and take measurements at both ends and near the center of each shot.

- In a nonriser-type mooring clean:

(1) First three links of each leg just below buoy's padeyes.

(2) Three links just above mudline.

(3) Three links about halfwayin-between.

- Take and record double-link measurements of cleaned links. (See Figure 3-41 for "go-no go" gauges.)

- Record length of one of the links cleaned at each area.

- Check for and record manufacturer's markings.

- Check for pitting, measure diameter and depth of any pits found, and record results.

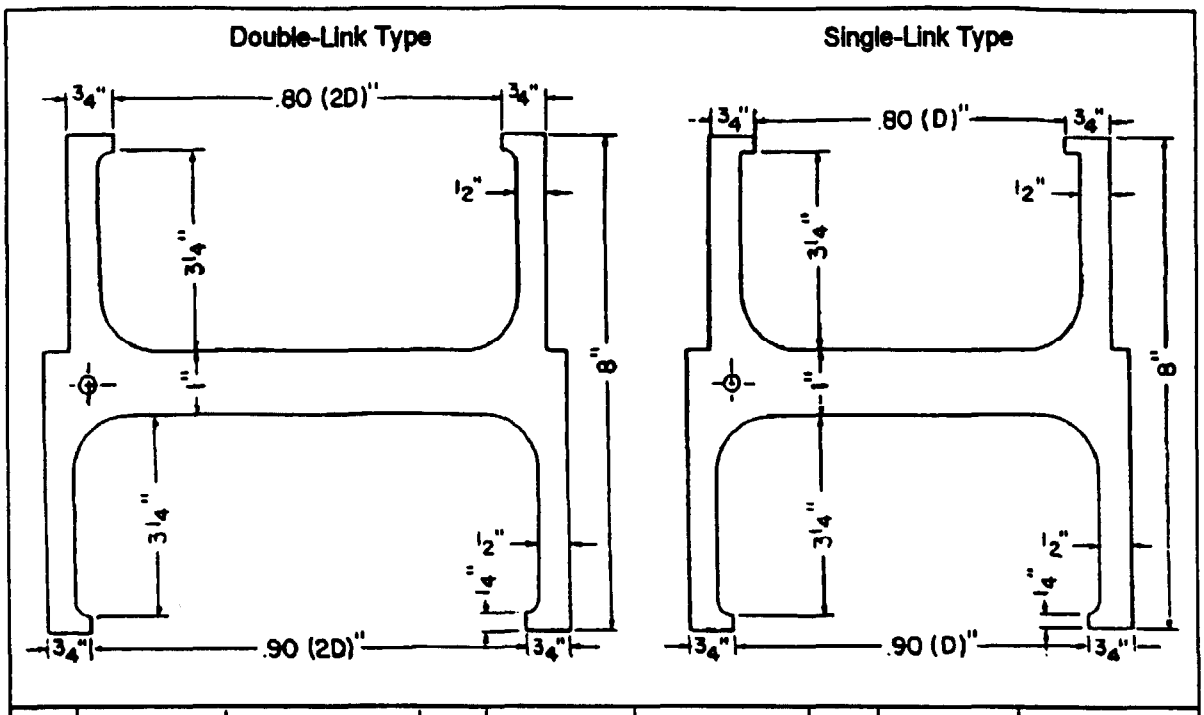
- Record water depth below buoy where each measurement is taken.

*b. Connecting Hardware*

- If visible, identify and record type of each (shackle, detachable link, anchor joining, etc.). Detachable links should be found on either side of the shackle and at the top and bottom of each chain shot.

- Record component's overall length and wire diameter.

- Report any loose, broken, or missing parts. If visible, note condition of tapered locking pin in a detachable link.




| | Single Link | | Double Link | | | Single Link | | Double Link | | | Single Link | | Double Link | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D" | .90D | .80D | .90(2D) | .80(2D) | D" | .90D | .80D | .90(2D) | .80(2D) | D | .90D | .80D | .90(2D) | .80(2D) |
| 6-1/2 | 5.850 | 5.20 | 11.70 | 10.40 | 3-1/2 | 3.150 | 2.80 | 6.300 | 5.600 | 2 | 1.800 | 1.600 | 3.600 | 3.200 |
| 6 | 5.400 | 4.80 | 10.80 | 9.60 | 3 | 2.700 | 2.40 | 5.400 | 4.800 | 1-7/8 | 1.687 | 1.500 | 3.375 | 3.000 |
| 5-1/2 | 4.950 | 4.40 | 9.90 | 8.80 | 2-3/4 | 2.475 | 2.200 | 4.950 | 4.400 | 1-3/4 | 1.575 | 1.400 | 3.150 | 2.800 |
| 4-1/2 | 4.050 | 3.60 | 8.10 | 7.20 | 2-1/2 | 2.250 | 2.000 | 4.500 | 4.000 | 1-1/2 | 1.350 | 1.200 | 2.700 | 2.400 |
| 4 | 3.600 | 3.20 | 7.20 | 6.40 | 2-1/4 | 2.025 | 1.800 | 4.050 | 3.600 | 1-1/4 | 1.125 | 1.000 | 2.250 | 2.000 |

Figure 3-41. "Go-no-go" gauges.

- Record water depth below buoy of each connecting component.

- Record any manufacturer's markings.

Past experience has indicated that the most severe wear occurs at the shackle connecting the mooring buoy padeye with the top link of chain. Special attention is required to inspect this shackle:

- Measure the least diameter of the shackle pin.

- Inspect whether the pin exhibits any outward movement.

- Check and record the condition of locking wire or pin at the end of the shackle pin.

*c. Swivel*

- Each riser subassembly should contain a swivel. Record swivel depth.

- Check swivel for marine growth.

- Record any manufacturer's markings.

**4. GROUND RING SUBASSEMBLY**

- Three typical types of ground ring assemblies are:

(1) A ground ring with four pear links attached.

(2) A ground ring with four anchor joining links.

(3) A ground ring with four shackles.

- Record type of ground ring assembly observed.

- Measure and record inside diameter (ID) of ring.

- Check and report any distortion of ring from circular that would indicate overstressing.

- Record height of assembly above bottom, or if the water is too deep, record depth below buoy.

- Using calipers, measure wire diameters of links attached to the ground ring and record results.

- Record any manufacturer's markings.

**5. GROUND LEG SUBASSEMBLY**

***a. Links***

- Record chain type installed (cast, forged, Dilok).

- Using appropriate tools, clean the following for measurements:

(1) First three links of each leg below the ground ring.

(2) Three links above mudline.

(3) Three links about halfway in-between these two areas.

- Measure and record double-link measurements of the cleaned links. (See Figure 3-41 for "go-no go" gauges.) If one or more legs should extend considerable distances before entering the bottom, clean links and take measurements at both ends and near the center of each visible shot. If chain is not in tension, single-link measurements should be taken and recorded.

- Record length of one of the links at each area.

- Check for and record manufacturer's markings.

- Check for pitting, measure diameter and depth of any pits found, and record results.

- Record each anchor leg length from ground ring to bottom and from where it touches bottom to the point it becomes buried.

- Using a compass, note and record the relative bearing of each leg from the ground ring.

- Repeat above steps for three links at each end of tandem anchor connecting chain (if visible).

***b. Connecting Hardware***

- Identify and record component type (shackle, detachable link, anchor joining, etc.).

- Record component's overall length and wire diameter.

- Report any loose, broken, or missing parts.

- Record any manufacturer's markings.

- Record position of each connecting component by leg number and number of feet from ground ring.

*c. Swivel*

- Each anchor leg subassembly may contain a swivel. If located, record position by its leg number.

- Record any manufacturer's markings.

**6. ANCHOR ASSEMBLY (if visible)**

*a. Anchor*

- Identify and record type (Stato, Stockless, LWT, Pearl Harbor, pile, PEA, etc.) (see Figures 3-34 and 3-35). Note whether or not anchor has stabilizers.

- Attach a pop float and record its bearing from the buoy using a compass.

- Determine and record anchor's orientation (i.e., flukes buried, flukes up, anchor on its side, anchor facing the wrong direction, etc.).

***b. Repeat all of the above for the tandem anchor.***

*c. Connecting Hardware*

- Identify and record component type and location.

- Record component's overall length and wire diameter.

- Report loose, broken, or missing components.

**7. PROPELLANT-EMBEDMENT ANCHORS (if visible)**

*a. Swage Fittings*

- Check for any loose, broken, or missing pins or parts.

- Check for fraying of the wire rope pendant where it enters the swage fitting and report any noted.

*b. Pendant/Downhaul Cable*

- Measure and record the wire diameter.

- Check for fraying, kinking, "birdcaging," or rusting of the cable and report any noted. Look for a "necking down" of the wire that may indicate the existence of a corrosion cell.

- Record the amount (in feet) of wire pendant visible between the anchor leg and the point that the pendant enters the bottom.

- Report any evidence of pendant cable movement on the bottom.

- Inspect and record any sign of wire rope pullout at the terminations.

**8. EQUALIZER (SPIDER)**

- Check for rust and wear.

- Note the amount of marine growth located within the equalizer.

## 9. CHAIN CATHODIC PROTECTION SYSTEM

*a. Anodes*

- Record anode size and location on the chain.

- Observe and record anode condition and determine whether or not its consumption is uniform.

- Record the color and estimate the thickness of the oxidation coating.

- Ensure secure attachment to the chain and the continuity wire.

- Using an underwater voltmeter (Section 3.4.5), measure and record the chain's electrical potential. (See 3.5.4.2 below for use of underwater voltmeter.)

*b. Electrical Continuity-Cables/Clips*

- Check and record cable's secure connection to the chain.

- Probe chain every 15 feet until anchor is reached or chain disappears into the bottom and record the potentials.

c. The ***ground legs and risers of mooring buoys*** are commonly protected from corrosion using sacrificial anodes. These anodes are consumed by galvanic action while providing protection for the chain. In order to be effective, electrical continuity between the anode and all chain links must be provided. For the ground legs which are often slack, this continuity is provided by a connecting wire attached to the chain. The tension in riser chain is normally sufficient to maintain electrical continuity. Cathodic protection systems for fleet moorings are described in more detail in Section 5.4.3.

**3.5.4.2 Cathodic Protection Inspection.** The most common method of cathodically protecting fleet moorings involves the use of 150- to 500-pound zinc anodes attached to buoy hulls and each shot of chain. Underwater voltmeters are used to determine the effectiveness of the system by measuring relative electrical potentials of the buoy and chain at certain distances from the anode. The electrical potential of the metal is the charge of the metal compared to a standard reference electrode, typically silver/silver chloride. Steel that is adequately protected from corrosion should have electrical potentials that fall between -0.80 and -0.90 volt, as illustrated in Figure 3-42.

A portable voltmeter and portable reference electrode can be used to measure the potential on buoy hulls, but due to water depth and questionable electrical continuity, an underwater voltmeter is required for inspection of the cathodic protection system on chain.

A greater potential indicates that the anode is overworking and serious damage could occur to the metal, while a lesser potential indicates that the system is not operating effectively and corrosion may be occurring.

Fleet mooring inspection divers will normally use a self-contained voltmeter, such as that illustrated in Figure 3-23, which consists of a digital display, surface readout facility, and rechargeable battery. Underwater voltmeter readings must be taken at 20-foot intervals on the chain, on each side of each anode, at each end at the continuity cable, and on each side of each swivel. Whenever readings are taken, potentials, depth, and element measured should be recorded. Note that a moored vessel can affect the cathodic protection system on the mooring buoy and chain and

cause the readings to be either higher or lower than normal.

### 3.5.5 Equipment and Tools Required

Chain measurements are best made with precut "go-no go" gauges, as illustrated in Figure 3-41, calibrated at 90 and 80 percent of original wire diameter. Calipers (24-inch minimum) are also required, with the measurements taken off a ruler attached to a Plexiglas slate. A 100-foot tape and scales 1, 2, and 3 feet long with large numbers suitable for photo documentation will be required. A diver's compass and accurate depth gauge, as well as survey buoys, will also be required.

The effectiveness of cathodic protection systems is measured as follows:

- On mooring buoys - either an underwater voltmeter as shown in Figure 3-23 or a portable voltmeter and portable reference electrode as shown in Figure 3-22 can be used.

- On chain - an underwater voltmeter is used.

To record any findings underwater, a grease pencil and Plexiglas slate are required. An underwater camera with extra film is required for photographic documentation and a video recording system may be required. An inclinometer is required for obtaining the angles of mooring chains in nonriser-type moorings and spread moorings. Marker tags are used to relocate or mark links or accessories. Transits and targets are required for locating buoy positions. Because UCT divers need high mobility, and because of the depth of water in which they will be working, the cleaning operations to be performed for inspection work generally require only hand tools, such as wire brushes and scrapers.

At times ROVs may be used to supplement mooring inspections (see Section 2.9).

## 3.6 CONCRETE STRUCTURES

### 3.6.1 Types of Marine Concrete Structures

Concrete is widely used in the marine environment as a construction material because of its many desirable properties. In its plastic state, concrete is easily mixed, handled, transported, and placed into forms. The strength of concrete can be regulated by adjusting the quantities of cement, aggregate, water, admixtures, and, in particu-

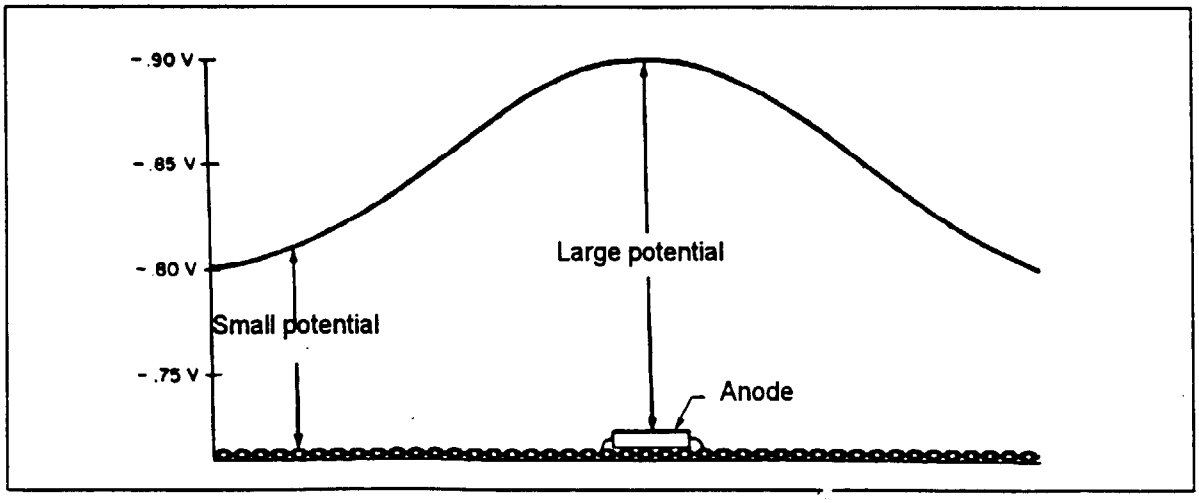



Figure 3-42. Cathodic protection system potentials.

lar, the water-to-cement ratio. This ratio is one of the prime considerations in concrete mix design not only to provide adequate concrete strength, but, equally important, to provide long term durability of concrete in the harsh marine environment.

The performance of a concrete structure is most affected by the care taken in its construction and installation. Properly made concrete is highly durable in marine applications, exhibiting resistance to corrosion of reinforcing steel, chemical deterioration, weathering, erosion, and structural damage. Concrete is relatively strong under compressive loading, and with steel reinforcing resists bending and tensile forces. Concrete can be cast in place at the job site, precast into the required shape at a concrete plant and shipped to the site, or prestressed before installation to accept additional loading. With proper procedures (see Section 2.10), concrete can be rapidly placed underwater where it will harden into good quality concrete.

Circular or square concrete piles (Figure 3-6) are widely used to support piers, wharves, and other structures. Concrete is used as a decking material for many waterfront facilities and in retaining wall structures, such as those needed for closed piers and wharves, bulkheads, quaywalls, drydocks, and seawalls. It is also used in pavements, bridge foundations, boat loadings and ramps, breakwaters, undersea cable and pipeline stabilization, and offshore structures.

### 3.6.2 Deterioration of Marine Concrete Structures

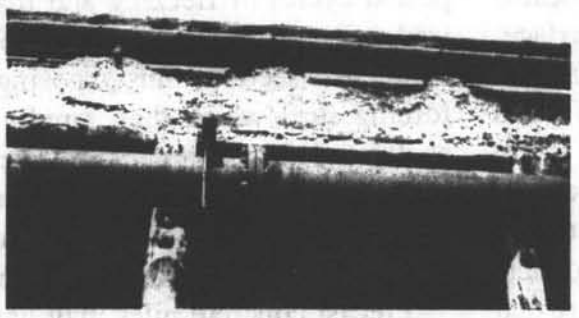
The most common damage resulting from the premature deterioration of concrete structures in or near seawater is cracking and loss of material (or cross section). Softening of the concrete due to chemical action is another form of damage but less common than cracking. As shown in Table 3-5, the damage to concrete is generally most severe in the splash and tidal zones, but does occur in all zones. The different exposure zones are shown in Figure 3-11.

Table 3-5. Types of Damage in Marine Concrete

| Description of Damage | Zone (Location)[a] | | Common Causes of Damage | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Observed | Most Severe | Corrosion of Reinforcement | Freeze-Thaw | Abrasion | Sulfate Attack | Chemical Reaction of Aggregates | Structural Overload |
| Cracking | All | T | X[b] | X | | | X | X |
| Loss of Material-[c] Exposed Reinforcement and/or Aggregate | All | S, T | X | X | X | X | X | X |
| Material | S, T, Su | S, T | | | | X | | |

[a]A = Atmospheric zone; S = Splash zone; T = Tidal zone; Su = Submerged Zone; M = Mud zone (see Figure 3-11).
[b]Rust stains on the concrete surface are generally a symptom of corrosion of the reinforcement.
[c]Loss of material from spalling, scaling, disintegration.





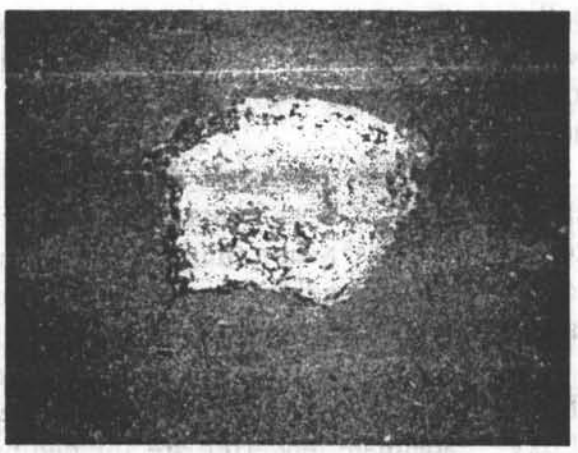


Figure 3-43.
Concrete deterioration.

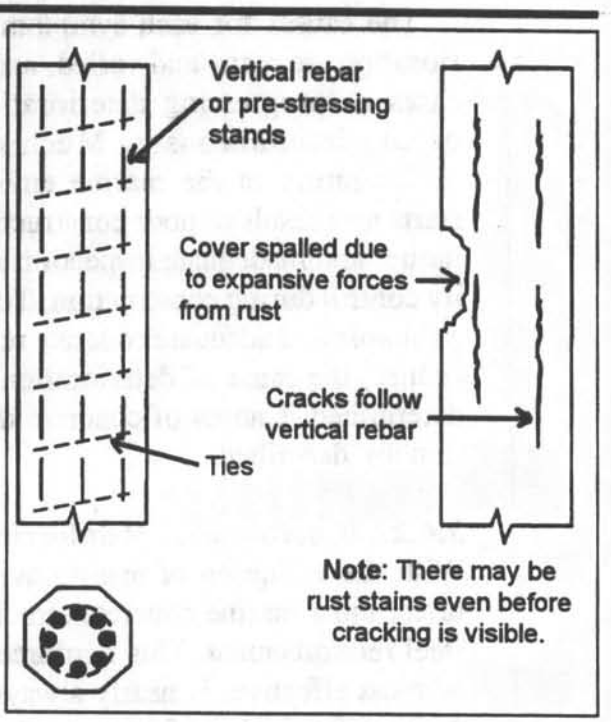



Figure 3-44
Examples of damage resulting from corrosion of reinforcement.

Deterioration of concrete waterfront structures is caused primarily by:

- Corrosion of steel reinforcement
- Repetitive freezing and thawing of moist concrete
- Abrasion
- Chemical deterioration
- Structural overloading

The three most common visual signs of concrete deterioration in marine structures are: cracking, disintegration, and spalling, as illustrated in Figures 3-43 and 3-44. Disintegration is defined as an overall decay of the concrete involving loss of strength of the cement and sand paste and subsequent loosening or loss of coarse aggregate particles. Spalling is defined as a localized area or fragment of concrete falling away from the structure. Both disintegration and spalling can expose reinforcing steel.

The causes for each symptom of deterioration are many and varied, and in most cases of progressing deterioration, they occur simultaneously. Much concrete deterioration in the marine environment starts as a result of poor construction techniques and inadequate inspection and quality control during construction. To develop a suitable and adequate concrete repair procedure, the cause of deterioration must be determined. Causes of concrete deterioration are described.

**3.6.2.1 Corrosion of Reinforcing Steel.** With the exception of mass gravity structures, most marine concrete structures use steel reinforcement. This reinforcement, to be most effective, is nearly always located within a few inches of the concrete surface, making the steel susceptible to corrosion if it does not have adequate cover of good quality concrete. Corrosion is more likely to occur if the concrete is overly porous or if cracking is initiated by some action.

The reinforcing steel corrosion products (rust) can increase the volume of the rusted area up to eight times. This leads to cracking of the concrete cover in lines parallel to the reinforcing steel. Eventually spalling results, and in cases of close reinforcement spacing, a complete delamination of the concrete surface can occur as illustrated in Figure 3-44.

All concrete is porous to some extent. The degree of porosity is dependent primarily on the water/cement (w/c)ratio of the concrete mix and on good construction practices. The lower the w/c ratio, the more dense (less porous) the concrete which limits the rate at which water, dissolved oxygen, and chloride ions reach the reinforcing steel, and lengthens the time for corrosion of the rebar to damage the concrete.

For example, reinforced marine concrete made with a w/c ratio of 0.6 to 0.7 (7 or 8 gallons of water per 94-pound sack of cement) will show rebar corrosion, cracking, and spalling in a very few years, whereas well made concrete with a w/c of 0.4 (about 4-1/2 gallons of water per sack of cement) will likely serve several decades or more before serious deterioration occurs.

**3.6.2.2 Freeze/Thaw Deterioration.** Freeze/thaw deterioration is the freezing of absorbed moisture or water in porous concrete exposed to subfreezing temperatures. This is one of the most common causes of concrete deterioration in the tidal and splash zones. Upon freezing, this entrapped water expands and cracks the concrete. Upon thawing, the cracked surface disintegrates. Repeated cycles of freezing and thawing can lead to partial or even total loss of the concrete cross section, thus exposing the reinforcing steel which then rapidly corrodes as illustrated in Figure 3-45. The best prevention of freeze\thaw damage is to use air-entrained concrete with a rich cement content and a low water/cement ratio.

Precast concrete piles may have a cast-in-place jet pipe that was not filled with concrete after the pile was driven. When the water in the pipe freezes, it can cause longitudinal cracks in the pile, as illustrated in Figure 3-46.

**3.6.2.3 Abrasion Wear.** Abrasion is defined as erosion of a concrete surface by the physical action (impact and rubbing) of external loadings or abrading agents. Deck slabs are subject to abrasion by vehicular traffic and loading equipment. Deck edges and wharf faces at berthing spaces without adequate fendering are abraded by moored vessels. Frequently, concrete piles and walls are abraded in the tidal zone by floating debris and ice moved by currents, waves, propeller wash, and tide changes. Less frequently, submerged concrete, especially at

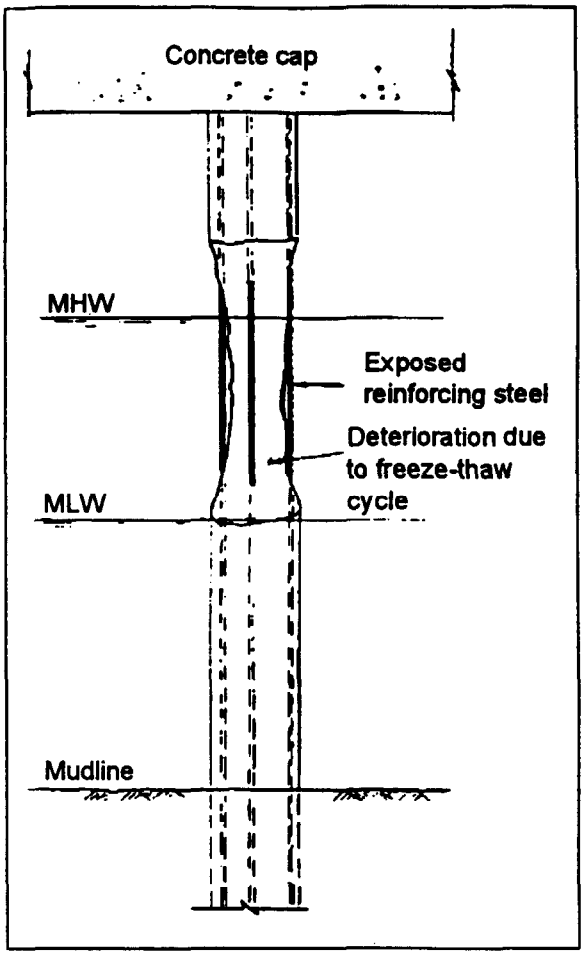



Figure 3-45. Freeze/thaw deterioration.

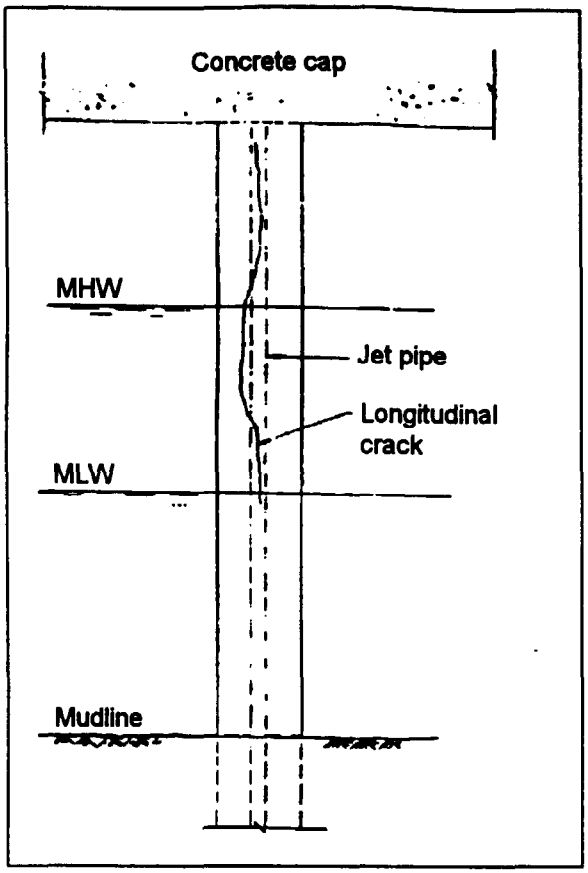



Figure 3-46. Internal freezing of jetted-in concrete pile.

the mudline, is abraded by silt, sand, and debris churned up by moving water. Figure 3-47 illustrates the effects of abrasion on a concrete pile.

**3.6.2.4 Chemical Deterioration.** The most significant and serious saltwater chemical reaction to hardened concrete is the combining of sulfates in seawater with chemicals in the cement paste, referred to as sulphate attack. This reaction can produce internal expansion and cause cracking. More commonly, however, the hydrate cement paste looses strength and becomes soft. Aggregate particles become exposed or fall from the concrete mass because of the weak cement paste.

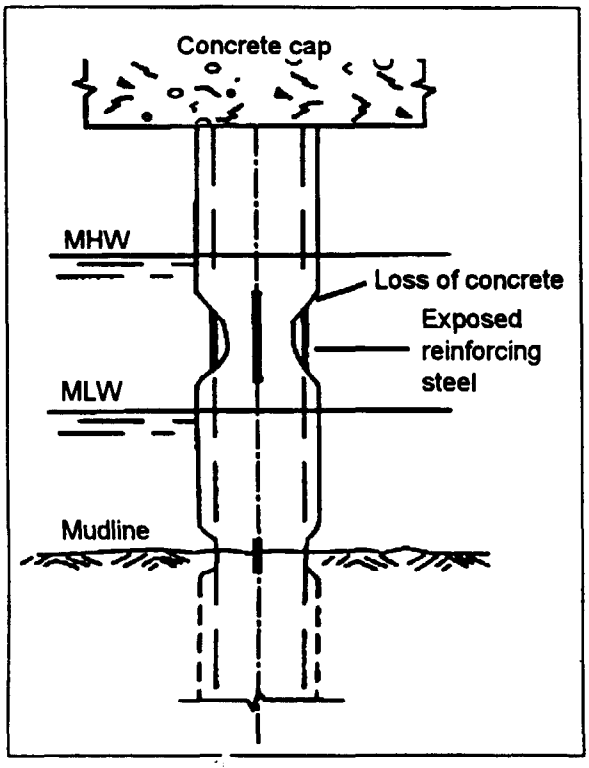



Figure 3-47. Abrasion of concrete pile.

**3.6.2.5 Axial Overloading.** Deterioration of concrete piles from axial overloading can be a cause of eventual failure of the pile. Overloading can result from superimposed "dead" and "live" loads exceeding the bearing capacity of the pile, and also from overstressing at the time of pile driving. Pile driving overloading often results in hairline cracks at the top of the pile or circumferential cracks at other locations along the pile that are difficult to see, as illustrated in Figure 3-48. As marine growth covers the pile, the cracks become extremely difficult to detect.

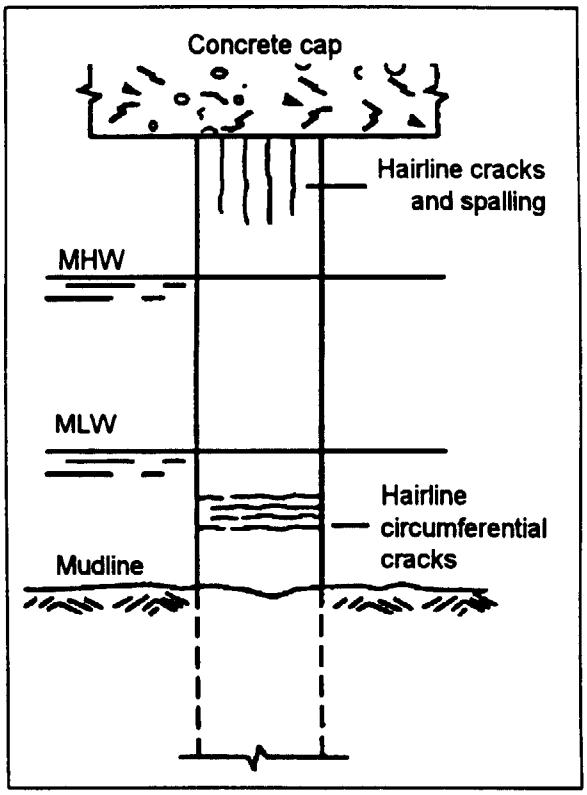



Figure 3-48. Overloading of concrete pile during pile driving.

**3.6.2.6 Shrinkage.** Shrinkage or contraction can occur from moisture or temperature changes. Hardened concrete that looses internal water due to evaporation will shrink. Any temperature decrease of the concrete will cause contraction. The major cause of microcracks within concrete is from high temperatures generated from the normal hydration of cement. The concrete hardens at a high temperature and later cools to ambient temperatures. Precast concrete members that have been steam cured are particularly susceptible to microcrack formation. If the shrinkage or contraction is restrained, internal stresses may develop in sufficient magnitude to cause significant cracks in the structure.

Variations in atmospheric temperature cause a change in temperature of a hardened concrete mass, which results in volumetric changes. Provisions must be made to permit this expansion and contraction process to take place. Failure to do so will result in contraction stresses (tension), which may cause cracking, or expansion stresses (compression), which may lead to spalling.

**3.6.2.7 Swelling.** Concrete that increases in moisture content by absorbing water or increases in temperature will swell or expand. Typically, swelling by water absorption is not a concern unless precast dry-concrete members are used. Temperature increases from daily and seasonal changes may cause cracking in some concrete members.

**3.6.2.8 Other Deterioration Factors.** The preceding has discussed deterioration in concrete caused by improper selection or proportioning of concrete materials, faulty construction methods and procedures, and attack by environmental forces. Of equal importance, and a major cause of much concrete deterioration, is poor design of concrete structural details.

A few examples of poor design and construction details that contribute to concrete failure and deterioration are:

- Congestion of reinforcing steel

- Lack of adequate cover for reinforcing steel
- Abrupt change in size of section
- Reentrant corners
- Lack of chamfers and fillets at corners
- Rigid joints between precast units
- Construction joint leakage
- Poorly designed scuppers, drips, and curb slots
- Inadequate drainage
- Too little gap at expansion joints
- Incompatibility of materials or sections

### 3.6.3 Concrete Inspection Procedure

**3.6.3.1 Visual Inspection.** Levels I and II visual inspection of concrete waterfront structures should proceed as shown in Table 3-6.

**3.6.3.2 Level III Nondestructive Inspection of Concrete.** The qualitative data obtained from visual inspections are sometimes inadequate to accurately assess the condition of the structure. In these instances, quantitative data obtained from nondestructive testing instruments can assist the facilities engineer in determining the condition of the structure. Three specialized instruments have been developed for underwater inspection of concrete structures. These instruments are the:

- **Magnetic rebar locator** - used to determine the location and orientation of rebar in concrete structures and to measure the amount of concrete cover over the rebar.
- **Rebound hammer** - used to evaluate the surface hardness of the concrete and obtain a general condition assessment.
- **Ultrasonic system** - used to obtain a general condition rating and indication of overall strength of the concrete based on sound velocity measurements through a large volume of the structural element.

Each instrument consists of an underwater sensor connected to a topside deck unit through an umbilical cable. The deck unit contains the signal conditioning electronics and data acquisition system. To operate the instruments, the diver has to position the underwater sensor on a previously cleaned portion of the structure surface and a person topside must operate the data acquisition system in order to collect and store the data. Each instrument is independently operated and provides unique information to help assess the condition of the concrete structure.

### 3.6.4 Equipment and Tools Required

To perform a thorough inspection, the marine growth on the structure must be removed. A "Barnacle Buster" or pneumatic chipping gun is an efficient method of removing marine growth from concrete surfaces. Various types of high-pressure water jet cleaning systems are also effective. Exercise care in the use of these methods because they may further damage a deteriorating concrete structure. If minimal marine growth is found in the splash/tidal area, small hand tools, such as wire brushes and scrapers, are sufficient. Refer to Section 2.3 for information on equipment for removing marine growth. A hammer for sounding and an accurate water-depth gauge will

Table 3-6
Concrete Structure Underwater Inspection Checklist

| Checkpoint | Description |
|---|---|
| 1 | Inspect the structure beginning in the splash/tidal zone. This is where most mechanical and biological damage is normally found. |
| 2 | Clear a section about 18 to 24 inches in length of all marine growth. |
| 3 | Visually inspect this area for cracks, abraided surface spalling, or mechanical damage, and exposed reinforcing steel. |
| 4 | Sound the cleaned area with a hammer to detect any loose layers of concrete hollow spots in the pile, structure, or soft concrete. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement. |
| 5 | Descend, visually inspecting the pile or structure where marine growth is minimal, and sound with a hammer. |
| 6 | Inspect in greater detail the base of mass structures, such as foundations, quaywalls, breakwaters, or bridge piers. These types of structures are prone to undermining by wave and current action, which, if not rectified, could lead to failure of the structure. |
| 7 | At the bottom, record the water depth along with any observations of damage on a Plexiglas slated. |
| 8 | After returning to the surface, immediately record all information into the inspection log.<br><br>NOTE: If signs of deteriorations are found, then a Level III inspection, involving either nondestructive or destructive tests, may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods. |
| | Exposed Area Under Pier or Along Wharf or Dolphin Assembly |
| 9 | Check pile caps and bearing, batter, and fender piles for damaged or broken members, cracks, and spalling of concrete, rust stains, and exposed reinforcing steel. |
| 10 | Sound the piling or structure with a hammer to detect any loose layers of concrete or hollow spots. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement.<br><br>NOTE: If signs of deteriorations are found, then a Level III inspection, involving either nondestructive or destructive tests, may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods. |

be required. Record observations on a Plexiglas slate with a grease pencil. Use underwater video cameras for permanent visual documentation.

**3.6.4.1 Magnetic Rebar Locator.** The magnetic rebar locator shown in Figure 3-49 is based on a commercial instrument that detects the disturbances in a magnetic flux field caused by the presence of magnetic material. The magnitude of this disturbance is used to determine the location and orientation of rebar in concrete structures and to measure the amount of concrete cover over the rebar.

The system consists of an underwater test probe, an umbilical cable, and a topside data acquisition unit (DAU) including printer.

The test probe consists of two coils mounted on a U-shaped magnetic core. A magnetic field is produced in one coil and the disturbance-induced magnetic field in the rebar is measured in the other coil. The magnitude of the induced current is affected by both the diameter of the rebar and its distance from the coils. Therefore, if either of the parameters is known, the other can be determined.

By scanning with the probe until a peak reading is obtained, the location of the rebar can also be determined. A maximum deflection of the meter needle will occur when the axis of the probe poles are parallel to and directly over the axis of a reinforcing bar, thus indicating orientation.

The underwater rebar locator is calibrated for rebar that varies from No. 3 to No. 16 in size. The meter can be used to measure the depth of concrete cover over rebar in the range of 1/4 to 8 inches thick, or conversely, it can measure the diameter of the rebar. The best accuracy ($\pm 10$ percent) is obtained for concrete cover less than 4 inches thick.

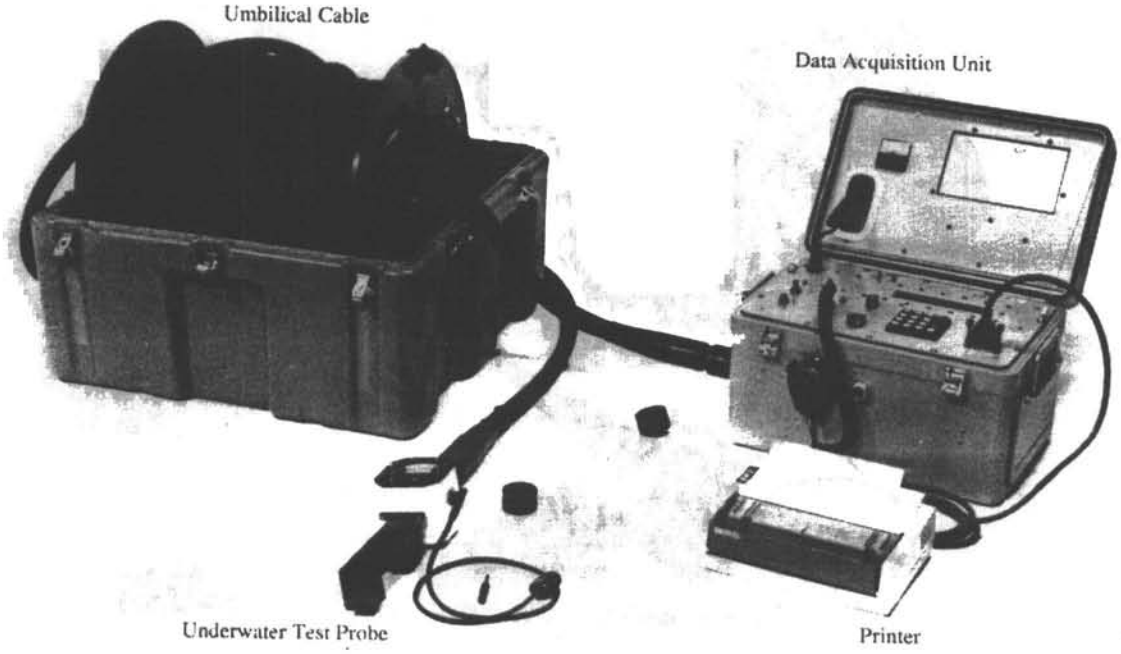



Figure 3-49. Underwater rebar locator system.

• **System Limitations.** The presence of other metallic objects in the vicinity where the measurements are being made can affect the operation of the rebar locator. For example, in heavily reinforced structures, the effect of nearby rebar cannot be eliminated and accurate depth readings are difficult or impossible.

If the separation of two parallel rebars is at least three times the thickness of the concrete cover, this effect can be neglected.

The presence of rebar perpendicular to the axis of the underwater probe has less effect on the measurement of concrete cover than that of parallel rebar, and in most instances it can be ignored.

**3.6.4.2 Rebound Hammer.** The underwater rebound hammer system, shown in Figure 3-50, is a surface hardness tester which can be used to obtain a general condition assessment of concrete. The system consists of an underwater rebound hammer, an umbilical cable, and a topside data acquisition unit (DAU) including printer. The rebound hammer is mounted in a waterproof housing which contains an electrical pickup to sense the position of the rebound mechanism. The umbilical connects the underwater rebound hammer to DAU that contains the signal conditioning electronics and data acquisition system.

The rebound hammer correlates the rebound height of a spring-driven mass after it impacts the surface of the concrete with the compressive strength of the concrete under test. The spring-driven mass slides on a guide rod within the tubular housing. When the impact plunger is pressed firmly against the concrete surface, a trigger releases the spring-loaded mass causing it to impact the plunger and transfers the energy

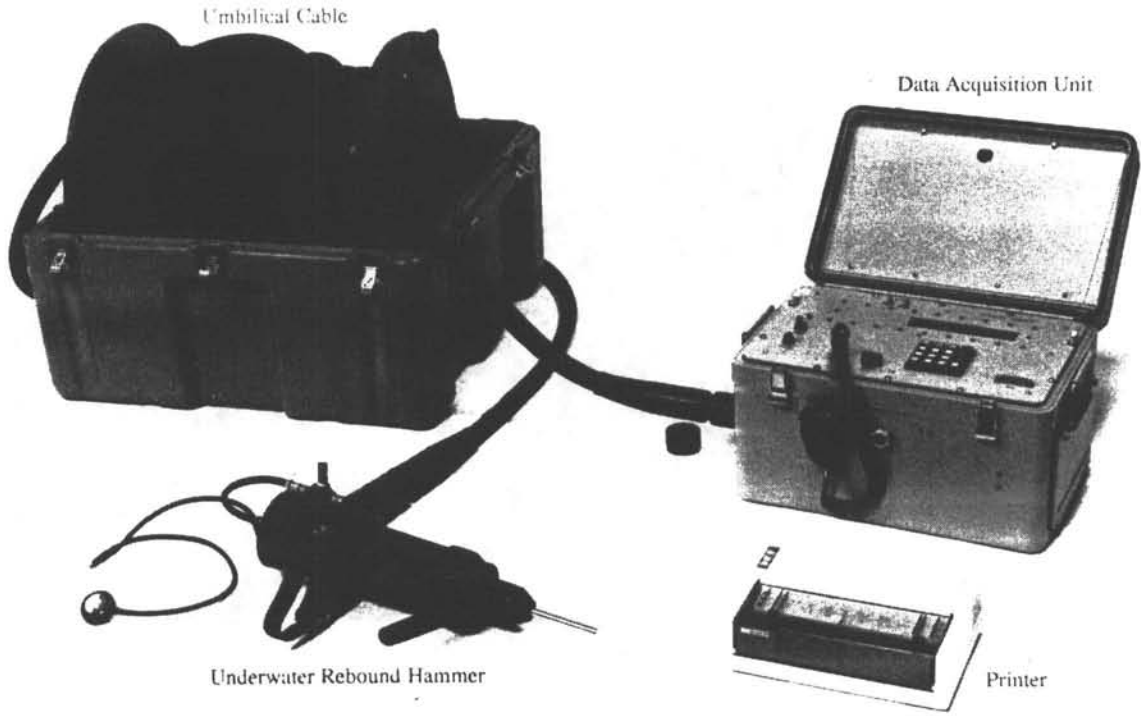



Figure 3-50. Underwater rebound hammer system.

to the concrete surface. The mass then rebounds and the rebound height is correlated to the surface hardness of the concrete.

**WARNING**

**Do not operate the rebound hammer with the impact plunger in contact with human body parts; serious injury can result.**

A general calibration chart that relates the rebound number to cube compressive strength for the underwater rebound hammer is shown in Figure 3-51.

The pressure housing has a depth rating of 190 feet and it is pressure compensated at 5 psi over the ambient pressure. Air is supplied to the rebound hammer from a scuba tank through the umbilical cable via an external pressure regulator to maintain the positive pressure differential inside the housing.

- **System Limitations.** The following characteristics of concrete can affect the correlation of the rebound number with the actual surface hardness and should be understood before using the instrument:

1. Higher rebound numbers are generally obtained from smoother surfaces and the scatter in the data tends to be less. Minimizing the data scatter increases the confidence in the test results. Therefore, underwater concrete surfaces must be thoroughly cleaned and smoothed with a carborundum stone (or similar abrasive) before measurements are taken.

2. Water-saturated concrete tends to show rebound readings approximately 5 points lower than for the same concrete tested dry. This affects the comparison of data taken above and below the waterline.

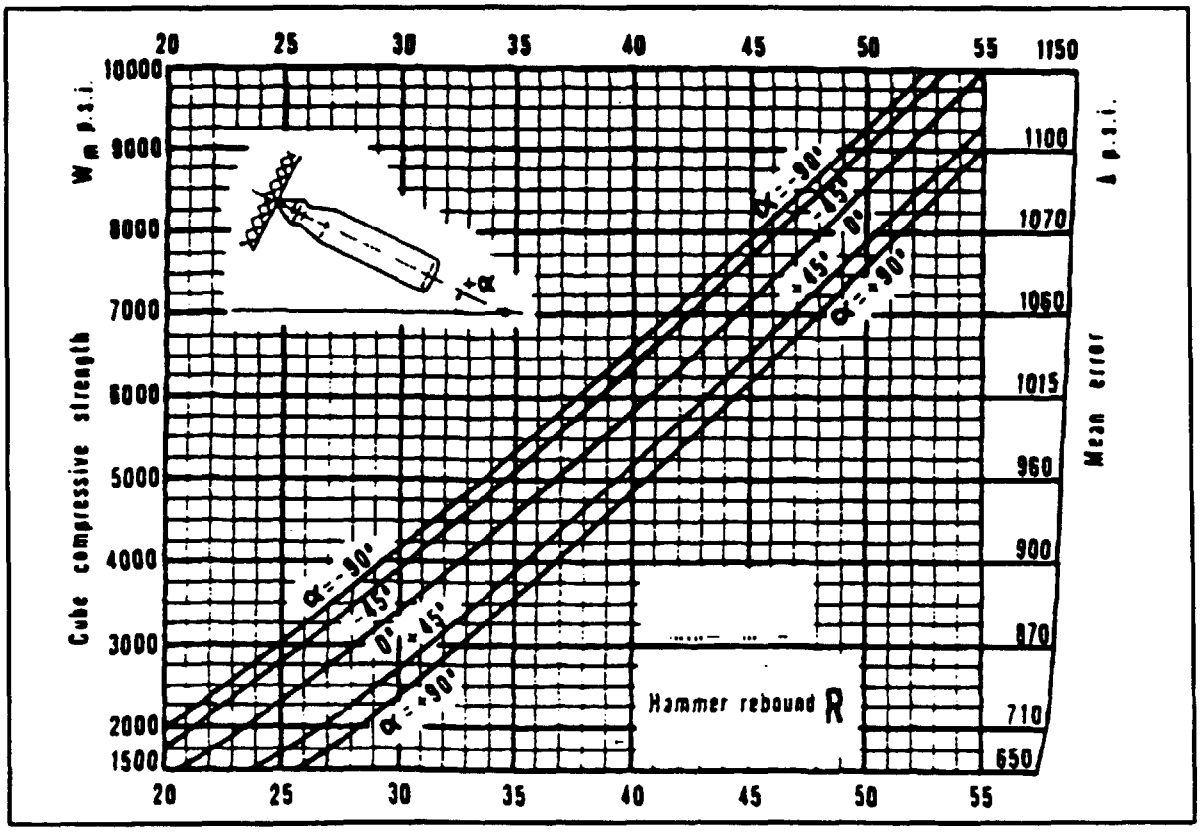



Figure 3-51. H-Meter calibration chart.

3. Type of aggregate and cement affects the correlation of the rebound numbers with actual compressive strength of the concrete under test. A calibration curve is required for each particular concrete mix to assure accuracy. Since this is not practical for most situations, the data should only be used for making comparative measurements from one location to another within a uniform concrete structure.

Because of these limitations, the estimation of concrete compressive strength obtained with a rebound hammer is only accurate to about ±25 percent. This applies to concrete specimens cast, cured, and tested under the identical conditions as those from which the calibration curves were established.

The rebound hammer is primarily useful for checking surface compressive strength or surface hardness and uniformity of concrete within a structure. It can also be used to compare one concrete structure against another if they are known to be reasonably similar.

**3.6.4.3 Ultrasonic System.** The ultrasonic system shown in Figure 3-52 is used to obtain a general condition rating and indication of overall strength of the concrete based on sound velocity measurements through a large volume of the structural element. It is recommended that the underwater ultrasonic system be used primarily for checking the uniformity of concrete from one test location to another in a given structure. If the data consistently indicate poor or very poor quality concrete, core samples must be taken and standard compression tests performed to confirm the results.

The system consists of two different underwater transducer holders for direct and indirect sound velocity measurements. An umbilical cable connects either the direct or indirect transducer holder to the topside DAU. The DAU contains most of the signal conditioning electronics and data acquisition system.

Ultrasonic techniques use the transit time of high-frequency sound waves through concrete to assess its condition. Ultrasonic testing procedures for concrete have been standardized by ASTM Standard C597 and test equipment is available from commercial sources for in-air testing. Measuring sound velocity in concrete requires using a separate transmit and receive transducer to avoid energy scattering and reflection problems. Sound velocity is calculated by measuring the time required to transmit over a known path length. The average sound velocity obtained should only be used as an indicator of concrete quality and not as a measurement of compressive strength. Table 3-7 presents some suggested condition ratings for concrete based on sound velocity measurements.

Table 3-7
General Condition Rating Based on Sound Velocity

| Condition Rating | Sound Velocity (ft/sec) |
|---|---|
| Excellent | >15,000 |
| Good | 12,000 - 15,000 |
| Questionable | 10,000 - 12,000 |
| Poor | 7,000 - 10,000 |
| Very Poor | <7,000 |

The two methods used to measure sound velocity in concrete are direct and indirect. The most preferred method is direct trans-

mission where the transducers are positioned on opposite sides of the test specimen and the waves propagate directly toward the receiver. This method provides maximum sensitivity with a well defined path length.

Indirect transmission is used when only one surface of the concrete is accessible, such as a concrete retaining wall: both transducers are placed on the same side of the concrete. With this method, energy scattered by discontinuities within the concrete is detected by the receive transducer.

• **Transducer Holders.** Two types of transducer holders are provided with the ultrasonic system. The direct transducer holder (Figure 3-53) is used to examine structures with accessible opposing surfaces; for example, concrete piles. The indirect transducer holder (Figure 3-54) is used to examine structures with only one accessible surface; for example, concrete bulkheads.

The direct transducer holder framework can be adjusted to accommodate concrete pile sections that range from 8 inches to 24 inches thick. The digital display of sound wave transit time provides feedback to help the diver position the transducer holder for optimum results.

The indirect transducer holder is very similar to the direct transducer holder in operation except for the path length measurement which is fixed at 12 inches. A suction cup was added to the indirect holder to force the transmit transducer firmly against the concrete surface under test and provide a reaction force for the diver. A small suction pump is used to pump water from the cup to provide a holding force of about 25 pounds depending on the surface condition of the concrete.

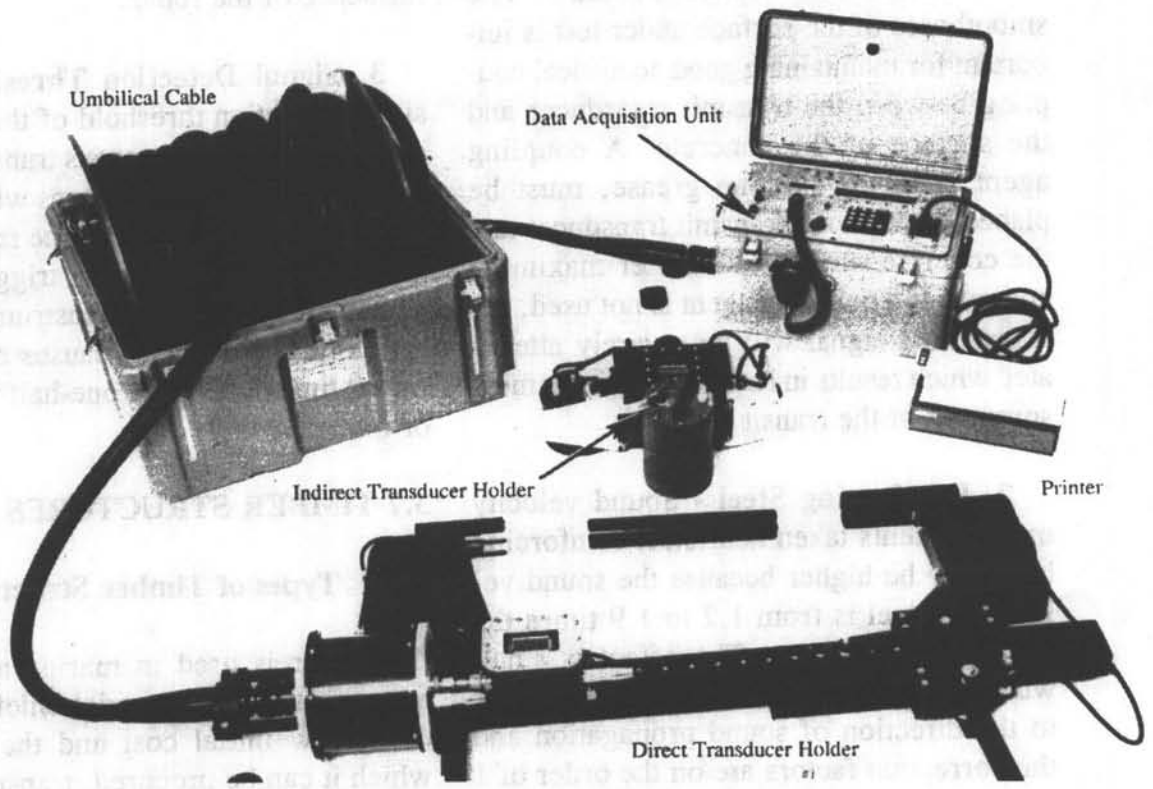



Figure 3-52. Underwater ultrasonic test system.

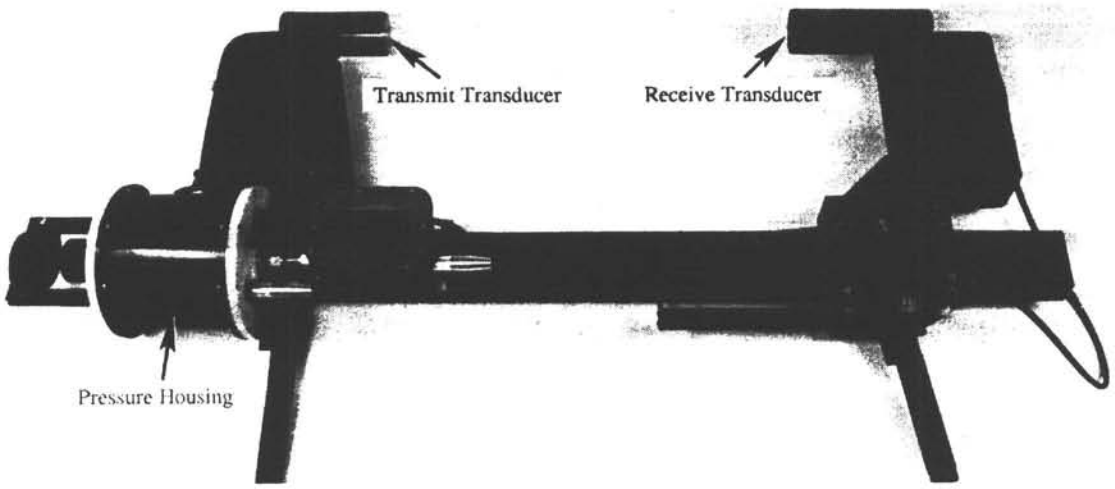



Figure 3-53
Director transducer holder.

• **System Limitations.** Results obtained with the ultrasonic test system are affected by the following factors which influence the quality of the data:

**1. Concrete Surface Finish** - The smoothness of the surface under test is important for maintaining good acoustical coupling between the transmit transducer and the surface of the concrete. A coupling agent, such as silicone grease, must be placed between the transmit transducer and the concrete surface to transfer maximum energy. If a coupling agent is not used, the transmitted signal will be severely attenuated which results in large errors in the measurement of the transit time.

**2. Reinforcing Steel** - Sound velocity measurements taken near steel reinforcing bars may be higher because the sound velocity in steel is from 1.2 to 1.9 times the velocity in concrete. The effect is small when the axis of the rebar is perpendicular to the direction of sound propagation and the correction factors are on the order of 1 to 4 percent depending on the quality of the concrete. If the axes of the rebar are parallel to the direction of sound propagation, reliable corrections are difficult. Therefore, it is recommended that sound transmission paths be chosen that avoid the influence of the rebar.

**3. Signal Detection Threshold** - The signal detection threshold of the ultrasonic system can cause erroneous transit time data to be recorded. This happens when the amplitude of the first peak of the received signal is below the threshold triggering level of the system. When the instrument detects a following peak, this causes an apparent transit time increase of one-half wavelength or more.

## 3.7 TIMBER STRUCTURES

### 3.7.1 Types of Timber Structures

Timber is used in marine applications as a construction material chiefly because of its low initial cost and the ease with which it can be procured, transported, and constructed into required shapes. Timber

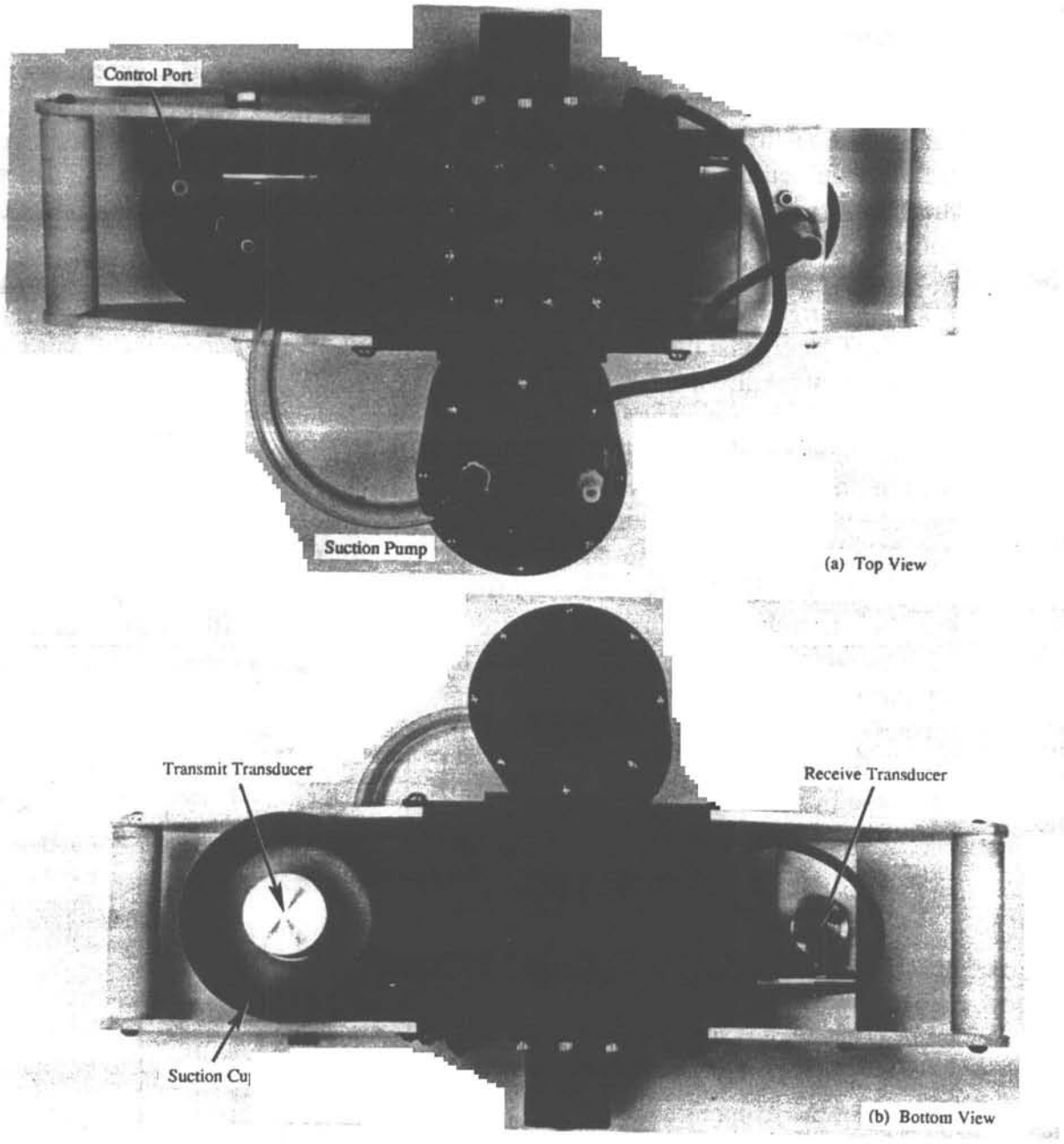



Figure 3-54. Indirect transducer holder.

has a wide range of uses in marine construction. It can be used as pile material for waterfront structures such as piers and wharves; as decking and framing material for the upper portion of waterfront structures, fender piles, and dolphins; and as construction material for bulkheads and retaining walls. Softwood timber, such as fir and pine, must be pressure treated with an appropriate preservative before it is used in the marine environment. Hardwoods, such as oak and greenhart, which are often used in fender systems, are not treated.

### 3.7.2 Deterioration of Timber Structures

Timber structures are subject to deterioration from decay or rot, attack by marine borers and insects, splitting and checking brought about by drying shrinkage or by the alternate wetting and drying cycle within the splash zone, overloading, corrosion of connections, abrasion, and ice heaving.

**3.7.2.1 Fungi and Rot Damage.** Several species of fungi exist by feeding on timber, causing a breakdown within the cellular structure of timber under attack. In the early stages, fungi attack is evident by a discoloration and softening of the wood accompanied by a fluffy or cottony appearance. Advanced attack will cause destruction of the wood cells and the appearance of fruiting bodies, such as mushrooms. Figure 3-55 illustrates the effect of timber rot. The rapidity of decay is dependent upon the fungi species, variety of wood, exposure, and climate. To live, fungi must have air, food (the wood), favorable temperature, and a moisture content of over 20 percent, which is generally higher than that of typical air-dried wood. Submerged timber will not rot because of a lack of air. Fungi growth takes place in all saltwater environments within the temperature range of 50 to 90°F. As the temperature level drops to freezing, fungi growth becomes dormant, but will reactivate when the temperature increases.

**3.7.2.2 Marine Borer and Insect Attack.** Marine borer attack is a very serious problem for timber structures in the splash and submerged zones. The ravaging effects of two large groups of marine invertebrates, the *Teredo* (commonly called shipworms) and the *Limnoria* (commonly called wood-gribbles), are well-documented.

Shipworms (*Teredo*) are mollusks and are distantly related to the oyster and the clam, even though the adult form is worm-like in appearance. Shipworm species are found in nearly all saltwater harbors and oceans of the world, except for the colder waters of the arctic and antarctic regions.

Adult shipworms eject their young into the water at birth. These miniature animals are driven by tides and currents until they settle on firm surfaces or die. Should they settle on submerged timber during the first 48 hours of their life, they begin to change in physical appearance, with the body beginning to elongate, while two clam-like shells begin to auger into the wood. The original hole in the timber surface created by the infant shipworm is no larger than the diameter of a pinhead.

As the shipworm continues to burrow and grow, it becomes more worm-like in appearance, with its body increasing in diameter to completely fill its burrow. In

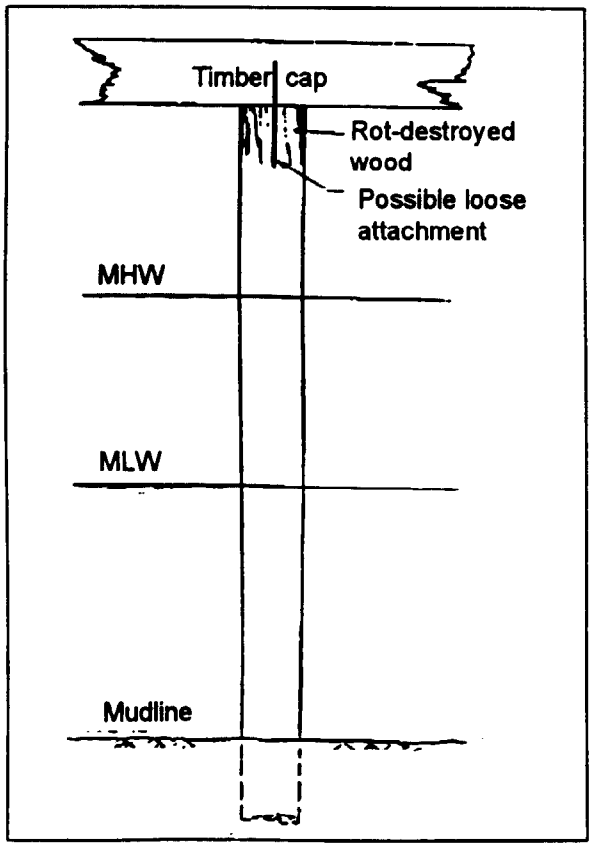



Figure 3-55. Rot of timber pile.

time, the animal orients its body parallel to the grains of the timber member. A calcium-like white excretion is left behind on the walls of the burrow track. As the exterior timber deteriorates via other means, these white trails become an obvious indication of shipworm presence. Eventually, the interior of a timber pile or beam under shipworm attack will become completely riddled with burrows, although externally no evidence of attack is apparent.

In tropical climates, shipworms have been known to grow to 6 feet in length and as much as 3 inches in diameter. In temperate climates, such as North America, shipworms generally range between 6 to 8 inches in length and about 1/2 inch in diameter. Figure 3-56 illustrates the damage caused by shipworms.

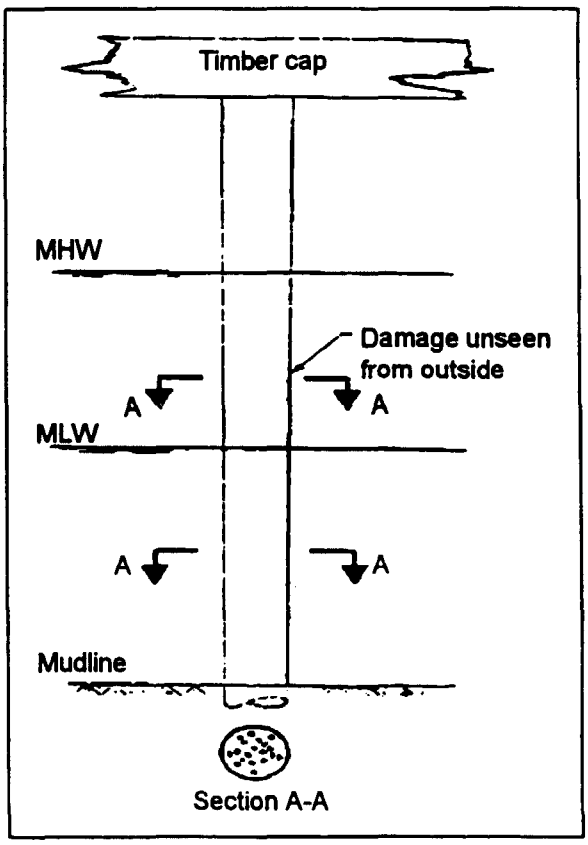



Figure 3-56. Shipworm (*Teredo*) damage of timber pile

Woodgribbles (*Limnoria*) are crustaceans related distantly to the crab and shrimp family. They are quite small, averaging only 1/8 to 1/4 inch in length. This tiny organism is a voracious wood chewer, with its appendages and mouth developed for rasping and biting.

At birth, the woodgribble mother retains the young within a pouch until they develop sufficiently to fend for themselves. She then releases them within her furrow and they proceed to dig side furrows. Ordinarily woodgribbles do not burrow deeply into the timber surface but limit their attack to shallow surface trenches. In timber piling, this results in a slow but continual reduction in pile diameter. Damage is most frequently found at the waterline or mudline, where the woodgribble population is the greatest. Severe attack will produce an hourglass appearance in piling, as illustrated in Figure 3-57, reducing the outside diameter of untreated pine or Douglas fir by up to 6 inches in 1 year.

Termites are the most destructive type of insect life to attack above-water and onshore timbers. They feed on the cellulose matter contained in timber. If termite damage is suspected, an ice pick makes an ideal tool to determine their presence, as a serious attack will eat away large interior portions of the wood just below the surface of the timber. Timbers most subject to attack are curbs and blocking on bulkhead fills.

**3.7.2.3 Shrinkage Damage.** Drying causes timber to shrink. After installation this drying process continues, especially in hot dry climates, and the timber members split and check. This shrinkage also causes bolts to loosen in connections which, in turn, causes slippage and deflections in timber members and even distortion and weakening of the entire assembly. Ordinarily, splitting or checking is not serious and is allowed for

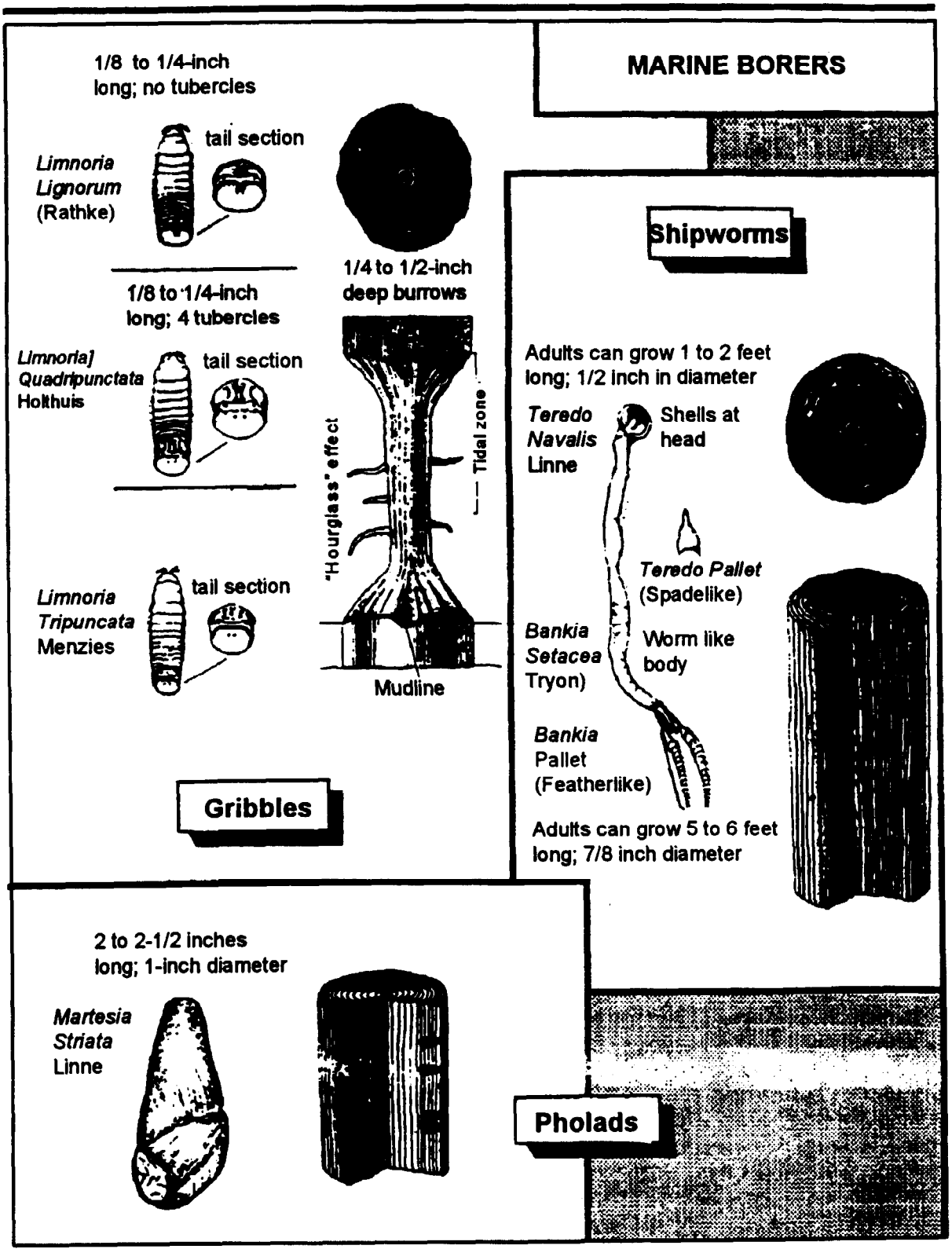



Figure 3-57. Three groups of marine borers.

in standard timber design specifications. However, splits and checks in excess of those allowed by the standard grading rules are potential troublemakers and should be closed.

Splitting and checking create an opening in the timber face or end that is an ideal means of access for insects and borers. These openings also tend to accumulate moisture and dirt, which can also easily lead to decay and rot. Should excessive moisture freeze, the split or check will widen.

**3.7.2.4 Overloading.** Axial and bending overloading of piles may be due to a continuous source of loading or to an infrequent type of loading. Materials being stored in a warehouse on a pier is a form of continuous loading. Short-time loading is exemplified by the impact of a vessel striking a pier or heavy vehicles passing over the deck of the pier. Timber fender faces are particularly subject to bending overloading during ship impact. Failure of one pile requires the adjacent piling to carry not only its own but also part of the damaged pile's load. Continual overloading will cause failure of the adjacent piling, leading to the eventual collapse of the entire structure. Figures 3-58 and 3-59 illustrate the effect of compression and bending overloading, respectively.

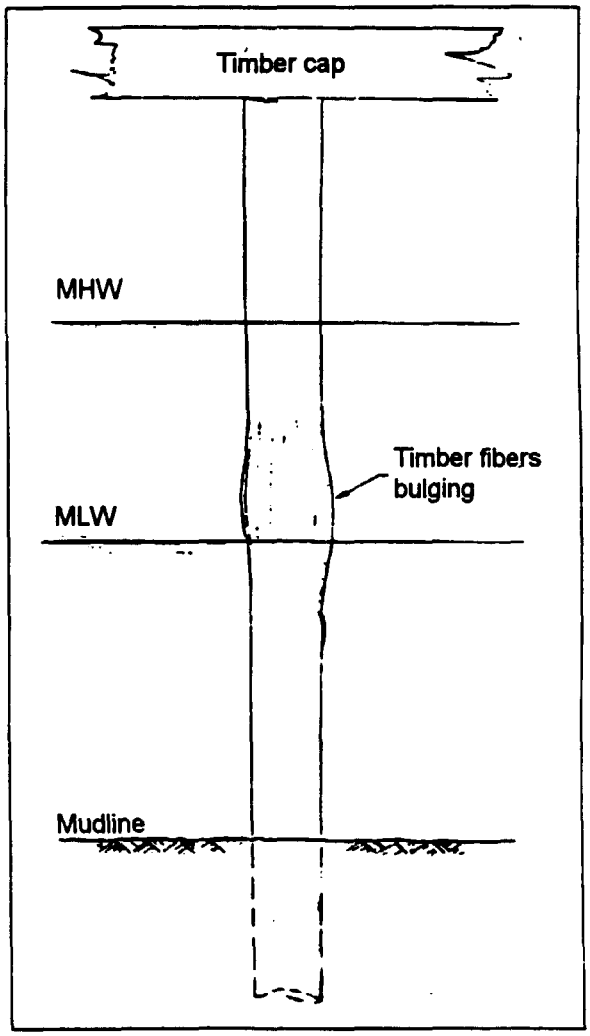



Figure 3-58
Compression overloading of timber pile.

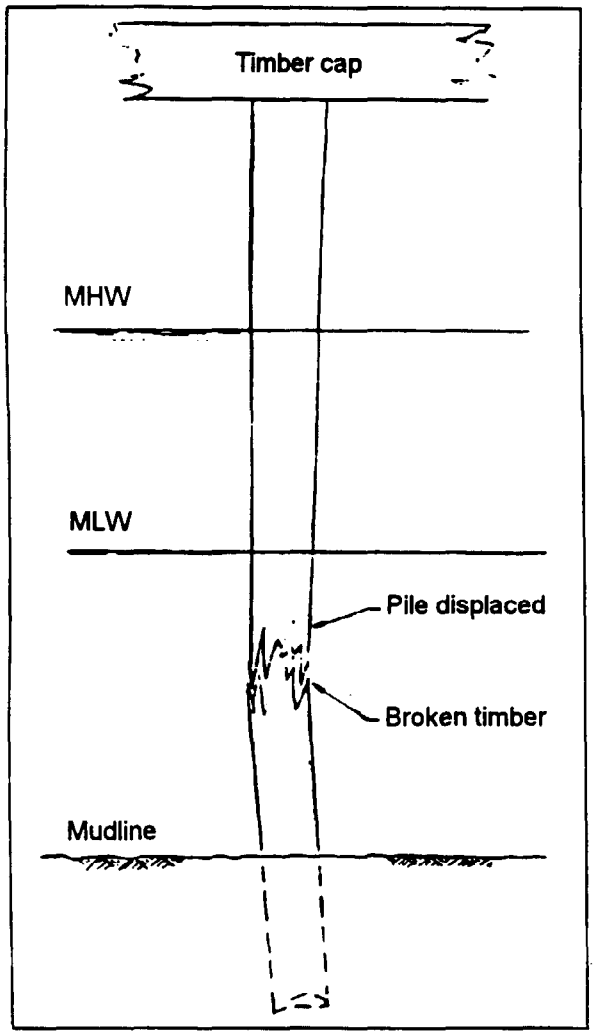



Figure 3-59
Bending overloading of timber pile.

**3.7.2.5 Structural Connection Corrosion.** The weak link in marine timber construction is the connecting hardware, since this steel hardware is subject to corrosion. Figure 3-60 illustrates one consequence of one type of hardware failure. Of prime importance to structure integrity are the proper sizing of pins and bolts and the use of Ogee washers in place of thin, flat plate steel washers. The pins and bolts are subject to corrosion, which is very difficult to prevent; therefore, all pins and bolts should be galvanized and oversized to provide a corrosion allowance, with a minimum diameter of 1 inch being supplied. More importantly, Ogee washers should be used. These tapered washers are made of corrosion-resistant wrought or cast iron and are equal in thickness to the bolt diameter. The outside diameter of Ogee washers is considerably greater than that of flat plate steel washers, making them far less subject to loosening under load because their greater bearing area prevents timber crushing.

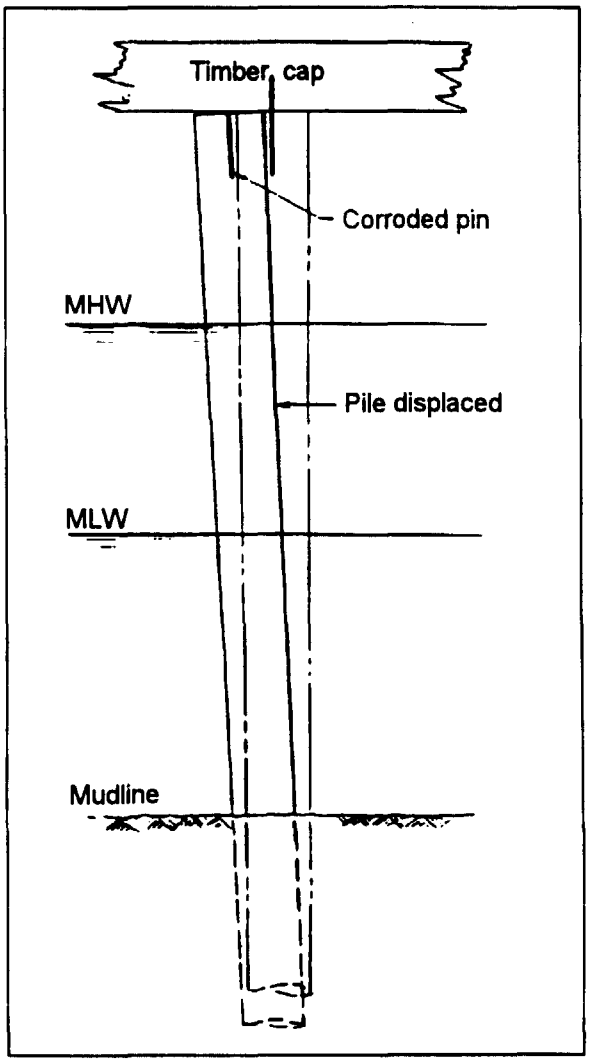



Figure 3-60
Timber pile hardware failure.

Bolts on timber fender faces are always countersunk. It is important to provide sufficient clearance for timber abrasion and wear between the top of the bolt and the timber face. These recesses should always be plugged with timber discs or filled with pitch or mastic to protect the steel components from corrosion.

Oversized and empty hardware holes are ideal access ports for insects and marine borers. These areas should be closely inspected to ensure the piles are not being bored into.

**3.7.2.6 Abrasion Damage.** Abrasion from suspended sand or silt and from ice during winter months will continually decrease the diameter of piles, as shown in Figure 3-61, unless some means of protecting the piles is used. The rate at which the pile is destroyed by abrasion depends on the amount of debris in the harbor, whether or not there is ice in the harbor, the activity of marine borers, and the velocity of the water moving past the pile.

Timber fender faces are subject to constant abrasion while a ship is in berth. The constant ranging of the vessel fore and aft and up and down will, in time, wear away the outer timber fibers, tending to expose the connecting hardware to contact with the vessel.

Attack by woodgribbles accelerates the rate of destruction of a pile by rendering surface fibers susceptible to removal by abrasion. Abrasion can usually be distin-

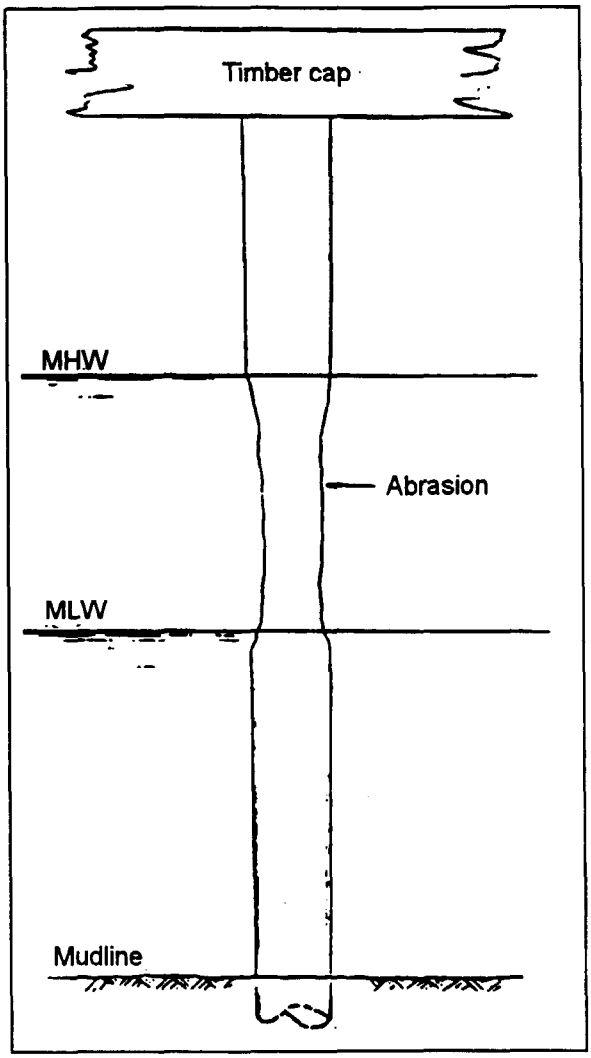



Figure 3-61. Abrasion of timber pile.

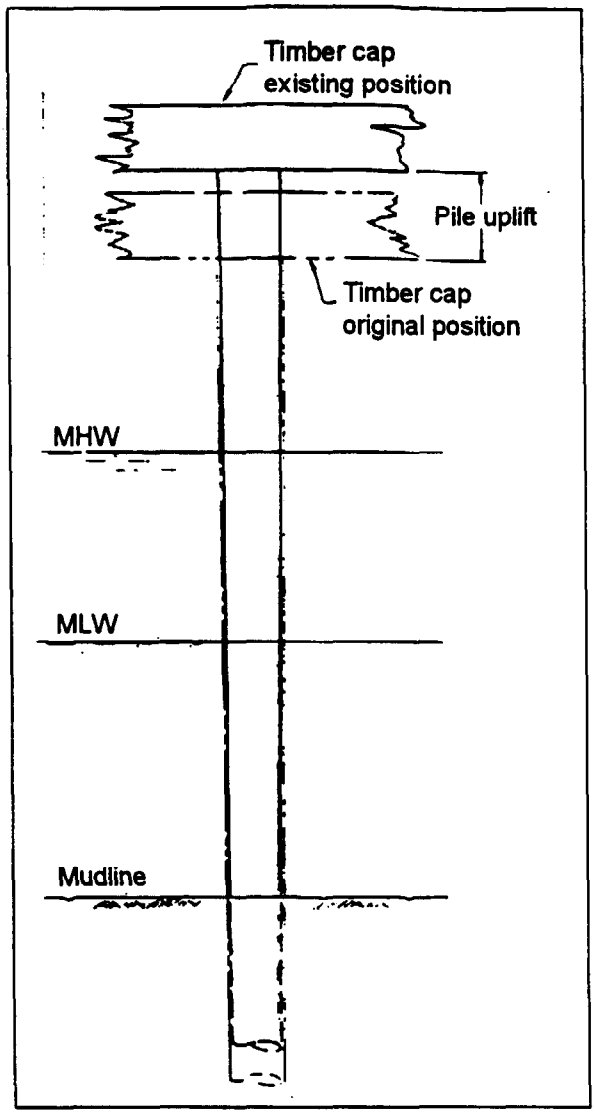



Figure 3-62. Ice heave of timber pile.

guished from woodgribble attack because abrasion is usually concentrated on one side of the pile while woodgribble destruction is uniformly distributed around the pile. Also, abrasion usually leaves the surface fibers of timber piles rough and protruding from the surface of the sound timber.

**3.7.2.7 Ice Heaving.** Timber piles used singly as mooring piles or in groups in light structures are subject to heaving by ice. Ice freezes to the pile and as the tide rises the buoyant force acting on the ice may cause the pile to heave as shown on Figure 3-62. In addition, ice expansion forces can loosen connections between piles and bracing.

### 3.7.3 Typical Inspection Procedure

Inspecting a timber waterfront structure should proceed as outlined in Table 3-8.

### 3.7.4 Equipment and Tools Required

To ensure a thorough inspection, the area must be cleared of all marine growth. This can be done using a "Barnacle Buster" or other types of high-pressure waterblasters. However, when using this equipment, great care must be exercised to prevent damage to the preservative-treated layer of timber.

Table 3-8
Timber Structure Underwater Inspection Checklist

| Checkpoint | Description |
|---|---|
| 1 | Start at the splash/tidal zones.<br><br>Note: A Level I inspection should be done first to identify areas of mechanical damage, repair, and new construction. |
| 2 | Clear a section of the structure of all marine growth and visually inspect if for surface deterioration. Do spot locations rather than cleaning entire structure. |
| 3 | Sound the cleaned area with a hammer and carefully probe with a thin-pointed tool, such as an ice pick. |
| 4 | Descend down the pile, sounding the structure with a hammer wherever there is minimal marine growth, as well as probing carefully with an ice pick. |
| 5 | At the bottom, note and record the depth of the water. |
| 6 | Record visual observations, such as presence of marine borers, losses of cross-sectional area, organism-caused deterioration, location and extent of damage, alignment problems, and condition of fastenings. Use calipers and scales as required. |
| 7 | Where internal damage from marine borers is suspected, ultrasonic tehniques are available to support the underwater inspection program. The ultrasonic equipment is only available as a contractor service at this time. |
| 8 | After finishing the underwork, return to the surface and immediately transcribe all observation data into the inspection log. |
| | Exposed Area Under Pier or Along Wharf or Dolphin Assembly |
| 9 | Check wood stringers, pile caps, bearing, and batter and fender piles for missing or broken members. Check dolphins for broken, worn, or corroded cables and cable connectors; and corroded, loose, broken, or missing wedge block, chafing strips and bands, or chock bolt hangers. |
| 10 | Visually examine piling for rot, fungi, and marine borer damage. |
| 11 | Sound the pile areas with a hammer and carefully probe with a thin-pointed tool such as an ice pick. |
| 12 | If an area is in question, take a small boring for laboratory analysis using an increment borer. Once the core is extracted, seal the hole with a creosote-treated plug to prevent easy access of borers to the interior of the pile.<br><br>NOTE: An engineer should be present whenever underwater inspections are made to explain to the diver exactly what he should look for: number and size of piles, type and depth of bulkheads, location of tiebacks, and cross bracing. The engineer shall evaluate the diver's observations and determine the degree of hazard. |

• Clean small areas with wire brushes and scrapers. Refer to Section 2.3 for information on marine growth removal.

• Sounding of the structure can be performed using a 3-pound sledge hammer.

• An ice pick or pick hammer is required for probing and an increment borer is required if cores are to be taken.

• Timber element dimensions can be checked using a ruler or tape measure.

• A simple fabricated or purchased caliper, as illustrated in Figure 3-63, is very effective for measuring the diameter of piles.

Inspection data can be recorded underwater using a Plexiglas slate with a grease pencil. Permanent documentation can be achieved through the use of underwater photography, either still photo or television.

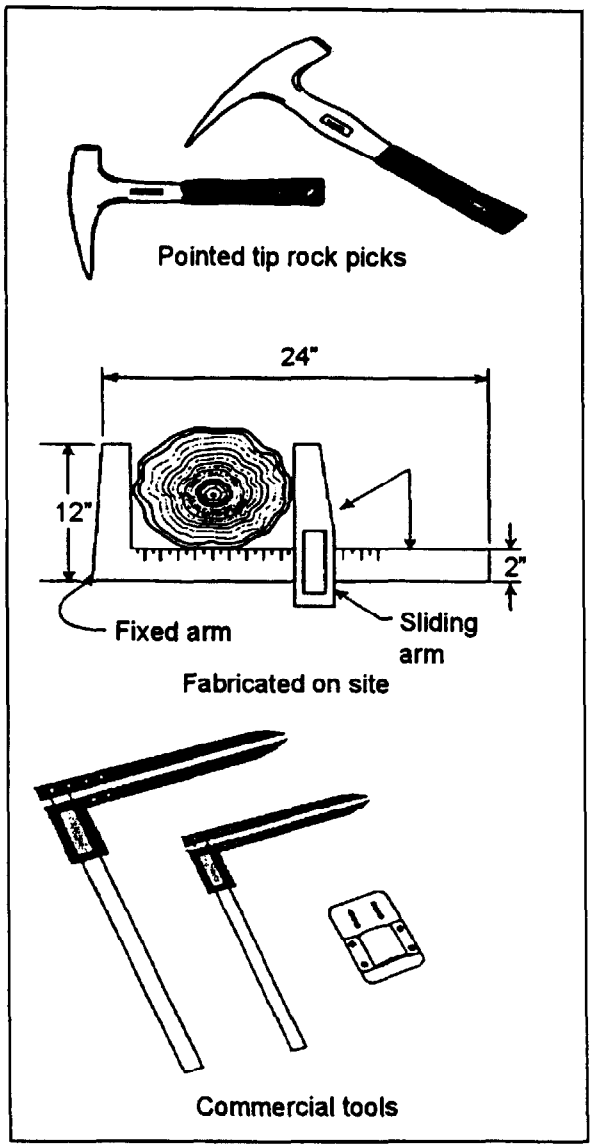



Figure 3-63. Timber pile inspection tools.

## 3.8 STONE MASONRY STRUCTURES

### 3.8.1 Types of Stone Masonry Structures

Although very few waterfront structures built today are constructed from stone masonry, it is still necessary to be familiar with the inspection of this type of structure. Throughout the 19th century, stone masonry was generally used in constructing graving docks, bridge piers, quaywalls, and wharves. Typically, the quarried stone used was granite set into lime mortar or portland cement mortar.

### 3.8.2 Deterioration of Stone Masonry Structures

Stone masonry structures typically develop problems at the joints between pieces of stone. Failures of these types of structures usually occur as a result of washout of the joints. In addition, increased earth or hydrostatic pressure causes joints to crack and stones to fall out. Scouring at the base of the structure because of wave and current action and loss of fill from behind the structure are two common types of damage that can lead to serious structural failure.

### 3.8.3 Typical Inspection Procedure

Stone masonry retaining walls, such as those found on quaywalls and wharves,

generally require only a very simple inspection, as follows:

- Begin the inspection at the waterline, checking for excessive weathering and abrasion deterioration, and loss of mortar from the joints.

- Inspect below the waterline, taking note of the general condition of the wall, and paying particular attention to the joints between each stone.

- If there are significant gaps between stones or stones are missing, note the location, depth, and length of missing stone.

- Continue to the bottom of the structure and note any undermining or scouring of the material under the wall structure.

- At any missing stone or undermining, probe the cavity to estimate the extent of the void (if any) behind or below the wall.

- Record the depth of the water at the base of the wall.

- After returning to the surface, immediately transcribe all information into the inspection log if information has not been communicated via hardwire. Also, record in the log the general condition of the wall above the waterline, especially noting all joints from which mortar has washed out.

### 3.8.4 Equipment and Tools Required

Since the underwater inspection of stone masonry structures involves only a cursory inspection of the joints between stones and the general condition of the wall and its foundation, only a few tools are required. A ruler is used to determine the width and depth of cracks and open joints, as well as the size of missing stones or pieces of stone. It is also useful for quantifying the amount of scouring that has occurred. A length of small-diameter rebar or other suitable probe can be used to check for voids in the fill behind or below the wall. A Plexiglas slate and a grease pencil are used underwater to record any pertinent information, or the information is communicated to topside personnel via hardwire. Small hand tools, such as wire brushes and scrapers, are also useful to clear off cracks and joints.

## 3.9 COASTAL PROTECTION STRUCTURES

Structures designed to reduce the erosive effects of wave action, or to protect harbors from excessive wave action and the formation of sandbars, are classified protection structures. The common coastal protection structures are seawalls, groins, jetties, and breakwaters. NAVFAC Mil-Hdbk-1025/4, "Seawalls, Bulkheads, and Quaywalls" and NAVFAC DM-26.02, "Coastal Protection," provide additional information on the design and configuration of coastal protection structures.

### 3.9.1 Seawalls

Seawalls are massive coastal structures built along the shoreline to protect coastal areas from erosion caused by waves and flooding during heavy seas. Seawalls are constructed of a variety of materials including rubble-mounds, granite masonry, or reinforced concrete elements (Figure 3-64). They are usually supplemented by steel or concrete sheet pile driven into the soil and are strengthened by wales and brace-type piles. Figure 3-65 shows three seawall configurations.

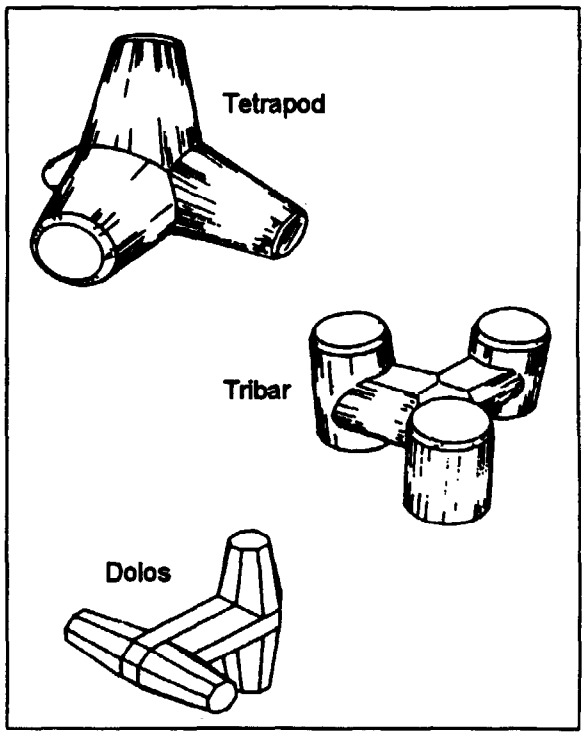



Figure 3-64. Precast concrete elements.

### 3.9.2 Groins

Groins are structures designed to control the rate of shifting sand by influencing offshore currents and waves so that erosion of the shoreline is minimized. Groins project outward, perpendicular to the shoreline, and are constructed of large rocks, precast concrete units, reinforced or prestressed concrete piles, steel sheet piles, or timber cribbing filled with rock. Figure 3-10 shows an example of a groin.

### 3.9.3 Jetties

Jetties are structures which extend from the shore into deeper water to prevent the formation of sandbars and to direct and confine the flow of water due to currents and tides. These structures are normally located at the entrance to a harbor or a river estuary. Jetties are usually constructed of mounds of large rubble to a height several feet above the high tide mark.

### 3.9.4 Breakwaters

Breakwaters are large rubble-mound structures located outside of a harbor, anchorage, or coastline to protect the inner waters and shoreline from the effects of heavy seas. These barriers help to ensure safe mooring, operating, loading, or unloading of ships within the harbor. Breakwaters may be connected to the shore or detached from the shore. There are three general types of breakwaters, depending on the type of exposed face. The exposed face may be vertical, partly vertical, and partly inclined, or inclined. Figure 3-66 shows a section of abreakwater.

### 3.9.5 Rubble-Mound Structures

Rubble-mound structures (Figure 3-67) are constructed on the seabed by dumping stones of various sizes from scows and barges until the mound emerges a certain distance above mean sea level. The outer layers of the mound are covered with armor consisting either of large stone or precast concrete units of a number of possible shapes (Figure 3-64). Rubble is irregularly shaped rough stones, ranging in size up to 1,000 $ft^3$ each and weigh up to 90 tons each. Cobble, also used in rubble-mound structures, is rounded gravel or gravel fragments between 2-1/2 and 10 inches in diameter. Rubble-mound structures are used extensively, chiefly because they are adaptable to almost any depth of water in the vicinity of harbors and can be repaired readily.

### 3.9.6 Deterioration of Rubble-Mound Structures

The four principal types of deterioration in rubble-mound waterfront structures are:

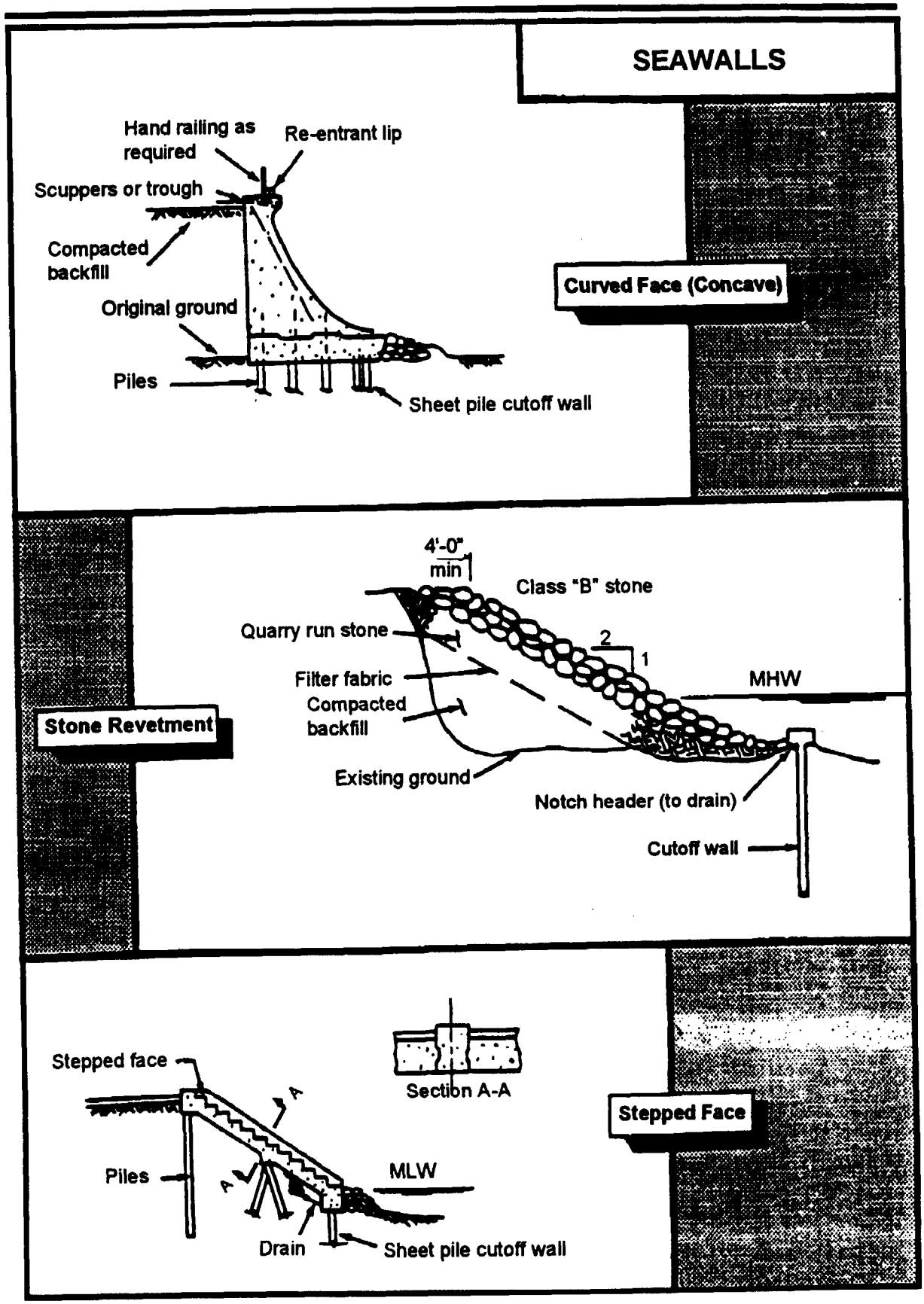



Figure 3-65. Seawall construction.

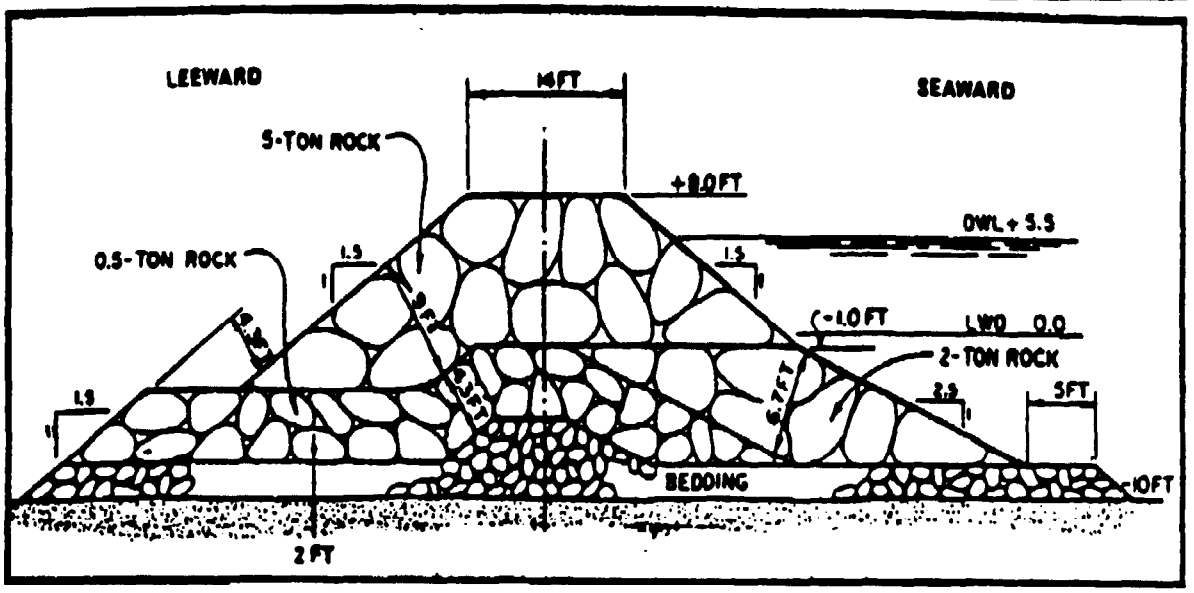



Figure 3-66. Typical breakwater section.

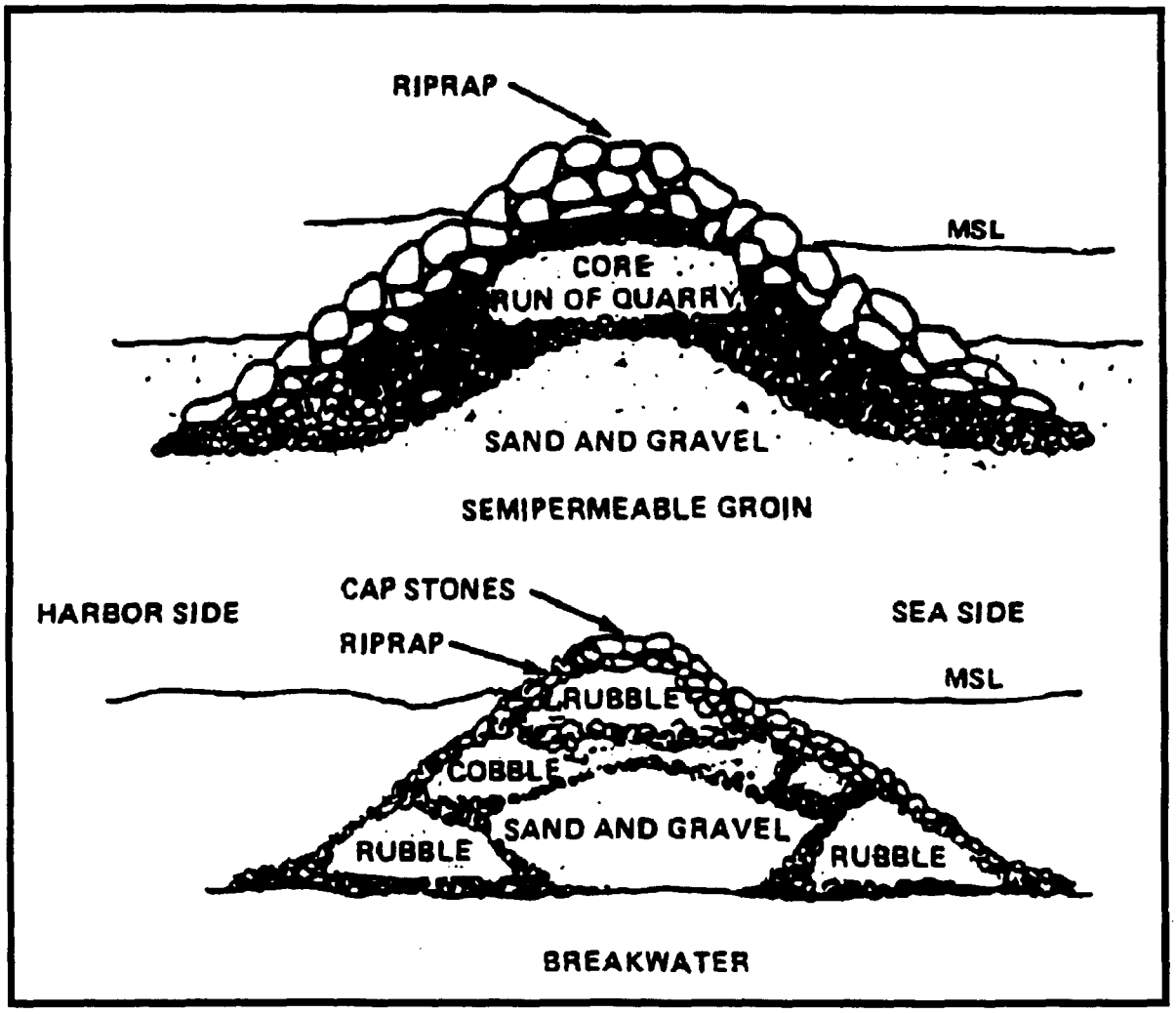



Figure 3-67. Typical rubble-mound structures.

- Sloughing of side slope
- Slippage of base material as a result of scour by currents
- Dislodgment of stones by wave action
- Excessive settlement of the seabed supporting the structure

During the inspection of seawalls, breakwaters, groins, and jetties, similar to those shown in Figure 3-67, the inspector should check for horizontal and vertical alignment. He should also be particularly watchful for signs of breakage or displacement of large stones or concrete armor elements, and washing out of substrate under the larger stones or concrete elements, particularly at the toe of the structure. These losses can be early signs of eminent structural failures if corrective action is not taken.

Other points to check include curbing, handrails, and catwalks (as applicable) for loose, missing, or broken sections, obstructions, and other hazardous conditions.

Inspection of rubble-mound structures should include:

- Erosion of core material by wave action.
- Erosion of small stones in riprap.
- Stability of armor stones or blocks.
- Breakage and displacement of concrete armor elements.
- Washing out of substrate at the toe of the structures.
- Undermining of foundation.
- High water mark; overtopping.
- Settling of structures.

### 3.9.7 Typical Inspection Procedure

Inspection of a rubble-mound structure should proceed as outlined in Table 3-9.

Table 3-9
Rubble-Mound Structure Surface and Underwater Inspection Checklist

| Checkpoint | Description |
|---|---|
| 1 | Swim around the base of the structure looking for beginning weaknesses in the base, such as washout of small stones and core material. |
| 2 | Note signs of detrimental wave action, such as scouring and sloughing. |
| 3 | Record all pertinent information on a Plexiglas slate. After returning to the surface, transfer the information into the inspection log. |
| 4 | Record the result of the above-water inspection, include a description of the alignment and general condition of the mound, such as dislodgement of stones, gaps, and other weaknesses. |

### 3.9.8 Equipment and Tools Required

Inspectingrubble-mound structures requires that divers be equipped with recording devices, such as a Plexiglas slate, grease pencil, and cameras.

## 3.10 GRAVING DRYDOCKS

### 3.10.1 Graving Drydock General Arrangement

Graving drydocks are waterfront structures that provide ship drydocking to allow repair or overhaul of underwater portions of ships, barges, and other waterborne craft. Although some stone masonry drydocks exist, most drydocks are primarily concrete structures with a steel or concrete end closure (caisson) to allow dewatering of the drydock. Figures 3-68 and 3-69 show the general arrangement of a typical graving drydock and caisson assembly.

**3.10.1.1 Caisson Assembly.** The drydock caisson provides a waterproof closure at the drydock opening to allow dewatering and flooding of the drydock. During normal operations, the caisson is moved into position at the entrance of the drydock and ballasted down by flooding internal chambers within the caisson. When positioned properly, the caisson seal makes contact with the drydock seat, and dewatering of the drydock commences. At this point, hydrostatic pressure pushes against the outside of the caisson and holds it in position against the seat. At the completion of drydock operations (ship overhaul, etc.), the reverse procedure is followed to flood the drydock and move the caisson from the drydock entrance. As the caisson is moved into and out of position during docking operations, damage to the caisson assembly may occur due to impact with the surrounding structure. Also, because the caisson is usually left in position at the drydock entrance for several months, exposure to floating debris and/or small craft may result in impact damage on the outboard side of the caisson.

The caisson seal (either wood/rubber or all rubber) located around the perimeter of the caisson makes contact with the drydock seat to provide the "seal" between the caisson and drydock (refer to Figure 3-70). Either steel or MONEL mounting studs/nuts/washers are used to attach the seal assembly to the caisson.

Drydock caissons are usually symmetrical about their longitudinal and transverse axes and have identical seal assemblies on two sides. This allows for reversing the caisson's inboard and outboard sides between docking operations. This also allows for a "dry" inspection of one side (inboard side of the caisson structure, but not the seal assembly) and alternates/minimizes "wet" exposure of the caisson structure and seal assembly between caisson overhaul.

**3.10.1.2 Drydock Seat.** As mentioned previously, the caisson seal assembly rests against the drydock seat to form the seal between the caisson and drydock. The surface of the drydock seat may consist of either a concrete surface, stone, or steel plating. In some cases, a drydock may have both an inner and outer seat. This configuration allows for two caisson positions at the drydock entrance area. A "dry" inspection of the inner seat can be accomplished when the caisson is positioned at the outer seat.

Some drydocks have the capability to "superflood." This is a condition where the water level inside the drydock is raised to a level higher than the level outside the drydock. When this occurs, the caisson shifts position and the outboard caisson seal rests against an opposing (inward facing) drydock seat.

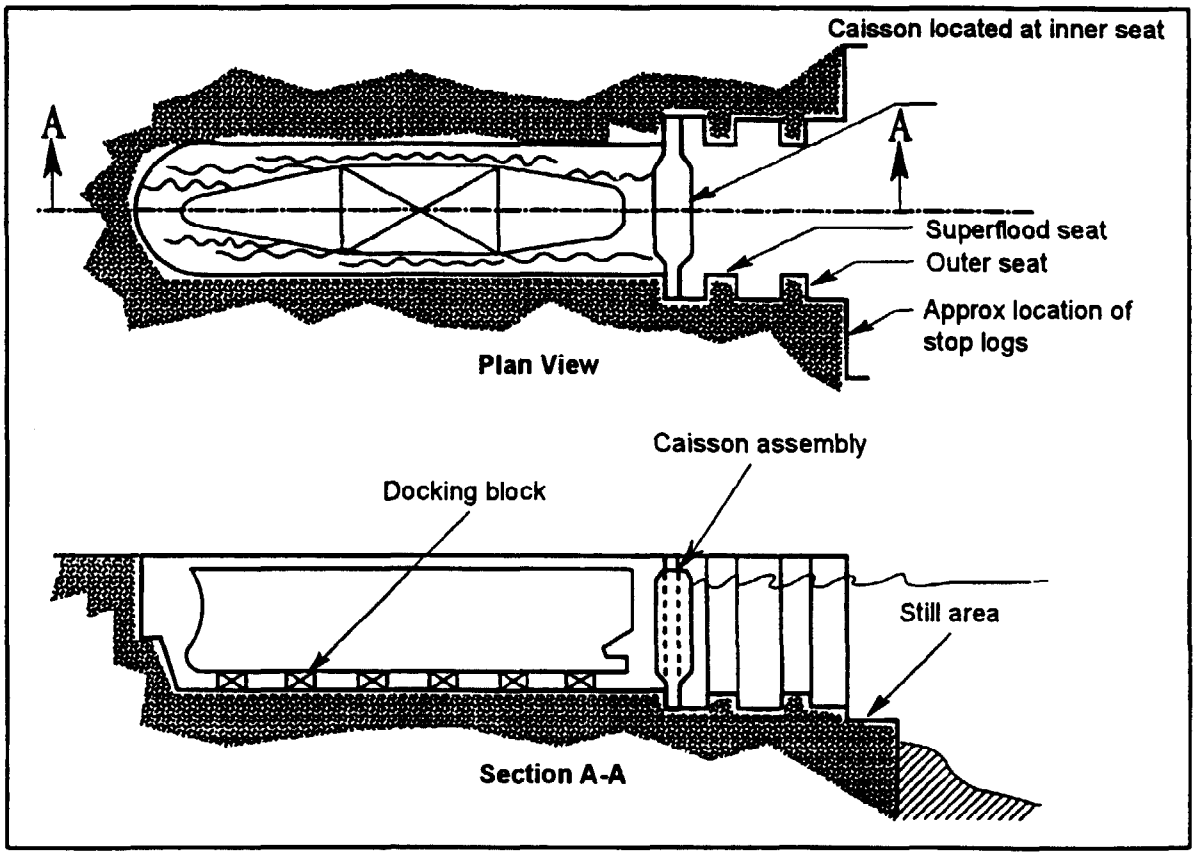



Figure 3-68. Graving drydock general arrangement.

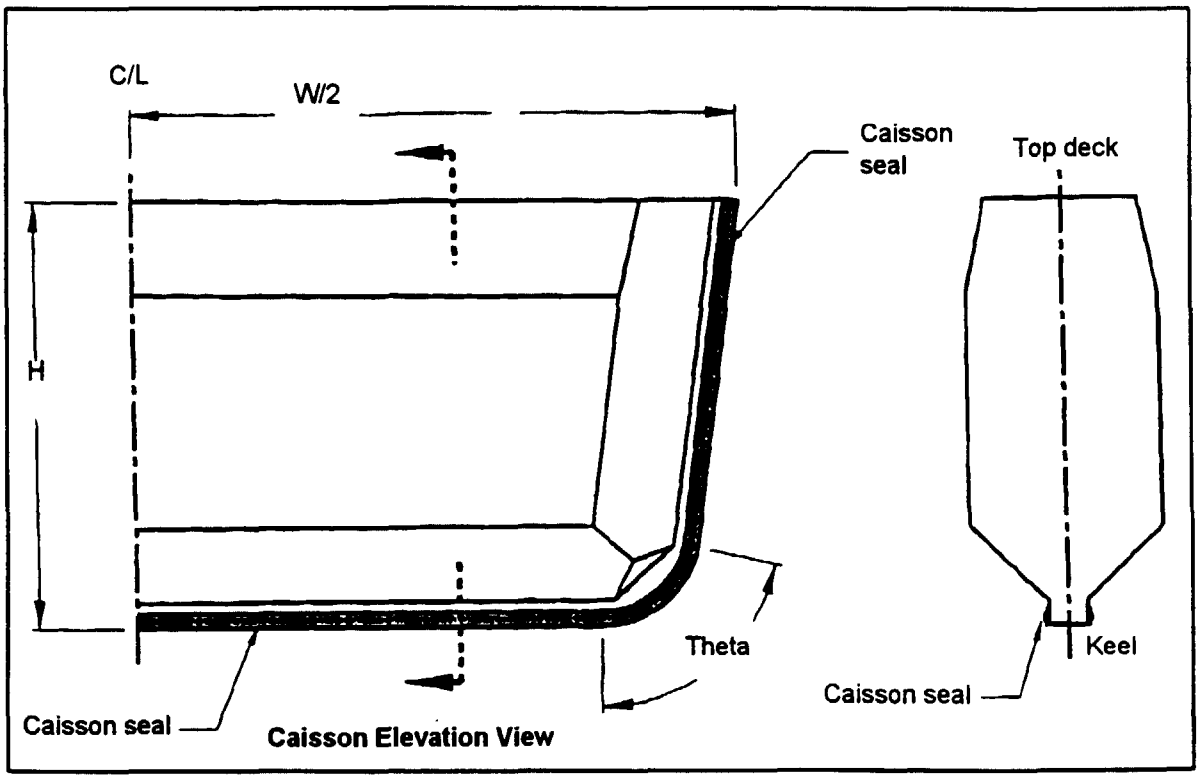



Figure 3-69. Drydock caisson general arrangement and seal location.

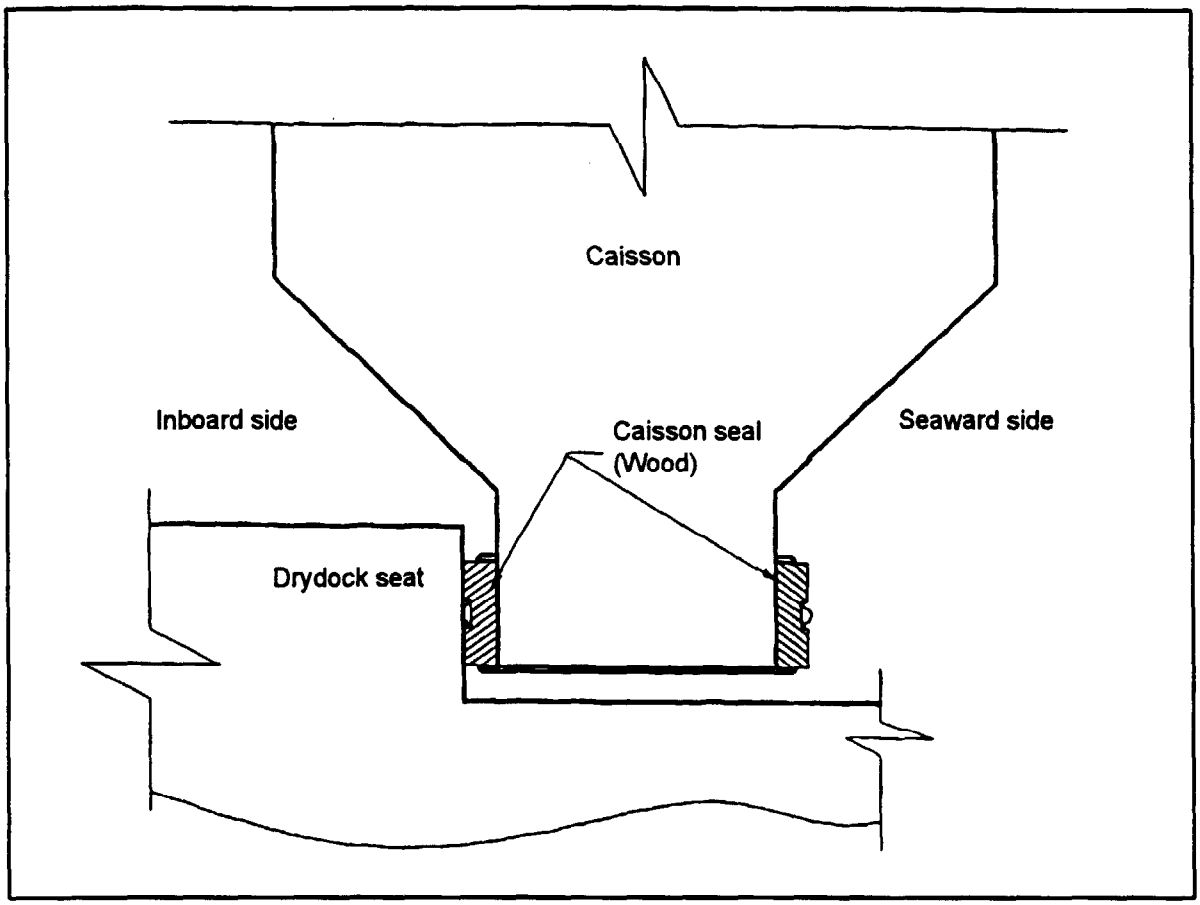



Figure 3-70. Plan view of drydock seat and caisson seal interface.

**3.10.1.3 Stop Logs.** Some drydock configurations flood the drydock through flooding sluice gates and tunnels. These tunnels provide a path for water into the drydock during pumping/flooding operations. The underwater intake to the flooding tunnel is usually located just outboard of the caisson assembly. A steel plate called a "stop log" is normally installed across the intake opening and provides a secondary seal for the sluice gates inside the flooding tunnel. It is sometimes necessary for divers to inspect the stop logs and correct excessive leakage past the stop log seals prior to maintenance on valves and pumps located inside the flooding tunnel.

**3.10.1.4 Drydock Sill.** The drydock sill is located at the outboard edge of the drydock concrete structure at the seafloor/drydock interface. The drydock structure usually extends 5 to 10 feet above the seafloor at this point. Mud/silt buildup is a common problem in this area and must be removed if it extends above the drydock sill level. Otherwise, interference at the seal area and/or difficulty in positioning the caisson may result.

**3.10.1.5 Docking Blocks.** Docking blocks are used to support the keels and hulls of ships, barges, and vessels during overhaul operations. They are positioned and fixed on the drydock floor prior to ship docking and flooding operations. However, during ship docking operations, docking blocks may be inadvertently moved out of position. If this condition is suspected, divers

are used to verify docking block position and in some cases remove (float) the blocks for subsequent reinstallation after dewatering the drydock.

### 3.10.2 Deterioration of the Graving Drydock Structure

In general, the concrete (or stone masonry) portion of the drydock is subject to deterioration through cracking, spalling, swelling, and disintegration, not unlike other concrete or stone masonry structures (refer to Section 3.6, Concrete Structures and Section 3.8, Stone Masonry Structures.) However, during drydocking operations various conditions exist where additional damage to the structure may occur - namely, during ship and caisson positioning operations. Contact between the ship and drydock structure may occur as a ship is moved into the drydock. Likewise, inadvertent contact may occur during positioning of the caisson. In either of these cases, damage to the drydock structure may occur as a result of impact.

### 3.10.3 Deterioration of the Caisson Assembly

The caisson, whether a concrete or steel structure, is also subject to damage as a result of drydock operations. Deterioration of the caisson may occur as a result of caisson positioning operations (impact and/or abrasion damage) or from long term exposure to seawater (corrosion, biofouling, marine organisms, and/or impact).

For a steel caisson, corrosion of the metal structure is always a concern. Although the caisson is painted and "zincs" replaced at regular intervals during overhaul periods (usually every 5 to 6 years), corrosion may be accelerated in areas where the steel has been exposed (scraped, impacted, etc.)

Damage to a concrete caisson may show up as cracking, loss of material, swelling of the concrete, chemical deterioration, and/or exposure and corrosion of the steel substructure. These conditions can be a result of impact, abrasion, wave action, poor construction methods/techniques, and long-term exposure to a seawater environment.

### 3.10.4 Caisson Seal Deterioration

The cross section of a DM-29 wood caisson seal is shown in Figure 3-71. The wood portion of the seal transfers the load (due to hydrostatic pressure) from the caisson to the drydock seat and provides the primary seal. The small rubber gasket provides a secondary seal. Several physical and environmental conditions exist that can cause either accelerated or eventual deterioration of the wood:

- Splintering
- Fungi
- Rot
- Marine borers
- Insect infestation

Of these, splintering and marine borers are the most prevelant.

Similar to the caisson structure, the seal assembly is also subject to impact and/or abrasion damage during caisson positioning operations. Wood deterioration can be confirmed by visual inspection and is evidenced by wood splintering and cracking where impact has occurred.

Several marine organisms attack and infest wood structures exposed to seawater. The types of organisms and their probability and rate of occurrence are based on several environmental conditions:

- Water temperature
- Humidity
- Sunlight exposure (variations/cycles)
- Wood type
- Wood preservative (when used)

In some areas, the speed of deterioration is surprisingly fast, particularly in a warm air/water environment. A summary of the most common organisms and their associated effect on wood structures is provided in Section 3.6.2, Deterioration of Timber Structures.

The rubber component of the DM-29 wood seal and the newer all-rubber seal configuration (Figure 3-72) are not normally attacked by marine organisms, and are thus considered immune to this problem.

### 3.10.5 Drydock Seat Deterioration

As with the drydock structure and caisson assembly, deterioration of the drydock seat due to impact and exposure to seawater may occur. The condition of the seat and its resistance to deterioration will vary based on the amount and severity of impact events, seawater exposure, and composition of seat surface (steel, concrete, or stone).

In cases where an inner and outer seat exist and where the caisson has been positioned at the inner seat, the outer seat can become fouled with marine growth. This condition must be rectified before the caisson can be positioned at the outer seat. A similar situation occurs before superflooding. The inward facing seat is normally exposed to seawater and marine fouling and must be inspected and cleaned prior to superflooding the drydock to ensure an adequate seal.

### 3.10.6 Typical Inspection Procedure

Underwater inspection of the graving drydock structure, caisson assembly, and associated components will most likely be accomplished at incremental component levels and not in a fixed, sequential order, as inspection requirements and frequency vary with each drydock component. A typical underwater inspection of a drydock facility will involve inspection of the drydock structure, caisson assembly, caisson seal, drydock seat, stop logs, and drydock sill area.

Procedures for underwater inspection of steel, concrete, timber, and stone masonry waterfront structures are discussed in Sections 3.4.3, 3.6.3, 3.7.3, and 3.8.3, respectively. In general, these inspection procedures are applicable to graving drydocks, caisson assemblies, and associated components.

### 3.10.7 Equipment and Tools Required

Equipment and tool requirements for inspection of waterfront steel, concrete, timber, and stone masonry structures are discussed in Sections 3.4.5, 3.6.4, 3.7.4, and 3.8.4, respectively. In general, these requirements are applicable to graving drydocks, caisson assemblies, and associated components.

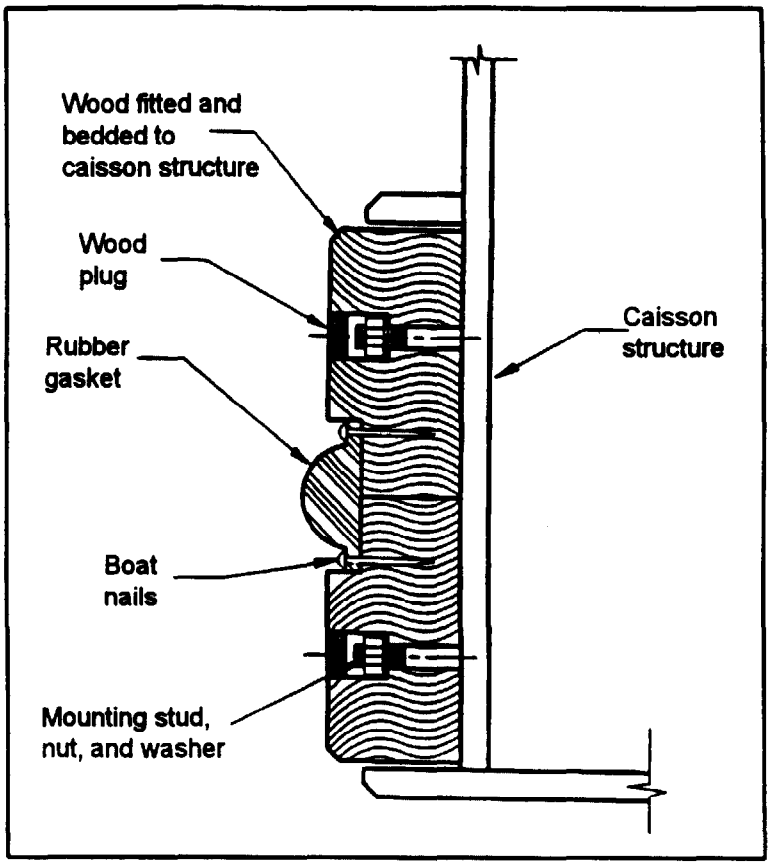



Figure 3-71. Typical caisson wood seal assembly.

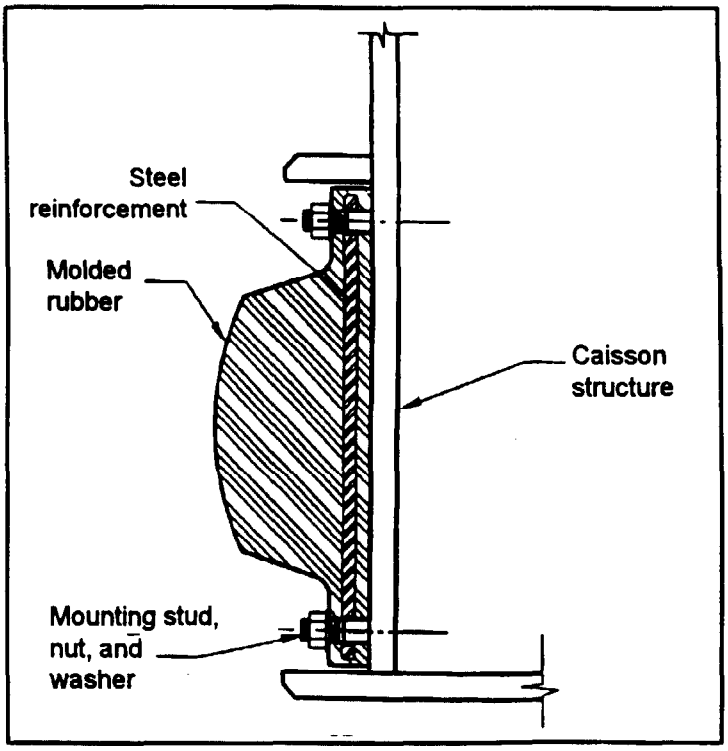



Figure 3-72. Steel-reinforced, all-rubber caisson seal assembly.

# Chapter 4

# SITE SURVEY PROCEDURES

## 4.1 SCOPE

A site survey is a report on specific conditions of a site. This report generally requires position control, which may be either geodetic (Lat/Long, Universal Transverse Mercator (UTM), State Plane,...) or local (X-Y, Range/Bearing). Examples of specific conditions and information to be gathered include:

- Bathymetry:
  - Slope
  - Scarps
  - Sand waves
  - Reefs

- Oceanography:
  - Conductivity
  - Temperature
  - Tides
  - Currents
  - Waves

- Geology and Geophysics:
  - Bottom material
  - Subbottom strata
  - Engineering properties
  - Kelp or coral beds
  - Faults
  - Rock outcrops
  - Ice scour
  - Reefs

- Location of:
  - Wrecks
  - Debris
  - Military mines, tank traps, and other military submerged facilities
  - Seafloor installations (well heads...)
  - Cables and pipelines
  - Fishing grounds
  - Anchorage areas

Typical site surveys include the following:

- Bathymetric surveys are conducted to select routes for cables and pipelines and to determine locations for shallow water arrays. As an example, they are specifically used to chart the route of the Offshore Petroleum Discharge System (OPDS) pipeline.

- Visual surveys of selected cable and pipeline routes are required to locate obstructions and damage to the cable or pipeline. A visual survey is especially important for installation of the OPDS SALM buoy to locate all potential bottom obstructions.

- Geophysical and geotechnical surveys are required to determine the characteristics of the seafloor material along a cable or pipeline route, or in the vicinity of a

new mooring or structure. Geotechnical surveys are required in advance of Elevated Causeway (ELCAS) installations for site selection and to determine requirements for pile driving.

• Construction surveys are required to establish locations for the installation of new facilities or document the as-built location of existing facilities.

• The establishment of survey control points is a special case which extends existing control points to the survey area.

Surveys requiring divers are usually limited to water depths of less than 120 feet, while bathymetric and geophysical surveys in water depths greater than 200 feet are usually outside the tasking of the UCTs. ROVs could supplement diver surveys in deeper waters or hazardous conditions.

The following sections discuss the preliminary planning requirements for a site survey (Section 4.2), typical procedures for conducting survey operations and equipment used (Sections 4.3 and 4.4), and methods of presenting the results (Section 4.5). These descriptions are general in nature, and the requirements of any particular survey may vary from those discussed.

## 4.2 SITE SURVEY PLANNING

### 4.2.1 Historical Information

Prior to conducting a survey, several steps should be taken to ensure a successful operation. All available information about the area should be obtained from up-to-date sources. Further information on NOAA bathymetric products is provided in Appendix E. Appendix A provides a list of addresses for relevant sources. Appendix C provides useful suggestions for site surveys. This information includes previous surveys of the area:

• Nautical charts from NOAA - a set of five catalogs is available from NOAA :

- **Catalog 1.** U.S. Atlantic and Gulf Coasts; including Puerto Rico and the Virgin Islands
- **Catalog 2.** U.S. Pacific Coast; including Hawaii, Guam, and the Samoa Islands
- **Catalog 3.** Alaska and Aleutian Islands
- **Catalog 4.** Great Lakes and adjacent waterways
- **Catalog 5.** United States Bathymetric and Fishing Maps

In addition, dates of latest editions (issued quarterly) should be consulted to verify that current maps/charts are being used.

• National Ocean Survey (NOS) (formerly United States Geological Survey (USGS)) topographic charts - both 7.5- and 15-minute series. These are land topography maps that provide good detail of the local area roads. This series also shows the location of selected control points. These come in several types:

- Topographic maps
- Topographic bathymetric maps
- Land use and land cover maps
- Orthophotoquads
- Orthophotomaps

These products are available from:

• NOAA tide tables are published for:

- Europe and West Coast of Africa (including Mediterranean Sea)

- East Coast, North and South America (including Greenland)
- West Coast, North and South America (including Hawaiian Islands)
- Central and Western Pacific Ocean and Indian Ocean

• NOAA tidal current tables and tidal current charts.

• NOAA United States Coastal Pilots are published for:

**Atlantic Coast**
- Eastport to Cape Cod
- Cape Code to Sandy Hook
- Sandy Hook to Cape Henry
- Cape Henry to Key West
- Gulf of Mexico, Puerto Rico, and Virgin Islands

**Pacific Coast**
- California, Oregon, Washington, and Hawaii
- Alaska, Dixon Entrance to Cape Spencer
- Alaska, Cape Spencer to Beaufort Sea

• The Coastal Pilots supplement the navigational information shown on the nautical charts.

• The following Defense Mapping Agency publications may be helpful (addresses in Appendix A):

- Guide to Marine Observing and Reporting - Publication 60C
- Sailing Guides (both planing and enroute guides)
- Fleet Guide (if site is near a major harbor)

• Existing Public Works drawings.

• Construction drawings for new facilities.

• Previous inspection reports, etc.

In addition, all available information on local tides, currents, winds, temperature, visibility, and daylight hours should be obtained. When practical, interviews with local fishermen, boaters, and nearshore residents can provide valuable background information for the survey (see Section 1.4).

The extent of the survey can be dictated by existing information. If a recent survey has been performed by another party, a rudimentary check of the existing survey's information could be all that is necessary to satisfy the job requirements. It is possible to gather all of the needed information without "going to the field."

### 4.2.2 Presurvey Decisions

A successful operation requires preparing a well thought-out plan for doing the survey. Decisions must be made early in the planning process as to what types of data are to be obtained. These decisions fall into the general areas of:

- Objectives of the survey
- Areal extent of the survey
- Horizontal control and accuracy required
- Navigation method
- Vertical control, contour interval, and accuracy requirements
- Geophysical data requirements
- Geotechnical data requirements
- Data logging requirements
- Data reduction requirements
- Data processing requirements
- Final report requirements

These decisions will influence the equipment required as well as the manpower and time required to perform the work.

In geographical locations where the team has not previously worked, a presurvey site visit is generally in order. This will aid in logistics planning and will allow the advanced party to determine site specific information. Use the site visit to gather information from local sources, such as fishermen, harbor masters, and local Coast Guard personnel. If any schools or universities in the area have oceanography, ocean engineering, geology, geotechnical, or geophysical programs, a recommend that someone visit the department.

## 4.3 BATHYMETRIC SITE SURVEY OPERATIONS

UCT personnel may be involved in any of the following specific types of surveys which will require the instruments indicated:

- Bathymetric or hydrographic survey
  - Horizontal control system
  - Navigation system
  - Fathometer
  - Tide gage and vertical control + vertical accelerometer
  - Sound velocity

- Seafloor features and as-built surveys:
  - Horizontal and vertical control
  - Navigation
  - Side scan sonar
  - Visual observation (diver or ROV)

- Geophysical survey
  - Horizontal and vertical control
  - Navigation
  - Subbottom profiler
  - Magnetometer

- Geotechnical survey
  - Horizontal and vertical control
  - Navigation
  - Bottom sampling
  - In-situ measurements

- Oceanographic surveys
  - Horizontal and vertical control
  - Navigation
  - Current
  - Conductivity, temperature, and depth (CTD)

The planning and execution of a bathymetric survey is basic to the planning and execution of all of the above surveys. This section discusses some of the considerations in planning and executing a bathymetric survey. Section 4.4 discusses specific details for other surveys.

In the planning phase, the following decisions are made:

- Type of survey - reconnaissance or detailed.
- Areal extent of survey.
- Contour interval, survey line spacing, and survey line direction.
- Method of navigation and method of horizontal control.
- Selection and establishment of control stations.
- Method of vertical control.
- Data logging requirements.
- Data reduction requirements.
- Data processing requirements.
- Deliverable product, including selection of map scale.

### 4.3.1 Type of Survey

A reconnaissance survey is generally conducted when adequate historical information is not available. It consists of widely spaced survey lines (sometimes referred to as vessel track lines), with diagonal tie lines (see Figure 4-1).

A detailed survey usually consists of a survey grid, with survey lines perpendicular to the bottom slope and tie lines parallel to the slope (see Figure 4-2). The spacing and number of tie lines can be varied to reduce the total number of survey line-miles. Maximum recommended tie line spacing is five times survey line spacing. Whenever possible, tie line and survey line spacing should be the same.

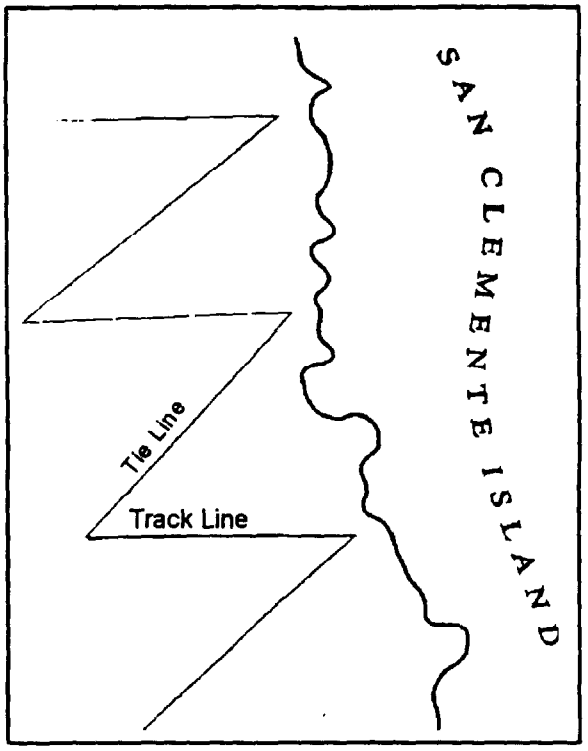



Figure 4-1. Reconnaissance survey.

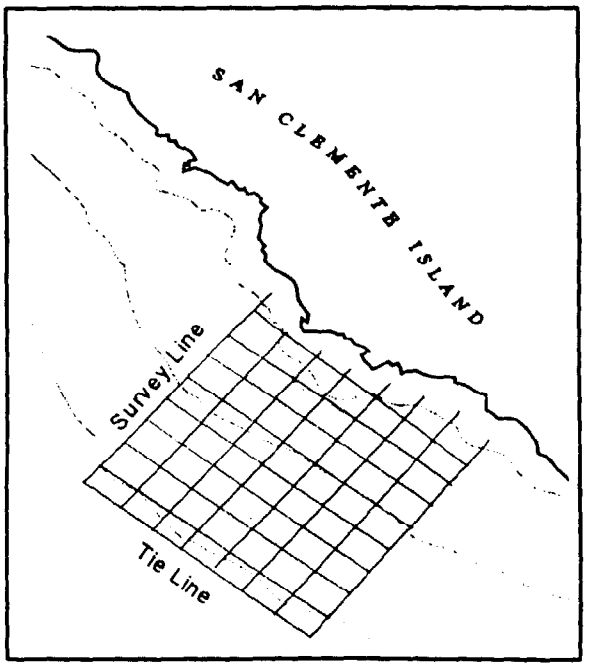



Figure 4-2. Grid survey

### 4.3.2 Areal Extent of Survey

The areal extent of the survey should be 10 to 25 percent larger than the project area. When laying out the survey lines, it is wise to allow additional area for a run-in and run-out length to allow the vessel to get on course prior to the first fix.

### 4.3.3 Contour Interval

The contour interval will usually be specified by the sponsor, if not it should be determined by consulting with the sponsor. Table 4-1 gives recommended contour intervals, based on average water depth. The contour interval will have a major effect on the selection of chart scale, survey line spacing, method of navigation, and methods of horizontal and vertical control.

Table 4-1
Recommended Contour Intervals[1]

| Water Depth[a] (ft) | Recommended Contour Interval[b] (ft) |
|---|---|
| <20 | 2 |
| 21 - 60 | 5 |
| 61 - 120 | 10 |
| 121 - 300 | 30 |

[1]For "as-built" surveys, twice the vertical inaccuracy is the contour interval (see Equation 4-2, page 4-12).
[a]Average water depth of mapped area.
[b]The contour interval should never be less than twice the vertical inaccuracy (see Equation 4-2, page 4-12).

**4.3.3.1 Line Spacing.** A major consideration in selecting the survey line spacing is the scale of the final bathymetric chart produced. Survey line spacing of less than 1/2 inch, at the final scale, is rarely of value and a generally recommended value is 1 inch at the final mapping scale. Therefore, at a 1:1,000 map scale, the minimum survey line spacing (0.5 inch) should be 500 inches or 42 feet. This close line spacing requires greater precision of horizontal and vertical control. This would not be an appropriate line spacing for either a civilian (standard positioning services) GPS survey (accuracy = ±150 feet) or a deep water survey using a fathometer with a footprint on the order of 40 feet. At a 1:5,000 scale, the recommended minimum survey line spacing (0.5 inch) is 208 feet, which is marginal for civilian GPS since, in general, it is desired that line spacing be two times navigational inaccuracy.

**4.3.3.2 Fix Interval.** Select the fix intervals along the survey line to provide four to five fixes per survey line interval when using a grid pattern or select the fix interval at 0.25 inch at final map scale when conducting a reconnaissance survey.

**4.3.3.3 Line Direction.** In general, survey line direction should be perpendicular to the bottom slope and tie lines should be parallel to the bottom slope. The exceptions will be route surveys and as-built construction surveys.

Route surveys are arranged with survey lines parallel to the proposed route, and tie lines perpendicular to the route. It is important in route surveys to have adequate areal coverage, 50 percent greater than the proposed lane is recommended.

As-built surveys are laid out relative to the axis of the project, with little or no excess areal coverage.

The following convention is recommended for line naming (Figures 4-3 and 4-4 show this convention):

- East-West (magnetic headings of 45° to 135° and 225° to 315°) line numbers are even (2,4,6...102,202,302...) increasing to the East.

- North-South (magnetic headings of 315° to 045° and 135° to 225°) line numbers are odd (1,3,5...101,201,301...) increasing to the North.

- Blocks of line numbers are assigned to areas, i.e., 1 - 499 area A, 500 - 999 Area B, etc.

- Fix numbers should be sequential by area, restarting the unit digit at 1 each new line and increasing to the north and east (see Figure 4-4). If using an integrated navigation system that allows it, fixes should be equally spaced (distance) rather than time based.

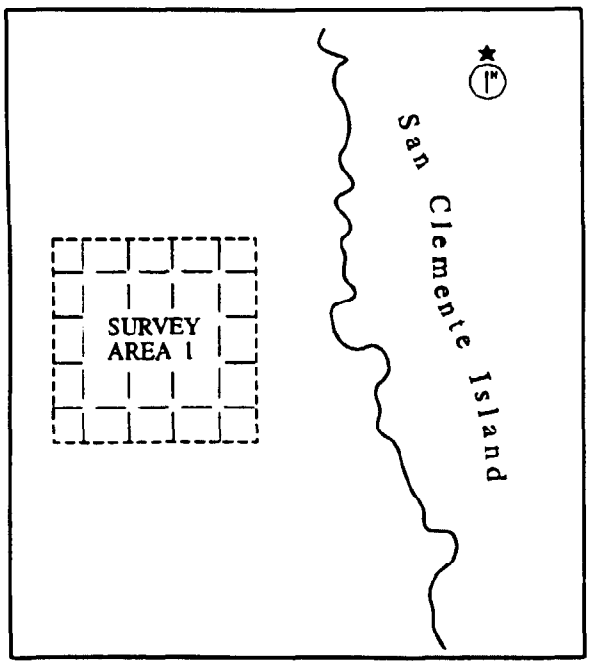



Figure 4-3
Example of line naming convention.

mended survey line spacing was previously presented, but in some cases it will be necessary to work with a minimum survey line spacing. This is necessary when maximum resolution of bottom features is required. Consider the example of 100-foot spacing for both survey lines and tie lines. A bottom feature could exist with significant vertical relief, as long as it is within the 100- by 100-foot grid square. In order to resolve this type of bottom feature, close line spacing is required. A lower limit on survey line spacing is either twice the navigational error or twice the "footprint" of the fathometer.

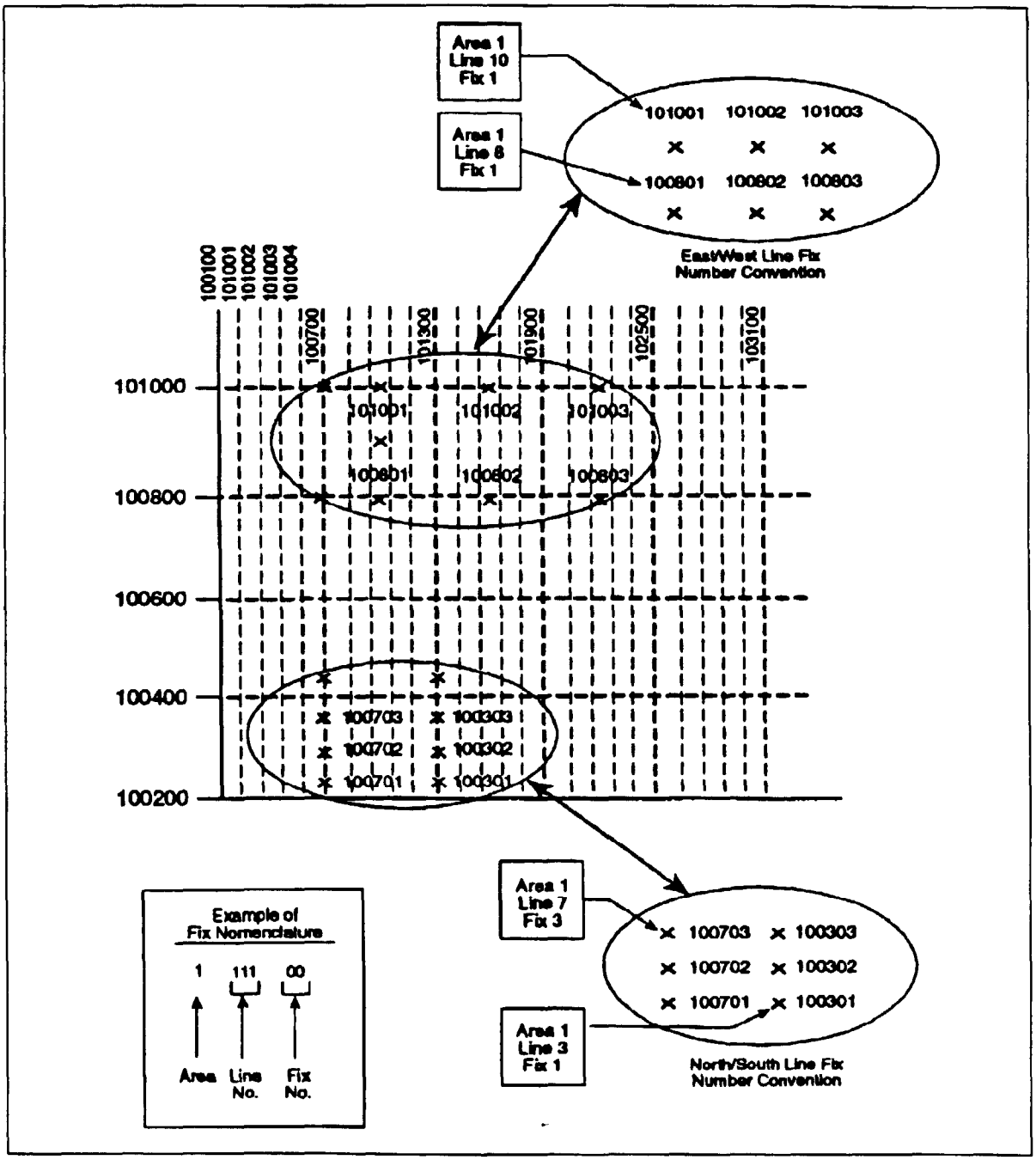



Figure 4-4
Examples of line name convention.

Every fathometer has a beam width given in degrees (Figure 4-5); the footprint of the fathometer is the width of the beam at the deepest point on the line. For example, a precision fathometer will typically have a 2-degree beam width, while a standard model will have a 19-degree beam width. The footprint is the cord of 2 degrees at a radius equal to the water depth. The footprint of a fathometer is given by:

$$\text{Footprint} = 2 * \text{depth} * \sin\left(\frac{\text{beam width}}{2}\right) \quad (4\text{-}1)$$

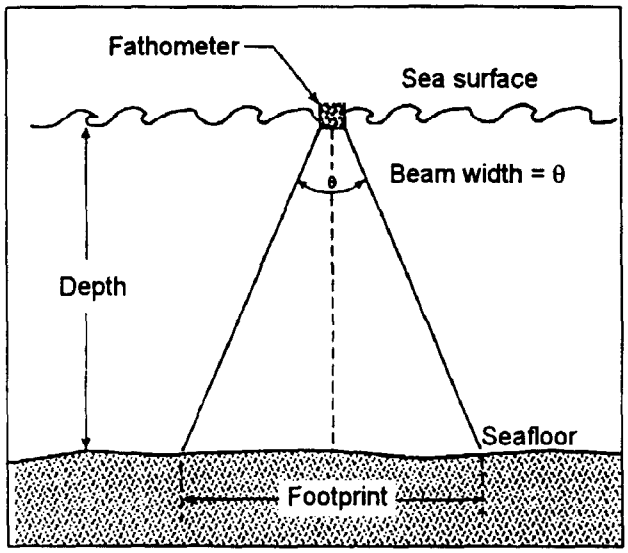



Figure 4-5
Fathometer footprint.

Thus, for a water depth of 60 feet and a 2-degree beam width, the footprint is 2 feet, while the footprint of a 19-degree standard fathometer in the same depth will be 20 feet. Thus, the minimum survey line spacing for the precision system would likely be controlled by the navigation accuracy, while the minimum spacing for the standard system would be 40 feet.

The density of soundings will depend on the survey line spacing and the fix interval along the survey line. As previously stated, the fix interval should be equal to one-quarter to one-fifth the survey line spacing. When using close line spacing, this is not possible and the maximum fix interval should be the line spacing.

Integrated navigations systems allow the user to specify fix intervals as distance, otherwise fix interval is specified as time. When fixes are based on time, the time should be selected to approximate the desired fix distance assuming constant velocity. Table 4-2 gives the times for a 100-foot fix interval at various speeds.

Table 4-2
Fix Interval Selection

| Speed (knots) | Time for 100 Feet (min) |
|---|---|
| 1 | 1.00 |
| 2 | 0.50 |
| 3 | 0.33 |
| 4 | 0.25 |
| 5 | 0.20 |

### 4.3.4 Method of Navigation and Method of Horizontal Control

In this discussion, navigation refers to real time position feedback to the vessel operator, and horizontal control (survey) is the measured position of the vessel at specified "fix" intervals. Generally, it is desirable for the method of navigation and the method of horizontal control to be the same, but sometimes this is not possible. An example would be a survey with no navigation and with horizontal control using theodolites on the beach, such as a traditional diver survey of an existing cable route. In this case, the theodolites simply track and record the position of the diver's towed buoy.

Methods of horizontal control vary from the simple diver's circling line and compass to Differential GPS. Other common methods are:

- Range poles
- Horizontal sextant angles
- Theodolites or transits
- Theodolites with Electronic DistanceMeters (EDM) (Hydro-I and II)
- Radio Navigation Systems (RNS) (Loran-C network)
- Electronic Ranging Systems (ERS) (Mini-Ranger and Del Norte)
- Acoustic Navigation Systems (ANS) (Diver Navigation System)

Other examples of acoustic navigation systems are Long Baseline systems (LBL), such as SonarDyne's low, medium, and extra high frequency systems and Ultra Short Baseline systems, such as Trackpoint II.

In most cases, horizontal control is maintained by measuring, or computing from indirect measurement, the offsets from known control points.

Two corrections need to be made to the horizontal control data:

- A correction for any offset between the control point on the vessel and the location of the depth sensor (fathometer transducer).

- A slant range correction if the horizontal control stations are not at the vertical datum.

Corrections for offset require that the heading of the vessel be known, or approximated, by the course made good. An example of large offset corrections occurs when conducting a side scan survey, where the sensor (towfish) is approximately a distance of one water depth behind the vessel.

Some horizontal control systems also provide some navigation capability but an integrated navigation system such as the HYPAC® software is usually desirable.

The horizontal datum should be selected based on the availability of control points, the equipment being used, and sponsor's requirements. When possible, it is desirable that the horizontal control be in UTM units with the UTM zone noted (when control points are given in geodetic (latitude and longitude), it is desirable to convert to a map projection grid, such as UTM or State Plan Coordinates).

The UTM system presents data in Northing and Easting coordinates with meters as the unit. This is easier for the navigator and helmsman to understand and is easier to plot. When integrated navigation systems are used, it is often possible to convert horizontal datums in real time. When using nonintegrated methods, it is best to work in the same system as the control points and convert datums when the final plots are made. NGS/NOAA provide computer software for conversion between coordinate systems and datums. The program "UTMS" will convert from North American Datum (NAD) 27 or NAD 83 to and from UTM (USGS - phone (301) 713-3242 for more information).

### 4.3.5 Selecting and Establishing Control Stations

The existing National Ocean Survey (NOS, formerly USGS) control stations should be used whenever possible. Control stations for both theodolite and ERS stations should have line-of-sight coverage of the survey area. For triangulation and trilateralization (transit, theodolite, and most ERS) systems, the stations should be located so that the angle of intersection at the vessel should be between 35 and 135

degrees, to minimize Geometrical Dissolution of Position (GDOP). To meet these requirements, it will frequently be necessary to establish new control stations. Typically, new control stations are created by extending existing control networks using standard land survey procedures. Alternate methods include ERS, Differential Global Positioning System (DGPS), and Kinematic DGPS.

New control stations should be tied to existing survey networks (geodetic control). When this is not possible, they should be tied into local base maps (7.5- and 15-minute quadrangle sheets or Public Works (PW) drawings). Of these methods, the least desirable survey is one which is based on an independent local grid.

The control stations used for hydrographic surveys should be Third Order Class II or better, in general. Table 4-3 gives the distance accuracies for various survey classifications.

Table 4-3
Survey Classifications

| Classification | Minimum Distance Accuracy |
|---|---|
| First Order | 1:100,000 |
| Second Order, Class I | 1: 50,000 |
| Second Order, Class II | 1: 20,000 |
| Third Order, Class I | 1: 10,000 |
| Third Order, Class II | 1: 5,000 |

For transit and theodolite surveys, two stations are generally adequate. These survey methods use triangulation and the shore stations should be selected so that the included angle, Figure 4-6, is between 35 and 135 degrees for acceptable accuracy. The best accuracy is achieved when the included angle is 90 degrees.

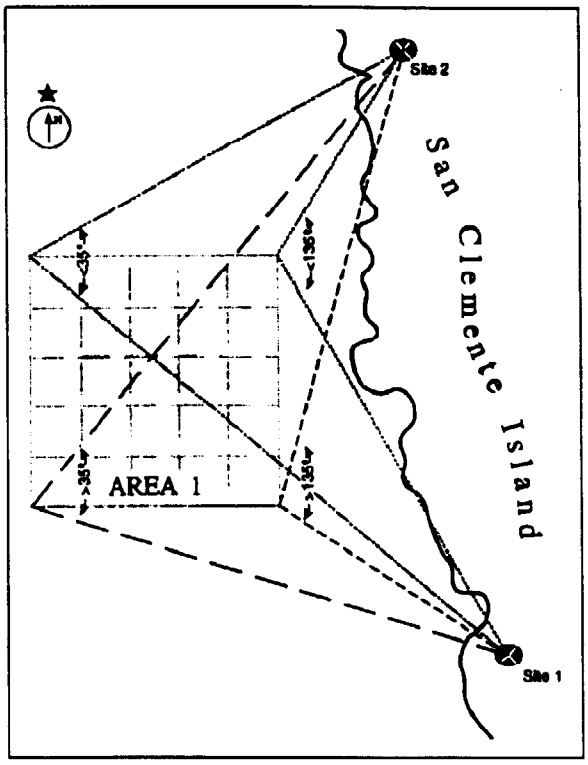



Figure 4-6
Example of layout for conducting survey using triangulation with transits and theodolites.

Electronic Ranging Systems (ERS) use trilateralization, and in general three or more control stations are desired. The same 35- to 135-degree included angle rule applies to this method when only two stations are used. When more control stations are used, the solution should be based on a least squared error calculation of all possible solutions.

The range and bearing system (Hydro-I and II) requires that only one control station be occupied, but another station is required in order to determine grid north. In the case of Differential GPS, a single station is required.

The success of the survey often depends on the selection of the benchmarks. Information on existing control stations is available from:

NOAA, National Geodetic Survey
N/CG17
SSMC3, Station 09202
Silver Springs, MD 20910
Ph: (301) 713-3242
Fax: (301) 713-4172

as either paper copy or ASCII files on computer disk. Benchmarks should be easily relocatable for future survey work and the field notes should provide detailed instructions for finding and identifying the benchmarks used. It is often desirable to set up witness post/marks for the benchmarks used. These could be stakes driven at the side of a road, tags on telephone poles, or paint marks on the road.

If there are insufficient benchmarks in the area of a project, it may be necessary to create one or more. The following methods should be used to establish new benchmarks:

- **On rock** - Mark the location with a 6- by 6-inch metal plate (stainless steel, brass, or bronze). An engraved X in the center of the plate will mark the exact location of the benchmark. The plate should have the date when it was installed and an identifying name engraved on it, along with the words "For Information Call (202) 433-3881" (NFESC Code ESC55) (recommended naming convention is "UCT-" followed by julian date and sequence letter, i.e., UCT-4151A, UCT-4151B,etc.). The plate may be fastened to the rock using small rockbolts (3/8 by 6 inches) after suitable holes are drilled in the rock using a hand star drill. An alternative method is to use lead masonry anchors driven into holes drilled into the rock. The plate could then be secured by standard hex bolts. Two remote monuments should be established 10 to 100 feet from the base monument. These should have the names UCT-XXXXA-RM-1 and UCT-XXXXA-RM-2. The location of the remotes should be such that anyone vandalizing the base or a remote will not see the others.

- **On soil** - Mark the location with a steel stake driven 3 to 4 feet into the ground. An 8- to 10-inch-diameter concrete pad, 18 inches deep, should be poured around the stake to ensure the position is securely marked. The stake and pad should protrude 2 to 3 inches above the ground level. The exposed steel stake should be filed flat and center punched. A plate with the same information, minus the engraved X, should be bolted to the pad using preset lead masonry anchors.

- **On beaches** - It is recommended that benchmarks not be set seaward of the dune line and that care be taken in setting benchmarks landward of the dune line because of the instability of sand, which may cover even a permanently placed mark. If it is necessary to set up on the beach, it is recommended that two remotes be established behind the dune line and that the project logs indicate that the base monument was a temporary monument. Any future survey would have to relocate the base station, in the same manner as when a base station is vandalized or destroyed.

After the benchmarks have been physically constructed, their position must be determined from a known benchmark. Known benchmarks to be used, in order of preference, are:

- Permanent Government benchmarks, such as NOS or State grid.

- Local survey markers, when the coordinates of the marker are known, i.e., the center of a manhole cover may be used by

local surveyors. Other local survey marks include lot corner stakes and other semipermanent markers.

- Specific portions of a large permanent object (e.g., "2 feet south of southern leg of antenna No. 3") or a specific corner of a building (e.g., "2 feet north or northeast corner of Bldg 1002"). It is prudent to put a marker at these locations. Generally, this will not meet the Third Order Class II requirement, but will meet the permanent object on a base map criteria.

### 4.3.6 Method of Vertical Control

For a bathymetric survey, vertical control has four parts:

- Datum selection
- Fathometer corrections (speed of sound and draft)
- Vertical motion (wave)
- Tidal corrections.

The overall vertical accuracy is the root mean squared (RMS) of the individual accuracies, assuming they are independent random errors. That is:

$$\text{Vertical Inaccuracy} = \text{Error (RMS)} = \pm [\text{Sqrt } \{(\text{Datum error})^2 + (\text{speed of sound error})^2 + (\text{draft error})^2 + (\text{vertical error})^2 (\text{tide error})^2\}] \quad \ldots\ldots(4\text{-}2)$$

The selection of a datum is usually driven by the available vertical control points, if they are related to mean sea level (MSL), then that should be the first choice for a datum. It is possible to convert datums, i.e., from MSL to mean lower low water (MLLW) or height above spheroid (for GPS derived data). When doing as-built surveys, the datum should be taken from the construction drawings.

The fathometer correction has two parts: (1) draft correction, and (2) velocity of sound correction. A modern survey fathometer will allow the draft and sound velocity to be entered and thus corrected for by the instrument. The final correction is for tide or the elevation of the water surface above the datum. Since tidal corrections are usually post-processed, it is recommended that both draft and sound velocity be post-processed. In using either method, it is imperative that good field notes be maintained, noting if draft and velocity corrections have been entered and what values have been used. If the recommendation to post-process draft and sound velocity are used, the entered values should be zero for draft and 1,460 m/sec (or 4,800 ft/sec) for sound velocity. Then when the tide correction is made, the data can be corrected using the following equations:

$$\text{Depth (m)} = \text{Velocity (measured)}/1{,}460 \text{ (m/sec)} \times \text{Depth (m-raw)} + \text{Draft (m)} + \text{Tide (m)} \quad \ldots\ldots(4\text{-}3)$$

$$\text{Depth (ft)} = \text{Velocity (measured)}/4{,}800 \text{ (ft/sec)} \times \text{Depth (ft-raw)} + \text{Draft (ft)} + \text{Tide (ft)} \quad \ldots\ldots(4\text{-}4)$$

When correcting for tide, make sure that the time of the depth reading corresponds to the time of the tide reading. This is especially critical when using the tide table and local times.

When correcting for sound velocity, make sure that the velocity (measured) is the average vertical velocity, not the surface or bottom velocity.

### 4.3.7 Data Logging Requirements

The logging, reduction, and data processing are critical in the development of

accurate surveys. The logging can take many forms, from the simple handwritten data to a fully integrated system. A desirable bathymetric survey system integrates horizontal control and the fathometer in a computer. In an integrated navigation system the logged data are: fix, time, X,Y,Z, where time is local time (HH:MM:SS) and X, Y, and Z are the coordinates of the fix and the raw (or processed) depth. In this case there is no data reduction and the processing is given by Equation 4-3.

When vertical motion is not automatically corrected or recorded, it is necessary to compare digital information against analog (chart paper) records to make sure that no systematic error has been added by the digital sampling. When interpreting chart records, the interpreter will generally correct for vertical motion (waves) while a digital sampling takes the absolute value of depth, which is depth + wave.

Even when integrated navigation is not available, it is helpful to automatically log the output of a sensor (fathometer or horizontal control system) using a personal computer's serial data (RS-232) input, the serial data output of the sensor, and a communications program.

Data annotation is also critical. The following is the recommended annotation for all chart type data:

At Start of Line (SOL)
- Survey Area
- Line Number
- Date and Time
- Start of Line Fix Number (SOL)
- Heading
- Speed
- Initial Instrument Settings (Gain,...)

At End of Line (EOL)
- Line Number
- Date and Time
- End of Line Fix Number (EOL)

At Each Fix
- Fix Number
- Time

At Any Change of Setting (Gain,...)
- Old Value
- New Value

When conducting surveys with towed sensors, it is critical that the offset of the sensors be recorded and taken into account when reducing the data. The position recorded is the position of the navigation antenna, not the position of an offset sensor, i.e., a side scan sonar towfish will be hundreds of feet aft of the vessel at the time of the fix. A highly integrated navigation system may allow you to input the offsets and will track one or more targets. Thus the value for position at a fix will be the true position of the target, not the position of the navigation antenna. When using towed systems, it is critical that the offsets be annotated.

In addition to the record annotation, a logbook should be kept noting the information contained in the annotation plus any operator observations.

Thus far, the emphasis has been on conducting a survey with an integrated navigation system, but at some time a survey may have to be conducted using manual recording techniques. The recommended procedure is to record fixes based on elapsed time, say every 2 minutes. A team of three people would be used, one to monitor time, one to log navigation, and one to annotate the fathometer chart. The annotation should be fix number and time.

### 4.3.8 Data Reduction

If the fathometer data was recorded on chart paper with fix marks and the navigation system recorded UTM northings and eastings, the data reduction process would create a fix versus depth listing from the fathometer chart which could be merged with the fix versus time-and-coordinate listing from the navigation system to produce a fix, time, X, Y, and Z listing, which could then be processed.

The application of tide corrections can be done with varying degrees of precision; for short lines a single correction is generally appropriate. For long lines or rapidly changing tides a linear approximation with time is generally appropriate, except near high and low tide. A point-by-point correction is the most accurate.

When reducing data, it is necessary to check between fixes, on the chart paper, to determine if the slope is flat or linear (up or down). If the slope is flat or linear, no special processing is required, but if local highs or lows occur, add an intermediate fix and record the high or low.

### 4.3.9 Data Processing

Once a vertically and horizontally corrected set of data exists, it needs to be contoured. This may be done by hand, on a computer graphics program, on a computer-aided drafting (CAD) program, or using integrated navigation system software such as HYPAC®. The importing of the survey data into a CAD program is desirable, since the final plots can easily be generated by the CAD program.

### 4.3.10 Deliverable Product

The deliverable product is generally a Public Works drawing of the bottom contours, with a number assigned by the local Public Works department (see Section 4.5 for more details on producing final drawings). The drawing scale should be ratio metric (1:1,000) rather than engineering (1" = 1'). In addition, the scale should be selected to either maximize use of the sheet or to match other drawings or maps. A North-up layout should be used. To maximize the use of the sheet, the maximum North-South (N-S) and East-West (E-W) dimensions of the project area should be determined and converted to inches. The usable height and width of the drawing sheet should be determined in inches.

The ratio of N-S divided by height and E-W divided by width should be determined. The map scale is the largest ratio rounded up to a standard scale. Table 4-4 lists the recommended standard scales. If the survey data is to be used with a set of construction drawings, the scale should be the same as the construction drawing. It is recommended that the map (ratio) scaling convention be used, thus 1" = 1' would be 1:12 and 1" = 100' would be 1:1,200. Finally, if the data is to be used with existing charts, it should be at the chart scale.

## 4.4 SURVEY OPERATIONS

This section will discuss specific issues about field operations using descriptions of notional and generally used equipment. Notional discussions will be general and can be applied to a class of equipment, while discussions about generally used equipment will discuss specific characteristics of brand name equipment. The following equipment will be discussed:

- Vertical Control Systems
  - + Fathometers
  - + Tide gages

+ Vertical motion sensors

- Horizontal Control and Navigation Systems

  + Optical Horizontal Control (Transits and Theodolites, including Hydro-I and II)
  + Electronic Ranging Systems (Del Norte Trisponder and Mini-Ranger)
  + Global Positioning Systems and Differential GPS
  + Acoustic Navigation Systems (Trackpoint II and Diver Navigation System)

- Side Scan Sonars

- Subbottom Profilers

### 4.4.1 Vertical Control Systems

When using a fathometer to conduct bathymetric surveys, the following areas need special consideration to achieve maximum accuracy:

- Sound Velocity
- Draft Correction
- Vertical Motion Correction

The fathometer measures time of flight for an acoustic pulse to travel from a transducer to the bottom and return. The time is converted to depth using the velocity of sound, but the velocity of sound changes with temperature, depth, and salinity. In most cases, sound velocity will be measured using a Conductivity, Temperature, and Depth (CTD) instrument, which converts conductivity to salinity and computes velocity using the following equation:

$$C = 1{,}449.2 + 4.623T + 0.0546T^2 + 1.391(S-25)\ldots$$

where

C = Velocity of sound in m/sec
T = Temperature in degrees centigrade
S = Salinity in parts per thousand

For most coastal ocean situations, except near river mouths, the salinity can be assumed to be 35 percent. Thus, if a CTD

Table 4-4
Standard Chart Scales

| Chart Scale | Nautical Miles Per Foot | Line Spacing for 1-Inch Plot Spacing (Rounded) |
|---|---|---|
| 1:250 | 0.04 | 25 ft |
| 1:500 | 0.08 | 50 ft |
| 1:1,000 | 0.16 | 100 ft |
| 1:2,500 | 0.41 | 200 ft |
| 1:5,000 | 0.82 | 400 ft |
| 1:10,000 | 1.64 | 800 ft |
| 1:20,000 | 3.30 | 1,600 ft |
| 1:40,000 | 6.58 | 3,000 ft |
| 1:80,000 | 13.16 | 6,000 ft |

is not available, the velocity can be estimated using temperature and depth. The velocity used should be the average velocity, the mid water velocity if the change is linear. A velocity cast should be made periodically and logged.

It is recommended that the velocity input to the fathometer be a constant (1,460 m/sec or 4,800 ft/sec), not the measured value. This allows the velocity to be entered in the data reduction phase and reduces the chance of input error. The velocity setting should be entered into the survey log each day.

Maintaining a constant transducer draft from day to day is important when the transducer is mounted over the side on a pole; it is fixed when using hull-mounted transducers or surface-towed transducers. A frequently used "confidence check" is the bar check. A bar check is done by lowering a flat plate target, or ballasted air-filled tube to predetermined depths, and comparing the known depth with the measured depth. If bar checks are conducted, the information should be logged and the chart paper saved as part of the survey information.

Vertical motion correction accounts for the difference between the measured depth and the depth relative to the selected datum. It has two components: tidal correction and wave correction. Tidal correction can be based on either tide tables, tide prediction software, or tide gauges. Tide corrections should be a part of every survey. The HYPAC® integrated navigation system offers automatic tidal correction as part of its data reduction routines.

When maximum precision is required, it is necessary to correct the data for wave action. This is frequently done with a vertical motion sensor, which then corrects the data in real time. If this is not possible, the "old-fashioned way" is "eyeball integration." To do this, several feet of the chart are laid out on a flat surface and the interpreter, with his left eye closed, places his right eye close to the chart and sights down the length of the trace. The wavy trace, due to wave action, becomes a broad trace, and the interpreter marks the center of the broad trace, and that is used as the depth value. When using digital systems, it is recommended that some quality control checks be made using "eyeball integration."

### 4.4.2 Horizontal Control and Navigation Systems

The four main navigation methods used for horizontal control of bathymetric surveys are:

- Optical
- Electronic
- Global positioning system
- Acoustic navigation systems

No matter which method is used, this part of the survey has to be done very carefully. Many surveys have had to be repeated because of inaccurate horizontal control.

**4.4.2.1 Optical Horizontal Control.** Optical horizontal control is usually done using either a theodolite, transit (or level), or a sextant. Theodolites, as illustrated in Figure 4-7, are tripod-mounted optical devices that are used for determining precise vertical and horizontal angles between points, as well as determining distances by triangulation methods. Most theodolites are easily modified to accept EDMs for more precise distance measuring requirements as in the Hydro-I and II systems (Figure 4-8).

Transits are less versatile than theodolites, since they measure only horizontal angles and are usually less precise. Transits, as illustrated in Figure 4-9, are tripod-mounted optical devices that are used

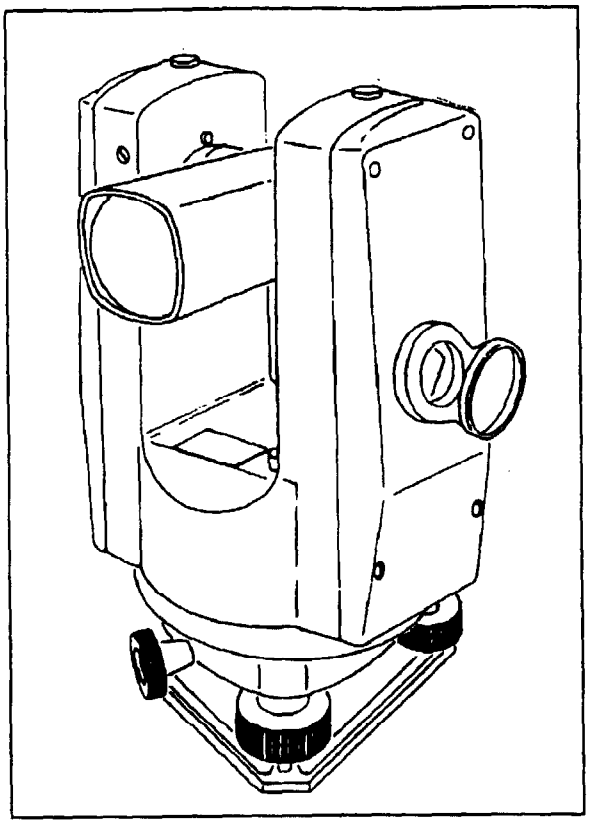


Figure 4-7. Theodolite.

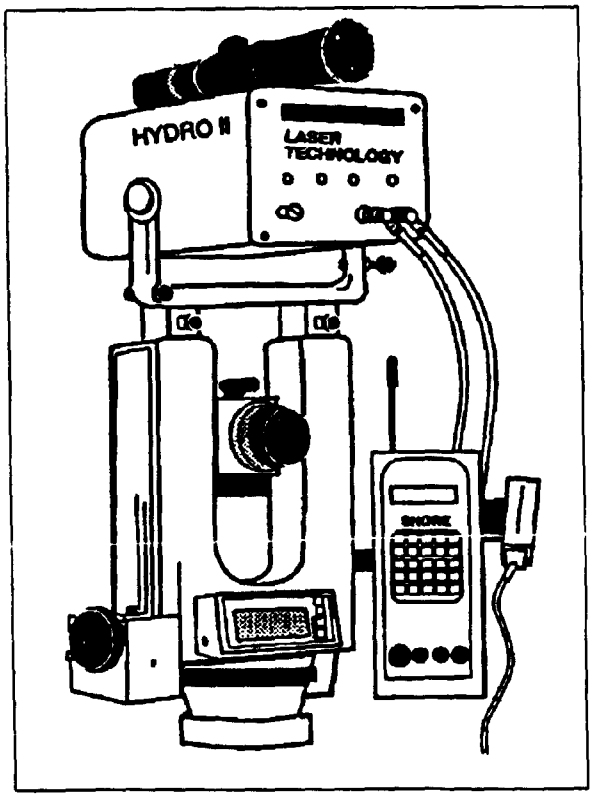



Figure 4-8. Automated hydrographic positioning system

to determine relative elevations and distances between survey points when used in conjunction with a surveying rod. When the instrument is mounted and leveled according to the operating instructions, the rod reading can be seen at the center cross hair position, and the stadia readings can be seen at the stadia markings inside the telescope, as illustrated in Figure 4-10. The difference between the stadia markings is typically 1/100 of the distance between the level and the survey rod (the distance is obtained by multiplying the difference by 100).

The third optical instrument (which is not commonly used) is the sextant. It is a good fallback if other equipment is not available.

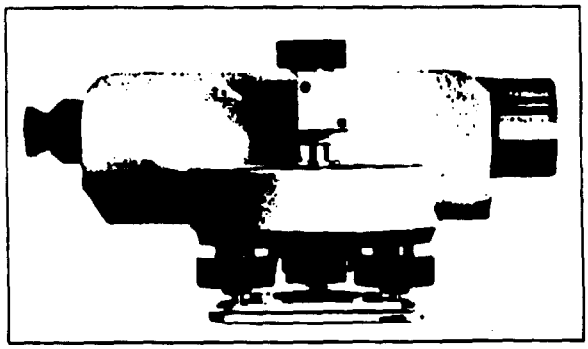


Figure 4-9. Automatic level.

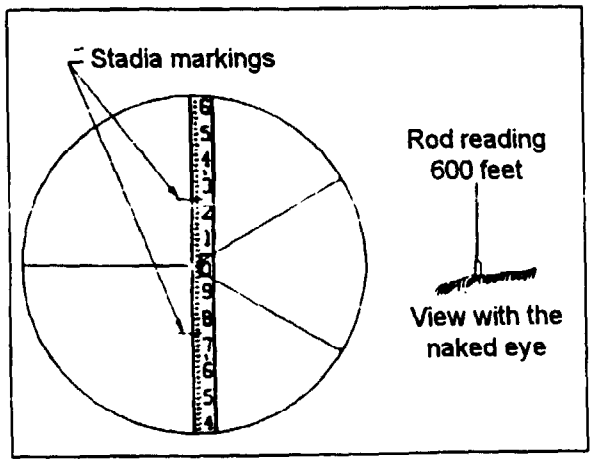



Figure 4-10. View of target through telescope.

There are three frequently used optical survey methods. One method uses two shore-based theodolites or transits to track the survey boat, as illustrated in Figure 4-11. The position of the boat is established by plotting the angles measured between a baseline (with a benchmark or landmark at each end) and the boat. Generally, the instruments are set up so that the other instrument is at zero angle and each instrument is read using right-hand angles, thus the instrument on the right (facing the ocean) will read angles of 0 to 180 while the other instrument reads 360 to 180. Assuming a two-man crew at each instrument, the procedure to record a fix every minute would be:

- **Fix minus 10 seconds**: Assistant #1 commands "standby" over the radio. Operators #1 and #2 begin continuous tracking of the target.

- **Fix minus 0 seconds**: Assistant #1 commands "Mark." Operators #1 and #2 make final adjustments to lock on target.

- **Fix plus 5 seconds**: Operators #1 and #2 read and call out the horizontal and vertical angles, assistants #1 and #2 log fix number, time, and angles.

- **Fix plus 6 to 50 seconds**: Operators keep target within field of view of instrument, generally slightly ahead of vessel.

The second method, using the Hydro-I or II systems, is a variation on the theodolite survey, where the information recorded is range and bearing, vice two bearings. In practice, the UCTs usually use Hydro-II (and Super Hydro) in conjunction with the HYPAC integrated navigation system. When used with an integrated system, the recording of fixes is automatic based on either time or distance.

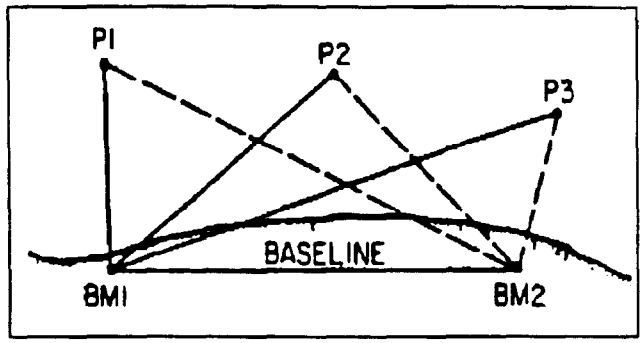



Figure 4-11. Sighting offshore objects.

This procedure is also applicable when locating fixed objects, such as marker buoys, but since the object is not moving it is not necessary to take both sightings simultaneously and the work can be performed by one crew with two setups.

The third optical method uses a sextant. An observer on the boat sights three onshore benchmarks and records the angles. This method is generally referred to as horizontal sextant angles and the data is reduced by resection. NOAA has an HP41 calculator program designed for this, or it can be done manually with a three-arm compass or within CAD software.

Each method can give accurate results when carried out by trained personnel. However, optical methods involve a large amount of field work, laborious calculations to plot locations, good visibility, and proximity to shore.

**4.4.2.2 Electronic Ranging Systems.** The UCT's most commonly used type of electronic navigation for a bathymetric survey is the Mini-Ranger III Electronic Positioning System (MRS III) (Figure 4-12). This system consists of a receiver-transmitter assembly with an antenna, a range console, and two radar transponders with antennas. It provides a means of accurately determining the position of a moving unit, such as a vessel, with respect to two microwave tran-

sponders located at fixed reference points. The range of the system is dependent on the relative heights of the shipboard antenna and the shore stations. The MRS III operates on the basic principle of pulse radar. The receiver-transmitter assembly, which is mounted on the moving unit, is used to interrogate the two transponders. The lapsed time between the transmitted interrogation signal and each of the two reply signals is used to determine the range of each transponder. This range information is displayed on the range console and shows range in meters or feet to each of the transponders.

To use this system, two or more benchmarks are set up on the beach as reference points for locating a vessel equipped with a depth recorder. The Mini-Ranger III's transponders should be secured against movement by the wind, since such movement will result in erroneous readings. These benchmarks are designated as reference points, one being a control station. The line between these reference points is called the baseline.

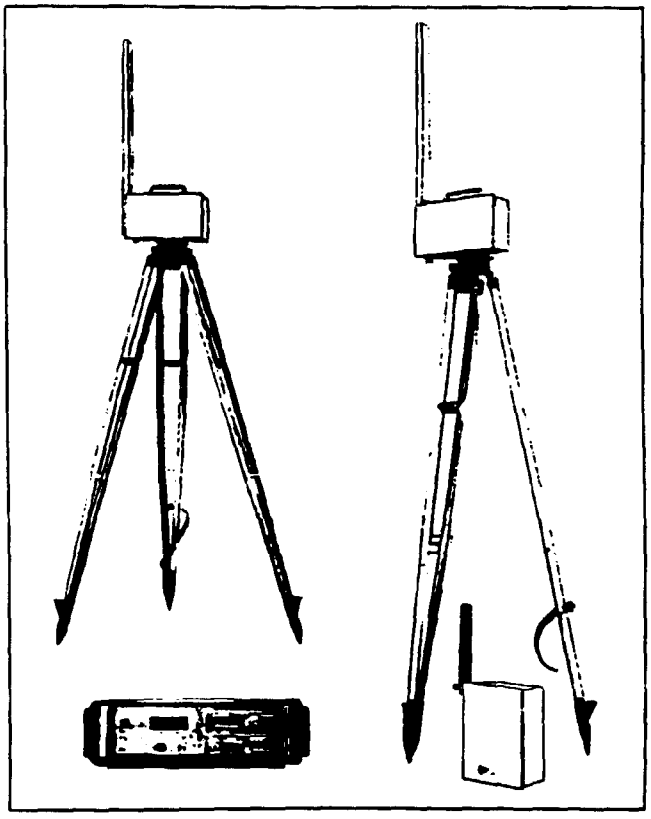


Figure 4-12. Mini-Ranger III system.

The basic Mini-Ranger III system displays the two ranges. It is necessary to manually plot the survey lines, and draw range rings around the transponder sites. This allows the manual plotting of the range data as the survey is being conducted.

The survey vessel is equipped with a Mini-Ranger III and a fathometer. The vessel transits the survey area, navigating to stay on the preplotted track lines. At specified time intervals, say 1 minute, simultaneous depth and position measurements are logged. The operation of the Mini-Ranger III requires some special training and experience.

The Mini-Ranger III tracking system is an integrated navigation system, which does not log external data. It consists of a range console, receiver-transmitter (RT 1 and 2), a data processor, a data terminal, and three reference stations, as illustrated in Figure 4-13. The system provides a means of locating a mobile station by trilateration. By knowing the location of stationary or fixed referenced stations, the position of a moving station may be determined or tracked relative to the position of the control station. The position of a mobile station can be determined using trilateration techniques from range and loop range measurements made by the control station.

When using electronic navigation equipment, it must be determined that there are no ship or harbor electronic navigation systems that may interfere with the survey instrument operating in the area. If there are such systems operating, and another means of horizontal control is not practical, it must be verified that the operating frequency of the other navigation equipment will

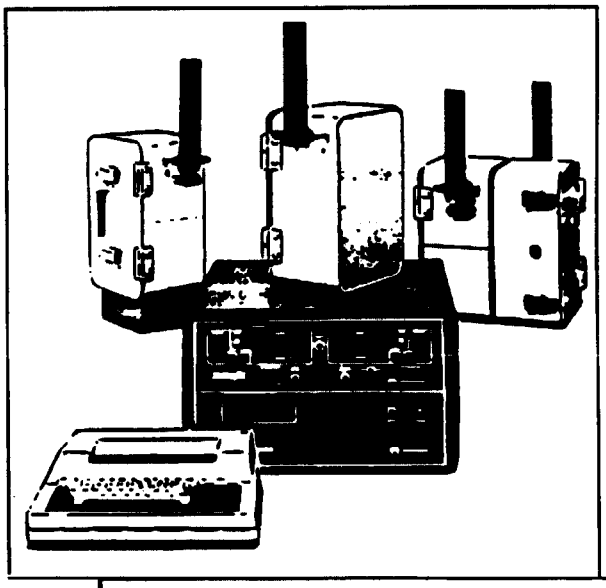
not interfere with the survey equipment. The Mini-Ranger III operates in the same frequency band as the radar on Navy ships; thus, conducting surveys where other Navy ships are operating may require special considerations.

In nearshore waters not accessible with a surface vessel equipped with ERS, diver-held surface markers can be located over desired points. The location of the surface buoy can be determined via a number of means, traditional surveying, bearings from multiple offshore fixes, and horizontal sextant angles. The location of a temporary shore station can be established using the EDM equipment, i.e., the equipment normally in the vessel is used to establish a temporary benchmark on shore.

**4.4.2.3 Global Positioning Systems and Differential GPS.** The current state-of-the-art positioning is done via GPS, DGPS, or Kinematic DGPS. A GPS receiver is used to acquire ranges from three or more satellites, much like an electronic ranging system (ERS). Using knowledge about the orbit of the satellite, the GPS receiver computes a position on earth from the ranges.

GPS receivers exist in two varieties, civilian (or standard positioning service) and military (or precise positioning service). Civilian GPS receivers receive a signal that has random errors added to reduce the accuracy, while military receivers are able to decode a signal and remove the errors. The random error is associated with selected availability (SA). When SA is on, the errors are added. When SA is off, the civilian receiver has the same performance as a military receiver.

The accuracy of a civilian receiver is $\pm 50$ meters, while a military unit is $\pm 15$ meters. Given an existing control network,



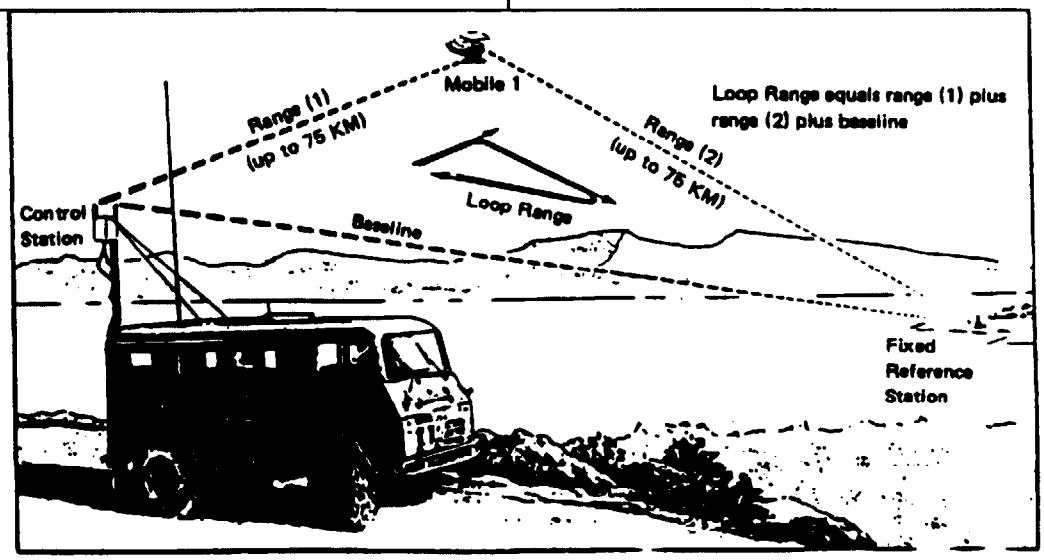



Figure 4-13. Mini-Ranger III tracking system.

it is unlikely that either military or civilian GPS systems will give Third Order survey results.

Two enhancements exist for GPS, the first is differential GPS and the second is real-time kinematic DGPS. Differential GPS consists of setting up a reference station at a known location and using it to transmit a correction to a remote (mobile) station on the survey vessel. The position of the reference DGPS receiver must be accurately surveyed and referenced to benchmark. Typical DGPS accuracy is 1 meter CEP or 2 meters at a 95 percent confidence. This accuracy is affected by satellite geometry.

Kinematic GPS uses special software and hardware to achieve centimeter accuracy. At this time, real-time kinematic GPS is just coming to market, in the near future it may be the survey system of choice.

**4.4.2.4 Acoustic Navigation Systems (Trackpoint II and Diver Navigation System).** The acoustic navigation systems commonly used by the UCTs are the Diver Navigation System (DNS) and the Trackpoint II System. The DNS is used for diver navigation while Trackpoint is used to navigate an ROV. Both systems are relative navigation systems; that is, you must have some means of determining the position of the DNS reference stations and you must track the position of the Trackpoint hydrophone, unless relative navigation is adequate.

The DNS (Figure 4-14) is a synchronous long baseline underwater acoustic navigation system, which, like the long baseline Electronic Ranging Systems, works best when the included angle is between 35 and 135 degrees. The DNS measures the range from two reference stations, and the length of the baseline between the stations, and computes the diver's position in an X-Y grid with its origin at the master reference station. Spar buoys are deployed at the reference station sites, which can be located using optical or electronic horizontal control systems. The DNS records the diver's X, Y, and Z position with each fix. Thus, the diver can track or relocate objects on the seafloor.

The Trackpoint system is an ultrashort baseline acoustic navigation system which tracks a beacon on an ROV, or if being used to navigate a vessel, tracks two or more beacons on the bottom. The system works best when the tracked object is within a cone, ±45 degrees of vertical. It can display the position of the target in either polar or rectangular coordinates. It can be used

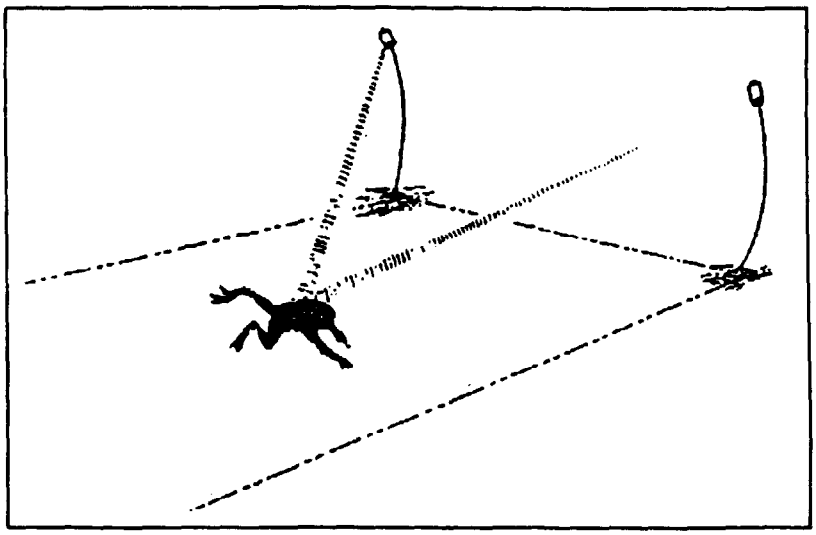


Figure 4-14. UCS diver navigation system.

to relocate an object if a beacon was placed on the object. The system requires special training to operate.

### 4.4.3 Fathometers

The echo sounding equipment most widely used by the UCTs in depth measurements is the fathometer (depth recorder) illustrated in Figure 4-15. This unit is a portable, survey-type fathometer designed to provide a detailed permanent recording of underwater topography in water depths between 2 and 410 feet.

The fathometer provides high-resolution recordings based on narrow transducer beam width, high sounding rate, and high signal frequency. Four selectable chart speeds are provided. Versatility is further enhanced by a TIDE and DRAFT control, a SPEED OF SOUND control, and a RANGE doubling control. Any changes in the settings of the preceding controls are permanently recorded on the chart paper for future reference. Fix marks are inscribed on the chart by a FIX MARK switch (a remote switch may be connected).

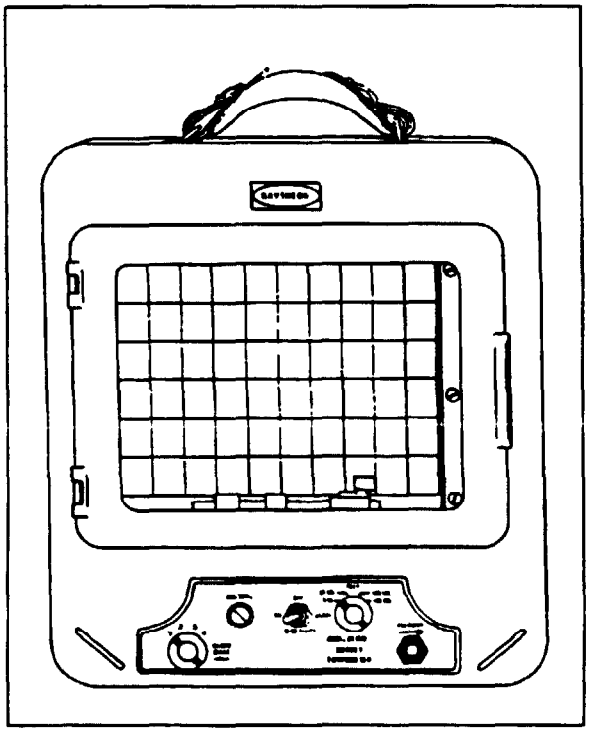


Figure 4-15. Fathometer.

The transducer is designed for precision survey work and other applications where a very narrow beam pattern is required. Such requirements result when extreme accuracy is needed in underwater laying of pipe or cable. The narrow beam pattern is also useful for more accurately defining steep sloping bottom contours and outlining relatively small bottom features.

### 4.4.4 Side Scan Sonar

Bathymetric surveys may be supplemented by side scan sonar. Side scan sonar consists of a towed receiver-transmitter, a cable to the tow ship, and a shipborne recorder. An acoustic pulse, similar to a fathometer's pulse, is sent out across the bottom. The pulse is returned from topographic variations and obstructions. Side scan sonar is particularly useful for finding pinnacles and other obstructions that may be missed by the fathometer. Planning, operating, and interpreting readouts of side scan sonar require a trained and experienced operator. Side scan sonar operations in less than 60 feet of water require special planning and operational techniques.

### 4.4.5 Visual Surveys

Once a cable or pipeline route has been established or an underwater construction site has been selected, a visual survey of the route should be made. Either divers or an ROV may be used. If divers are used then the Diver Navigation System is the preferred method of navigation. If an ROV is used then an Ultra Short Baseline Navigation System is the preferred method of navigation. Visibility permitting, photographs and video coverage of the features offer a

valuable means of interpretation. With limited visibility, diver sketches may be substituted for photographs. Targets of interest may include: large rocks and boulders, large debris, cables or pipelines, and rock or coral outcroppings. Observations are recorded via diver-to-surface communications, underwater television, still photographs, or sketches prepared on either waterproof paper or a Plexiglas slate.

### 4.4.6 Geotechnical and Geophysical Surveys

Geotechnical data along a cable or pipeline route or for a shallow water array are often required. On soil seabeds it is necessary to classify and determine the areal and vertical extent of soil layers. It is extremely important to accurately establish and record the location of all samples and in-place tests. The specific types, numbers, and locations of samples and tests required depend on the nature of the project and should be established in consultation with the "user" of the geotechnical survey.

A set of six geotechnical diver tools is available to allow divers to collect accurate geotechnical site survey data and samples. The set includes the six tools plus items needed for operation and maintenance. The geotechnical tool kit (available through OCEI) is highly portable and designed to be transported and operated without the necessity of a large ship deployment or other platform-based systems. The tools, illustrated in Figure 4-16, are divided into two groups: six hand-powered and auxiliary-powered tools.

The hand-powered tools are:

- **Impact Sediment Corer.** This tool is capable of obtaining core samples to subbottom depths of 2.5 feet. It consists of a plastic core tube, a stainless steel head with attached handles, and a steel impact hammer.

- **Miniature Standard Penetration Test.** This tool is used to determine in-situ density profiles of noncohesive sediments. It consists of four basic components: cone, drive shaft, drive head and guide tube, and a drive weight.

- **Vane Shear Tool.** This tool consists of a torque wrench, drive shaft, and a four-bladed vane. Different sizes of vanes are provided for use in various types of soil to determine shear strength properties.

- **Rock Strength Tool.** This tool consists of a Schmidt test hammer enclosed in a watertight Plexiglas cylinder. The tool measures the in-situ compressive strength and modulus of exposed rock.

The auxiliary-powered tools are:

- **Vacuum-Assisted Sediment Corer.** This tool consists of three major components: a jet eductor, a core tube apparatus, and a gasoline-engine-powered water pump. Core samples in sediments to subbottom depths of 10 feet may be obtained with this tool.

- **Water Jet Probe.** This device consists of a probe and a gasoline-powered water pump. The same pump is used with the vacuum-assisted sediment corer.

In addition to these diver-operated tools, geotechnical surveys frequently involve deeper coring and sampling using devices such as the vibracore, cone penetrometer, expendable doppler penetrometer, and resistivity probes. Personnel from NFESC Code ESC50 can provide assistance with this specialized equipment.

The geotechnical report may provide a summary of soil conditions along the pipeline route and soil test results obtained from the drop cores. The results of soil tests conducted by soils laboratories usually include:

- Core number, location, and water depth
- Soil classification
- Grain size analysis
- Atterburg limits
- Water content
- Wet weight
- Specific gravity
- Undrained shear strength (Su)
- Consolidated undrained shear strength (Cu)

Geophysical surveys are used to remotely sense the geology of an area. The most common types of surveys are: seismic reflection, seismic refraction, and magnetics. The first two are used to profile the geologic strata, while magnetic surveys are usually concerned with location of bedrock. Reasonable estimates of the depth of soil strata can be obtained using nearshore acoustical subbottom profiling techniques (reflection

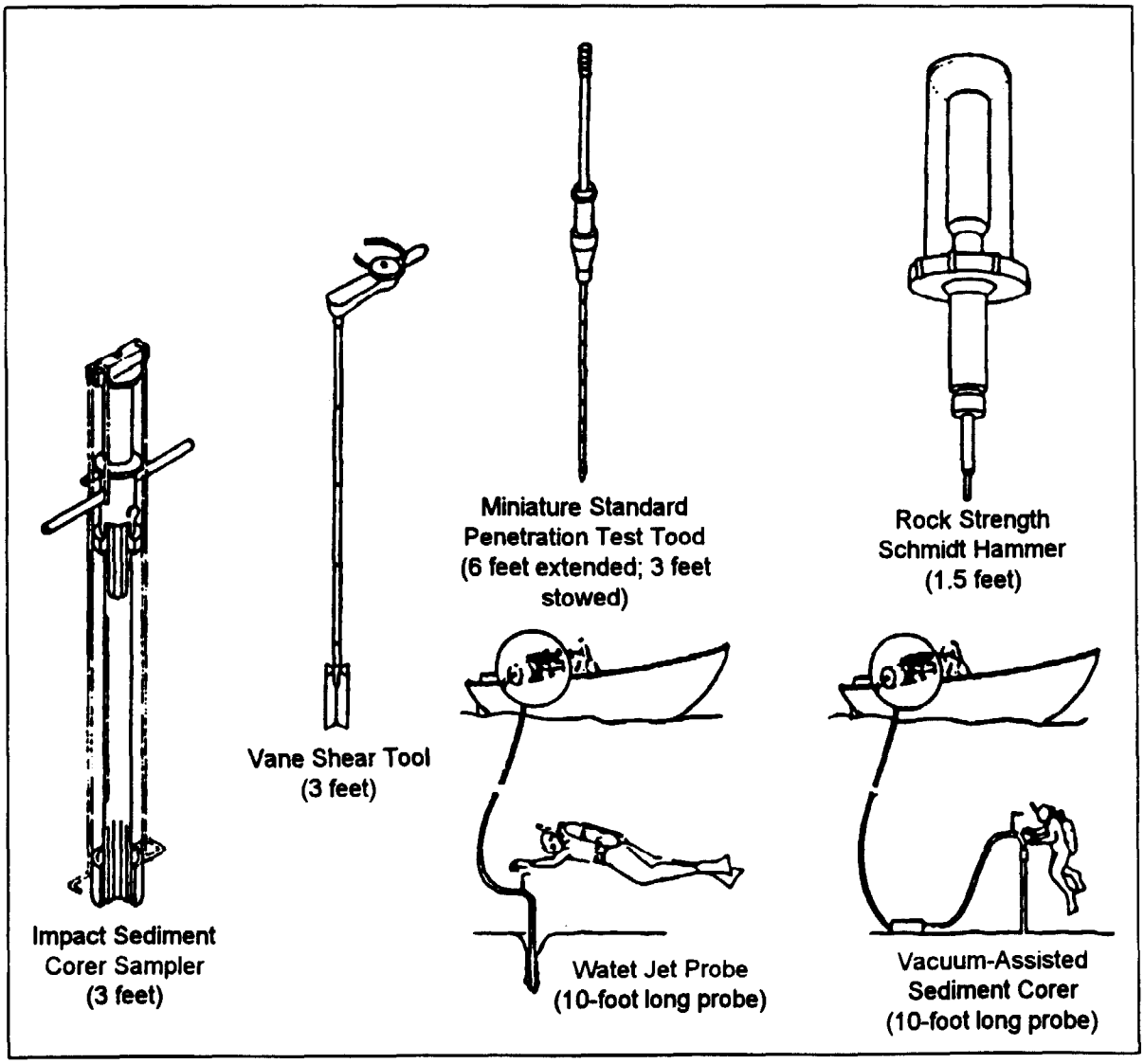



Figure 4-16. Geotechnical diver tool.

and refraction). An experienced operator, however, is required to obtain reliable readings from this equipment, and trained engineers should interpret the data.

### 4.4.7 Specialized Underwater Construction Surveys

**4.4.7.1 Construction Surveys.** To accurately lay out an underwater construction site may require very specialized techniques. The accuracy of the Diver Navigation System is 3 feet. If more accurate underwater surveys are required then other methods will be necessary. With high frequency acoustic systems it is possible to get accuracies of a couple of inches under the right conditions.

The most accurate surveys are conducted using conventional surveying hardware, theodolites, and tapes. Consider the problem of establishing a Third Order survey of two hydrophones located on the seafloor. If they were 1,000 feet apart, a Third Order survey requires 1/10 foot accuracy. An approach would use triangulation from two onshore theodolites, located over Third Order benchmarks to a target at the top of a controlled-buoyancy survey spar, which is used in place of the standard rod. The length of the spar is known and the survey spar is instrumented to measure its angle in two orthogonal directions. The "rod" is located over a point on the seabed by the surface support vessel and lowered into position. Two theodolites each track the spar, and upon reception of a "go ahead" through the communications link, readings are recorded. These readings should be taken when an inclinometer inside the spar reads close to vertical. Five to ten successive readings should be taken to obtain reproducible results. For nighttime surveying, a flashing strobe light can be fixed to the top of the spar. The spar is lowered and raised by ballasting and deballasting. This method is especially effective for construction site surveys where high accuracy is desired. The bottom location can be fixed by installing a stake driven into the seabed.

**4.4.7.2 Quality Control Surveys.** The UCT may be tasked with assisting in the quality control inspection of underwater facilities. This type of survey requires that the UCT become familiar with the intended arrangement and details of the facility prior to making the inspection. Divers then inspect the facility to determine if it was constructed in accordance with design drawings. A visual record of the inspection should be made using still photography or underwater video.

### 4.4.8 Cable Surveys

When conducting an inspection of an oceanographic cable, determining the location of the cable is second in importance only to visually inspecting the cable. In this case, the Diver Navigation System (Section 4.4.2.4) would be used. The range of the DNS is 3,000 feet with a mirror image. Figure 4-17 shows a typical setup. The master transmitter is located to the left, when looking from shore. The slave transmitter is approximately 3,000 feet away and both master and slave are positioned 3,000 feet offshore. Using this configuration a nautical mile of cable can be surveyed with one reference station setup. As the diver tracks the cable and logs his observations, the diver also records fixes. At this point the data is all relative to the master and slave baseline. But after processing the X-Y data, using the real world position of the master and slave spar buoy, the data is in real world coordinates.

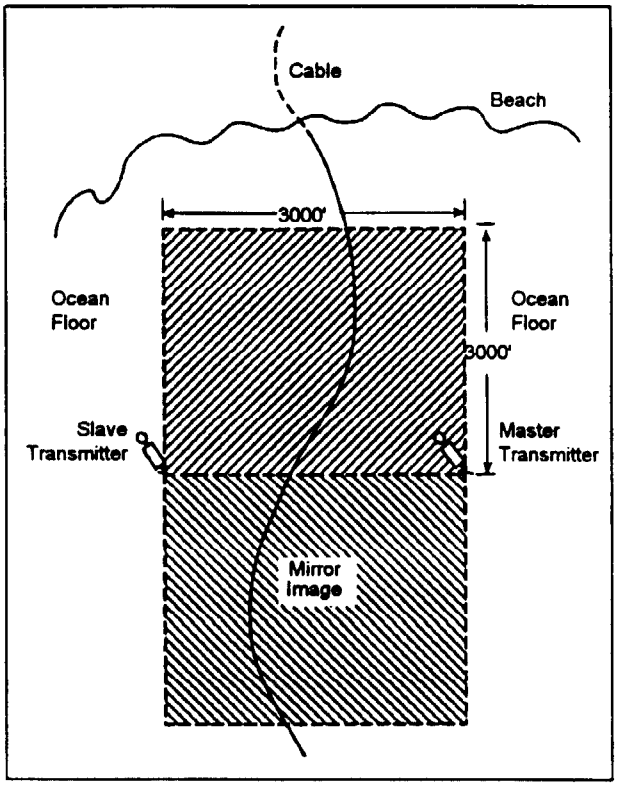



Figure 4-17. Cable route survey using diver navigation system

**4.4.8.1 Onshore Cable Surveys.** Sufficient benchmarks should be established so that all of the cable to a depth of 100 feet is visible from two benchmarks. If the site has been previously inspected, permanent benchmarks should have already been established. In this case, they should be checked to see that they are still in good condition and still provide the required visibility. If so, then all that is required is to confirm their positions. If new benchmarks are required, they should be established as described in Section 4.3.5 and with the following points in mind:

- Visibility of cable track from the position.
- Distance from other benchmarks (needs to be great enough for triangulation, about 0.75 mile).
- Accessibility of position during different weather and tide conditions.

**4.4.8.2 Underwater Cable Surveys.** The goal of the underwater survey is to determine the position and depth of the cable at 100-foot intervals and be able to relate these charted positions back to the cable. The cable will be surveyed using the diver navigation system. The master and slave reference stations are set up, perpendicular to the cable track (see Figure 4-17), with the master on the left (facing offshore). The location of the master and slave are recorded using Hydro-I or II to locate the DNS spar buoys.

After recording a baseline, the diver tracks the cable, using either the cable tracking system (Section 5.2.3), the BC&PL (Section 2.2.8), or visual observation. Assuming the diver starts at the shore end, he would record his first fix, track the cable until the Y value had decreased by 100 feet, then record the next fix. This method (measuring a 100-foot change in Y value) does not estimate the length of the cable. If needed, the length of the cable can be computed assuming a straight cable between fixes using:

$$\text{Cable Length} = \text{Sqrt}[(X2 - X1)^2 - (Y2 - Y1)^2]$$

This would continue until the baseline was crossed (i.e., 3,000 feet of the cable had been surveyed). Once the baseline had been crossed the fixes would be recorded based on increasing Y values. After 6,000 feet, the reference stations would have to be moved seaward 6,000 feet and resurveyed.

**4.4.8.3 Marking the Cable When the Cable is Visible.** In all portions of the track where the cable is visible, a permanent brass tag will be placed at each of the 100-foot stations. These tags, shown in Figure 4-18, will be provided by

NFESC Code ESC55 in packages of 1 to 60. The tags will assist a returning diver in relating his physical position back to the chart. Should there be more than one cable at a particular site, a 1/4-inch hole will be drilled in the corner of one set of tags to differentiate one cable from the other. Should three cables be on-site, two holes will be drilled in the third set and so on. The tags will begin with the zero tag placed as close to the intersection of the cable with mean sea level as the surf will allow, and then increase numerically as the cable progresses seaward. Some tags are inscribed with the cable number (i.e., "BS S-Y" or similar).

Along with attaching the tags at each station and taking a DNS fix, the bottom type and water visibility will be recorded on the diver's slate. The DNS depth sensor is in the receiver, thus the diver should ensure that he is either prone at the tag, kneeling at the tag, or standing at the tag when the fix is taken, and that he follows the same procedure at each tag. The fix number and tag number should be recorded on the slate. Should the cable be more than 3 feet off the bottom, the height of the cable should be noted.

If the cable appears to be buried in the bottom for its entire length, the assumed path of the cable will be searched out to a depth of at least 60 feet. This will be done to see if the cable appears at some short lengths at certain spots. If the cable appears, its position will be surveyed and the standard depth/visibility information taken. The search can be conducted by starting at the shore end, just beyond the surf zone, and moving up the beach (increasing X) 50 feet, then moving offshore (decreasing Y) 100 feet, then searching down the beach (decreasing X) by 100 feet. As the survey proceeds offshore, the distance up and down the beach can be increased to produce a fan-shaped survey.

It should be noted that in cases where the cable is buried less than 6 inches, its path may be followed by probing the bottom with a knife or rod or by using the cable tracker as discussed in Section 5.2.3.

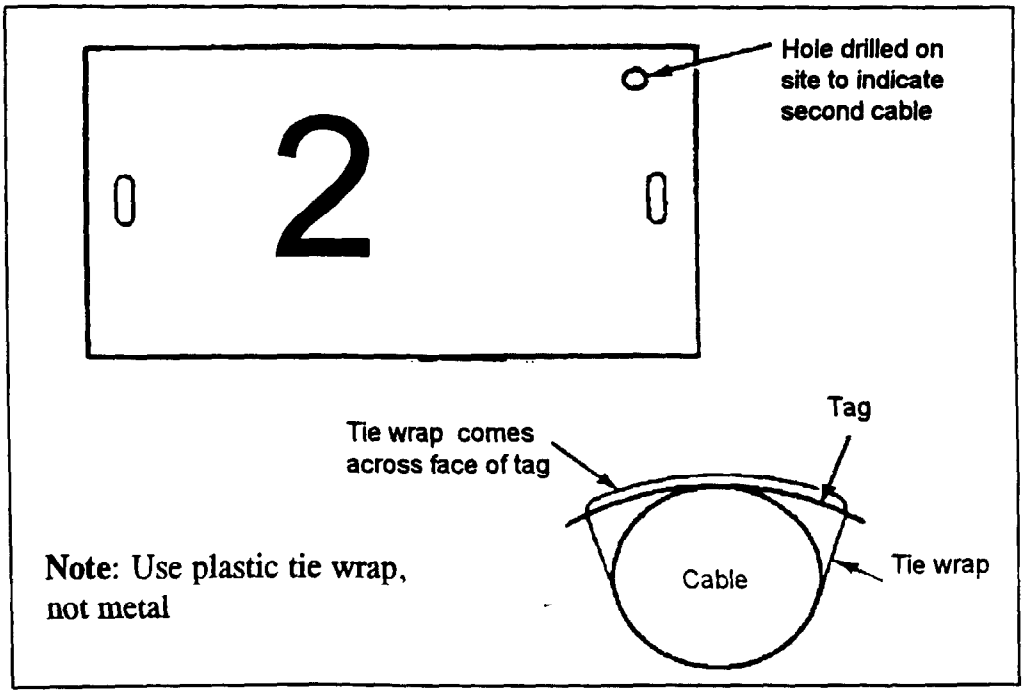



Figure 4-18. Brass identification tags.

## 4.5 PRESENTATION OF SITE SURVEY RESULTS

The format used for reporting the results of bathymetric surveys is usually a map. The most effective map is one that is clearly drawn and annotated. The drafter of the map should keep in mind that others will be needing the map for various purposes. The map should be large enough to include all pertinent information but not so large as to become difficult to handle in the field. Figure 4-19 is a typical map made from a UCT bathymetric survey. The datums used for the survey and the location and elevation of all benchmarks used should be clearly indicated. The relationship of the datum used to any other datums in the area, if known (e.g., MSL, MHW, MLW), should also be indicated. It is sometimes advantageous to plot findings as overlays to maps made by the National Ocean Survey or similar agencies; this will eliminate the expense of making an entire map and will also make the information transferable to any standard map.

The raw data should be reduced and processed to create field working plots so that any missing information can be obtained, and conflicting or erroneous data corrected before leaving the site. The raw data should be included in the final report along with reduced data and maps.

The bathymetric information along a proposed cable or pipeline route is often presented as a profile showing depth as a function of distance. The vertical scale should be about 10 or 20 times the horizontal scale, as shown on Figure 4-20. When slopes are critical, it is advisable to show the critical slope at the plot scale as part of the legend.

The results of visual surveys are usually presented in the form of a brief report describing the findings with relevant photographs attached (NFESC has a procedure to embed digital photos into AUTOCAD drawings, this is a good way to file the photos). The report is usually issued as an attachment to the bathymetric survey results.

The results of geophysical surveys along a cable or pipeline route are generally presented as a projected profile of seafloor soil material classification and pertinent properties versus elevation along the route. The vertical scale is usually 10 or 20 times the horizontal scale, as shown in Figure 4-21.

The results of location surveys and quality control surveys, as well as the other surveys described above, should be presented in a project completion report. A sample outline for a typical project completion report is given in Section 1.7.

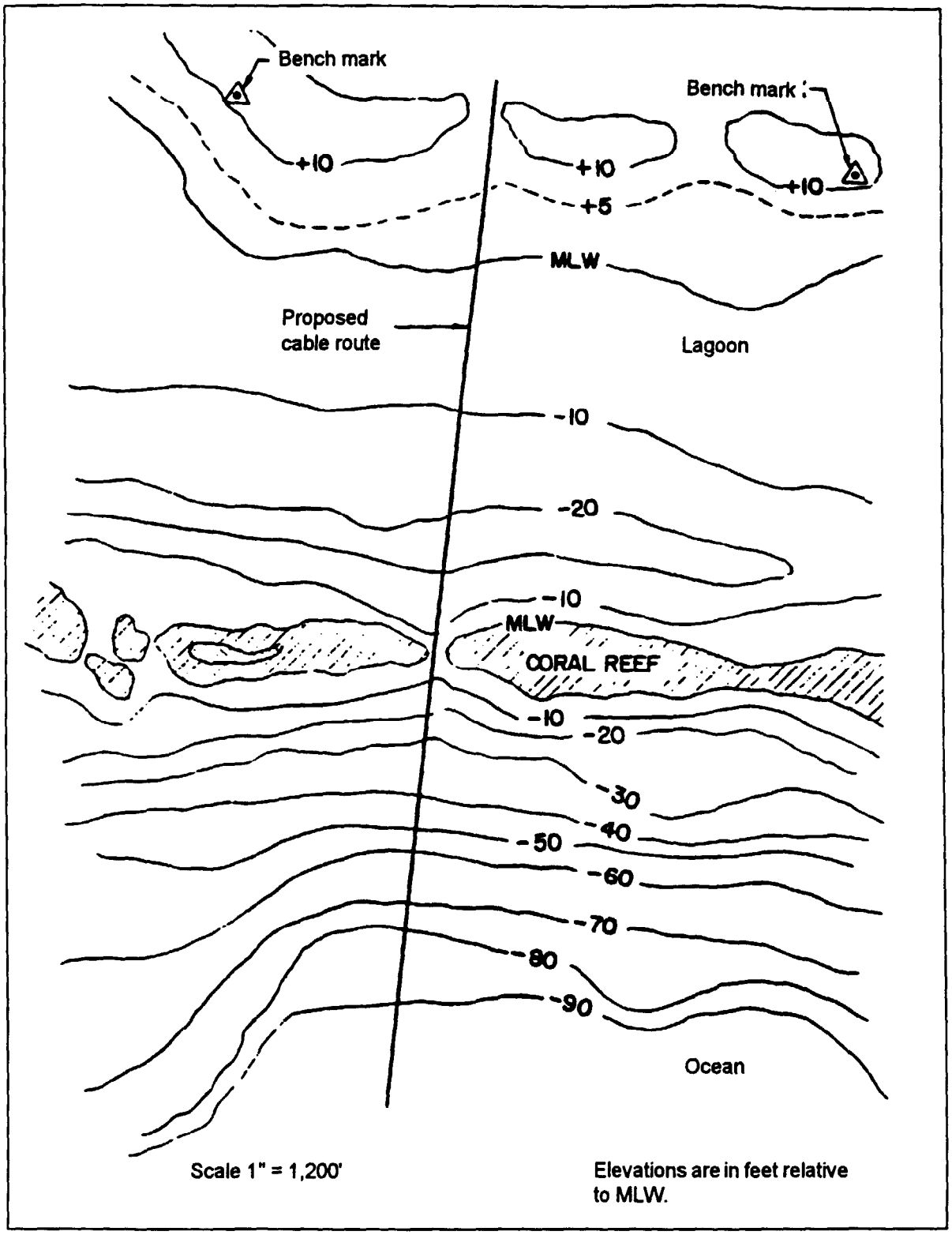



Figure 4-19. Typical bathymetric survey map.

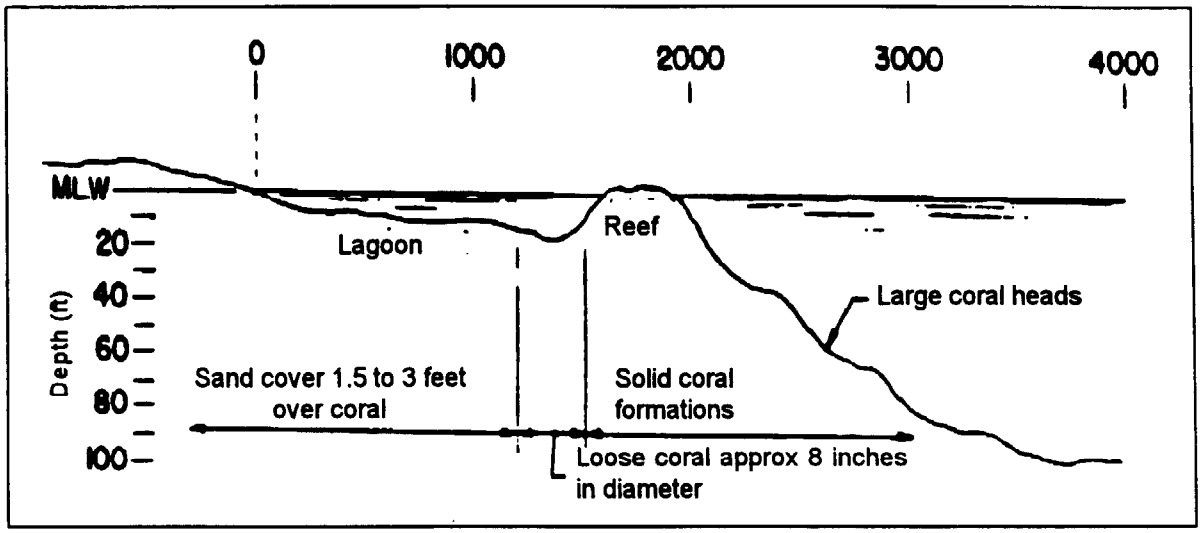



Figure 4-20. Typical bathymetric survey route profile.

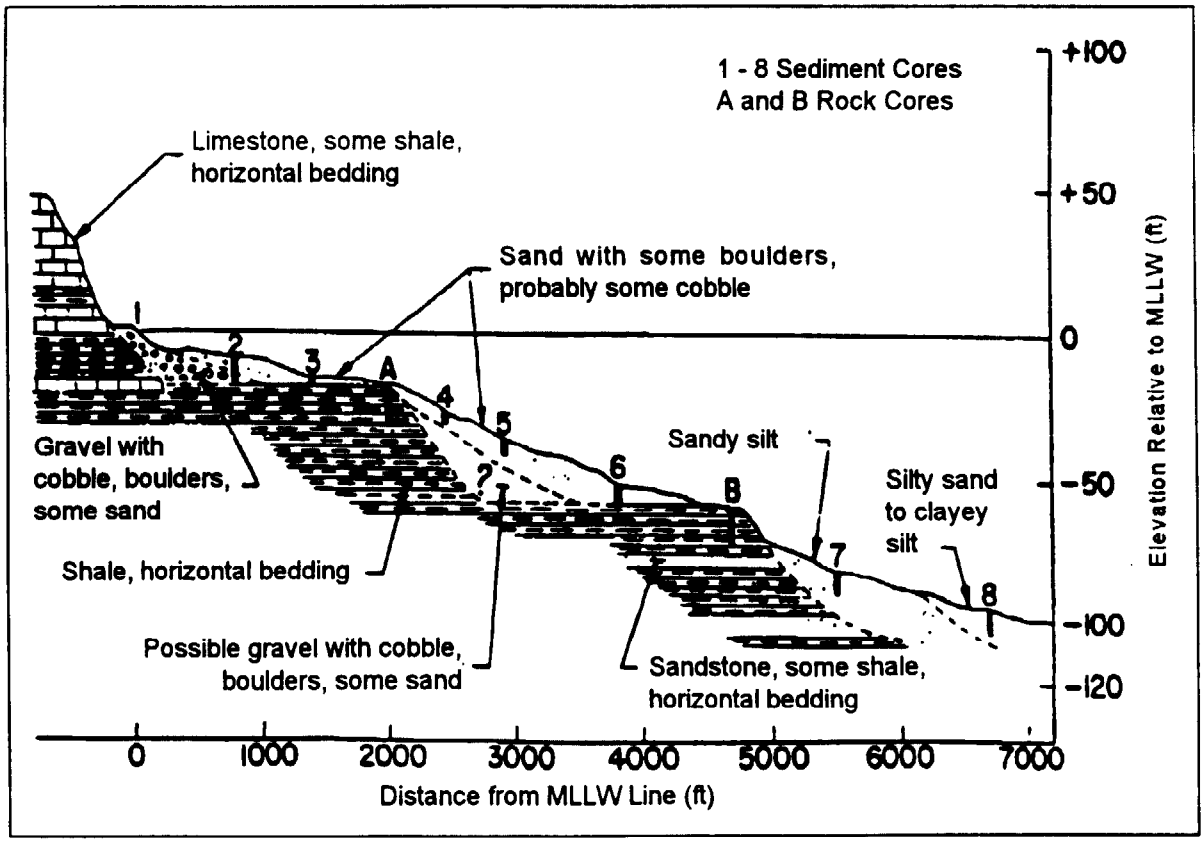



Figure 4-21. Typical geophysical survey route profile.

# Chapter 5

# UNDERWATER MAINTENANCE AND REPAIR PROCEDURES

## 5.1 SCOPE

A major area of work performed by the UCTs is related to the maintenance and repair of facilities in the marine environment. Typical tasks involve maintenance and repair of cables, pipelines, fleet moorings, pile and sheet pile structures, cathodic protection systems, and scour protection. Maintenance consists of checking and keeping in good repair the various systems or combinations of systems designed and installed to protect a facility when it was originally built. Repair consists of restoring the facility to its original condition, or a predetermined lesser condition, after deterioration has taken place, or restoring or replacing the original protection system.

General techniques for most of the maintenance and repair operations with which the UCTs would be tasked are described in this chapter as follows:

- Section 5.2 - underwater cables
- Section 5.3 - underwater pipelines
- Section 5.4 - fleet moorings
- Section 5.5 - steel piles
- Section 5.6 - steel sheet pile structures
- Section 5.7 - concrete piles
- Section 5.8 - concrete sheet pile structures
- Section 5.9 - timber piles
- Section 5.10 - timber sheet pile structures
- Section 5.11 - cathodic protection systems
- Section 5.12 - scour protection

Remember that each maintenance and repair task can vary from those described in the above sections and may impose unique circumstances. Therefore, the final techniques used must be determined by the personnel familiar with the particular operation on a case-by-case basis.

For each of the maintenance and repair tasks described in this chapter and normally carried out by the UCTs, a table is provided that presents specific characteristics of:

- A typical task
- Size of crew needed

- Any special training the crew may require
- Expected productivity of the crew
- Equipment required
- Materials required
- Potential problems that may be encountered.

The **"Description of Task"** presented at the top of each table describes the characteristics of a typical unit of work within a major maintenance or repair project. It is intended to cover the "worst case" (i.e., a situation where the full range of materials and equipment will be required). In actual practice, a particular task may not require some of the materials and equipment listed. For example, for the repair of a steel pile by concrete encasement, the task description in the table states that the pile will be encased from 1 foot above the high waterline to 2 feet below the mudline. If the actual task did not require the encasement to extend below the mudline, a jetting pump would not be required and the productivity of the crew would be somewhat higher.

As for the personnel requirements, Section 1.5 describes the assumptions made regarding the size and training of the crew. The productivity of the crew is based on a UCT detachment with average experience and capability working under good conditions and the assumption that the described task is a typical one in a project that requires a number of the same tasks.

The tables include a list of potential problems to show the need to be prepared for contingencies. The lists contain only those problems, related directly to the task, that have been experienced and reported in the past; they do not completely list all problems that may arise. The UCT detachment must be prepared to cope with all contingencies, particularly when at a remote site.

For successful operations, it is essential for the UCT detachment to be prepared for specific site conditions. Section 1.4 lists the information about the site that should be obtained before deployment. Other useful information is provided in Appendix C.

## 5.2 CABLES

### 5.2.1 Electromechanical Cables

The UCTs will be involved with the maintenance and repair of nearshore cables that connect deep-sea cables, offshore platforms, or underwater devices to onshore terminals. The types of underwater electromechanical and signal cables usually encountered are listed in Table 5-1 and illustrated in Figure 5-1.

Undersea cables are subject to many hazards, such as anchor-inflicted damage, storm surf/surge, trawler fouling, scouring, ice, marine organisms, and earth-mass movements. Drag anchors can be a hazard to undersea cables because of the chance of an anchor being pulled across a cable and damaging it. Trawler fouling should be considered in areas of heavy industrial fishing.

Scouring is the removal of the ocean floor soils by currents or wave action, which may decrease the depth of burial of the cable, exposing it to abrasion by gravel and sand.

Ice is a hazard to undersea cables because of the possibility of floating ice scouring the seafloor and hitting the cable and of ice encasing an inshore cable and dislodging it when the ice mass shifts.

Marine organisms are mainly of concern because of the detrimental effect of marine

growth on metal connectors and anchors.

Earth-mass movements (earthquakes) are cause for concern because a significant shift or change in the sea bottom topography could crush, kink, or bury a cable and cause it to fail.

### 5.2.2 Fiber Optic Cables

Some examples of fiber optic cables are summarized in Table 5-2 and Figure 5-2. The differences between fiber optic or electro-optic cables and conventional electrical cables are primarily internal. Fiber optic cables contain one or more small glass fibers that serve as the signal carriers. An optical fiber is essentially a guide for light waves. The glass fiber has a core that keeps the light totally internally reflected as it bounces down the fiber.

Optical fibers provide a lot more communications channels for a given cable size than coaxial leads or twisted pairs.

In most cases, fiber optic cables look and handle just like their conventional all-electrical counterparts because the electrical power conductors and mechanical strength components remain unchanged. For cables larger than about 1/2 inch in diameter, the presence or absence of optical fibers inside makes virtually no difference in the cable's external properties. In fact, in most cables the optical fibers are encased in metal tubes or layers of wires so they behave very much like just another electrical conductor. Hence, cable tracking and handling is basically the same as an electrical cable of the same size.

The three conditions under which fiber optic cables must be treated differently from electrical cables are when:

- The cable has a very small diameter
- Splicing
- Testing

In some cases, fiber optic cables are used in systems without any electrical power at all. In those cases, the cables can be as small as 0.050 inches in diameter (unarmored, for deep water applications). Even the shore cables are typically only about 0.500 inches in diameter. These cables have working loads ranging from about 2,000 pounds to as low as a few hundred pounds. They are installed from small craft or even aircraft. They may be pulled ashore by hand or with small vehicles (instead of the large bulldozers or other construction equipment needed for heavy armored cables).

Splicing fiber optic cables requires special tools and very clean operating conditions. A fiber optic fusion splicer is required, plus molding equipment to restore any buffer materials and associated electrical conductors. Fiber optic cables generally are spliced only at the factory or aboard cable ships. However, some smaller cables can be spliced in the field. There are no standard splicing kits or methods available to the UCTs; each new cable requires its own splicing methods and those are provided by the system developer.

Testing a fiber optic cable requires, in addition to the electrical tests normally performed, an Optical Time Domain Reflectometer (OTDR). The OTDR sends a light pulse down the fiber and looks for reflected signals that indicate damage to the fiber. This test requires a specially trained technician or engineer. Cable ends should be capped when performing OTDR tests.

> **CAUTION**
> **While the laser used in this instrument is not particularly high power, avoid direct beam contact with the eyes.**

Table 5-1. Communication Cables

| Cable Type | Overall Diam. (in.) | Armor Diam. (in.) | Air Weight (lb/ft) | Water Weight (lb/ft) | Breaking Strength (1,000 lb) | Bending Radius (ft) |
|---|---|---|---|---|---|---|
| SD Coax: | | | | | | |
| List 1 | 1.25 | none | 0.87 | 0.32 | 17.0 | 3 |
| List 3A | 2.21 | 0.3 | 5.27 | 3.54 | 56.4 | 3 |
| List 4A | 2.72 | 0.3 | 7.26 | 5.26 | 48.5 | 3 |
| List 5A | 3.5 | 0.3 | 14.7 | 11.4 | 168.9 | 3 |
| SB Coax: | | | | | | |
| AA | 2.67 | 0.3 | 9.2 | 7.0 | 130.0 | 3 |
| A | 1.83 | 0.3 | 4.1 | 2.8 | 42.4 | 3 |
| General Range Cable (0.057/ 0.180 ) | 1.07 | 0.04 | 0.24 | 0.09 | 4.0 | 3.5 |
| Harbor Defense Type 203 | 1.6 | 0.13 | 2.4 | 1.5 | 15.0 | 3 |
| 21 Q AA | 4.41 | 0.3 | 20.6 | 13.9 | 230.0 | 5 |
| 21 Q A | 4.04 | 0.3 | 11.0 | 7.6 | 102.0 | 5 |
| 21 Q D | 3.12 | 0.11 | 5.2 | 2.8 | 120.0 | 5 |

**Note:** The information provided in this table may not be accurate for all installations. Variations exist depending on the particular installation site. The user should verify this information if conducting a detailed analysis or design.

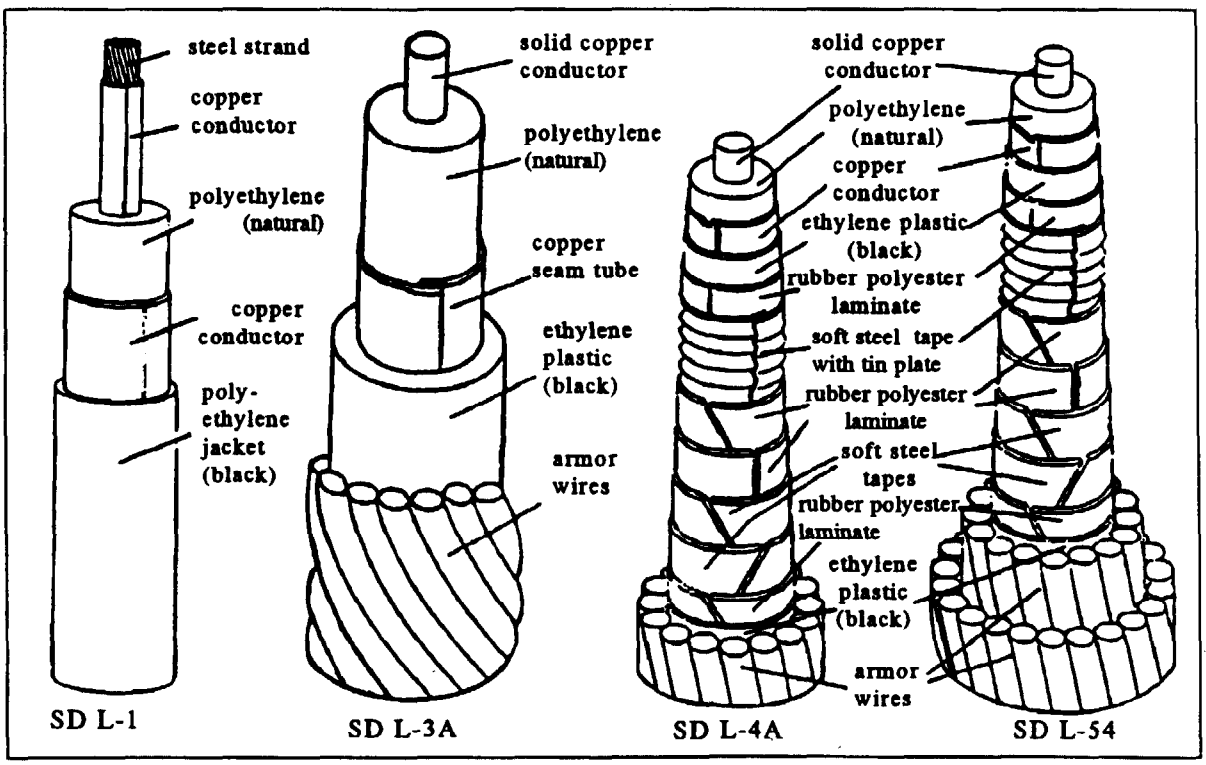



Figure 5-1. Typical communication cables common to UCT operations.

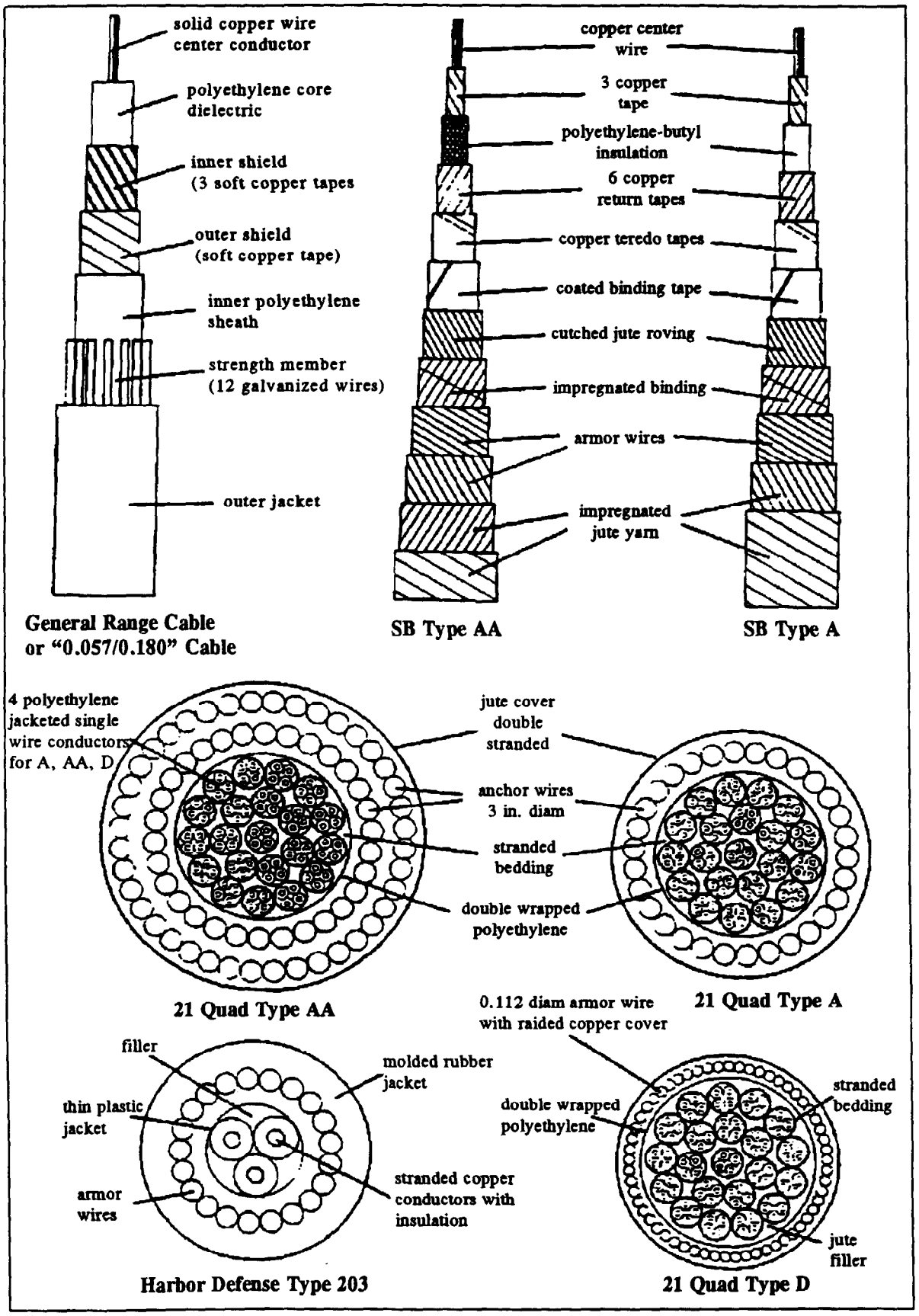



Figure 5-1. Typical communication cables common to UCT operations (continued).

Table 5-2
Fiber Optic and Electro-Optic Cables

| Cable Type | Overall Diam. (in.) | Air Weight (lb/ft) | Wet Weight (lb/ft) | Breaking Strength (1,000 lb) | Bending Radius (ft) |
|---|---|---|---|---|---|
| FDS Deep Water Truck | 0.525 | 0.237 | 0.159 | 8,000 | 1.75 |
| FDS Light Armor Tank | 0.910 | 0.890 | 0.610 | 57,000 | 1.75 |
| FDS Medium Armor Tank | 1.84 | 3.8 | 2.8 | 60,000 | 3.0 |
| FDS Heavy Armor Tank | 2.66 | 8.9 | 6.5 | 120,000 | 5.0 |
| ARIADNE/ADI Shore | 0.50 | 0.278 | 0.191 | 18,000 | 2.0 |
| ARIADNE Trunk | 0.093 | 0.00848 | 0.00539 | 600 | 1.0 |

In general, fiber optic cables can be handled, installed, and stabilized by existing UCT technology. However, each new fiber optic cable system is still a new experience and is usually part of some developmental system. The installation will be supported by technical personnel from Navy laboratories or contractors to provide any special guidance required.

### 5.2.3 Cable Tracking and Fault Location

To determine the cause and location of a cable fault, it is necessary to locate the existing cable route. The first step is to research the as-built drawings to determine the installed cable route. Past history has shown that as-built information is, at best, sketchy and, in many cases, nonexistent. Cable location surveys should be conducted with the procedures described in Section 4.4.8. In locating and surveying the cable, some success has been achieved through the use of magnetometers. For example, the buried pipe and chain locator discussed in Section 2.2.8 may be used to track armored cables. A significant problem in the use of magnetometers is that they respond to any magnetic anomaly in the area, resulting in time lost checking on false readings. Another method is the use of a steel probing bar to locate the cable, but this method is very time consuming and costly.

An effective commercially available cable tracking system developed for UCT use consists of a diver-held electronic probe, a shore-based (dry) signal generator, and an underwater signal injector. This system provides the capability to locate the track cables on the beach as well as underwater. It also provides a mechanism to estimate the burial depth of cables. It is considered an "active" system in that it tracks a tone that is specifically placed on the conductors of the cable.

The probe, illustrated in Figure 5-3, is a submersible hand-held electronic device that is designed to detect a 25- and 1,024-hertz magnetic field. Depending on the strength (current level) of the impressed signal, the probe will track exposed or buried cable from about 100 feet away to its

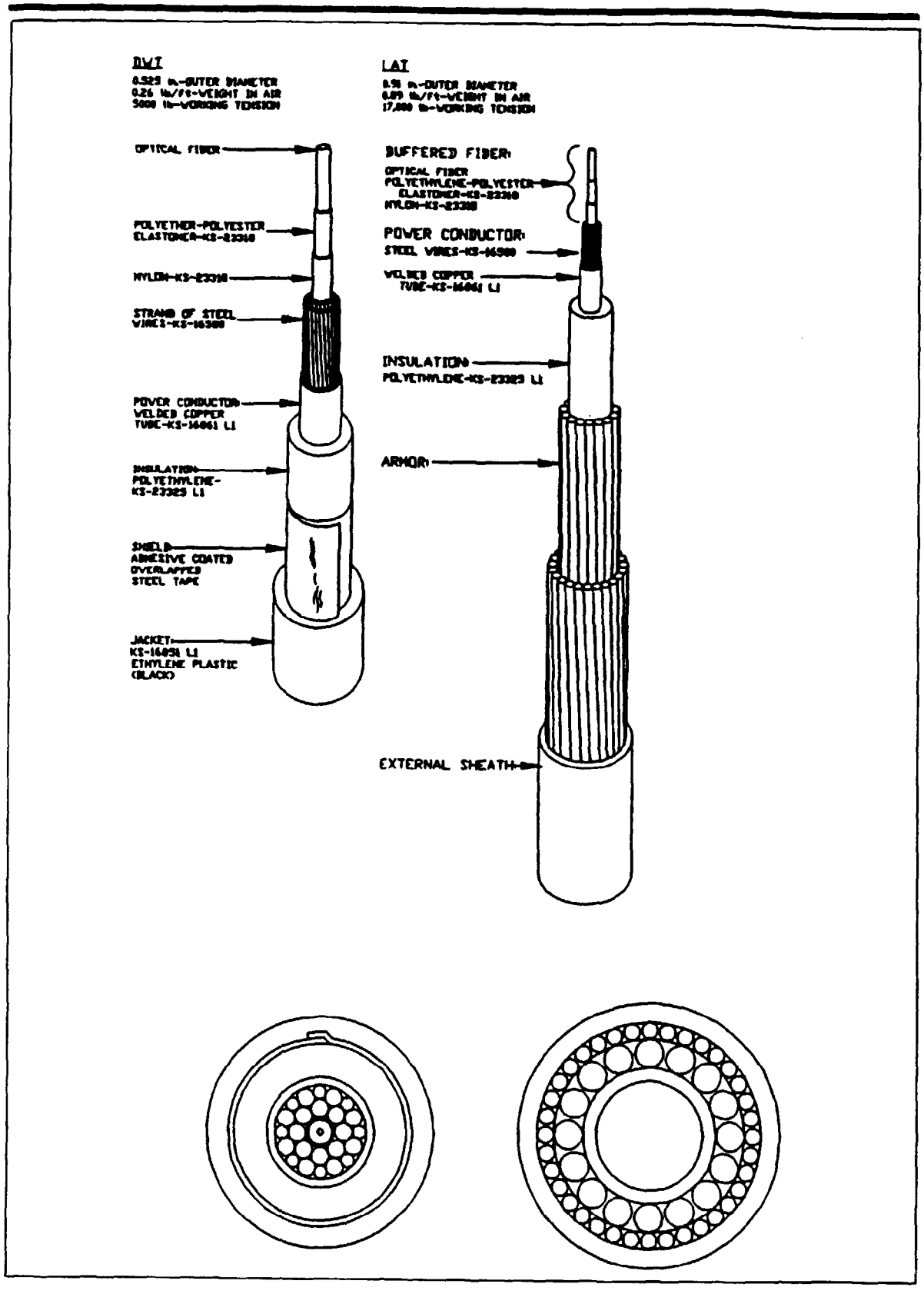



Figure 5-2.
Typical fiber optic cables common to UCT operations.

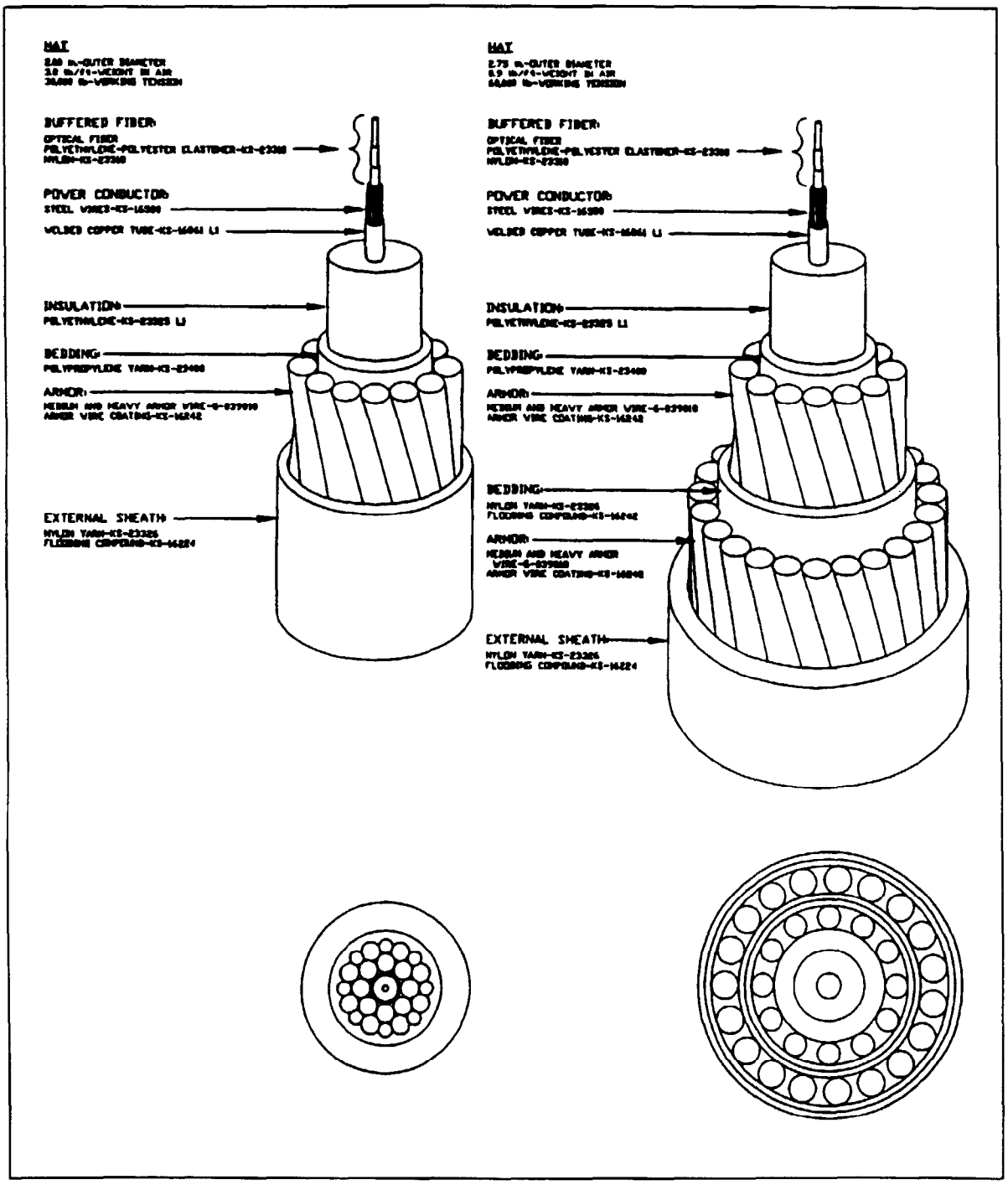



Figure 5-2.
Typical fiber optic cables common to UCT operations (continued).

exact location. The probe may be used underwater, on the beach, or from a vessel. Depending on the strength of the tracking tone impressed in the conductors or the cable, the probe may be used to locate cables in up to 100-foot water depths from the water surface (100-milliamp signal at 25 hertz).

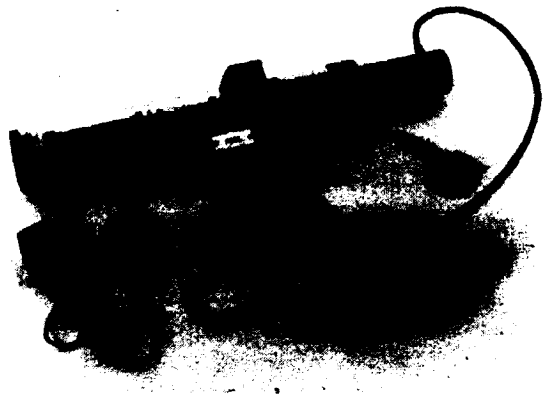


Figure 5-3
Diver-held cable tracking probe.

Detection and tracking of a cable with the probe is accomplished by interpretation of either a meter display (mounted on the back end of the probe) or audible output from a diver ear phone. The primary detection technique used in tracking a cable is called the "null" method (Figure 5-4a). As the probe is brought within range of the cable (with induced signal), the meter deflections (or audible output) begin to increase. When the probe is oriented with its axis directly pointing at the cable, the meter deflections reduce to a "null." Because the "null" is very sharp, this technique can be used to identify cables that are laying within 2 to 3 feet of each other.

The depth of buried cable can be established using the null mode, as shown in Figure 5-4b. A visual marker is placed directly above the cable (this is the position of the vertical null reading). The probe is then rotated at a 45-degree angle to the seabed and backed away from the marker until the probe indicates another null reading. By knowing the horizontal distance between the point of vertical null reading and the point of 45-degree null reading, the depth of the cable can be estimated.

In order to locate or track the cable, an appropriate magnetic field must be impressed onto the cable conductors by either the dry signal generator or the submersible signal injector. The dry signal is generally used to hard-wire either a 25- or 1,024-hertz signal onto a conductor of the cable. Access to the shore end of the cable is required when using the dry signal generator. The submersible signal injector shown in Figure 5-5 is used to inductively couple a tracking tone onto all of the conductors in the cable through a split torrodial core that is hinged together. This system operates at 1,024 hertz only.

Generally, the signal strength required for tracking with the cable can vary between 20 milliamps (when tracking within 10 feet of the cable) to 100 milliamps (for tracking from 70 to 100 feet away from the cable). If possible, it is preferred to operate at 25 hertz since lower frequency signals do not attenuate as fast as higher frequency signals (hence providing increased tracking range with the diver probe).

### 5.2.4 Cable Inspection

Once the cable is located, it should be followed to determine the location and cause of the fault. This can be done visually by divers or by using ROVs. The general location of a fault can also be determined by testing with a cable fault locator instrument, such as a Time Domain Reflectometer (TDR) (available in the OCEI).

It is important for the diver inspector to document the extent and position of all damage and potential situations which may pro-

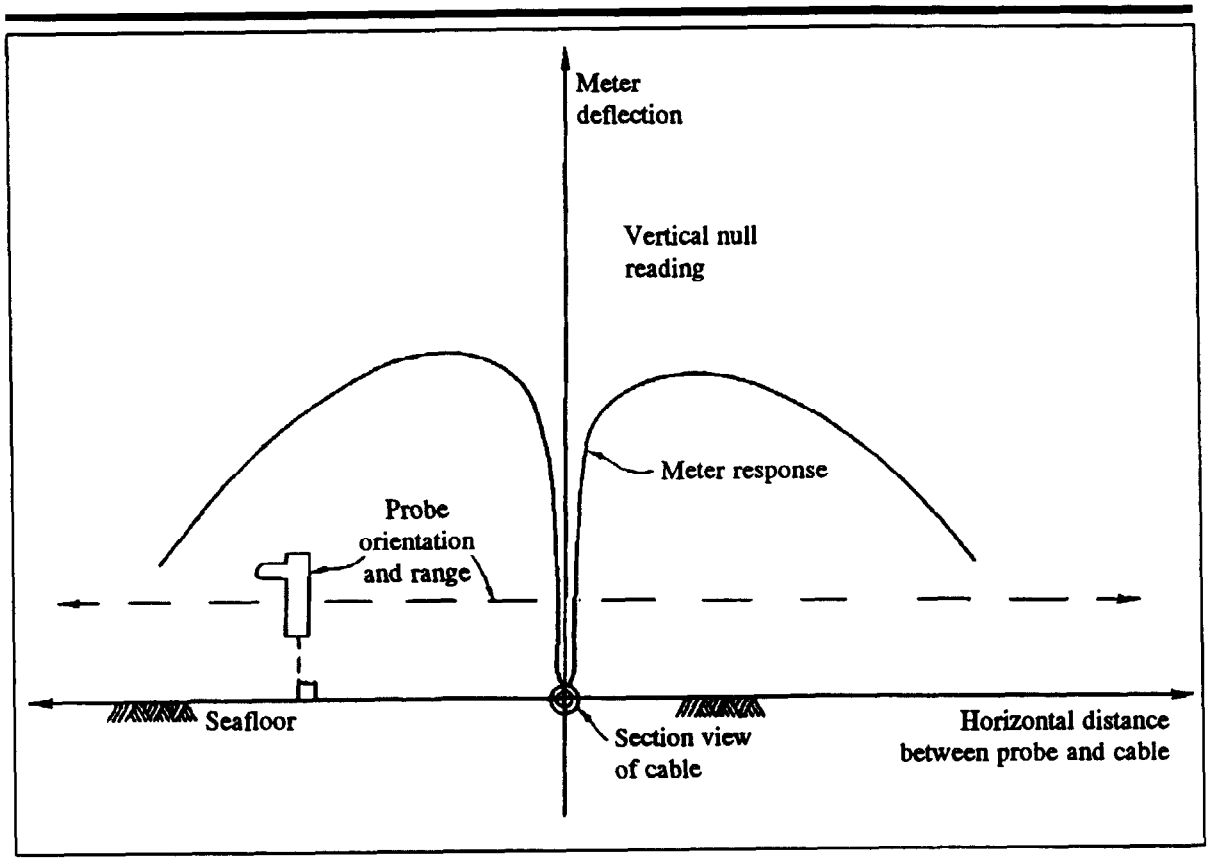



Figure 5-4a. Null technique for tracking with the diver probe.
**Note** that the probe is held vertically.

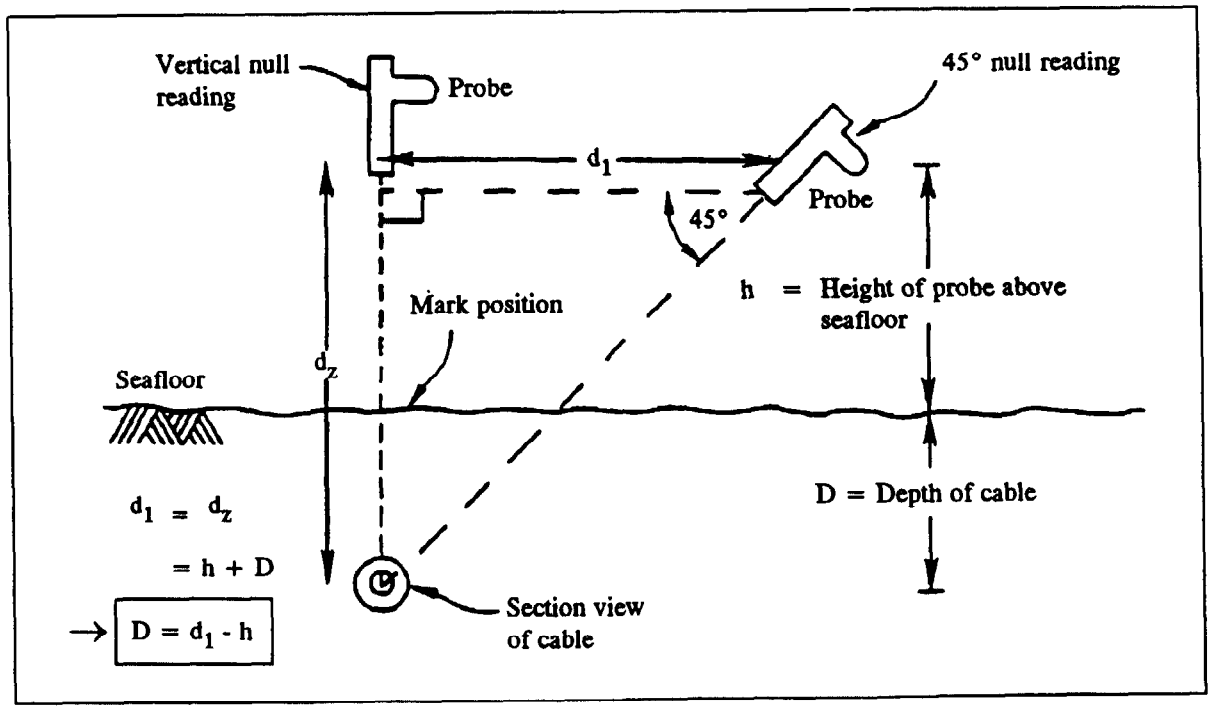



Figure 5-4b. Estimating the buried depth of cables.
**Note** that probe is rotated from vertical to 45° from vertical.



Figure 5-5. Submersible cable injector can be used either on land or underwater.

duce future damage (such as suspensions and abrasion). This will provide a comparison basis for future surveys. Table 5-3 provides a summary of the most significant abnormal conditions that should be observed and recorded during the cable inspection. Other specific information may be requested by the customer or on-site engineers. Measurements and other information desired for specific conditions are listed in Table 5-4. The information is the same for both electromechanical and fiber optic cables.

In some cases the cable inspection may involve underwater junction boxes and instruments where cable terminations or connectors may be installed. Terminations should be inspected for the conditions shown in Figure 5-6.

Some **considerations for cable surveys** include:

- Tag and record the position and condition of all abnormal situations, even though they may not have been specifically requested by the sponsor (Section 4.4.8.3).

- Provide video and/or photographic and written documentation. Provide coverage from all possible angles. It helps to have a size reference such as a hand or ruler in the photo/video documentation. The number tag should be visible in the documentation.

- Include position using the Diver Navigation System (fix number) or other positioning and tagging procedures as described in Sections 4.4.2 and 4.4.8.3.

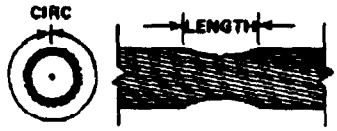
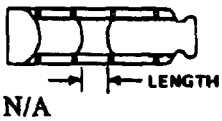
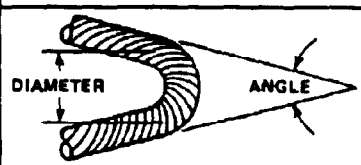
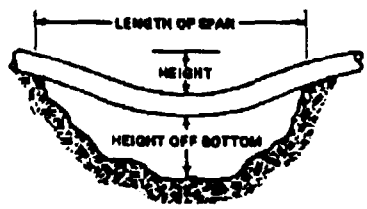
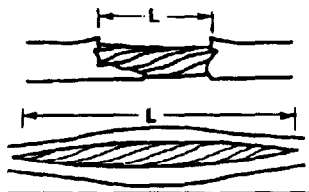
- Inspect all bolts on split pipe sections for condition and tightness, look for damaged or separated split pipe sections.

- Physically verify that all stabilization anchors are holding and not loose or have broken free of the seafloor. Check the stabilization system for corrosion of the bolts or brackets. Some anchors will have an-

Table 5-3
Matrix of Observations - Cable Inspection Survey -
Observation of Condition of Cable System

| Cable | Abrasion Protection System | Immobilization System | Cathodic Protection System | Environment | Junction Terminations of Cables |
|---|---|---|---|---|---|
| Extensive damage to outer coating<br><br>Deterioration of armor wires<br><br>Broken armor wires<br><br>Broken cable<br><br>Sharp bends<br><br>Suspensions<br><br>Kinking or birdcaged armor<br><br>Protruding cable core<br><br>Buried cable<br><br>Amount of marine growth<br><br>Evidence of non-wave-induced loads<br><br>Large deviation from expected track of cable | Deterioration of abrasion protection material (corrosion or abrasion)<br><br>Loose nuts and bolts<br><br>Missing nuts and bolts<br><br>Evidence of non-wave-induced loads<br><br>Missing or separated sections<br><br>Amount of marine growth<br><br>Location of the end of the split pipe protection | Missing of bent fasteners<br><br>Long spans without fasteners<br><br>Deterioration of clump anchors or fasteners<br><br>Movement of anchor<br><br>Movement of cable between fasteners<br><br>Loose fasteners<br><br>Uncovering of trenches<br><br>Missing concrete or rock overburden on trenches<br><br>Damaged or missing rock-bolts or U-rods | Missing or damaged anodes<br><br>Overall reduction of anode size<br><br>Pitting of anode<br><br>Amount of marine growth<br><br>Poor contact of anodes<br><br>Condition of "jumpers"<br><br>Inorganic fouling of anodes | Evidence of major wave action<br><br>Presence of natural or man-made debris<br><br>Evidence of seismic action<br><br>Evidence of local fishing<br><br>Abrupt change in amount of marine growth in area of cable<br><br>Erosion or accretion of sediment along cable<br><br>Presence of ice scours tracks | Termination of cable stopper<br><br>Condition of termination<br><br>Damage to wire or out near termination or junction<br><br>Sharp bends, kinks |

Table 5-4. Damaged Cable Observations

| Discrepancy | Tolerance | Measurement to be Taken | Illustrations | Photo Required |
|---|---|---|---|---|
| Broken armor wires | 0 | Number of wires |  | Yes |
| Abrasion of:<br>a. Cable | ±5% | Circumference | a.  | Yes |
| b. Split Pipe | ±5% | Length | b.  | |
| c. Rock | ±5% | Width, length | c. N/A | |
| Corrosion | N/A | N/A | N/A | Yes |
| Bends/Kinks | ±5% | Diameter or angle subtended |  | Yes |
| Missing/loose split | 0 | Number of sections loose | — | Yes, as appropriate |
| Missing/loose nuts | ±5% | Number of bolts | — | Yes, as appropriate |
| Birdcaged armor wire | ±5% | Circumference length |  | Yes |
| Suspension | ±5% | Length of span<br>Height<br>Height off bottom |  | Yes |
| Dog leg | — | Angle subtended |  | Yes |
| Jacket damage | ±5% | Length of damage |  | Yes |

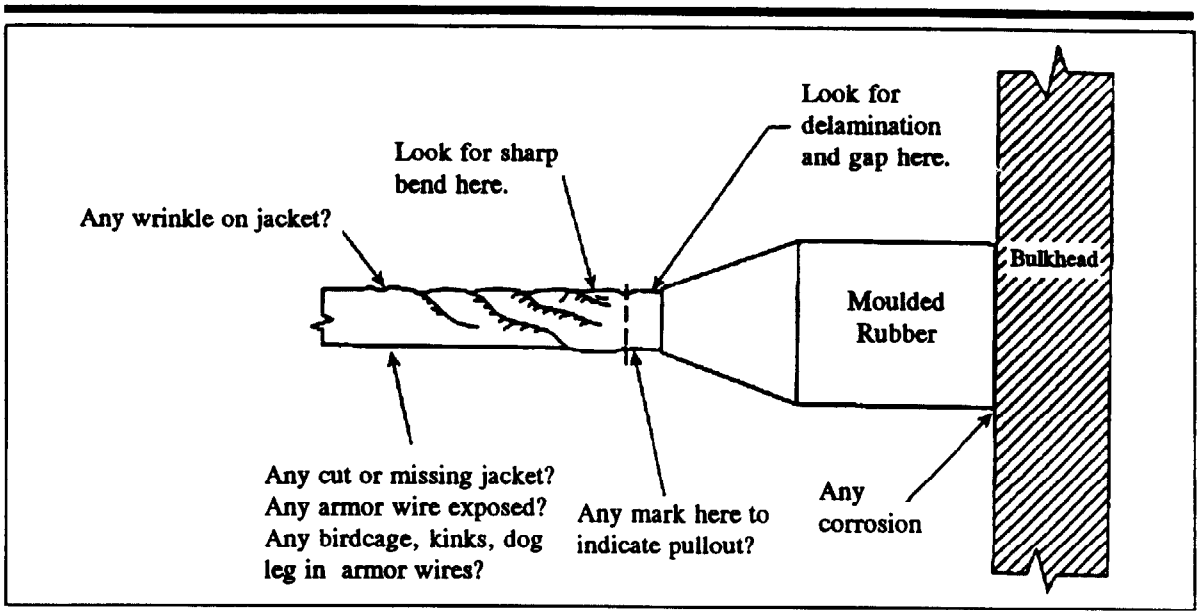



Figure 5-6. Cable termination inspection guide.

odes installed, these should be inspected as discussed in Sections 4.2.1 and 5.11.

- All locations where cables cross or are wrapped around pipelines or other cables should be checked at the contact interface for abrasion damage. If abrasion is present or anticipated then chafing gear may need to be installed. This may require the use of lift bags to separate cables. Ideally, crossing cables should be separated and anchored to prevent further contact. The decision and correction method will depend upon the particular installation and needs to be made by the customer or on-site engineering.

- Look for exterior damage such as cuts, abrasions, missing jacket or jute wrap, broken or corroded armor wires, reduction in cable diameter, and other conditions as described in Tables 5-3 and 5-4.

- Where cables are suspended, check for damage at either side of the suspension. May need lift bags to inspect under the cable.

- Inspect under birdcaged armor to locate rocks or other objects that may be trapped in the cage and abrading the cable jacket. Remove these objects and protect the birdcaged section to prevent further intrusions.

### 5.2.5 Cable Handling

After the fault has been located and its position documented, the cable may need to be raised to the surface so that repair work can be performed. The cable protection method usually dictates the surfacing method to be used. If a cable is buried, it should be unburied by some excavating technique, such as jetting. If the cable is protected or immobilized by a mass anchor system, such as split-pipe, this protection must be removed for an appropriate length to allow surfacing. Split-pipe protection is especially difficult to remove because the bolts used to fasten the two halves of the pipe are often badly corroded. A hydraulic grinder, a nut splitter, a chipping hammer, or an impact wrench can be used to remove these bolts. Diver-controlled lift bags are helpful in raising the protected cable into working position.

Execution plans for cable handling and repair operations are normally prepared by NFESC Code ESC55 in consultation with the UCTs. In most cases, UCT personnel will be directly involved with both planning and conducting the operation.

The information below provides personnel a general familiarity with cable handling for repair operations.

The retrieval, redeployment, and handling of most cables require a well thought-out plan that must be executed by experienced personnel. Because of the complexity of this operation, it must be planned well in advance to ensure that all support craft, materials, support and operational personnel, and technical representatives for splicing and handling of the cable are on hand at the right time.

**5.2.5.1 Cable Retrieval and Handling.** Cable has a delicate and complex structure and should be handled with care. It should not be loaded beyond its design strength. If a cable is pulled beyond its yielding point, the conductors inside the cable will be permanently damaged. It must not be bent beyond the minimum bend radius specified by the manufacturer. If a fairlead sheave or cable chute diameter is too small and is used under high tension, the cable will suffer both electrical and mechanical damage. Therefore, use as large a fairlead sheave as practical and as light a tension as practical in handling the cable.

Cable also has a limited tolerance to twisting. When such tolerance is exceeded, it will either form hockles or kinks. Both can cause permanent damage to the cable conductors and strength members. Therefore, we should avoid strangling the cable by rotating the bitter end. The exterior jacket is usually made of a soft plastic material which is easily cut and scraped. It is not designed to be dragged over sharp metal edges. When handling the cable, be sure to elevate the cable between support points at all times.

A well-equipped splice barge is required to conduct the cable repair operations and is normally used as the command headquarters for the at-sea cable handling operations. Prior to arrival at the site, the splice barge should be outfitted with all necessary cable handling, lifting, and firefighting equipment, mooring winches, splicing hut, crew facilities, and replacement cable section. The mooring winches, auxiliary line handling and lifting equipment, and all fairleads should be mounted and tested to ensure adequate strength. Since the barge will be moored during the operation, other support craft, such as a small boat and a tug or work boat, will be necessary on continuous or standby status throughout the operation. The replacement cable should be tested for electrical continuity and placed on a powered reel having adequate braking and pulling capability or placed on a puller-tensioner winch.

Before starting cable retrieval, a favorable weather window is required so that splicing operations can proceed uninterrupted.

The splice barge is moved over one end of the cable to be repaired and entered into a four-point moor.

- The existing seafloor cable is cut, capped, and a stopper attached to the shoreward end. The seaward end of the cable is marked with a surface float.

- A retrieval line is attached to the stopper and led to the stern cable chute. The line, fairleads, and retrieval winch must be arranged on deck so as not to interfere with the repair cable track.

• The shoreward end of the cable is raised using the retrieval line and winch to a point where the cable is sound enough to be spliced.

• It may become necessary to haul in short lengths of the cable by securing it with a stopper at the inboard end of the stern chute, cutting the cable, and reattaching the winch line for a new pull.

• The splice hut is placed on station and the retrieved end of the cable is securely stopped off, cut, and placed into the splice hut. The leading end of the new (repair) cable is then pulled into the splicing hut.

**5.2.5.2 Cable Splicing.** A typical splicing operation is performed by specially trained cable splicing technicians assisted by UCT personnel. When the electrical tests of the cable are completed, the splicing operation should start. During the splicing procedure, the cable over the stern should be monitored to prevent excessive loads and the mooring lines adjusted to account for tidal, current, and wind changes. The cable should also be inspected periodically on the bottom by divers to assure that no chafing is occurring.

When the shoreward splice is completed, the splicing hut is moved clear of the cable payout area. Then:

• The cable tension is taken up on the cable payout reel (or winch) and the cable stoppers removed.

• The barge is then moved on its moor along the cable track while cable is payed-out. The splice must be eased overboard and proper cable tension maintained at all times.

• When the barge approaches an appropriate distance beyond the seaward end of the damaged cable, the cable payout should stop.

• The seaward cable is then retrieved in the same manner as the shore end.

• The barge continues about 200 to 300 feet past this point, allowing the seaward end to be brought onboard.

The point to cut the repair cable must be carefully measured, as the payout and pickup of the cables cannot be used to adjust cable tension once the cut has been made. The cut is best made at high tide, with cables below the maximum allowable tension. The cable ends are brought into the splice hut and electrical continuity tests are performed. After the electrical tests have been completed, splicing operations can start as before.

**5.2.5.3 Cable Redeployment.** After splicing operations have been completed, the splice hut is removed and cable redeployment is started.

• A stopper is placed on the cable at the stern of the barge and a hauling line rigged to the line-retrieval winch.

• As the barge is hauled back along the newly installed repair cable, the winch and line pulls the cable up over the stern. This movement must be stopped periodically to relocate the stopper and hauling lines and should continue until the seaward cable splice case is on the bottom.

• A stopper is placed on the bow end of the cable and attached to an auxiliary pendant line.

- Divers in a small boat attach a stopper to the cable at the waterline at the stern end.

- Using the hauling line, winch, and mooring lines, the barge will move astern until both stoppers are just outboard of the cable chutes, at which time the bow line should be stoppered off on deck.

- A cable saddle is then rigged and made ready to receive the cable bight.

- It is necessary to hold the barge against the prevailing wind or current by pulling on the moorings or with the assistance of tugs or workboats, so that the opposite moorings will be under minimum tension.

- The barge is then moved perpendicular to the cable track so that the slack mooring lines can be rigged above the cable. This mooring line transfer can be done by: (1) **running** extra lines over the cable, attaching them to the mooring buoys, and then releasing the old mooring lines; or (2) **stoppering** off the mooring lines on short pendants, removing the ends from the winches and running them over the cable and back onto the winches.

- The repair cable should be made slack by pulling in on the stern hauling line.

- When slack, the cable bight is placed in the cable saddle.

- The cable stopper lines should be lowered into the water, the load of the cable transferred to the cable saddle, and the stoppers removed by divers.

- With the barge perpendicular to the cable track, the cable saddle and bight are lowered to the bottom (this maintains an adequate departure angle).

- When the saddle is on the bottom, the divers remove it from the cable and lay out the slack in a manner to prevent vertical loops and avoid obstructions on the bottom.

If applicable, the cable should be anchored to the seabed using an appropriate anchoring method as described in Section 6.2.2. The barge can then be released from its moorings.

A summary of the operations required for a "typical" cable repair project, with an estimated time required to carry out each operation, is presented in Table 5-5. The estimated times shown in the table are based on good weather and sea conditions. The cable is not anchored to the seabed. The total estimated on-site time required to complete the project is 5 to 7 days.

## 5.3 PIPELINES

Marine pipelines are used for liquid transfer, such as at a petroleum-oil-lubrication (POL) facility, sewer outfalls from treatment facilities, and general utilities, such as gas and water. Pipelines are constructed of such materials as steel, cast iron, concrete, plastic, and aluminum. Undersea pipelines typically are subject to most of the same hazards as undersea cables, including anchors, scouring, ice, marine organisms, and earth-mass movement.

The main disadvantage with steel pipe is its susceptibility to corrosion, which can be counteracted by cathodic protection. Deterioration of the pipe will usually occur if the cathodic protection system is faulty. A sacrificial anode system will fail when the anodes either erode completely or become ineffectively small. A faulty impressed current system is usually caused by broken wires or missing electrical connections.

Table 5-5
Estimated Time Requirements for Cable Repair Operations

| Task Description | Estimated Time Required (days) |
|---|---|
| Stern of splice barge plumbs capped end. Diver attaches retrieving line. Haul splice barge stern as first capped end is hauled up to barge, into chute, and brought into position for splicing. | 1 |
| Maintain fixed position/constant tension on first cable while repair cable splice is made and tested. Haul barge along preplanned track to lay cable on bottom. | 1 |
| Bow of splice barge plumbs capped end. Diver attaches retrieving line. Manipulate cable reel to maintain proper tension on cable to stern. Haul barge to bow as second end is hauled up to barge, into chute, and into position for splicing. Pay out repair cable to suit. | 1 |
| Maintain fixed position/constant tension on second cable while repair cable is cut to suit and while cable splice is made and tested. Haul barge to stern to pass second splice over bow chute, bottom it, and pay out about 50 more feet of the new cable onto bottom sternward from splice. | 1 |
| Maintain fixed position. Rig side mooring legs to pass over cable at both bow and stern. Rig cable saddle over the side of splice barge. Lift cable from chutes and splicing line and place over the side and onto saddle. Rig saddle lowering away gear. Rerig side mooring legs to corners. Haul barge perpendicular to cable track, while at the same time lowering sector, tending away from barge. Divers observe and report lead of cable on saddle. Adjust load on hauling mooring legs to provide required tension at saddle as lowering away continues until saddle bottoms. | 1 |
| When cable saddle bottoms, divers trip cable restraining gear and cable drops from saddle; saddle floats upward. Laying operation completed. Barge breaks moor. | 1 |

Steel pipe sections have flanges on each end to allow a watertight connection to exist between adjacent sections. Shifts in pipe position may cause these flanged connections to come apart, causing a leak in the system. Pipelines that carry fluids having a lower specific gravity than water, such as oil, can incur additional problems. The differences in the specific gravities may cause the pipeline to become buoyant, particularly large-diameter pipelines. Anchoring devices that are used with these pipelines are also subject to deterioration.

Often problems are encountered in locating buried pipelines. A good first step is always to check for any available "as-built" information. Since steel is affected by magnetic fields, a magnetometer can be used to locate the pipeline. As discussed in Section 5.2.3, the information obtained by magnetometers can be misleading. Because of the large magnetic mass of steel pipelines, magnetometers are effective for locating pipelines than for locating cables. The buried pipe and chain locator discussed in Section 2.2.8 is an excellent tool for locating buried ferrous pipelines. A probing bar can also be used to locate the pipeline. A buried pipeline may show up on the image produced by a subbottom profiler, but it requires an experienced operator to interpret the data, and pipelines less than 2 feet in diameter may be difficult to detect.

### 5.3.1 Pipeline Repair Safety

When working on damaged marine pipelines, there is always the potential for injury to personnel and environmental damage. The repair crew should carefully assess the situation before proceeding with repairs. Identify the contents of the pipeline and determine if any of the following hazardous materials or conditions exist:

- Toxic or poisonous to personnel
- Flammable
- Explosive or suffocating
- Environmentally polluting

Personnel working on pipeline repairs involving hazardous materials must have an understanding of the hazards and have adequate personal protective equipment that is in good condition. Where the material carried is flammable or explosive, the pipeline should be purged. One method used involves flushing the pipeline with water before proceeding with repairs. Use caution as water will not remove all hazardous materials.

In general, personnel should not be allowed access to a spill area until the contaminated area has been clearly defined. If the likelihood of public access exists, suitable warnings should be placed and areas cordoned off to restrict access.

For some spilled products, the possibility of an oxygen-deficient atmosphere exists. In these cases, approved respiratory-protective equipment should be available for use.

**CAUTION**

**Where toxic hazards exist that contaminate the surrounding water and are dangerous to the diver, only approved diving gear suitable for the application should be used. Consult the U.S. Navy Diving Manual.**

After hazard mitigation, determine what pipeline repair techniques can or cannot be used. For example, if the pipeline carries explosive or flammable materials then electric-arc or flame cutting and welding should not be used.

The location of other local cables and pipelines should be determined including those that cross each other.

### 5.3.2 Leak Location

The most common result of pipeline failure is leaking of the product. Usually the leak occurs at a bolted or welded connection as a result of pipeline movement, vibration, and subsequent seal damage. Leaks may also occur as a result of corrosion, abrasion, and contact with anchors, trawl boards, and forces from storm surge, etc.

- A substantial leak can usually be located by observing the discharge of the pumped material.

- Gas injected into the fluid stream can provide a stream of bubbles, while leaking water is more difficult to detect. Isolate sections of the pipe and use pressurized air.

- Colored dies can be injected into the liquid stream to help provide a visible trail.

- Metal pipelines buried in bottom sediments may be tracked using the buried pipe and chain locator discussed in Section 2.2.8.

### 5.3.3 Preparation for Repair

Once the damaged area has been located, the next step is to prepare the pipeline for the repair. This includes the following steps:

- Identify pipeline materials since they will dictate the repair method.

- Secure all pumping stations and tag out equipment. If the flow cannot be stopped then reroute the flow or reduce flow to lowest rate.

- If the pipeline contains explosive, toxic, or flammable material, then determine the proper mitigation method for specific material.

- If the pipeline cannot be flushed and it contains flammable or explosive materials, then welding or thermal cutting techniques should not be used because of the danger of explosion.

- Remove all obstructions around the damaged pipe section.

- Measure and draw a diagram of the pipe, identifying damaged areas. Sketches, photographs, and/or videos can help topside personnel assess the damage and plan for repairs. Some commercial repair couplings require reasonably round pipe for an effective seal. Refer to manufacturer's directions. Measurements should include wall thickness and out-of-roundness.

- Clean all marine growth from the pipeline to at least 2 to 3 feet on either side of the damage.

- Cut, grind, or bend protruding material from the damaged area to provide a smooth contour for the patch or coupling.

- For severely damaged pipelines it may be necessary to add new sections of pipe. In this case, remove damaged pipe sections and measure/sketch a layout for a replacement section. Elevation changes as well as horizontal distances and bearings of remaining pipe ends will be needed to fabricate replacement pipe sections.

### 5.3.4 Pipeline Repair

A number of techniques are available to repair damaged pipelines. Selecting the method and the equipment to be used will depend on factors such as: nature of material carried in the pipeline (flammability, environmental compatibility, health hazard); the diameter and material of the pipeline; nature and extent of the damage; site conditions; permanency of the repair; and operating pressure of the pipeline.

Manufacturers of commercial products for conducting pipeline repair are listed in Appendix A. Available repair products vary from simple clamps to complex couplings capable of sealing and tapping into pressurized pipelines. The categories of commercially available **equipment for both land and underwater pipeline repair applications** are:

- *Clamps and Couplings*: Both flexible and rigid clamps for repairing leaks.

- *Misalignment Flanges*: Specifically designed to accommodate angular misalignment.

- *Bolted Couplings*: Gasketed couplings for attachment to pipe and joining pipe sections together.

- *Transition Couplings*: For joining pipes of different diameters, or where there is a separation between pipes.

- *Hot Tap Couplings*: Provide a means of tapping into active pipelines for diverting flow or plugging the line without leakage. Primarily designed for tapping into oil and gas production files.

- *Welded Flanges and Couplings*

- *Compression Flanges*

The discussion below considers the following techniques:

- Expedient on-site fabricated patching techniques.

- Commercial patches.

- Concrete encasement.

- Replacing damaged pipe with new pipe sections.

**5.3.4.1 Clamps and Fabricated Patches** (for minor repair to low-pressure noncritical pipelines). In some applications it may be appropriate to make repairs using patches that are fabricated on site. In most cases these repairs should be considered temporary but may be made more permanent by encasing the patched pipe section with concrete or wrapping with fiberglass tape impregnated with a water-activated resin. Figure 5-7 shows some simplified on-site, fabricated patch configurations.

Any of these techniques may be useful depending on the size of the hole, internal pressure in the pipeline, and required final integrity of the seal.

In all cases the pipe surface to be patched must be thoroughly cleaned of marine growth. Jagged material and protrusions should be smoothed before applying the patch.

- For temporary patches on small holes in low pressure pipes where a seal is not critical, use a clamp or clamps in combination with a patch and an elastomeric gasket or other sealing material such as an underwater setting epoxy.

• The clamp should be a minimum of 1-1/2 inches wide. The repair may be made permanent by encasing the damaged section in concrete as discussed later. Small piping may be wrapped with fiberglass tape impregnated with a water-activated resin (Appendix A). For large diameter pipes, chain binders and wire rope in combination with turnbuckle binders and other cinching mechanisms may be used to hold the patch in place.

• On steel pipelines the most permanent repair is made by welding the patch to the pipe. However, underwater welding requires considerable experience and skill, and is not recommended unless experienced personnel are available. Consult the U.S. Navy Underwater Cutting and Welding Manual, NAVSEA SO300-BB-MAN-010.

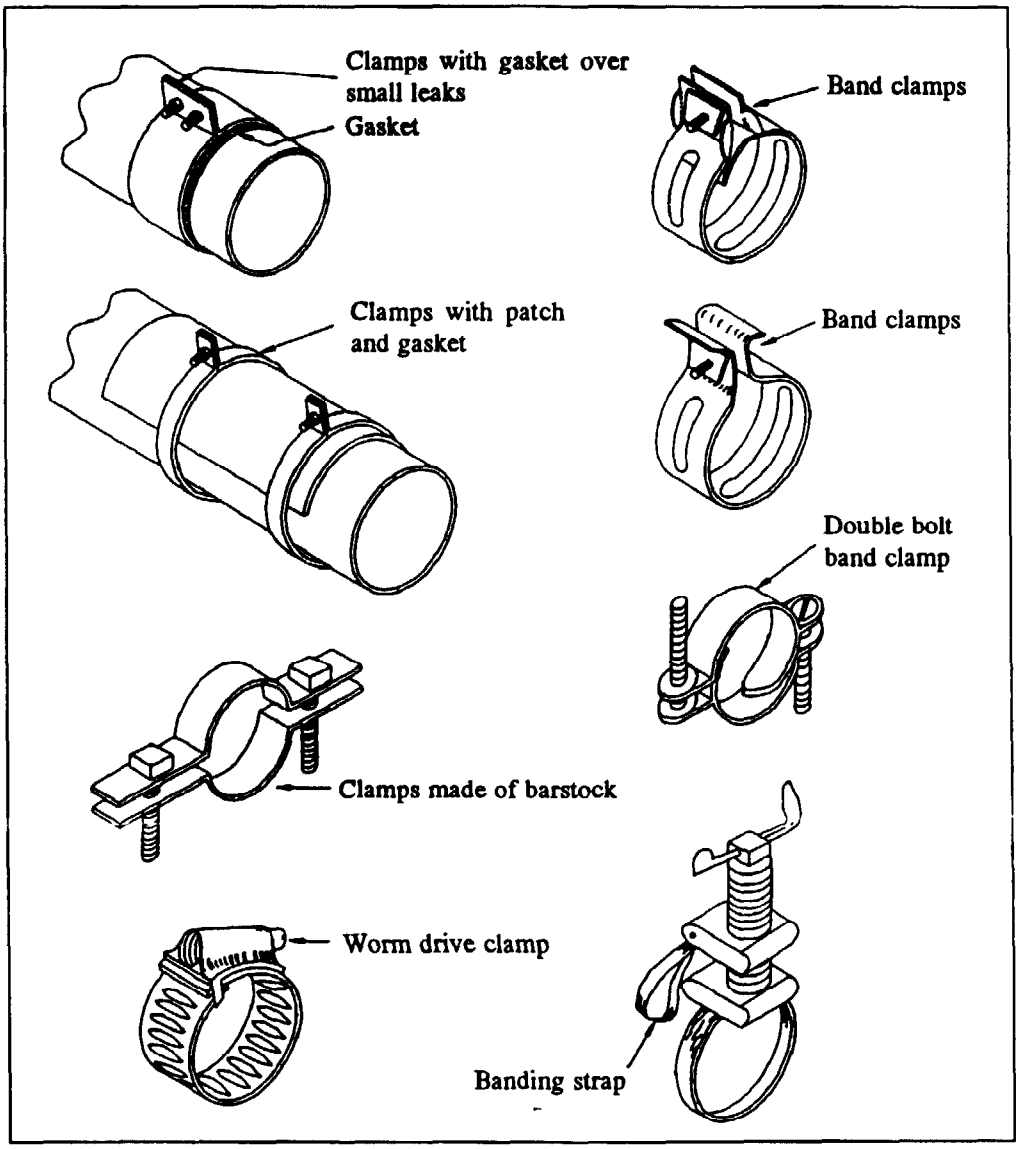



Figure 5-7. On-site patches and clamps used in conjunction with various materials (steel, plastic, etc).

• On metal pipelines, the pipeline repair patches and clamps should be reviewed to determine potential problems with corrosion.

• **Estimating Patch Thickness** - If the steel pipeline carries pressurized gas or fluid then it is necessary to select the thickness of the patch and strength of the clamp or attachment method so that it will not rupture under pressure. The patch should be formed to fit the contour (diameter) of the pipe.

Thickness of a steel pipe patch, either welded or clamped, may be approximated by the following formula:

$$t = (p \times d)/6{,}000$$

where:

t = patch thickness (in.)

p = anticipated pressure in pipeline

d = outside diameter of pipeline

**NOTE**

**Do not use this method for internal pressures greater than 300 psi. Pressures should preferably be less than 50 psi.**

For plastic patches on low-pressure pipes (less than 50 psi), the recommended thickness can be determined from:

$$t = (p \times d)/800$$

• **Estimating Patch Dimensions** - For the situation where the patch is attached by clamps (not welded), the patch must extend far enough beyond the damaged area to provide an effective seal.

The minimum size of a patch (refer to Figure 5-8 ) can be estimated as outlined in Table 5-6.

**5.3.4.2 Commercial Repair Patches.** Commercial pipeline repair products are available through industrial and pipeline suppliers in pipe sizes up to 6 feet in diameter. They are generally categorized by service application such as: gas and air service, private and industrial water, wastewater, and petroleum products. Some of the commercial products are specifically designed for seawater. Couplings are available for pressures to 1,500 psi and others can be fabricated for higher pressure service.

Appendix A provides a list of manufacturers of pipeline repair materials. Manufacturer catalogs specify applications and provide appropriate service information such as size, materials to be transported, and internal pressure.

**CAUTION**

**Take particular care to be sure that the proper repair product is selected when it will be used for pressurized service, natural gas, petroleum, or corrosive materials service. Improper use could cause escaping line content to result in property damage, environmental contamination, and serious injury or death.**

Some examples of commercially available clamps are provided in Figure 5-9 together with repair applications in Figure 5-10. The clamps come preassembled with gaskets for sealing. Some of the clamps such as the utility repair clamp may be used to join the ends of two pipes together.

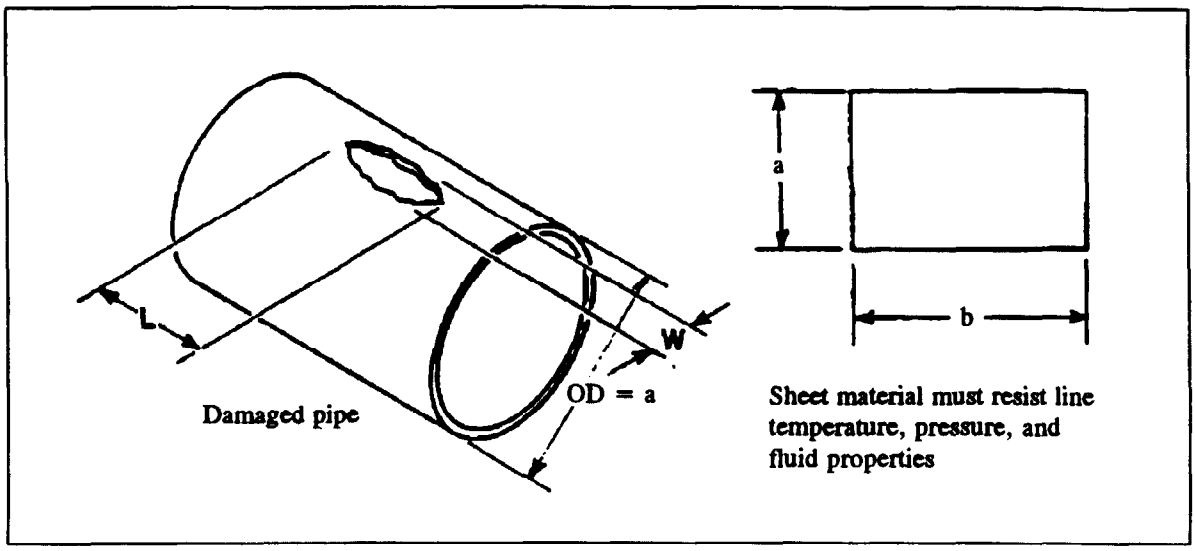



Figure 5-8
Dimensions for using Table 5-6.

Table 5-6
Estimating Patch Dimensions

| Pipe Outside Diameter | Patch Width (a) | Patch Length (L) |
|---|---|---|
| Less than 6 inches | a= OD + w | b = L + 8 |
| Between 6 ans 12 inches | a = w + 10 | b = L + 16 |
| Between 12 and 24 inches | a = w + 14 | b = L + 16 |
| Greater than 24 inches | a = w + 24 | b = L + 24 |

Where: OD = Outside pipe diameter
W = Total width of damage
a = Width of patch
L = Total length of damage
b = Length of patch

**NOTE:** This type of repair should not be used on any pipe that operates at 300 psi or greater, and is bested suited for pressures less than 50 psi. The application and design should be reviewed by engineering where it involves hazardous materials or pressured media.

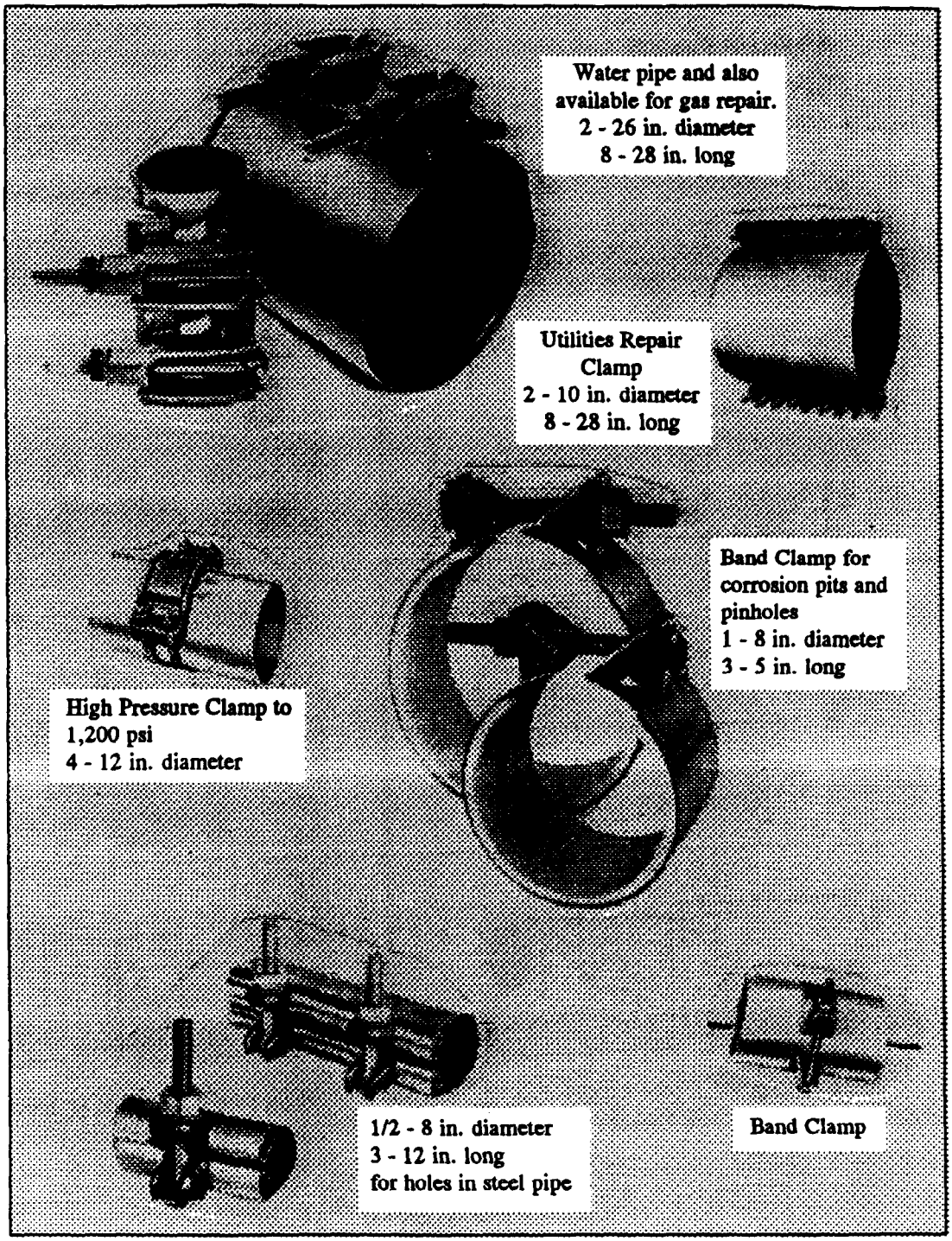



Figure 5-9
Examples of commercially available pipe repair clamps.

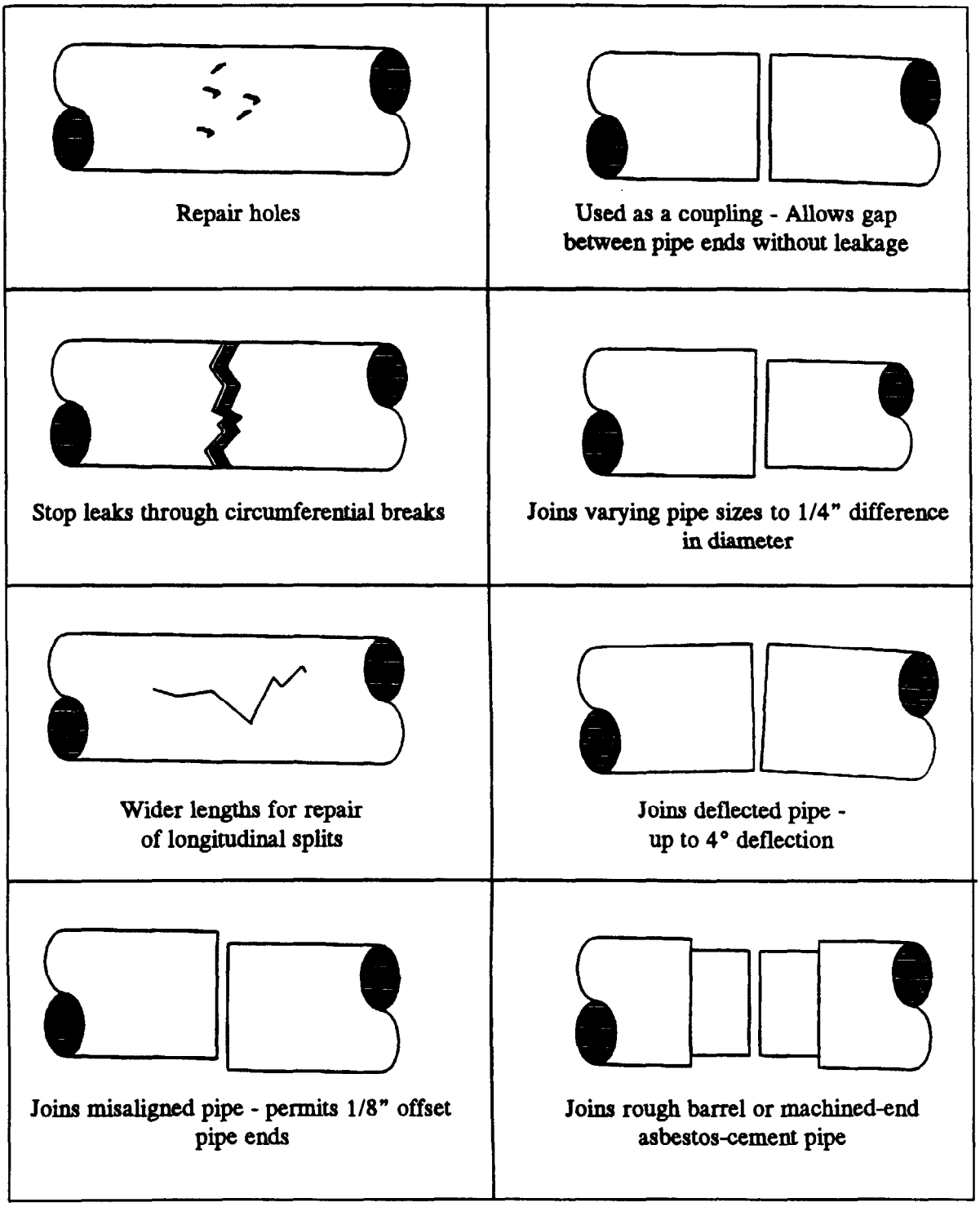



Figure 5-10
Examples of where pipeline repair patches and clamps might be used (steel, plastic, etc.).

**CAUTION**

**Using mechanical clamps to join the ends of two pipes together will require the anchoring of both pipe sections to prevent separation due to vibration, internal pressure, or wave action.**

Preparation of the pipe to receive the patch is the same as for fabricated patches. Marine growth must be thoroughly cleaned from the surface to provide a smooth seal. Be sure to grind and cut off all projections and debris from the surface. Then, follow manufacturer's assembly procedures. Often, pipe coatings made of polypropylene, epoxies, etc., must be removed before using commercial couplings.

**CAUTION**

**For long term use in seawater, the repair materials selected should be reviewed by a corrosion consultant to determine the need for active or passive cathodic protection systems (refer to Section 5.11 of this manual).**

**WARNING**

**Be sure to select a coupling that will meet the pressure and service requirements of the particular application.**

**5.3.4.3 Replacing Damaged Pipe Sections.** When the damage spans a large section making patches impractical or when the alignment of a completely severed pipe prohibits the use of simple couplings, then the following options may be considered:

- Install a new pipeline (see Section 6.3).
- Cut out damaged pipe section and replace with similar pipe and couplings.
- Encase damaged pipe section in concrete (for low psi service).
- Install flexible conduit pipe to replace damaged section.

**Replacing a damaged section involves:**

- Cutting away the old pipe.
- Fabricating a replacement section to fit between the cut ends.
- Joining the sections together.
- Stabilizing the repaired section.

Various methods for cutting the old pipe are discussed in Section 2.2.7, Mechanical Cutting and Section 2.4, Thermal Cutting and Welding.

**WARNING**

**Before using thermal cutting techniques, be sure that the line to be repaired does not contain any explosive or flammable materials.**

An alternative method used for providing precision cuts in pipe is shown in Figure 5-11. The oil hydraulically-powered WACHS cutting machine has been successfully used underwater and is capable of cutting pipes from 6 to 72 inches in diameter. The machine travels around the pipe while a rotary cutter simultaneously cuts and bevels the pipe. Although the tool is generally used for preparing pipe sections for welding, it provides an excellent joint for all types of joining methods. Hydraulically-operated guillotine pipe saws are also available, but they are much heavier and bulkier than the WACHS cutter.

A variety of commercial products are available from several manufacturers for joining the ends of pipe together. Commercial couplings are also available for joining pipes of different diameters as well as for bell-end pipes. Figure 5-12 shows a few commercial joining couplings. Pipe coatings such as polypropylene, epoxies, concrete, etc., will need to be removed prior to using commercial couplings.

The procedures involves the following:

- Cut out the damaged section.
- Cut an insert length of pipe to fit between existing ends.
- Slide coupling components over existing pipe and new insert.
- Slide the insert between pipe ends.
- Assemble and tighten couplings.

Couplings are available for pipes from 1/2 inch in diameter up to 14 feet in diameter. Long versions are available for the case where the ends of the pipes to be joined are widely separated. Most couplings will also accept various degrees of misalignment. Gaskets are available for most pumping materials.

**CAUTION**

**Care must be taken when using pipe couplings to be sure that the joined pipes are securely anchored, otherwise the pipe may come loose from the coupling when subjected to wave forces, surge forces, and even from internal fluid pressure and flow in the pipeline.**

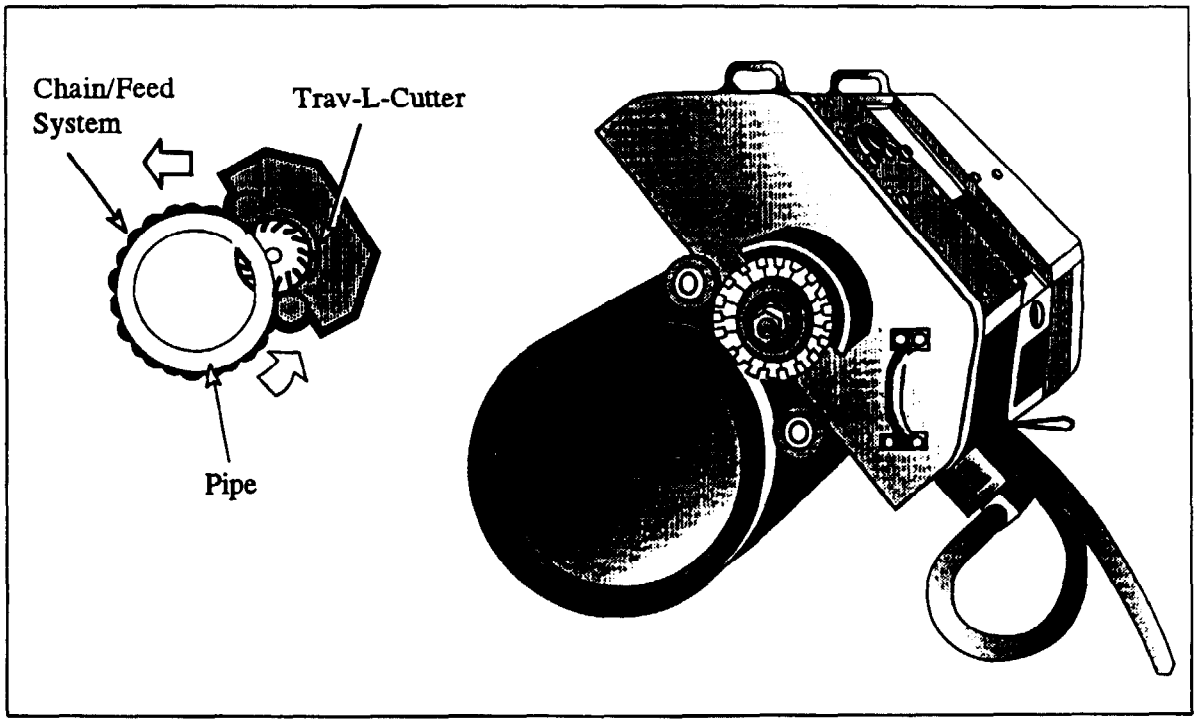



Figure 5-11
The WACHS Trav-L-Cutter is a portable milling machine.
It cuts and bevels at the same time on pipes from 6 inches in diameter and up.
The cutter has been used to 600-foot water depth.

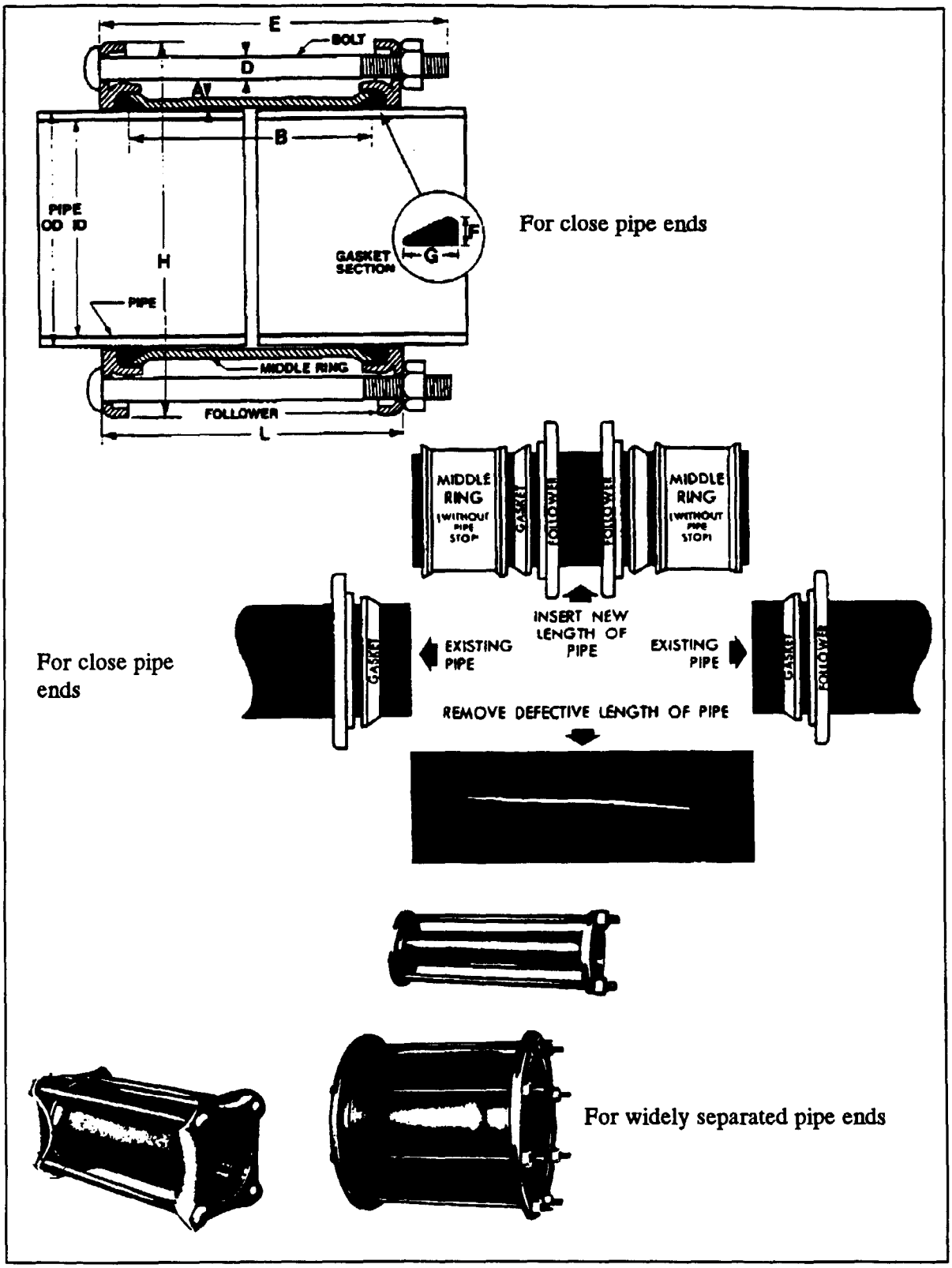



Figure 5-12
Examples of commercial pipe couplings for joining steel, cast iron, and concrete pipes up to 73 inches in diameter. Pressure ratings from 1,500 psi for 1/2-inch diameter to 200 psi at 73-inch diameter (from Dresser, 1991).

**5.3.4.4 Concrete Encasement (for low psi service).** Manufacturers of flexible forms (see Appendix A) for piling repair also tailor their products for encasing pipelines in concrete. Concrete encasement (Figure 5-13) can provide a longer term solution than patching by itself. It is applicable where the damage covers long lengths of the pipe and where the pipeline is otherwise in good shape.

A pipeline repair encased in concrete also has several distinct advantages: concrete provides some protection from abrasion and other physical damage, the heavier assembly is more stable on the seafloor, and the patched area is excluded from seawater.

One disadvantage to concrete encasement is that the repaired section is much larger in diameter making it more susceptible to future damage from wave forces and anchor/trawl board contact.

Concrete encasement also produces the potential for accelerated corrosion of the pipe adjacent to the concrete-pipe joint interface with seawater. A corrosion engineer should be consulted for advice. Because of the potential for accelerated corrosion at the joint, this technique is not recommended for use where the uncoated remainder of the pipeline is already severely corroded.

Concrete encasement must not be used without first patching (or covering) all holes in the pipe, otherwise the concrete may fill and block the pipeline or, as a minimum, severely restrict internal flow.

The method of concrete encasement of pipelines (or cables) is similar to repairing wood pilings:

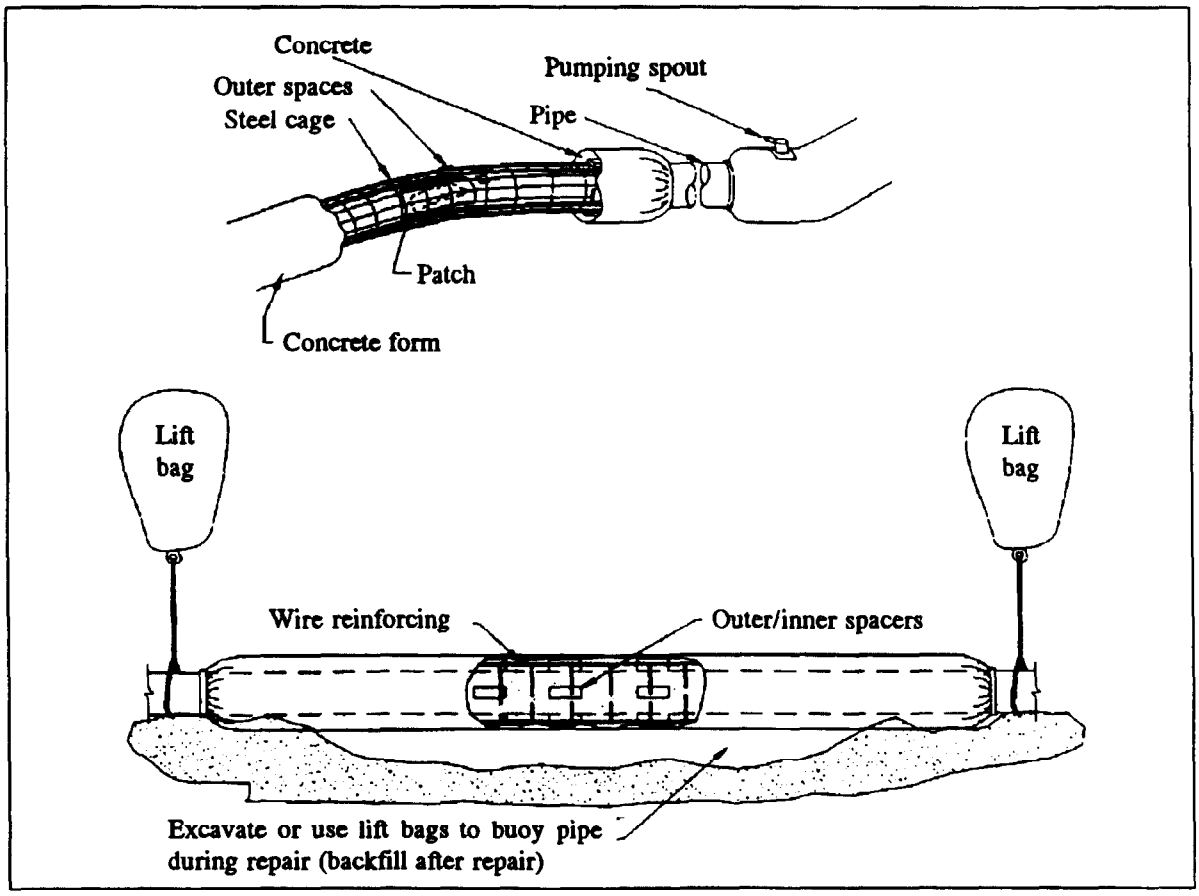



Figure 5-13. Example of pipeline repair using concrete casing.

• First clear debris, remove marine growth, and smooth out jagged projections from the pipe.

• Excavate under the pipeline along the damaged section over the length of the concrete form. An alternative to excavation is to use lift bags at the outboard ends of the repair area and along the length to suspend the pipeline off the bottom.

• Fabricate/install patches over damaged areas of pipe.

• Install steel reinforcing along the length and circumference. Use spacers to ensure proper spacing between the pipe, the reinforcing, and the flexible form. A minimum of 1.5-inch spacing is recommended between the pipe reinforcing and reinforcing form to provide a minimum of 3 inches of concrete cover. The final selected spacing and reinforcing steel dimensions will depend on the particular application. They should be reviewed by a structural engineer and the fabric form manufacturer.

• Install fabric form and secure ends.

• Pressure pump concrete to fill form. Particular care must be taken to make sure all voids are removed as the concrete is pumped. The diver should knead or manipulate the form to help remove voids. It is best to fill from the lowest point to the highest point.

• Backfill under the pipe or remove the lift bags to set the pipe on the bottom, as necessary.

**5.3.4.5 Flexible Pipe.** Another repair product worth mentioning is flexible pipe, sometimes referred to as conduit. Flexible pipe is available from at least two manufacturers (see Appendix A) and was developed for use in repairing underwater oil and gas pipelines. Flexible pipe is extremely expensive and generally not available off the shelf; rather components are manufactured to suit specific applications.

Flexible pipes are constructed from successive layers of steel and thermoplastic materials such as shown in Figure 5-14. The result is a pipe that will have the strength and durability of steel and the flexibility of reinforced hoses. Each manufacturer has couplings (flanges) designed specifically for the pipe. These flanges must be installed by the factory on the flexible pipe. Thus the repair method must be planned well in advance or limited by the length of flexible pipe on hand.

As with all pipeline repair methods, attention must be paid to ensure the flexible pipe is compatible with the internal pressure and the type of material being transported. Installation techniques must be evaluated to ensure that the minimum bend radius is not exceeded.

**5.3.4.6 Specialized Equipment.** Equipment is available to fabricate bypassing damaged pipeline section. For example, hot-tap assemblies are available for tapping into live pipelines. The equipment can cut a hole large enough to allow either plugging off the main pipeline or branching the flow around the damaged area. Hot-tap equipment includes a bolt-on saddle, shut-off valve, and machining equipment for penetrating the pipeline.

## 5.4 FLEET MOORINGS

As discussed in Section 3.5.3, fleet moorings are subject to several causes of deterioration. The methods of repair and maintenance of deteriorated fleet moorings can be classified into three general areas:

in-place repair, total replacement, and cathodic protection.

### 5.4.1 In-Place Repair

In-place repair of fleet moorings may consist of repair of the buoy's protective coating, fender system, or buoyancy chambers or partial replacement of mooring chain components. Repair of the buoy's protective coating is required from time to time because of abrasion or impact damage. It is necessary to first clean the exposed steel, as described in Section 2.12.2, as well as the coating surrounding the steel. An epoxy-polyamide protective underwater coating, such as those described in Section 2.12, is then spread by hand over the cleaned exposed steel and at least 1/2 inch over the surrounding cleaned coating.

Mooring buoy fender systems, especially those made of wood, require periodic replacement. Replacement rubber fenders of Type R, Class RS, Grade 72S (A,B,D) rubber composition are recommended for use. Buoys that are 9 feet 6 inches in diameter and larger require D-shaped rubber fenders that are 8 by 8 inches in cross section, while 6- by 6-inch fenders are used for smaller buoys. Rubber fenders are usually fabricated in eight preformed sections to fit the circumference of the buoy.

Buoys may suffer from buoyancy loss because of a crack or hole in their structure. Some of the lost buoyancy may be recovered by installing packets of foamed plastic inside the buoyancy compartments. Polystyrene foam, such as Styrofoam, is relatively inexpensive to purchase in quantity and can be cut to any desired shape. Syntactic foams produced by bonding hollow glass or plastic balloons together in an epoxy resin are highly resistant to water penetration and are quite suitable for use.

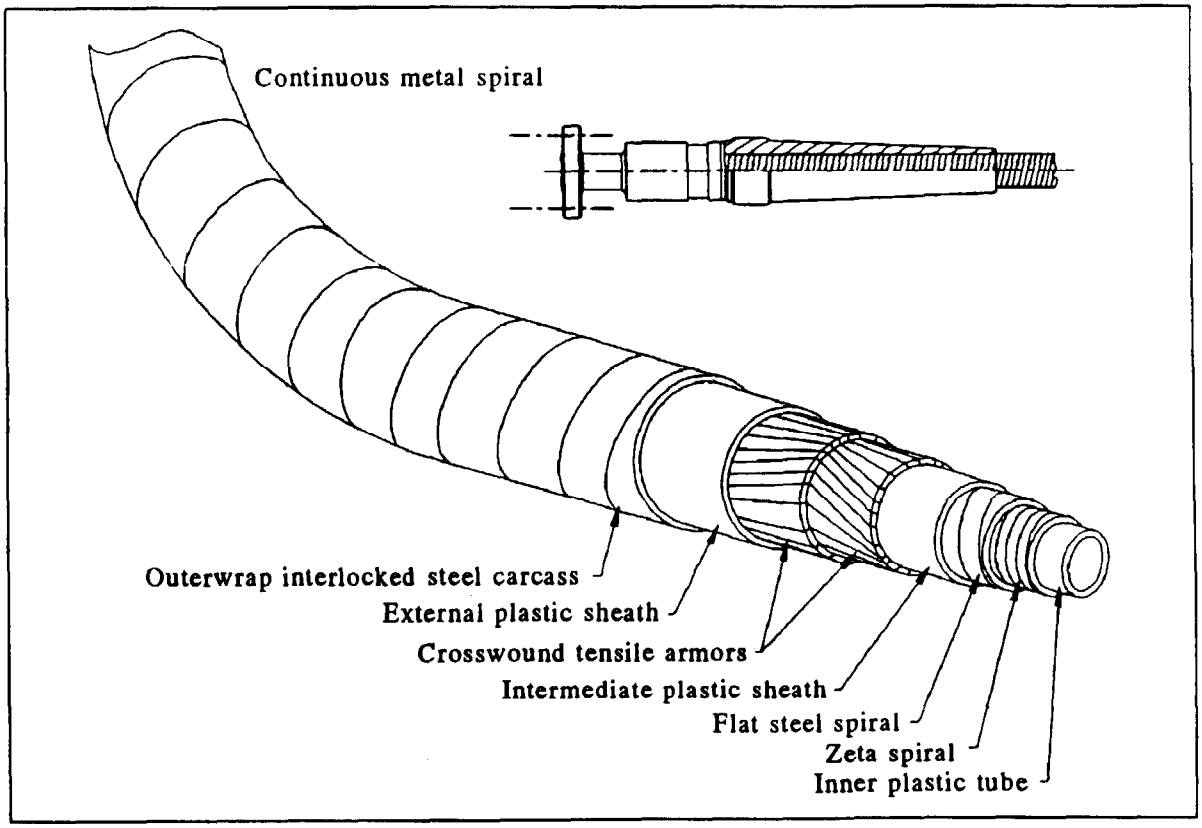



Figure 5-14. Example of flexible pipe and couplings.

Two-part expandable polyurethane foams are also available. With these foams the buoy must first be pumped free of water. The two parts of the foam are then mixed together according to the manufacturer's directions and poured into the buoy. Care must be exercised to make sure that too much foam is not mixed. Also, gases given off from some of these foams may be hazardous. The user should check with the manufacturer before using these types of products.

**5.4.1.1 Buoy Replacement.** Partial replacement of the components of a fleet mooring is often all that is required to bring the mooring up to a level of normal service capacity. A defective riser mooring buoy (Figure 3-32) can be exchanged in place without removing the entire mooring.

- The mooring buoy is lifted by a surface-platform-mounted crane into the air and washed down with a high-pressure stream of seawater.

- The single riser chain is then secured to a corner bitt or cleat, and the buoy is separated from the riser chain by removing the detachable chain joining link or safety shackle located directly under the buoy on the padeye. If necessary, the chain may be cut with a cutting torch.

- New or refurbished joining links should be used to secure the replacement buoy to the riser chain.

- If new or refurbished joining links are not available, the existing joining link should be cleaned, coated with a preservative grease, and reused to secure the replacement buoy.

- The new mooring buoy is then lowered back into position.

The in-place exchange of telephone-type buoys is more complicated because of the increased number of connections of the ground leg chains to the buoy, but the procedure is essentially the same.

**5.4.1.2 Mooring Leg Overhaul.** In-place repairs may also include overhauling mooring legs. For this operation, a work barge should be outfitted with a double drum winch for chain inhaul and reinstallation and a work crane for anchor retrieval and reinstallation. To detach the bitter end of the mooring leg chain, slack must be provided at the padeye by rigging either the double drum winch or crane to take the load off the chain. Once the chain is slack, the bitter end can be detached, either by the chain joining link or safety shackle or, if necessary, by cutting with a cutting torch.

Mooring leg recovery, as illustrated in Figure 5-15, uses the double drum winch to recover the mooring leg over the bow of the work barge in a hand-over-hand fashion over a bow-mounted anchor chain roller.

- With the chain load transferred to a 1-inch winch inhaul wire, the chain is inhauled over the roller. The recovery should be accomplished with the in-water chain hanging vertically to the maximum extent possible, which requires the barge to transit backwards over the mooring leg.

- When the inhaul wire line is brought to the right-angle snatch block, the inhaul wire from the other winch is attached to the chain at the bow, the inhauled length of chain is secured to a 25-ton padeye near the snatch block, and the previous inhaul wire is removed.

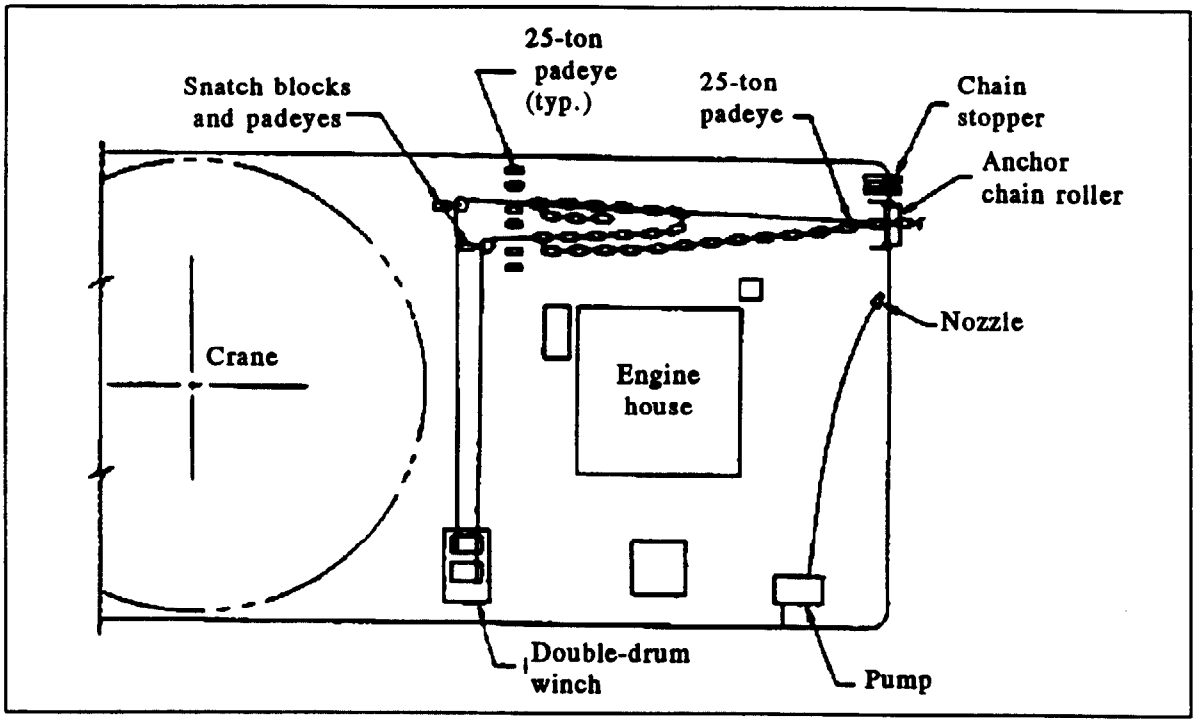



Figure 5-15. Recovery of mooring leg.

This procedure should be repeated until the chain remaining in the water equals the water depth plus freeboard, plus a nominal 20 feet. During inhaul, the chain should be waterblasted to remove mud and debris and then carefully laid on deck to aid in inspection and reinstallation.

The crane should be used to recover the remaining bights of chain as well as the anchor.

- The load from the winch should be transferred to the crane and the inhaul wire removed.

- The crane should be raised to the maximum height and the chain maneuvered into the chain stopper, as illustrated in Figure 5-16.

- The stopper gate should be closed and the load transferred to the stopper.

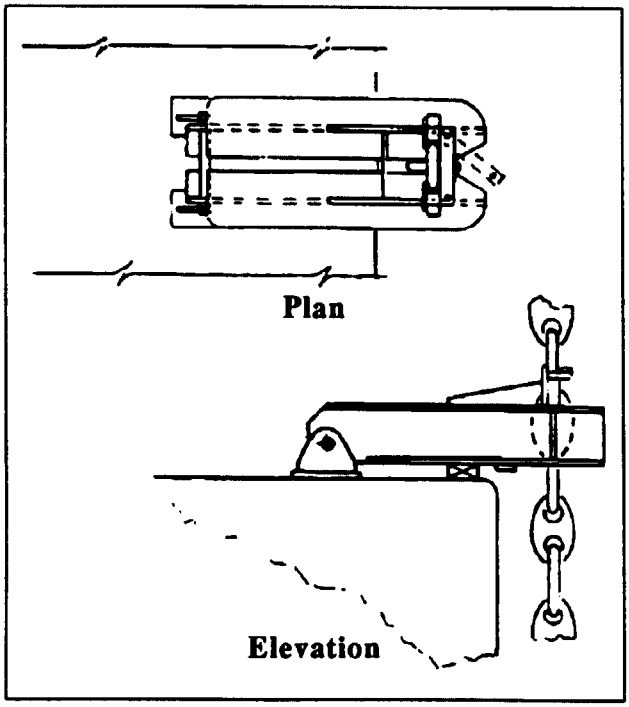



Figure 5-16. Mooring leg chain stopper.

- After waterblasting the chain, it should be placed on the deck.

- The crane hook should be resecured to a link inboard of the stopper, the load taken on the crane, and the chain released from the stopper.

- The remaining chain should be hauled in and the anchor placed on deck after cleaning thoroughly.

Recovered mooring legs should be thoroughly inspected for wear and corrosion. Any components showing greater than 30 percent loss of material must be replaced. All data are to be recorded, including jewelry size and specifications and length. The anchors should be sandblasted to remove encrustation and scale. Each mooring leg should be reinstalled immediately after recovery and refurbishment. Reinstallation should be performed in accordance with installation procedures described in NAVFAC DM-26, Harbor and Coastal Facilities, and NAVFAC MO-124, Mooring Maintenance.

### 5.4.2 Total Replacement

It may be necessary to replace a fleet mooring because the deterioration is so widespread that other repair methods would be uneconomical. Riser moorings are recovered by removing the buoy and then removing one leg at a time:

- The mooring buoy is lifted into the air to expose the ground ring.

- After the ground ring and legs are exposed, one leg is laid across the corner bitt to steady the chain.

- A buoy and line are attached to the leg, and the first A-link below the detachable link is then severed by cutting with a torch.

- A second leg is then picked up and separated in the same manner.

- The last leg is secured to a corner bitt, and the leg is separated by removing the detachable link to which the ground leg is attached.

- Again, a buoy and line are attached to the leg.

- The mooring buoy is then washed off with a stream of seawater and brought on deck.

Each of the legs and anchors are retrieved, raised by a crane, washed down, and stored neatly on deck. A new fleet mooring is then installed in accordance with NAVFAC DM-26 and NAVFAC MO-124 installation procedures.

While the above procedure appears to be relatively simple and straightforward as described, it is actually a difficult and dangerous operation. The weights and forces involved are extremely high and any miscalculation or mistake could have disastrous consequences. It is recommended that total replacement be undertaken only by personnel experienced in the procedures.

### 5.4.3 Cathodic Protection

Cathodic protection is a highly desirable maintenance technique for fleet moorings. A system consists of:

- Sacrificial anodes to provide the necessary electrical current.

- Wire ropes for imparting electrical continuity throughout the ground tackle

- Fittings necessary for joining the components of the system to the mooring and to each other.

There are three types of sacrificial anodes typically used in fleet mooring cathodic protection systems:

- Buoy
- Link
- Special-D anodes

Buoy anodes are mounted directly on the buoy in a location that is not subjected to impact by moored vessels. They have a nominal length of 36 inches, a nominal cross-sectional area of 16 $in.^2$, and a nominal weight of 150 pounds.

Link anodes are cast on special chain links that are joined directly onto the ground tackle system before the mooring is laid. The anode castings have a nominal length of 24 inches, a nominal cross-sectional area of 80 $in.^2$, and a nominal weight of 500 pounds.

Special-D anodes are the same size as link anodes. An insulated copper wire is passed through a 3/4-inch-diameter steel pipe core cast inside the anode, bared and soldered at each pipe end, and potted with epoxy to reduce the stress on the connection. These wires extend about 30 feet from the anode, where they are joined in place to wire ropes. The wire ropes are periodically woven back and forth through the ground tackle and joined to it using metal hose clamps to provide the necessary electrical continuity. Wire ropes are typically 5/8- to 3/4-inch-diameter galvanized steel wire.

Buoy anodes are supported by a pair of brackets welded directly to the buoy shell that have threaded fittings for simple installation/replacement of anodes. Link anodes are joined to the ground tackle by a standard joining link. Special-D anodes can be secured by clamps to the wire ropes which, in turn, are joined to the ground tackle by common metal hose clamps.

Buoy anodes usually are installed ashore during buoy overhauls, but are easily replaced on-site by lifting the buoy out of the water and removing and replacing the nuts from bolts or threaded studs.

Link anodes are usually installed ashore when the ground tackle is being overhauled. These anodes are located where shots of chain are joined together.

Special-D anodes typically are installed by divers. The anode leads must be sufficiently long and located such that the anode will not be displaced by movement of the ground legs from mooring forces. Wire ropes can either be installed after the ground tackle has been arranged on the deck of the installing vessel or in place by divers. The wire rope is loosely woven back and forth through about every eighth link and then clamped to every eighth link. The coating should be scraped away from the steel at this location to ensure a good contact surface.

## 5.5 STEEL PILES

As described in Section 3.4, there are a number of different causes of deterioration of steel in the marine environment. There are also many methods for the repair and maintenance of steel piles. Selecting the method to be used depends on: (1) the extent of the damage, (2) economics of the repair, and (3) physical and environmental factors at the site.

The pile plays an important role in the integrity of the overall structure and deterioration can result in serious reduction of

the capacity of the pier or structure. Therefore, it is important that an engineering structural analysis be conducted to verify that the repair method will provide the needed structural support for the intended application.

> **CAUTION**
> **Before beginning construction operations, block off construction area from all traffic. Notify port authority to secure marine traffic in the area and obtain clearances to proceed from appropriate local authority.**

Repair and maintenance methods fall into five general categories:

- Concrete encasement
- Partial replacement
- Complete replacement
- Coatings/wrapping
- Cathodic protection

### 5.5.1 Concrete Encasement

An outline of the procedures for repairing steel piles using concrete encasement is provided in Table 5-7. Planning and estimating data are included in Table 5-8. Some general information is provided below. Refer to the figures in Table 5-7 for an outline of the procedure. The repair procedure involves:

- Cleaning the pile
- Installing steel reinforcing, spacers, and forms about the pile
- Pouring concrete to fill the space between the pile and the form

Nonmetallic spacers are used to: (1) maintain a uniform concrete thickness, and (2) ensure a minimum (1-1/2 inches) distance between pile and reinforcing steel and reinforcing steel and form. Each form manufacturer provides detailed instructions relating to installing their specific designs.

Both flexible and rigid forms are available and manufacturers are listed in Appendix A. Forms may also be fabricated from materials on site. Selecting the form type will depend primarily on availability and choice of the designer or construction crew.

Flexible forms fabricated from a porous fabric are usually left in place. Both open and closed top models are available. Open top fabric forms are usually suspended from the piling or overhead structure. A method for suspending open top flexible forms from sheet H-piling is shown in Figure 2 of Table 5-7. Open top forms are filled to overflowing. The concrete grout fill is topped with an epoxy cap or nonshrinking grout at a 45-degree angle as shown in Figure 5-17.

Rigid forms are open top and bottom and are normally removed and reused after the concrete has **completely cured**. Rigid forms can be commercial or fabricated from material found at the construction site. Translucent form jackets are recommended, as they provide the ability to view the level of the concrete, and to make corrections if there are any discontinuities in the repair material. Rigid forms require a bottom seal and base plate to hold the form in place. A temporary friction clamp and base plate conforming to the pile contour can be fabricated and attached to the pile at the bottom of the repair area (Figure 3 of Table 5-7). The rigid form rests on the base plate to form the bottom seal which prevents leakage of the concrete.

Table 5-7
Repairing Steel Pile with Concrete Encasement

| Procedure |
|---|
| **Problem:** Slight to moderate deterioration (less than 35 percent) of the cross-sectional area has occurred; or protection against corrosion and abrasion is required.<br><br>**Description of Repairs:** Flexible or rigid forms together with reinforcing are used to provide a concrete encasement around damaged pile. Follow form-manufacturer's directions. Install casing extending from 1 foot above MWH to 1 foot below mudline.<br><br>• Clean the steel pile of marine growth and loose rust. Use high-pressure water blasting if necessary.<br><br>• Install steel reinforcing mesh around the pile, using spacers to provide minimum 2-inch clearance between the pile and reinforcing, and between form and reinforcing.<br><br>• Blocking between form and pile (Figure 1) may be needed to seal bottom of form and prevent concrete leakage during filling.<br><br>• Pump concrete using 15-psi minimum pressure through suitable pipes or hoses extending to lowest point. Keep discharge end submerged in concrete.<br><br>**Flexible Form Closed Bag Type:** Figure 1 - Wrap the form around the pile with blocking at bottom; close zipper; secure form to the pile at top and bottom with mechanical fasteners or banding. Insert fill tube to bottom of bag and fill to overflow with concrete.<br><br>**Flexible Form Open Top Bag:** Figure 2 - Suspend fabric form from structure or friction clamp as shown in detail using turnbuckles, or chains to steel hanger ring. Install blocking and secure form to pile at bottom using banding or clamps. Fill with concrete.<br><br>**Rigid Form Open Top:** Figure 3 - Fabricate and install base plate to seal bottom and hold form in place. Install bands every 12 inches; install pump band at lowest possible point. Fill form with concrete grout pumping through lower pump band. Vibrate form to ensure full concrete placement within form. Leave forms in place; remove bands only after concrete has set.<br><br>**Backfill mudline.** Cap open top forms with epoxy grout to provide a 45-degree cap.<br><br>**Application:** The method will not restore full bearing capacity lost due to deterioration. Partial restoration may be gained by bolting steel angles, channel or plate to the piles before the concrete encasement (Figure 4). Obtain engineering guidance for strengthening requirements. |

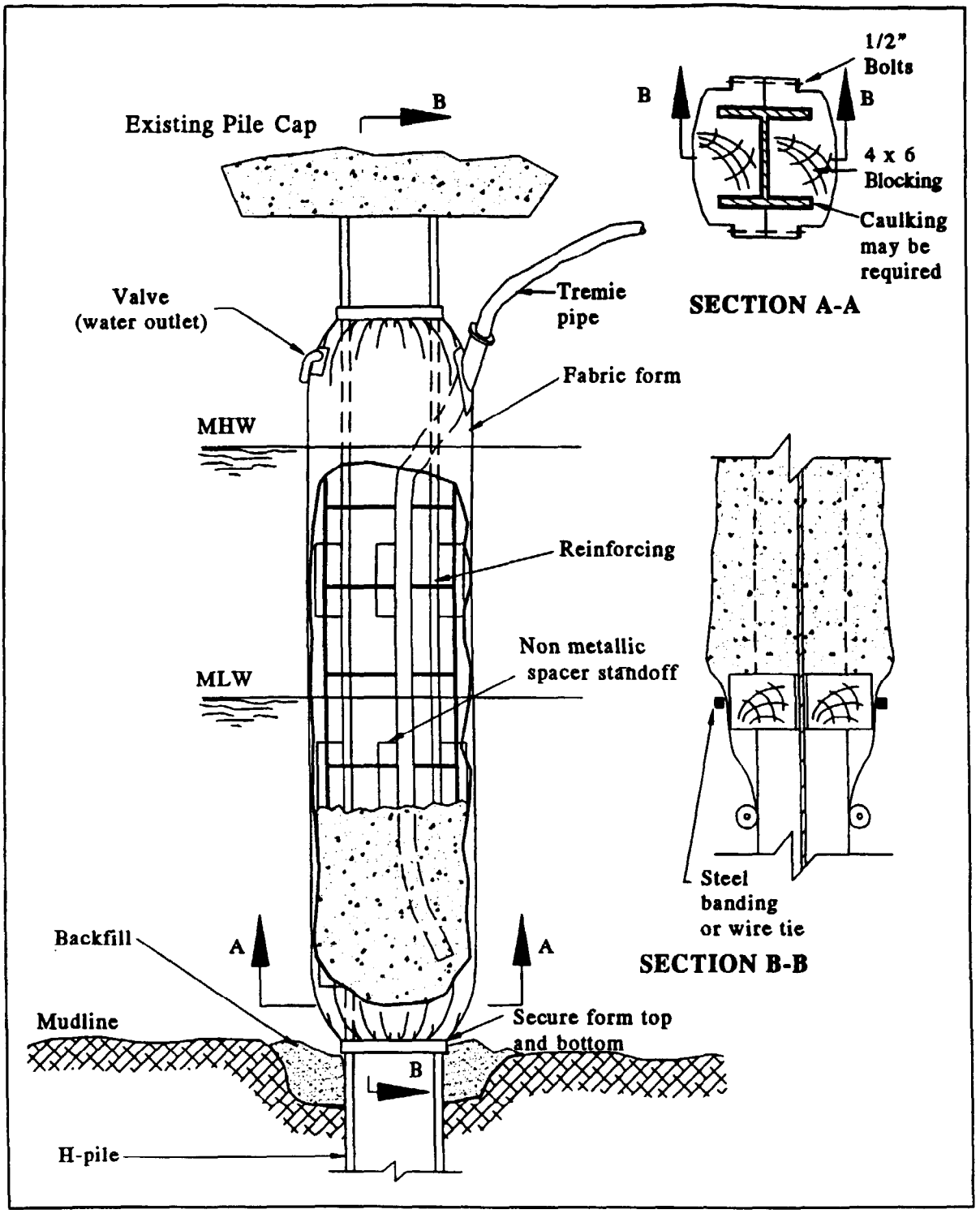



Table 5-7
Figure 1. Flexible form closed bag.

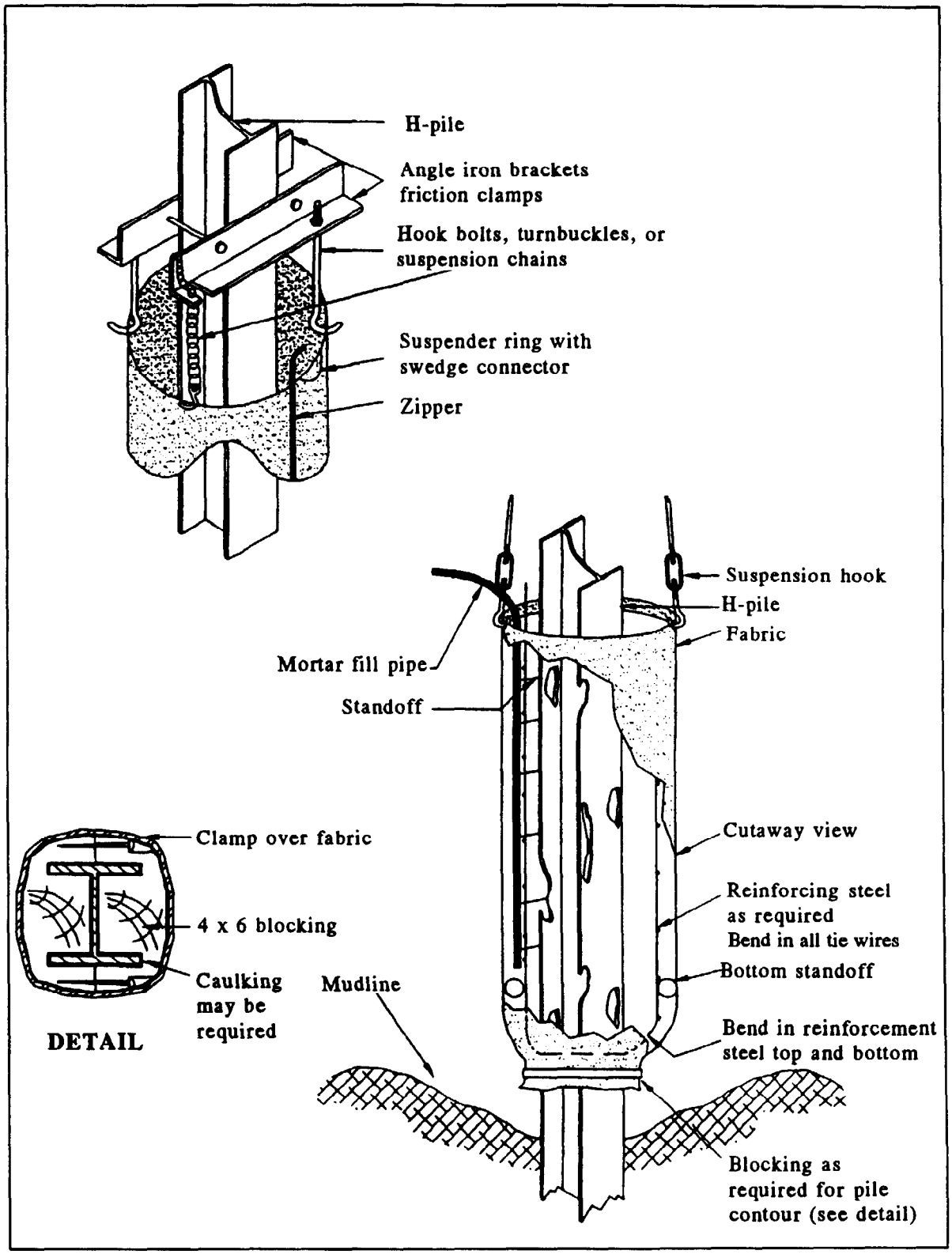



Table 5-7
Figure 2. Open top form arrangement.

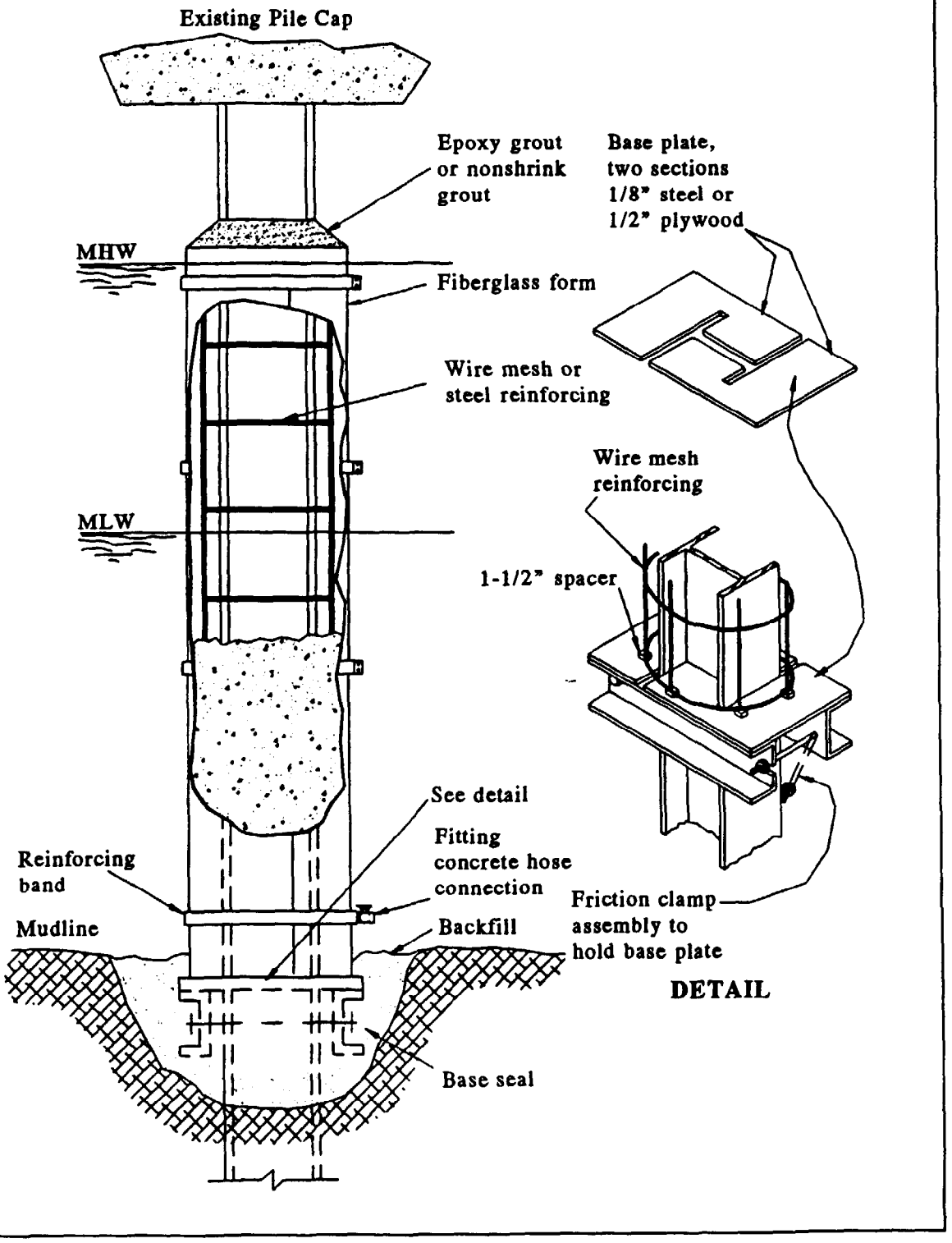



Table 5-7

Figure 3. Rigid form concrete encasement of steel pile.

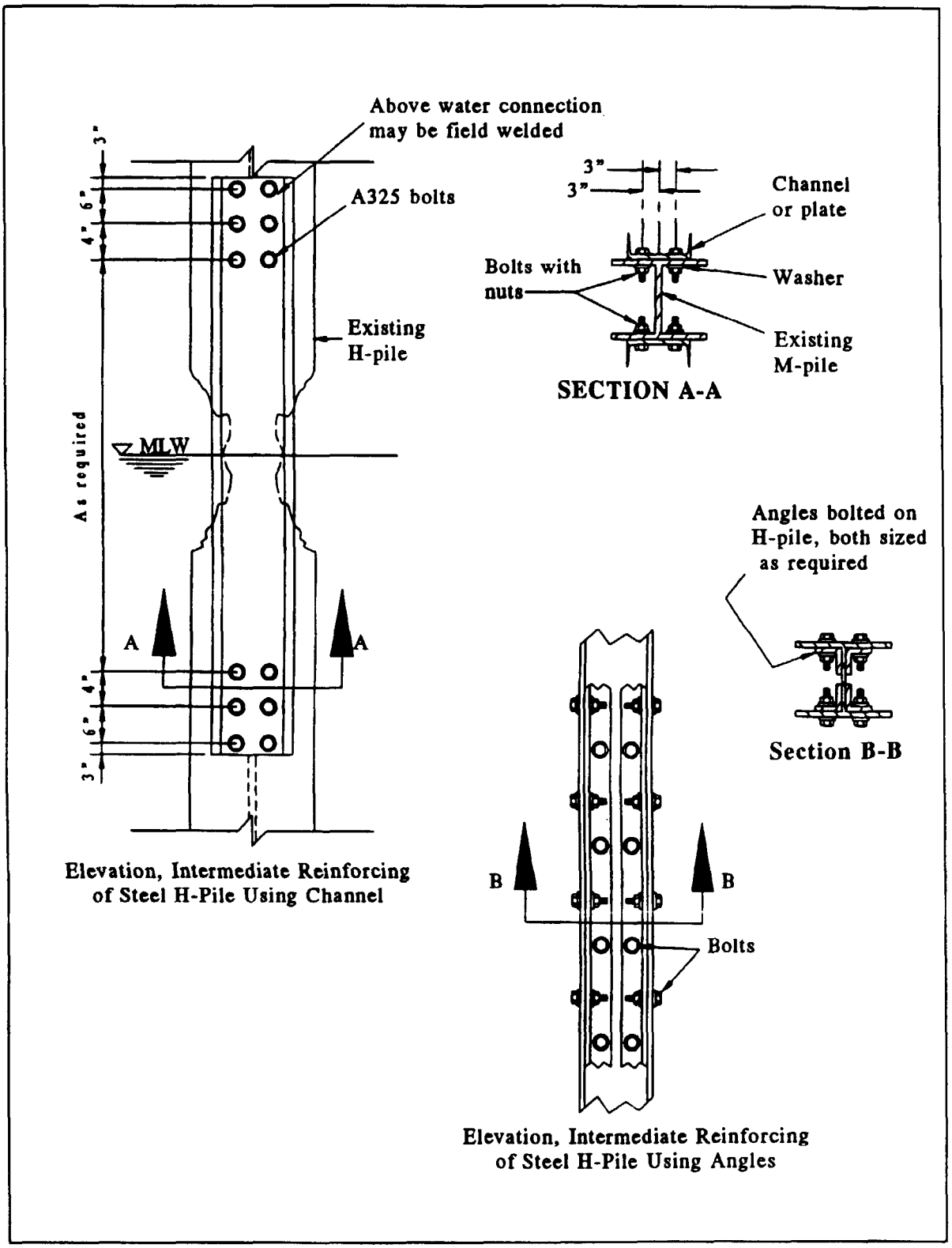



Table 5-7

Figure 4. Reinforcing of H-pile using angle, channel, or plate.

Table 5-8
Planning and Estimating Data for Steel Pile Repair Using Concrete Encasement

**Description of Task:** Install a concrete encasement. The total length of encasement is 20 to 30 feet. Reinforcing the pile is not required.

**Size of Crew:** Dive station and two support laborers.

**Special Training Requirements:** Familiarity with the type of concrete form jacket.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, hydraulic power unit, concrete pump with adequate hose, concrete slump cone, air jetting pump and hose, rigging equipment, float stage, scaffolding. If ready-mix concrete is not available, provide a concrete mixer and wheelbarrows, shovels, etc. as needed.

**Productivity of Crew:** 10 hours per pile repair.

**Materials:**

**Form Material** - Either flexible or rigid forms may be used. Follow manufacturer's recommendations regarding lengths and diameter of forms, top and bottom closures, spacers, bands, straps, and special fittings. Forms are ordered prefabricated in the required length and diameter. For flexible forms, allowance on the length must be made for extra fabric that may be required around blocking at the top and bottom of the jacket.

**Spacers** - A conservative estimate of the number of spacers must be made. Rough water and batter piles will require more spacers.

**Wire Mesh Reinforcing** - Usually 6x6-10/10 welded wire fabric is adequate. Width of wire required is based on its circumference, taking into consideration the thickness of the spacers between the pile and reinforcing and allowing at least a 12-inch overlap of ends.

**Concrete** - To determine the amount of concrete required to fill the form, be conservative. Allow for reduction of concrete volume due to loss of water through the permeable fabric, enlargement of the jacket caused by stretching, and waste. Usually an allowance of 10 percent extra concrete is sufficient. If ready mix is not available, provide for hauling, stockpiling, and protecting cement, aggregates, clean water, and admixtures, and schedule extra man-hours.

**Form Reinforcing Straps and Special Fittings** - Rigid forms usually require reinforcing straps. The spacing and number required depend on the type of form and the hydrostatic pressure of the concrete fill. Some types of reinforcing straps are reusable, but an allowance should be made for a loss of between 10 and 20 percent of the straps each time they are used. Closure forms, blocking hangers, inlet valves, and clamps will be required, the number and type depending on the forming system being used.

**Potential Problems:** Potential ripping of fabric forms requires familiarity with repair procedures and the availability of repair equipment. Potential unzipping or unlocking of form seams requires familiarity with banding or strapping procedures with form partially full of concrete.

The steel piles must be cleaned of rust, scale, and marine growth. Failure to do so would result in poor bond between the concrete and steel. It is also important to ensure that the concrete be poured within 72 hours following cleaning to ensure that new marine growth will not have formed on the pile surface. For warm waters it may be necessary to further restrict this allowed time period.

The flexible-form clamping and sealing arrangement on steel H-piling is more elaborate than for round pilings; blocking must be provided to fill the channel voids and provide a seal and clamping surface for the flexible form. Some examples are shown in Figure 1 of Table 5-7.

Concrete should be pumped using 15-psi minimum pressure through a suitable pipe or hose which extends down to the lowest point in the form. It is important to start filling with the hose at the bottom and to keep the discharge submerged in concrete during the pouring operation. This procedure will prevent voids forming. Care must be taken when using the hose-tremie method as there is a tendency for the hose to become snagged on the wire mesh reinforcing. Some forms have built-in filling and overflow ports where the lower port is used for filling. Filling from a bottom port is preferred over extending the hose to the bottom of the form.

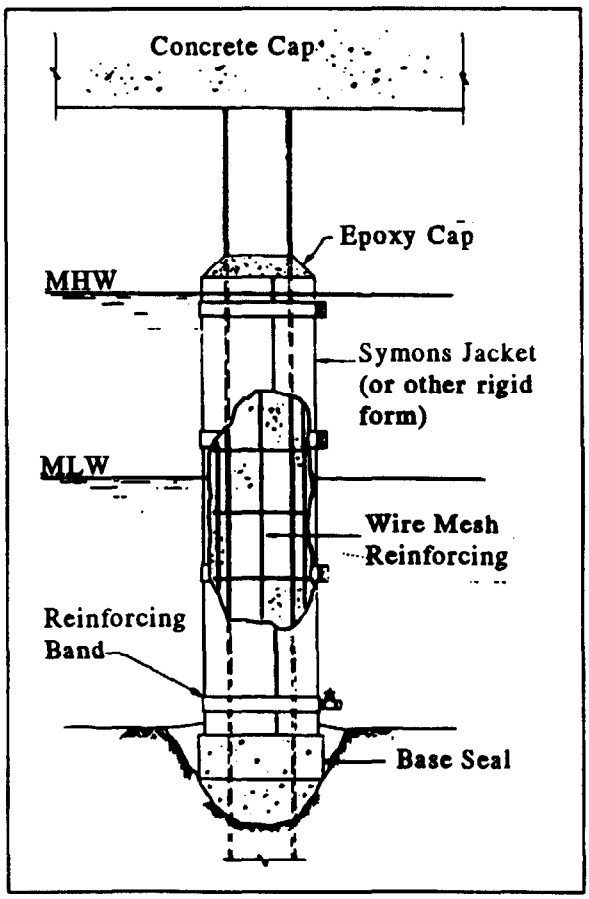



Figure 5-17. Fiberglass rigid form concrete encasement of steel pile.

Where a pile has deteriorated to the point where it has not lost more than 50 percent of its cross-sectional area, concrete encasement can be used to both strengthen the pile and to provide protection from further corrosion. Concrete encasement is the most commonly used method for repair of both pipe and H-piles. Concrete encasement is not suitable for severely damaged pile.

For steel pile concrete encasement to be successful, the form must extend fully over the damaged pile section and continue at least 3 feet above and below the damaged pile area.

**CAUTION**

**Although much of the damage to steel piling is found in the splash zone and just below MLW, partial concrete encasement in these areas alone can result in accelerated attack just below the encasement. Therefore it is recommended that the encasement of pilings extend to below the mudline as shown in Figure 5-17 in order to avoid accelerated attack. Encasement should extend as a minimum from 1 foot above MHW to 1 foot below the mudline.**

If a partial encasement is used below the splash zone, then a cathodic protection system should be installed to prevent the accelerated corrosion just below the encasement. The cathodic protection may be achieved by either attaching sacrificial anodes to the piling or through an impressed current cathode protection system.

Concrete encasement is also used as a corrosion and abrasion protection technique for piles in the splash zone. If the encasement is only in the splash zone and does not extend below MHW, accelerated attack due to the partial encasement will not occur.

By itself, concrete encasement will not restore the full bearing capacity lost due to deterioration of the steel cross section. Although not general practice, increased bearing capacity may be gained by bolting steel angles or channels to the piles along the damaged section before the pile is encased in concrete as shown in detail on Figure 4 of Table 5-7. Above water the reinforcement may be welded to the pile. Care must be exercised to ensure that the connections are made to sound metal.

### 5.5.2 Partial Pile Replacement

Damaged sections of H-piles (and piles of other shapes) can be repaired by replacing part of the pile. The technique involves cutting out the damaged section and splicing in a new (in-kind) section of H-piles as described in Table 5-9. Planning and estimating data are provided in Table 5-10.

Partial replacement can restore a significant portion of the structural strength lost in the deteriorated section. The success of strength recovery will depend upon the care taken to align the new section with the existing structural members.

Structural analysis is required to evaluate loading conditions and for sizing the structural repair elements and to determine the structural capacity of the repaired pile and attendant structure.

During the repair procedure, temporary deck supports may be needed to transfer the load from the pile being repaired to adjacent piles.

A major concern with partial replacement is corrosion. The new steel will be anodic to the old steel when first installed. All new metal should be cleaned and painted before installing. The need for installing local cathodic protection should be reviewed by a corrosion engineer.

Encasing the replacement section in concrete using the procedures described in Section 5.5.1 would provide an acceptable alternative to eliminate corrosion problems. Concrete encasement needs to extend from above the HWL to 1 foot below the mudline to prevent accelerated corrosion occurring below the encasement.

The **basic repair procedure is:**

- Brace surrounding structure to adjacent piles.

- The damaged section of pile is cut out at an elevation where the pile is of sufficient cross-sectional area to support the anticipated loading. Cutting methods are discussed in Section 2.4. It is important to be sure that the bottom and top cuts are square.

- A joining cap is fabricated by welding steel angles and plate to a steel bearing plate as shown in Figure 1 of Table 5-9. The joining cap is mounted and bolted to the lower section.

- A new H-pile section is then cut to fit the missing length with a steel bearing plate welded to the bottom. Holes are drilled in the bearing and shim plate to match the joining cap.

Table 5-9
Partial Replacement of Steel Pile

**Problem:** Moderate to heavy deterioration - greater than 35 percent of the cross-sectional area of the H-pile is damaged.

**Description of Repair:** Remove damaged section and add new section.

**CAUTION: Rope off upper deck to prevent vehicles transiting repair area.**

- Clean growth and loose rust. Install temporary supports as required to support pier during repair. This may include installing temporary piles adjacent to repair area or bracing deck to adjacent piles.
- Cut out the damaged section being sure ends are square and grind smooth.
- Fabricate:

(l) Joining cap as shown in Figure 1 and a bolt pattern template for later use in fabrication of shims.

(2) A 1-inch-thick plate (minimum) with holes match-drilled to joining cap. Weld plate to new pile section.

- Drill mounting holes in lower pile section using joining cap as template and mount joining cap using appropriately sized nuts/bolts and lock washers.

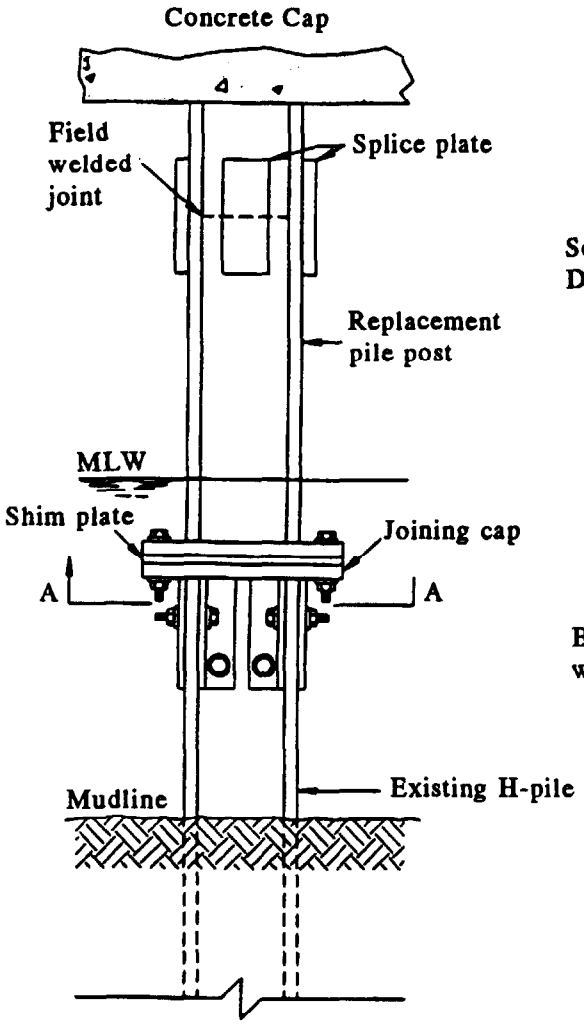
**For Replacement of Intermediate Section** (upper joint above waterline):

- Fabricate replacement H-pile section with the 1-inch plate welded on one end.
- Install new section in position with nuts/bolts and lock washers. Use welded splice plates to join replacement pile to existing upper pile (above HWL).

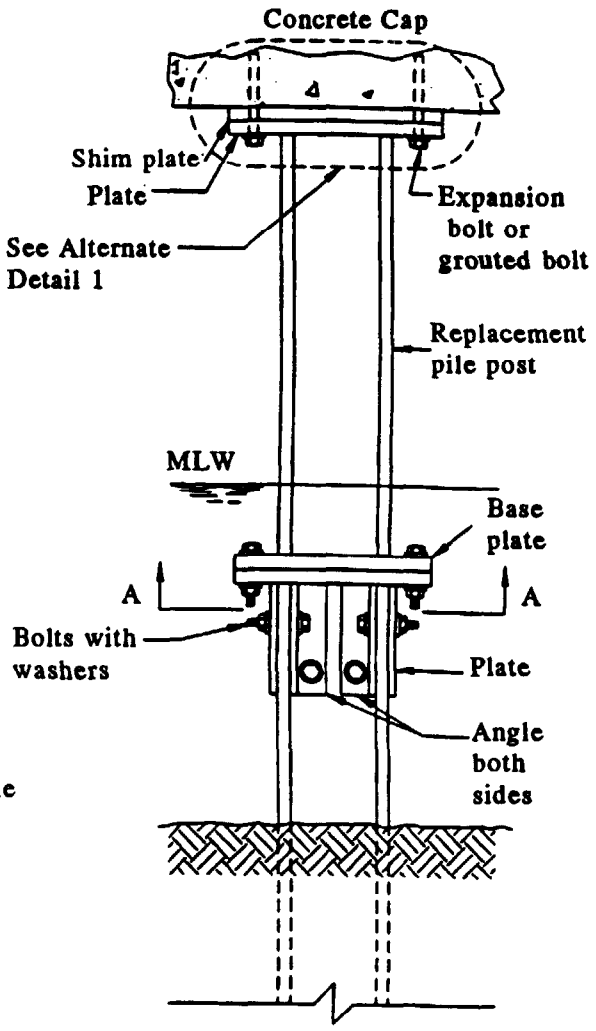
**For Upper Section Replacement:**

- Fabricate new section to fit under concrete cap and weld 1-inch plate at both ends.
- Install new section. Loosely bolt lower bearing plate to bottom section using shims as necessary.
- Attach to pile cap. Use expansion bolting or drill and grout to concrete, or lags to timber cap.
- As necessary, hard pack grout to fill void and allow to fully set.
- Tighten lower and upper fasteners.

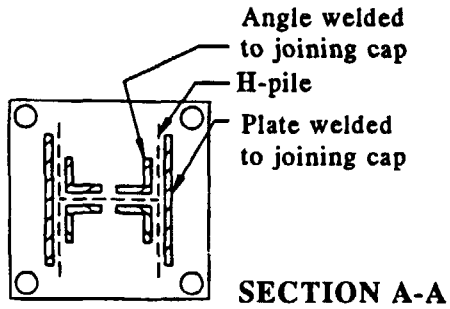
Note: This method restores the structural strength but corrosion is likely to occur at uncoated sections. The repaired section may be encased in concrete to extend life expectancy.



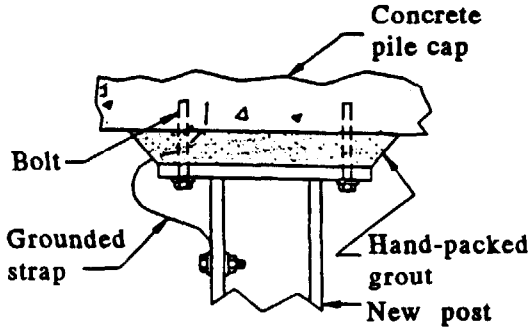

Replacement of Intermediate Section of Steel H-Pile




Replacement of Upper Section of Steel H-Pile




Joining Cap




Alternate Detail 1

Table 5-9
Figure 1. Partial replacement of steel H-pile.

Table 5-10
Planning and Estimating Data for Steel Pile Repair Using Partial Replacement

**Description of Task**: Repair a severely deteriorated steel H-pile by replacing a section of the pile from 1 foot above the high waterline to 2 feet below the low waterline. Total length of repair is 10 to 20 feet. Pile is located near the edge of the structure.

**Size of Crew**: Dive station, welders, crane operator, two laborers.

**Special Training Requirements**: Familiarity with underwater cutting techniques, above-water welding, removal of marine growth, underwater lifting procedures, and drilling procedures.

**Equipment Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, oxygen arc cutting torch equipment, hydraulic drill with bits, hydraulic power unit, rigging gear, crane or lifting equipment, float stage, scaffolding, oxy-acetylene torch equipment, clamp-type template for cutting piles.

**Productivity of Crew**: 20 hours per pile repair.

**Materials**:

**Replacement Pile Section** - The replacement pile section should be long enough to span the measured distance between the bottom cut and the top cut on the damaged pile, minus the thickness of the bearing plates. If replacement is to be performed to the bottom of the concrete deck, allowance must be made for "swinging" room in bringing the pile under the deck, which is taken up by a shim. The best repair will result if the replacement pile is of the same cross section as the existing pile.

**Plates** - Plate thicknesses will depend on details of splice. Allow for waste.

**Angles** - Angle sizes will depend on details of splice. Allow for waste.

**Bolts** - Bolts should be ordered slightly longer than normally required. Expansion bolts are required for some details. Order extra nuts/bolts for losses due to dropping.

**Potential Problems**: Since new steel is anodic to old steel, the new steel replacement section has a high susceptibility to corrosion if not protected.

• Underwater attachment of the new section to the lower joining cap is accomplished by using bolts and lock washers. The upper joint is attached by welding splice plates to both H-pile sections.

• Alternately, direct attachment of the new pile post to the pier deck may be accomplished using a bearing plate welded to the top of the pile post and bolted to the pile cap. Shim plates can be used to fill the gap between the new post cap and pile cap. Or, grout can be hand packed and allowed to set before tightening the joining bolts.

• Install cathodic protection system or encase the repair section in concrete.

### 5.5.3 Complete Pile Replacement

A repair technique that may be economical in some situations consists of replacement of the entire pile. Two methods are described in Table 5-11. The first method requires cutting a hole through the existing deck and driving a new pile. A new concrete or steel pile is driven straight down between adjacent piles and a new pile cap is formed under the deck and around the new pile. Horizontal reinforcing bars need to be welded to the top of the steel replacement pile to ensure adequate load transfer from the deck to the pile. A pile cap is formed under the deck and around the new pile and filled with concrete to fill the space in the deck to the top of the new pile.

The second method requires cutting a hole for interior piles only, i.e., those not along the face of the berth. A steel pile is driven at an angle and then winched laterally into place and shimmed under the existing pile cap alongside the damaged pile. Care must be taken to minimize bending of the new pile or the adjacent structure while pulling the pile into place. The pile is designed to resist the bending moment resulting from pulling it into place, in addition to the vertical live load. All new steel should be cleaned and painted before installation.

The complete pile replacement method can restore the full load capacity of the pier or wharf. However, the technique requires the use of heavy pile driving equipment which may not be available at the site.

Before driving a new pile it is important to survey the bottom and clear the area of debris.

### 5.5.4 Protection of Steel Pile by Wrapping

A newly installed steel pile or an existing pile with slight corrosion deterioration (less than 15 percent) can be protected from further deterioration by using polyvinyl chloride (PVC) wrappings. Wrapping PVC sheets around the pile cuts off oxygenated water access to the steel surface. The oxygen trapped in the water between the pile guard and the steel is depleted after a short period of time and the corrosion processes are halted. Manufacturers of suitable pile wrap are listed in Appendix A.

To avoid possible acceleration of corrosion at the bottom of the wraps, it is important that the wraps on steel piles extend to at least 1 foot both below the mudline and above the high waterline.

The general procedure that is similar to that used for timber piles, as discussed later in Section 5.9.4 and described in Table 5-33, is not repeated in detail here.

The pile is first cleaned thoroughly to remove marine growth and sharp projections. Mud or riprap is removed to expose the pile at least 1 foot below the mudline.

Table 5-11
Procedure for Complete Replacement of Steel Pile

**Problem:** Moderate to heavy deterioration (greater than 35 percent) of the cross-sectional area, or damage, has occurred to a steel H-pile.

**Install New Pile Between or Adjacent to Damaged Piles** (Figure 1):

- Cut an opening in the concrete deck near damaged piles.
- Drive new steel or concrete pile through hole and cut off below the top of concrete deck.
- Weld steel horizontal reinforcing bars to top of steel replacement pile and under the pile where new pile cap will be poured to ensure adequate shear transfer.
- Fabricate form for a pile cap under concrete deck. The form should extend under the deck to ensure load transfer between deck and pile.
- Pour concrete to cast new pile cap.

**Adding Pile Under Existing Deck or Pile Cap** (Figure 2):

- Cut an opening through the concrete deck immediately adjacent to the damaged pile.
- Drive a new steel pile at an angle and cut off below the existing deck.
- Winch the pile to vertical using come-along, hydraulic rams, etc., with cables attached to adjacent structure. Carefully monitor adjacent members and new pile to ensure they are not bent during the process.
- Weld a 1-inch or thicker steel plate to top of pile with holes cut for fasteners.
- Shim with plates or grout as necessary between the pile and deck (pile cap). Fasten using suitable sized expansion bolts or drill and grout anchor bolts.

**Application:** This method restores the structural strength lost with the deteriorated pile.

**Note:** Bolts must resist load from pile as it tends to become straight.

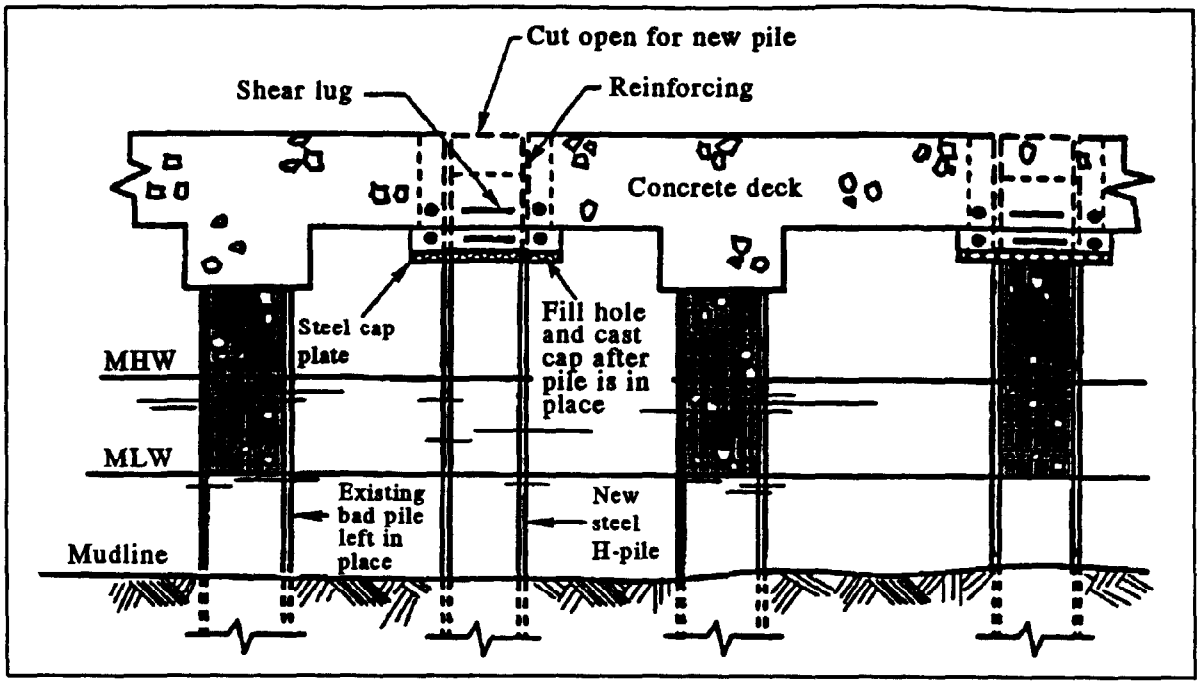



Table 5-11
Figure 1. Addition of steel piles to existing structure with new pile cap.

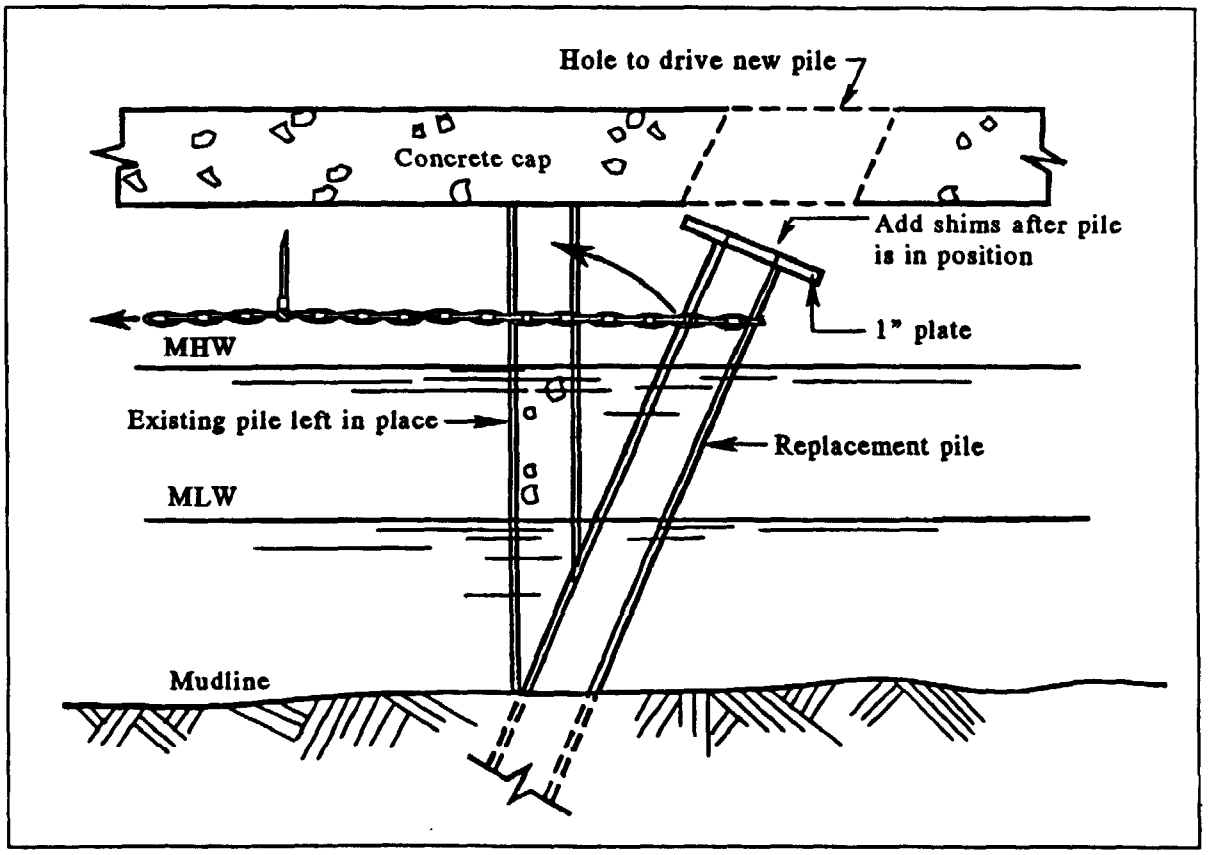



Table 5-11
Figure 2. Addition of new steel pile adjacent to existing pile cap.

For the technique to be effective, a seal must be installed top and bottom to prevent flushing of water. For H-piles this is accomplished by installing expanded styrene blocks to fill the channel voids approximately 1 foot above MHW and at the bottom of the pile section to be wrapped (Figure 5-18). The foam blocks are slightly larger than the channel dimensions so they must be forced into place. Manufacturers of pile wraps provide styrene blocks which can be cut to fill the void.

A sealing compound is applied along the edges where the blocks come in contact with the pile. A foam gasket is then wrapped around the pile at the block to provide a sealing surface for the pile wrap.

High-impact styrene covers are installed over the exposed edges of the H-pile, along the length of the wrap. The covers bridge the channel gap. These covers protect the pile jacket from being ruptured from floating or submerged debris. Finally, the pile wrap is installed and strapped into place according to manufacturer's instructions.

### 5.5.5 Underwater Coatings

The application of underwater coating to steel piles is generally not recommended. If used, the procedure requires thorough cleaning of the steel both above and below the waterline. The coating must be applied within 72 hours (less for warm tropical waters) of cleaning to ensure that marine growth has not reformed.

Manufacturer's recommendations need to be carefully followed. Epoxy and polyamide coatings will be sensitive to water temperature. Water temperatures above 70°F are desirable. The materials are generally unusable at temperatures below 55°F.

The use of underwater coatings involves the application of hazardous materials. MSDS on all materials will need to be obtained from the manufacturer along with their recommended handling procedures. The necessary environmental permits or letter of permission will need to be obtained as described in Section 1.4.4.

### 5.5.6 Cathodic Protection

Cathodic protection is another means of controlling corrosion of the submerged portion of steel in waterfront structures. Two types of cathodic protection systems are used for marine structures. They are: (1) the sacrificial anode system, and (2) the impressed current system. Both systems require periodic inspection and maintenance.

The sacrificial anode system can be retrofitted into the waterfront structures using procedures within the scope of this manual. Planning and estimating data are provided in Table 5-12. The selection, installation location, and connection method for the anodes needs to be designed by an experienced corrosion engineer for each specific application.

Installation of impressed current cathodic protection systems is beyond the scope of this manual. For a detailed discussion of cathodic protection systems refer to Section 5.11.

## 5.6 STEEL SHEET PILE STRUCTURES

Techniques used for repairing sheet pile structures include:

- Patching
- Coating the face with concrete
- Installing a new concrete cap and face
- Installing a new tieback system
- Replacement of damaged wall

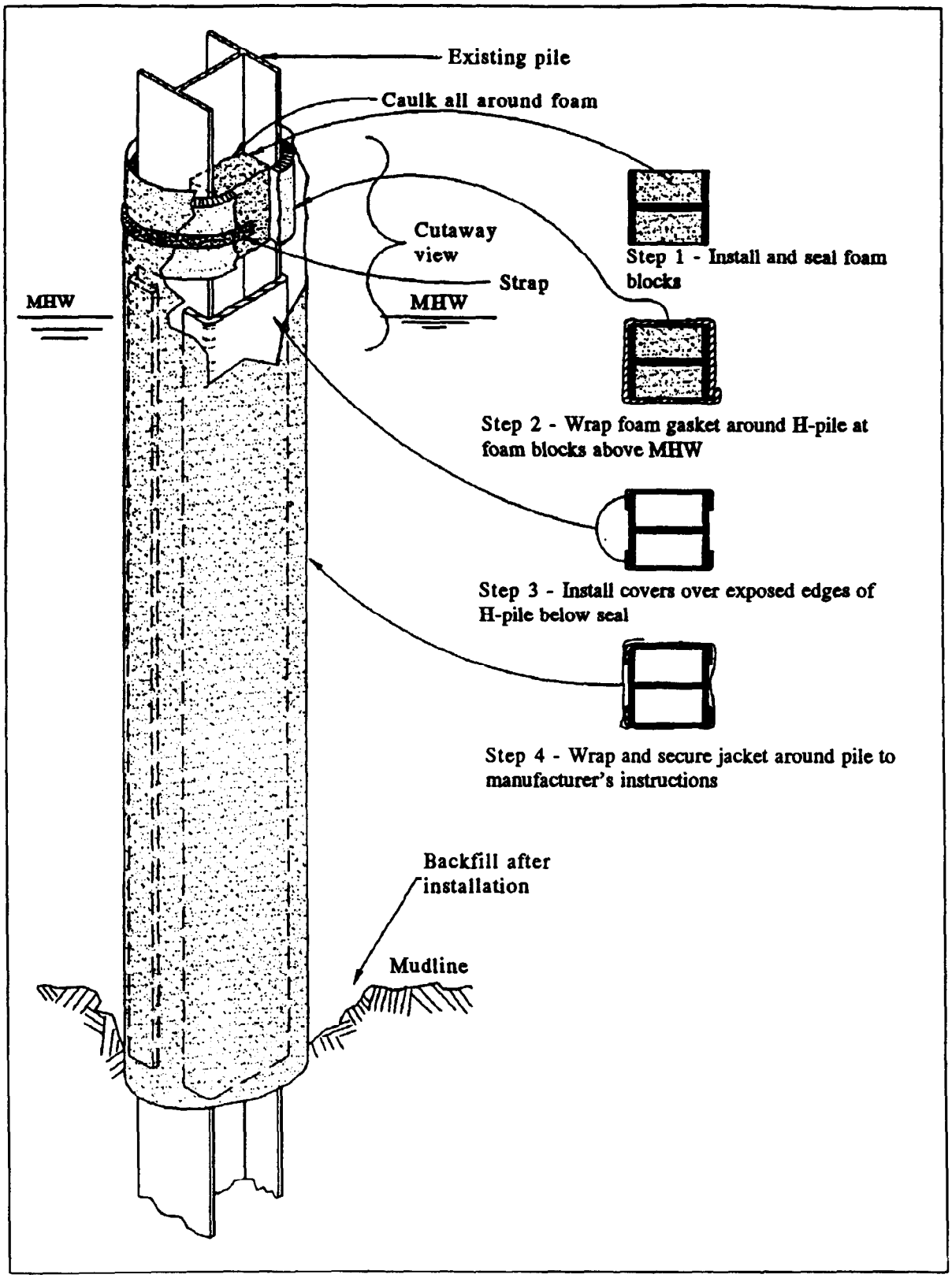



Figure 5-18
Pile "wraps" are used on steel H-pile.
Seal at top prevents water from flushing. Bottom is sealed by mud or poured concrete.

Table 5-12
Planning and Estimating Data for Steel Pile Maintenance
Using Cathodic Protection

**Description of Task:** Install a sacrificial anode on a steel pile below low waterline. A 40-pound anode is attached to the pile with a welded connection.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with removal of marine growth, underwater lifting procedures, and underwater welding.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, welding machine with leads, welding torch, lift bags/rigging gear, float stage or work platform.

**Procedure:** The location and attachment method will vary depending on the specific application site. The system should be designed by an experienced corrosion engineer. Attachment methods may include bolting, welding, or explosively-actuated fasteners.

**Productivity of Crew:** 1-1/2 hour per anode.

**Materials:**

**Anodes** - A sacrificial anode should be placed on each pile to be protected for maximum protection. Wire leads can be run to diagonal or horizontal bracing members between piles and bonded in place for further protection.

### 5.6.1 Patching

Small holes in steel sheet pile structures, 1/2 inch to 1 inch, can be covered with epoxy patches as described in Table 5-13 with planning and estimating guides in Table 5-14. Manufacturers of underwater curing epoxies are listed in Appendix A.

A successful bond between the epoxy and steel surface requires thorough cleaning of the sheet pile surface. All marine growth and loose rust must be removed and the surface cleaned to bare metal. A rough surface provides better gripping power for the epoxy patch. Mechanical cleaning tools and a high-pressure waterblaster can be used for cleaning below the waterline. The epoxy material must be applied within 72 hours (less for warm waters) following cleaning before new growth has a chance to form. Epoxies will not stick to wet surfaces. Therefore, the technique used is to smear the epoxy (kneaded and pressed) over the surface to drive off the water and produce an intimate contact between the epoxy and sheet pile surface.

Each manufacturer has a specific set of instructions which will include application methods, hazard warnings, pot life after mixing, and minimum cure temperatures.

Most underwater epoxies will not cure below 50°F. However some manufacturers have special formulations of resins to cure at temperatures down to 40°F. The cure time increases as temperature drops: a low temperature epoxy might take 24 hours to achieve an initial cure and up to 14 days to achieve maximum strength. It is also noted that the maximum strength of epoxy cured at 40°F will be significantly less than the same epoxy cured at 60°F.

Underwater epoxies are hazardous materials and require appropriate shipping and handling procedures. Wear protective gloves during mixing and applying.

Epoxies can be used as gasket material in conjunction with steel, wood, or plastic sheet patches. Various mechanical fasteners are used to join the patches to the sheet pile (toggle bolts, stud gun, etc.). Care must be taken to ensure that the patch and fastener material does not create accelerated corrosion problems. The use of nonmetallic patch and fastener materials is preferred.

Where there are too many holes to cover practically with small patches, a technique that may be used is to cover the large holes with patches and use pressure grouting techniques to fill voids behind the wall as illustrated in Figure 5-19. Pressure grouting requires specialized equipment which may not be readily available for UCT operations.

### 5.6.2 Concrete Capping and Facing

A number of techniques can be used to repair a deteriorated sheet pile wall. Before proceeding with the repair, it is important that a structural analysis be made to validate the soundness of the existing sheet pile to carry additional load from a new cap or concrete face and determine the need for additional tiebacks.

Replacement of the deteriorated top of the steel sheet pile retaining wall structure may be accomplished by installing a cast-in-place concrete cap on the wall as described in Table 5-15. The repair may also require partially coating the front and back surfaces with concrete.

As in the case of partial concrete encasement of pipe and H-piling, accelerated corrosion can occur at the bottom of a partial concrete encasement of sheet steel piling. Ideally, the encasement should be terminated above MHW and continued to below the mudline. Alternatively, cathodic protection should be installed to control the accelerated corrosion attack.

Table 5-13
Patching Small to Medium Holes in Steel Sheet Pile

**Problem:** Small to medium holes exist in sheet pile wall, condition of sheet piling is sound with minor corrosion (Figure 1).

**Description of Repairs:** Thoroughly clean area to be repaired removing all marine growth, rust scales, loose materials and debris.

**Epoxy Patch:** Use only for minor repair of small holes/pits. Follow manufacturer's directions. Use protective rubber gloves while mixing materials. A rough irregular surface will provide a better bond. Technique generally not effective below 55°F water temperatures.

Smear mixed epoxy material over area to achieve uniform coverage. The smearing action displaces water at the surface providing necessary contact between epoxy and surface. Fiberglass cloth may be used for reinforcement

**Steel Plate Patch:** Determine size of patch and prepare patch to fit needed contour. Select method of attachment. Fabricate gasket and install patch.

- Alternative Patch Materials:
  - Cut and bent steel plate is fitted over damaged sheet pile
  - Locate a section of steel or plastic sheet pile with the same contour as the seawall.

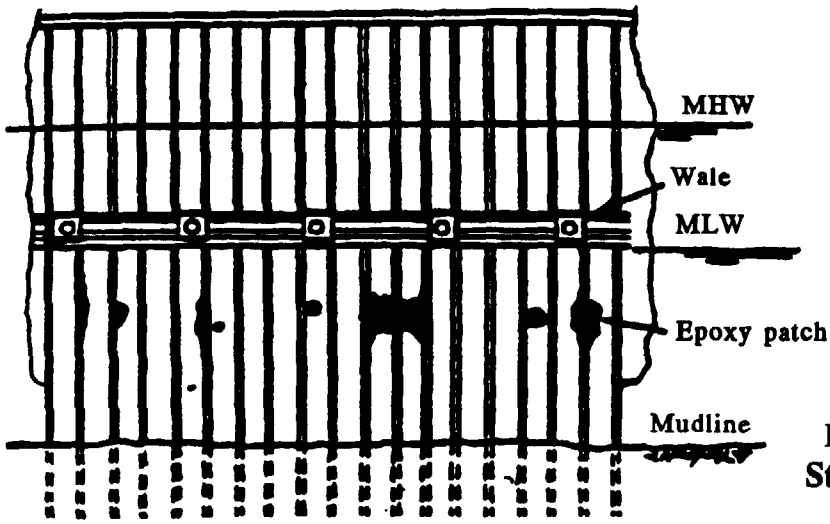
- Methods of attaching patch to sheet pile wall include:
  - Drive studs with stud gun and bolt patch in place
  - Use a Tucker Patch technique on larger holes
  - Weld patch in place if experienced underwater welder available (generally not recommended)
  - Use toggle type bolts or bolts with L-shaped ends to catch pile wall

A gasket between patch and seawall can provide a seal to reduce surge or current-induced washout of back fill material. Gasket materials include:

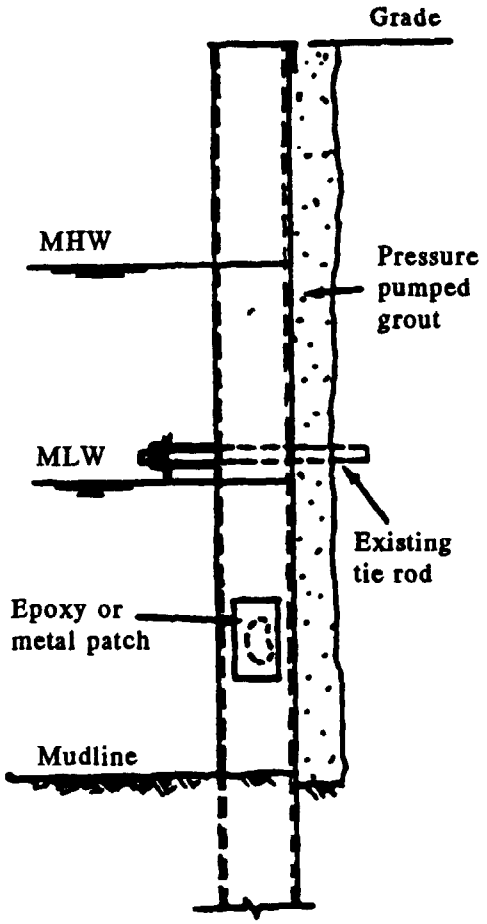
- Fabricate a gasket from sheet rubber
- Apply wide grouting bead of flexible material to patch and allow to set before installing
- Apply underwater epoxy grouting material to seawall just prior to installing patch

Alternatively install patch without gasket and use pressure grout techniques either through the patch or from the surface to fill behind patch and seawall.

**Application:** This technique will not prevent further corrosion and its success is dependent on the soundness of the surrounding sheet pile. Continued deterioration particularly near wale and tieback rods could lead to seawall failure. Obtain engineering assistance for guidance.

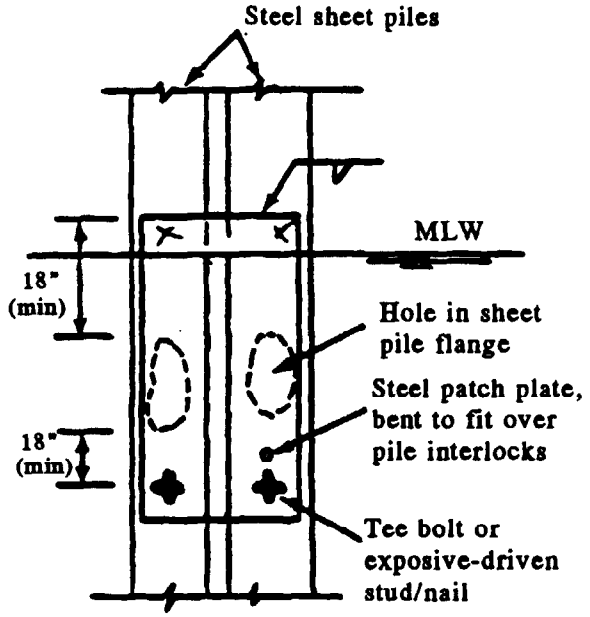



**Epoxy Patching of Steel Sheet Pile Wall**




**Pressure Grouting of Steel Sheet Pile Wall**

(Note: Requires pressure gravity pumps.)




- Form patch to fit
- or use sheet pile of sane profile
- or Tucker Patch

**Steel Plate Patching of Steel Sheet Pile Wall**

Table 5-13

Figure 1. Repairs to steel sheet pile walls using various patching techniques.

Table 5-14
Planning and Estimating Data for Steel Sheet Pile Repair Using Epoxy Patch

**Description of Task**: Repair a deteriorated steel sheet pile wall by patching with fabric mesh covered with hand-applied epoxy mastic. A 1-$ft^2$ area below the low waterline is to be patched.

**Size of Crew**: Dive station, one laborer

**Special Training Requirements**: Familiarity with procedures for removal of marine growth and placement of epoxy mastic underwater.

**Equipment Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, protective clothing for personnel handling epoxy materials, float stage or work platform.

**Productivity of Crew**: 1 hour for a 1-$ft^2$ patch.

**Materials**:

**Fabric Mesh** - The fabric mesh must cover the entire hole to be patched as well as extending over the surrounding sound metal. The area of the holes to be patched should be estimated and a 25 percent allowance made for extra material.

**Epoxy Patching Compound** - Epoxy patching compounds are usually purchased in two-component kits with an aggregate additive. A 1-gallon kit might include 1 gallon of each component plus aggregate, resulting in more than a 2-gallon yield. Patching coverage is measured in square feet per gallon. The required patching yield is obtained by taking the square footage to be covered and dividing by the square foot per gallon coverage rate. The square footage should be based on the size of the fabric mesh, which is considerably larger than the size of the hole being covered.

**Potential Problems**: If water temperature is less than 60°F, proper adhesion to the sheet pile may not occur. Successful patching requires a neutral or positive charge on the structure; negatively charged steel repels the negatively charged epoxy patching compound. Underwater application may be difficult. Skin irritation may occur if individual is sensitive to the epoxy material.

Table 5-15
Installing a Concrete Cap and Partial Face on Sheet Pile Wall

**Problem:** Major damage to steel sheet pile precluding the use of patches for repair.

**Caution:** Block off pier deck from traffic. Notify port authority to secure marine traffic and obtain clearances to begin construction.

**Description of Repairs:** (Figure 1). Concrete cap and partial face is installed over damaged area. Engineering required to: validate soundness of existing sheet pile to carry additional load of new cap; determine the need and design for additional tiebacks; provide recommendations for concrete dimensions, reinforcing steel dimensions, and placement; and evaluate the need for corrosion protection.

- Remove existing surface treatment (decking) to provide access to front and back of seawall.
- Clean sheet pile to be capped with high-pressure waterblasting. Use sandblasting above waterline.
- Excavate behind the wall to allow installation of cap and backface if required. Concrete behind sheet wall may not be required.
- Excavate trenches and install new tieback system with wale as required. Electrically isolate tieback assembly from sheet pile using insulation washers and collars.
- Install reinforcing both front and back and attach by welding to existing sheet pile.
- Fabricate and install forms to provide a minimum 6-inch thickness of concrete both front and back.
- Pour front and backface at low water level.
- Install forms for concrete cap and pour when ready.
- Remove forms after concrete has cured, backfill behind seawall, and replace decking.
- Install fender system as required.

**Application:** Restores structural strength at top of wall and prevents loss of soil through holes in sheet wall. Requires installing a cathodic protection system to prevent accelerated corrosion at the underwater interface between concrete cup and sheet pile.

**Inspection Requirements:** Annually inspect sheet pile area immediately under concrete cap.

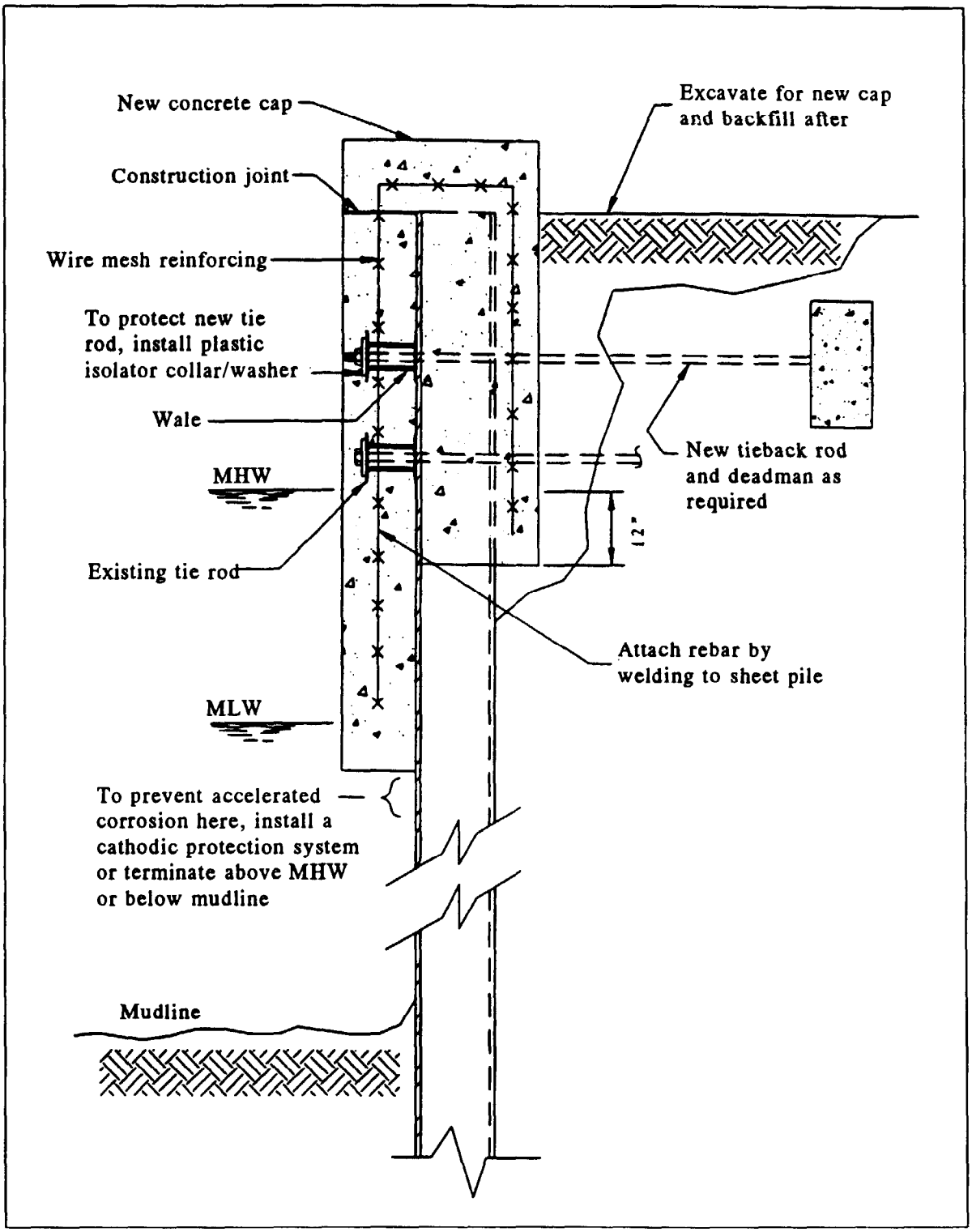



Table 5-15
Figure 1. Concrete capping of steel sheet pile wall.

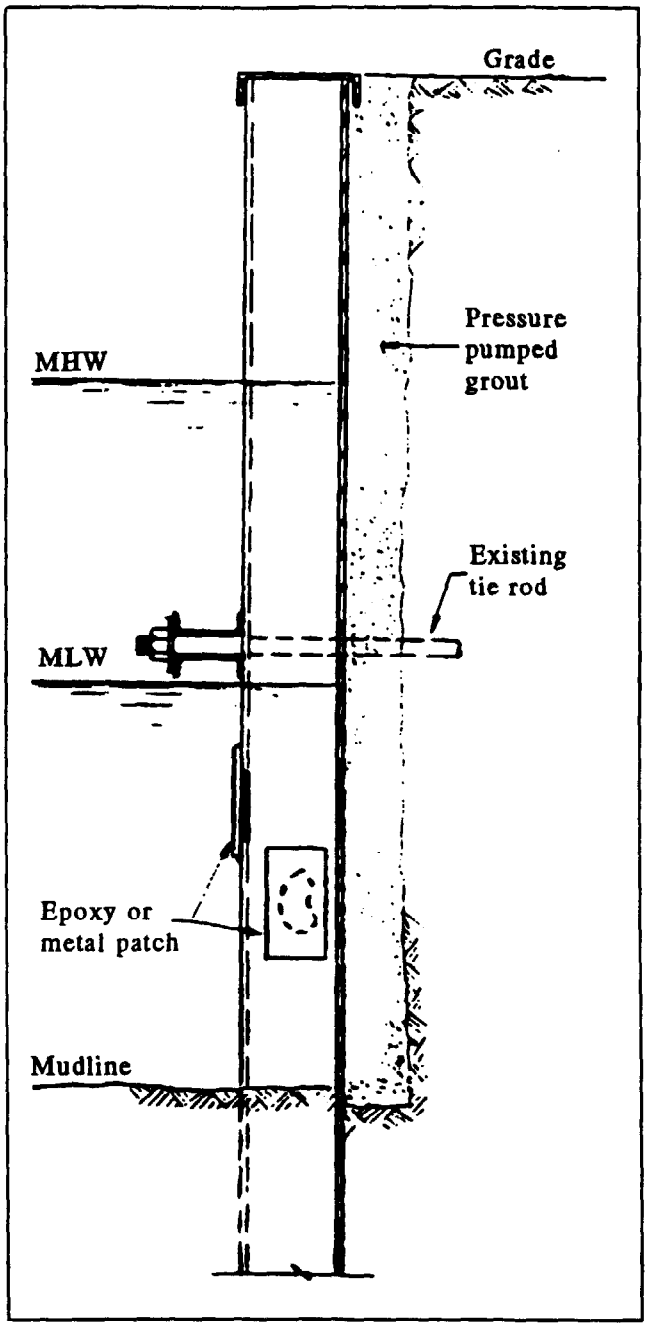



Figure 5-19. Pressure grouting of steel sheet pile wall.

Installation of a concrete cap requires removal of the existing surface pavement or decking and excavation inboard of the sheet pile. When this has been accomplished, an inspection should be made to determine the condition of the tieback system and the need for replacement. If a new tieback system is installed (Section 5.6.4), care must be taken to electrically isolate the new tie rod from the existing sheet pile; otherwise, accelerated corrosion of the tie rod will occur.

Reinforcing steel is installed and forms are constructed outboard and inboard as necessary. Reinforcing should be welded to the existing sheet pile with steel spacers to maintain orientation. Shear lugs can also be welded to the sheet pile to help hold the concrete in place.

The outboard concrete face should be poured first and allowed to partially harden. The new cap and inboard concrete should be poured simultaneously. Allow the concrete to cure for 7 days before removing forms. Once set, the new concrete is cured then backfill and decking are replaced.

### 5.6.3 Replacement of Damaged Sheet Pile Wall

Where the existing steel sheet pile structure has been damaged to the point where patching or concrete facing would not be effective, a replacement wall may be necessary. The repair involves the use of heavy construction equipment and normally would not be done solely by UCT personnel. The procedure involves driving a new sheet pile either outboard or inboard of the existing structure as described in Table 5-16.

Before commencing construction, a survey should be conducted including a soils evaluation and diver inspection of the existing structural components: sheet pile wall, tie rods, and wale. This information will be used to conduct an engineering structural analysis to determine suitability of existing structure for the repair method.

Table 5-16
Replacement of Damaged Sheet Pile Wall

**Problem:** Existing steel sheet pile structure has been damaged beyond repair by patching resulting in loss of backfill, weakened structure, and reduced vertical load capacity of deck. Repair involves the use of pile driving equipment and normally would not be done solely by UCT personnel.

**Description of Repairs:** A new steel sheet pile wall is installed outboard of the existing sheet pile and is joined to the existing sheet pile by a tie rod. Conduct a soils evaluation and diver inspection of existing sheet pile wales, tie rods, to provide information for an engineering analysis of the structure and determine suitability of repairs. A new sheet pile can be installed inboard if environmental restrictions prevent outboard installation.

**CAUTION: Before beginning construction: Secure area from marine and vehicular traffic. Obtain clearances from local authorities.**

**New Sheet Pile Outboard Existing Wall:** (Figure 1) If existing tieback system is in good condition, then proceed with installation of new wall, otherwise install new tieback anchor system. See tieback anchor installation procedure (Section 5.6.4).

- Drive new sheet piling outboard of existing sheet piling and install new wale.
- Drill holes through wale/pile large enough for tie rod and electrical isolation collars.
- Install connecting rod through sheet pile and attach to anchor system on existing sheet pile, wale, or tie rod.
- The new sheet pile wall **must** be electrically isolated from the existing (Figure 2) wall to reduce the effects of galvanic corrosion. Install insulating sleeves and washers as shown in detail.
- Backfill between walls as directed by engineering and install new surface treatment.

**New Sheet Pile Behind Existing Wall:** (Figure 3) (Primarily provides a method of reducing loss of backfill behind an otherwise structurally sound existing sheet pile wall.)

- Remove decking and excavate behind wall to determine location of existing tieback anchor system and install timber wales to act as template for driving new sheeting.
- Drive new sheet pile wall: At tie rod location drive sheeting at a slight angle, notch, and force together.
- If new sheet piling is more than 1 foot behind existing, then cut tie rod outboard of new wall and provide new wale system on new sheet piles and remove existing sheet pile.
- Backfill and install surface decking.

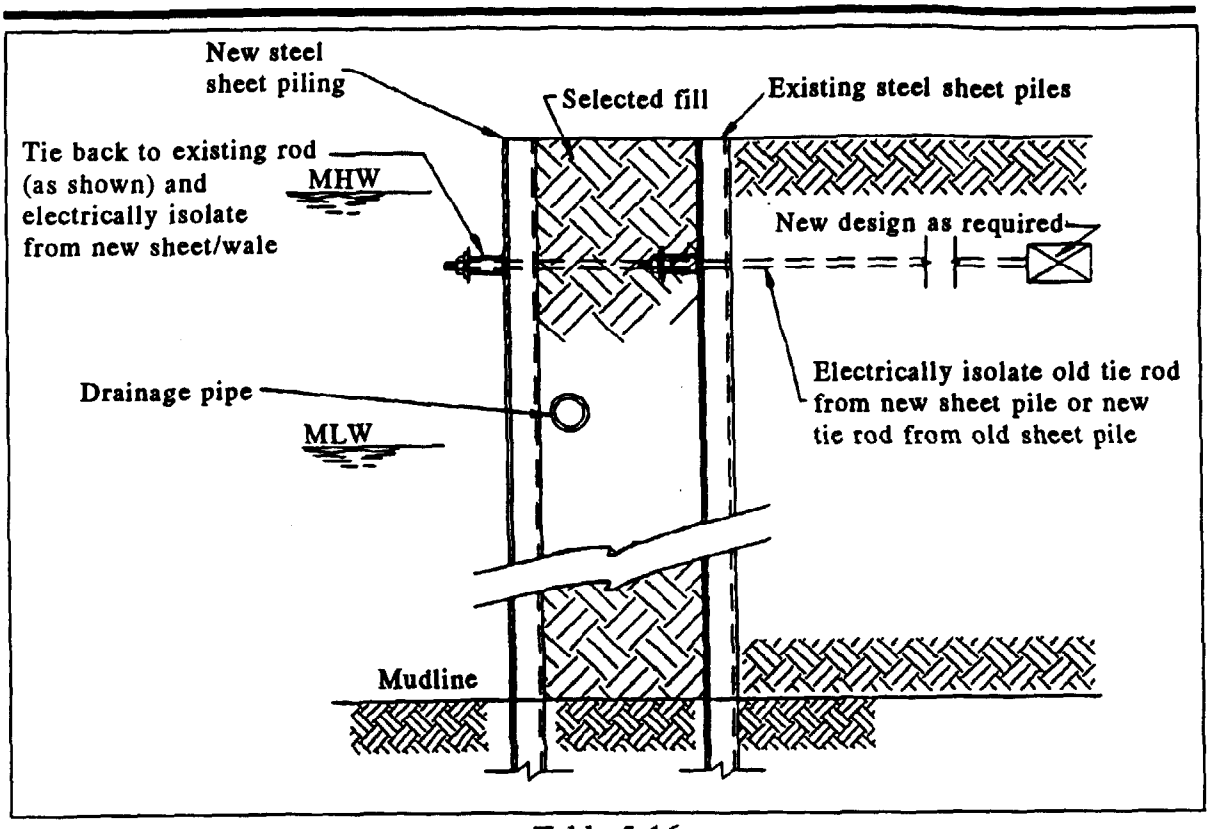



Table 5-16

Figure 1. New steel, tied back wall in outboard of existing wall.

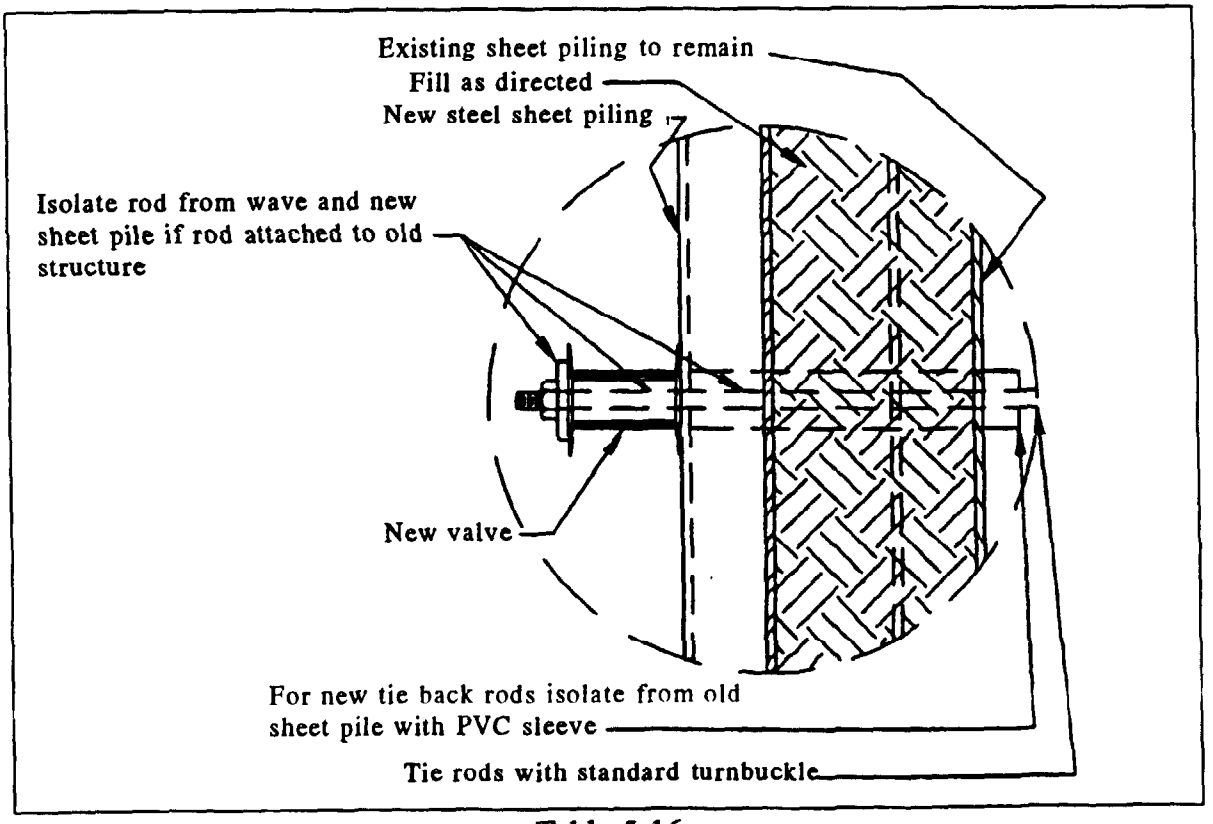



Table 5-16

Figure 2. New sheet pile wall must be electrically isolated from existing wall.

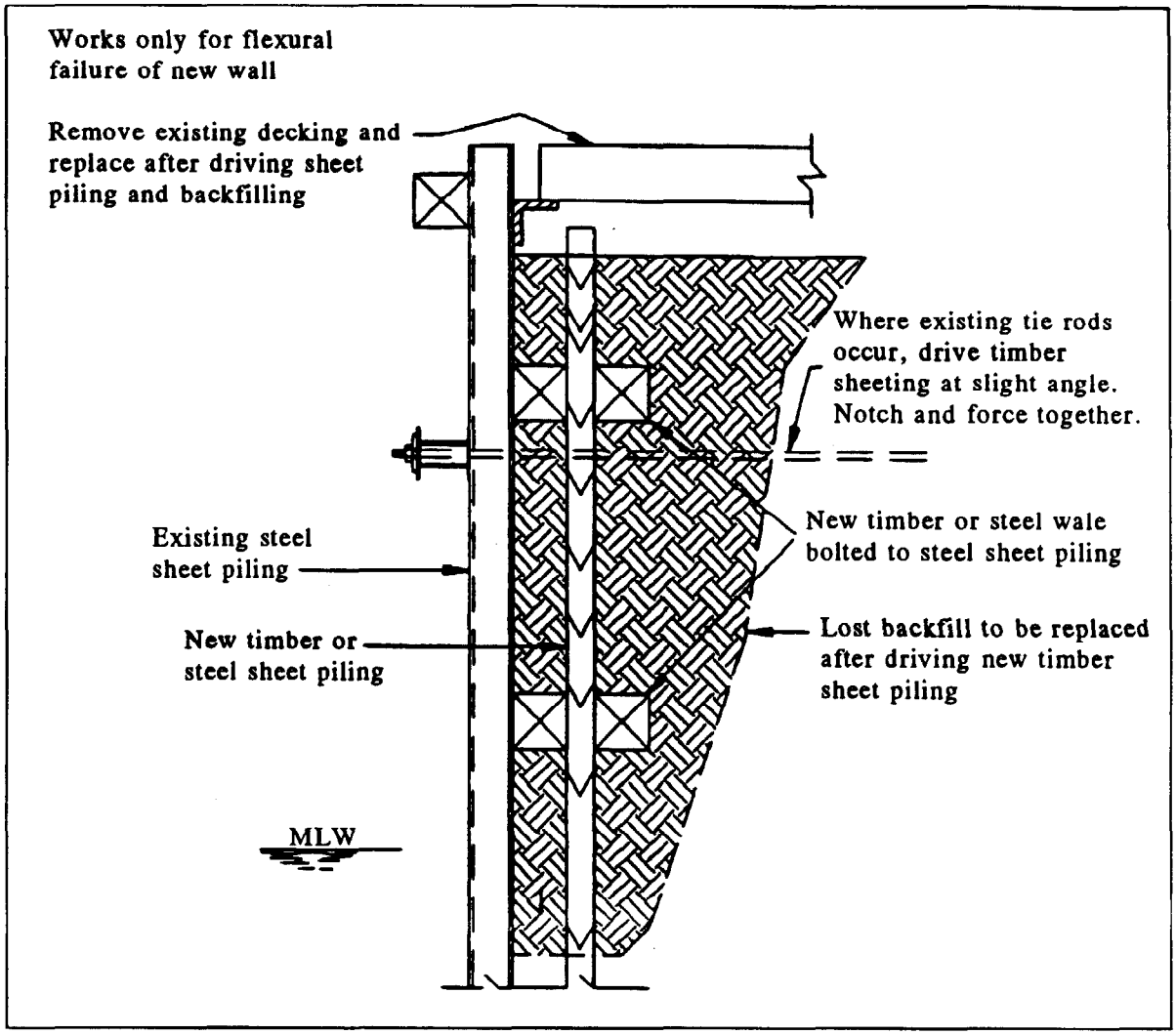



Table 5-16
Figure 3. New steel or timber sheet piling behind existing sheet piling wall.

The preferred approach is to install the new wall outboard of the existing wall (Table 5-16). This will reduce the requirement for removing decking and excavation behind the existing wall. However, local environmental restrictions may prohibit a new outboard wall requiring that a new structure be driven inboard.

New steel is anodic to old steel so that if the old wall is not removed, the new sheet pile wall must be electrically isolated from the existing wall to reduce the effects of galvanic corrosion. Also, where a new tieback system penetrates old sheet pile, use PVC sleeves, collars, and washers to electrically isolate the new tie rod from the old sheet pile.

Where an old tieback system is used to support the new wall, PVC insulators are needed to isolate the rod and bolts from the new sheet pile and wale.

The sheet pile wall may also be repaired by constructing a new concrete face. Construction of a full concrete face is more desirable than a partial face because it eliminates accelerated corrosion which can occur at the bottom of the concrete face. One procedure for installing a concrete face is

described in Table 5-17. The procedure involves driving timber sheet pile to provide a form for the concrete.

### 5.6.4. Tieback System Installation/ Replacement

Movement of sheet pile walls can sometimes be arrested by installation of a new tieback system or by replacement of a deteriorated system.

A new tieback system will require installating both a new wale and anchor system. The new wale is installed slightly above the existing wale. Selecting the omponents of the system and placing the anchor must be made based on structural calculations.

Types of tieback anchors that may be used include: pile anchors, deadmen, plate and auger anchors, and grout-injected anchors. Selection of the anchor type will depend on local soil conditions and availability of installation equipment.

Grouted-in anchors are an excellent method for providing tieback restrains; however, they require heavy duty specialized equipment to drill the access hole from the outboard side of the sheet wall. Once the hole is drilled, pressure grout pumps are used to form a concrete bulb at the end of the hole. A tie rod is inserted into the grout before it sets.

Screw (or auger) and driven-plate anchors provide effective holding power but require heavy duty equipment to provide high reaction forces for inserting the anchor to the required depth. These techniques are not usually used by UCT personnel.

Table 5-18 provides a discussion of general procedures for replacing tieback systems using a trenched-in deadman anchor. The procedure is applicable in situations where the surface is accessible to trenching machinery. A trench is dug from the wall back the required distance to the anchor location at the depth of the wale. The trench length, depth, deadman anchor size, and connecting hardware needs to be determined by engineering based on a knowledge of the local soils conditions and expected loading on the wall.

An important consideration in installation of any new structural material near the ocean is minimizing the potential for galvanic corrosion. Care must be taken to electrically isolate the new tie rod from the existing old sheet pile. PVC washers, sleeves, and collars provide good protection. All new metal, such as a new wale, should be protected by painting.

Care needs to be taken on tightening up the new tie rods to prevent overstressing or bending the existing wall. Local slope failure of backfill may prevent the pile from returning to vertical unless the backfill is excavated. If the top of the sheet pile has moved more than 6 inches, then excavation behind the wall is definitely recommended before attempting to pull back the sheet pile. Wall load modification may be required as discussed below.

### 5.6.5 Wall Load Modification

Sheet pile wall movement can sometimes be arrested by changing the soil loading acting on the wall. For example, stone riprap dumped against the exterior toe of the wall will add resistance to the movement. Alternatively, or in addition, backfill can be removed from behind the wall and replaced with a lightweight granular fill. This type of fill has the advantage of being free-draining, which reduces the hydrostatic pressure behind the wall and allows the water level on both sides to balance.

Wall load modification is usually carried out by shore-based construction forces.

Table 5-17
Installing Concrete Face on a Steel Sheet Pile Wall

**Problem**: Major corrosion damage to face of the steel sheet pile with greater than 30 percent of face corroded through sheet resulting in loss of backfill. Existing strength of sheet pile wall is adequate for planned use.

**Description of Repairs**: (Figure 1) Existing sheet pile wall is covered with concrete over damaged area extending from mudline to deck.

- Clean surface of damaged sheet pile to remove marine growth and loose material and rust from face of sheet pile.

- Excavate behind seawall to a depth above MLW to provide attachment for blocking and new wales. If not feasible to excavate, then blocking may need to be hung from top of wall or attached to brackets welded to face of sheet pile.

- Place and fasten 4x12 blocking against existing seawall to provide a guide and spacing for outer concrete form. Alternatively use sections of pipe for blocking material.

- Install two wales: one close to top and one at the blocking.

- Weld shear lugs to sheet pile wall extending 4 inches from wall or as directed by engineering.

- Install steel reinforcing in center of pour area.

- Drive timber sheet pile wall to 3 feet below mudline in front of blocking.

- Pour by tremie or pumping methods and allow 7 days cure before removing forms.

- Backfill behind seawall.

**Application**: Used to stop the seepage of soil backfill.

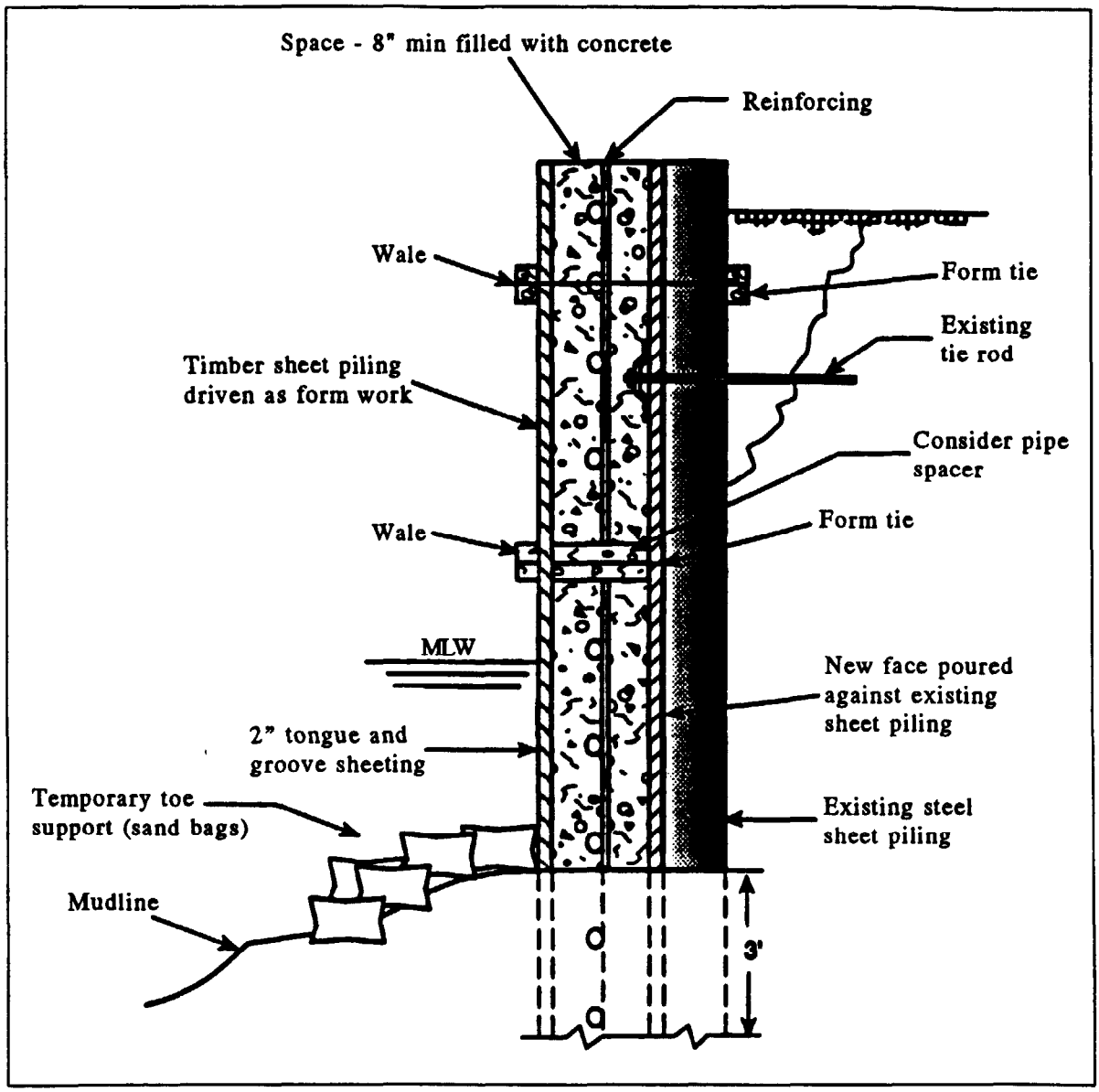



Table 5-17
Figure 1. Repairs of an existing sheet pile wall.

Table 5-18
Replacing Tieback Systems for Steel Sheet Pile

**Problem:** Slight to moderate top movement of sheet pile wall due to tieback failure.

**CAUTION: Before beginning construction: Secure area to prevent marine and vehicle traffic from using facility. Obtain clearances from local authority.**

**Description of Repairs:** Install a new wale slightly above the existing wale and install new tieback system. Engineering personnel should determine tieback system design including the need and design for corrosion protection (anodes) and adequacy of existing sheet pile to accomplish longer span (distance to mudline). Various types of tieback anchors may be used such as: pile anchors; deadman, plate, and auger anchors; and grout-injected anchors. Selection will depend on local conditions. Grout anchors require specialized equipment for drilling and applying pressurized grout and are generally beyond UCT procedures. Plate and auger type anchors require high reaction forces to install and also require a large access hole cut in the sheet pile to accommodate driving the anchor to depth.

**Trenched-In Deadman or Pile Anchor** (Figure 1):

- Dig narrow trench(s) to wale depth between seawall and deadman location and excavate for the anchor.

- Install anchor; install tie rods with turnbuckles through new wale and sheet pile; and secure to the deadman anchors. Take care to electrically isolate the tie rod from the wale/sheet pile by using oversized holes in sheet pile and insulating washers and collars at the penetration point.

- Take up slack on turnbuckles and tie rod nuts. If the sheet pile bulkhead does not move back to vertical during the tightening process, it may be necessary to repeat the process by shortening the rod between the turnbuckle and the sheet pile. Local slope failure of backfill may prevent the sheet pile from returning to vertical unless the backfill is excavated. If the top of the sheet pile has moved 6 inches or more then excavation is recommended to prevent wall distortion during pullback. If directed, install a cathodic protection system on the tie rod.

- Install drainage system, backfill trenches, and replace any removed surface material or decking.

NOTE: Sheet pile movement can sometimes be arrested by changing the soil loading or by reducing the hydrostatic pressure behind the wall. Options include:

- Stone riprap dumped against exterior toe of wall will add resistance to toe movement and provide erosion protection.
- Remove backfill behind the wall and replace with lightweight granular fill.
- Install drainage system behind wall.

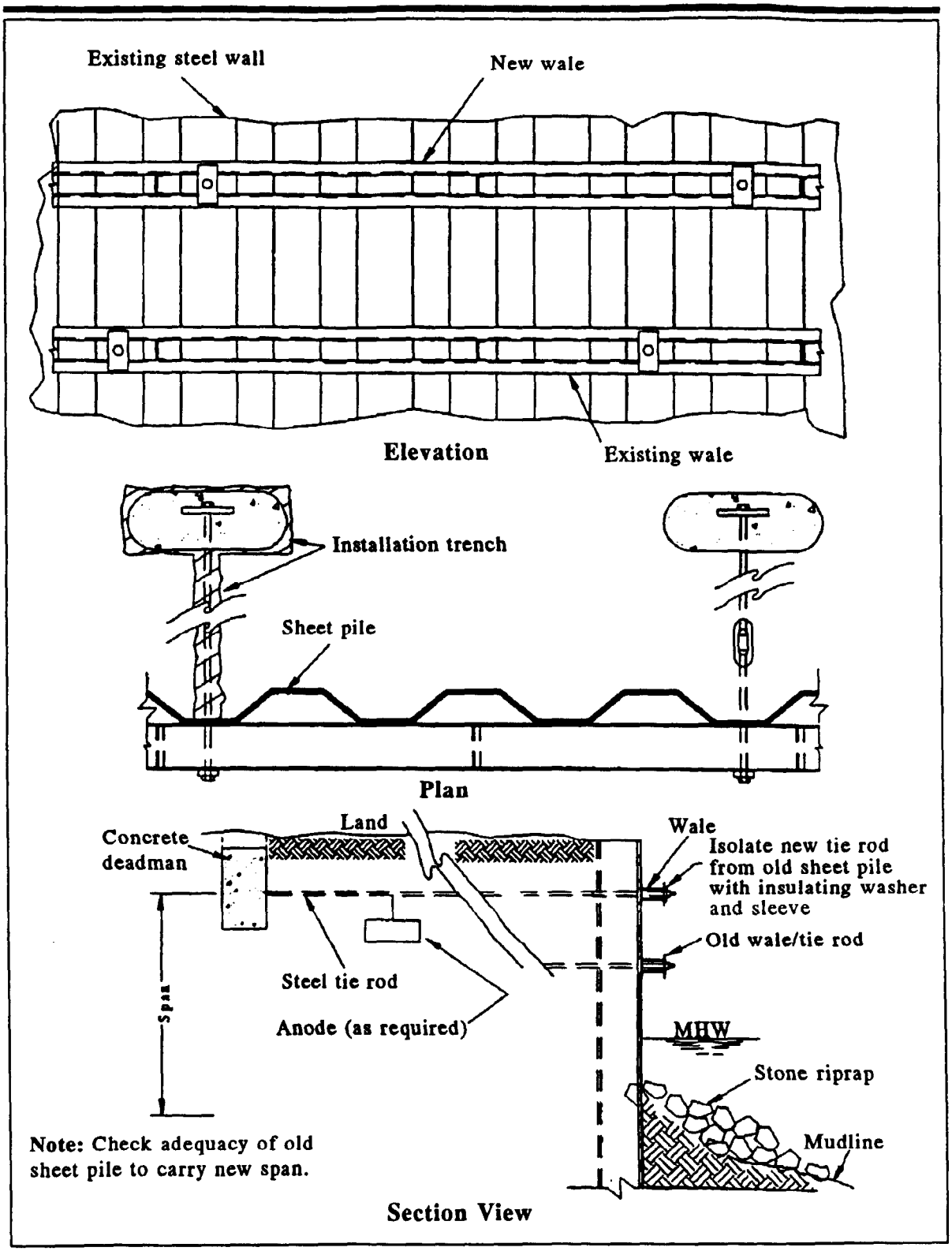



Table 5-18
Figure 1. Installing or replacing tieback systems for steel sheet pile wall.

### 5.6.6 Coating

Underwater coating, as discussed in Section 2.12, can be applied in the splash zone and below the waterline on steel sheet piles that are not severely damaged. Best results will be achieved if the protective coating is applied from the top of the sheet pile to a point below mean low water where the existing coating is sound.

Table 5-19 provides planning and estimating data for maintenance of steel sheet pile walls using coating.

### 5.6.7 Cathodic Protection

Cathodic protection is used to a great extent in the preventative maintenance of steel sheet pile structures. Both sacrificial anode and impressed current systems are used. Sacrificial anodes are bolted or welded to the steel piling in sufficient numbers to provide the required amount of protection. For the cathodic protection system to work effectively, positive electrical connection must be maintained between the individual sheet pilings. Impressed current cathodic protection systems require that the anodes be placed off the face of the wall, thereby limiting the usable surface of the wall for berthing. For a detailed discussion of cathodic protection systems, refer to Section 5.11.

Figure 5-20 illustrates a combination coating/cathodic protection system for a steel sheet pile wall.

Table 5-20 provides planning and estimating data for maintenance of steel sheet pile walls using cathodic protection.

## 5.7 CONCRETE PILES

As described in Section 3.6, there are many causes of deterioration of concrete piles in the marine environment. There are also many methods for the repair and maintenance of concrete piles. These repair and maintenance methods fall into four general categories:

- Concrete encasement
- Epoxy patching/injection
- Replacement
- Wrapping

Shotcreting may be used for restoring concrete piles above the waterline, but this method requires special equipment and training and is not normally performed by the UCTs.

### 5.7.1 Concrete Encasement

Concrete encasement is generally used for concrete piles that have not deteriorated to the point that the pile is not intact and the steel reinforcing is in good shape. In some cases where the pile is broken, the reinforcing steel may be parallel spliced by welding as directed by engineering.

The general procedures for repairing concrete using concrete encasement are described in Table 5-21. They are essentially the same as for steel piles as described in Section 5.5.1. Planning and estimating data are included in Table 5-22. Some general information is provided below. Refer to the figures in Table 5-21 for an outline of the procedure.

The repair procedure involves:

- Cleaning the pile
- Installing wire reinforcing, spacers, and forms about the pile
- Pouring concrete to fill the space between the pile and the form

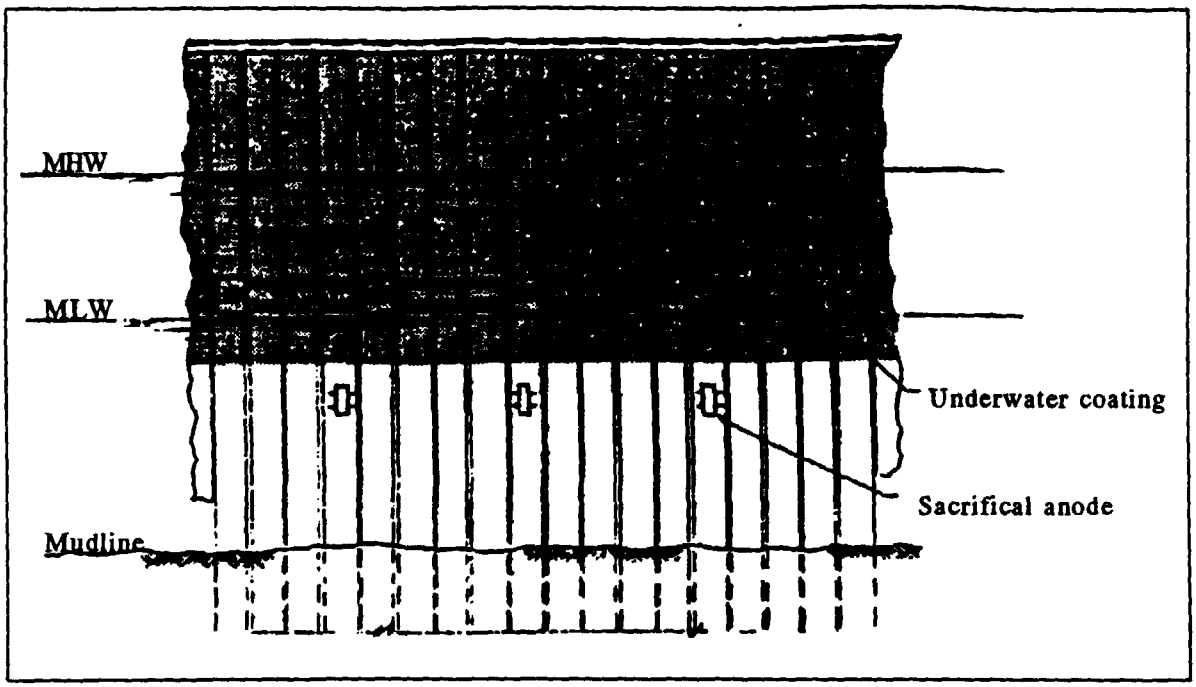



Figure 5-20. Coating/cathodic protection of steel sheet pile wall.

Nonmetallic spacers are used to maintain a uniform 4-inch-thick concrete coating and ensure a minimum (2 inches) distance between pile and reinforcing steel and reinforcing and form. Form manufacturer's provide detailed instructions relating to installing their specific designs.

Both flexible and rigid forms are available and manufacturers are listed in Appendix A. Forms may also be fabricated from materials on site. Selecting the form type depends primarily on availability and choice of the designer or construction crew.

- **Flexible Forms** - These forms are fabricated from a porous fabric and are usually left in place. Both open and closed top models are available. Open top fabric forms are suspended from the piling or overhead structure and are filled to overflowing. The concrete grout fill is topped with an epoxy cap or nonshrinking grout at a 45-degree angle as shown in Figure 5-17.

- **Rigid Forms** - These forms are open top and bottom. They are removed and reused after the concrete has completely cured. Rigid forms can be fabricated from material found at the construction site. A bottom seal and base plate are required to hold the form in place. A temporary friction clamp and base plate conforming to the pile contour is fabricated and attached to the pile at the bottom of the repair area (Figure 3 of Table 5-21). The rigid form rests on the base plate to form the bottom seal.

The piles and any exposed reinforcing steel must be cleaned of rust, scale, and marine life. Failure to do so would result in poor bond between the concrete and pile. It is also important to ensure that the concrete be poured within 72 hours following cleaning to ensure that new marine growth will not have formed on the pile surface. For warm waters, it may be necessary to further restrict this allowed time period.

Table 5-19
Planning and Estimating Data for Steel Sheet Pile Maintenance Using Coating

**Description of Task**: Coat a steel sheet pile with underwater protective coating in the splash zone and below the low waterline. Unit area to be coated is 1 $ft^2$ below the low waterline.

**Size of Crew**: Dive station, one laborer.

**Special Training Requirements**: Familiarity with procedures for removal of marine growth and application techniques for underwater protective coatings.

**Equipment Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, protective clothing and gloves for personnel handling the coatings, float stage or work platform.

**Productivity of Crew**: 30 $min/ft^2$ below water.

**Materials**: **Epoxy-Polyamide Splash Zone Compound** - Hand-applied coatings which can be applied underwater or to wet surfaces are commonly called splash zone compounds. Surface preparation by abrasive blasting or high-pressure water jet cleaning is adequate for application of splash zone compounds. The surfaces should be cleaned within 24 hours of coating application. The coating is normally supplied in two-component kits. The components should be mixed at ambient temperatures above 70°F. Although easier to mix when water is added, this practice will result in a coating that will not cure properly, therefore water should never be added when mixing the components. The coating is applied by smearing it over the surface to a thickness of 1/8 inch to 1/4 inch using a gloved hand. Typical coverage is 4.5 to 9 square feet per gallon of coating.

**Potential Problems**: If the water temperature is less than 50°F, normal formulations of splash zone compounds will not cure properly. Underwater application of the coating may be difficult. Prior to ordering a large quantity of the coating, a test application should be made under conditions identical to those anticipated, including surface preparation and temperature to ensure that good adhesion and proper curing will be achieved. Skin irritation may occur due to contact with the uncured compound if the individual is sensitive to the material. Regarding health, environmental, and safety concerns - the recommendation in the manual to wear gloves when applying splash zone compounds is good. In many cases, local environmental restrictions require that the abrasive blast media and paint be collected and not fall into the water. Abrasive blasting and the application of some paints may also be locally regulated. Particular care should be taken when removing lead-based paint. When removing lead-based paint, the worksite generally needs to be enclosed and all of the paint that is removed needs to be treated as hazardous waste. In addition, special precautions must be taken to prevent contact with or inhaling of the old paint or contaminated blast media.

Table 5-20
Planning and Estimating Data for Steel Sheet Pile Maintenance
Using Cathodic Protection

**Description of Task:** Install a sacrificial anode on a steel sheet pile below low waterline. A 40-pound anode is attached to the pile with a welded connection.

**Size of Crew:** Two divers, one laborer.

**Special Training Requirements:** Familiarity with removal of marine growth, underwater lifting procedures, and light underwater welding.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, welding machine with leads, welding torch, stud driver, lift bags/rigging gear, float stage or work platform.

**Procedure:** Clean area to bare metal where anode is to be attached. Anode may be attached by bolting, welding, or using a stud driver.

**Productivity of Crew:** 1 hour per anode.

**Materials:**

**Anode** - The number and spacing of the anodes must be determined by a cathodic protection engineer.

Table 5-21
Concrete Encasement of Concrete and Timber Piles

**Problem:** Precast concrete pile deteriorates due to sulfate attack, spalling, or cracks; or 10 to 50 percent of timber cross-sectional area has been lost due to marine borer attack.

**Description of Repairs:** Flexible or rigid forms together with reinforcing are used to produce a partial or complete concrete casing around damaged pile. Follow form manufacturer's directions. As required, excavate below mudline to expose deteriorated pile.

- Thoroughly clean pile of marine growth using scrapers, waterblaster, and sandblaster.

- Clean exposed rebar with wire brush. Remove deteriorated concrete, or wood, rust, and loose scale.

- Exposed/deteriorated reinforcing may be parallel spliced as directed by engineer.

- Install steel reinforcing around pile, use spacers to provide minimum 2-inch clearance between pile reinforcing and reinforcing form.

- Pump concrete using 15-psi minimum pressure through suitable pipes or hoses extending to lowest point. Keep discharge submerged in concrete.

**Flexible Form - Closed Top:** Figure 1 - Wrap form around pile, close zipper, secure form top and bottom to pile with mechanical fasteners or banding. Insert fill hose through fill port and project to bottom of bag.

**Flexible Form Open Top Bag:** Figure 2 - Wrap the form around pile and suspend from deck structure or friction clamp using turnbuckles or chain. For timber piles, use spikes to hold up form. Secure form at bottom using mechanical fasteners or clamps. Insert fill hose to bottom and fill to overflowing. Cap top of form with epoxy or nonshrink grout to provide a 45-degree top.

**For Rigid Form:** Commercial forms (Figure 3) or forms fabricated using T&G (Figure 4), wood, fiberglass, plywood, or steel may be used. A base plate/clamp (Figure 3) must be fabricated to hold form in place and also provide a bottom seal for concrete during pour. Alternately, the soil at bottom of hole may be used as seal. Assemble form around pile and install bands at 12-inch intervals (or per instructions from manufacturer). The bands hold form in place during pour. Install band with fill fitting band at lowest location. Fill to overflow with concrete. Cap top of form with epoxy or nonshrink grout to provide a 45-degree top. Form and bands are removed after concrete is set (48 hours).

**NOTE:** Past construction operations used creosoted timber to provide chaffing protection from marine traffic or ice. Where environmental regulations prevent using creosote, substitute CCA or AZCA salt. When used, chaffing should extend from 1.5 feet above MLW to 2.5 feet below pile cap.Time between surface prep and concrete placement should be less than 36 hours in warm water and 72 hours in cool water.

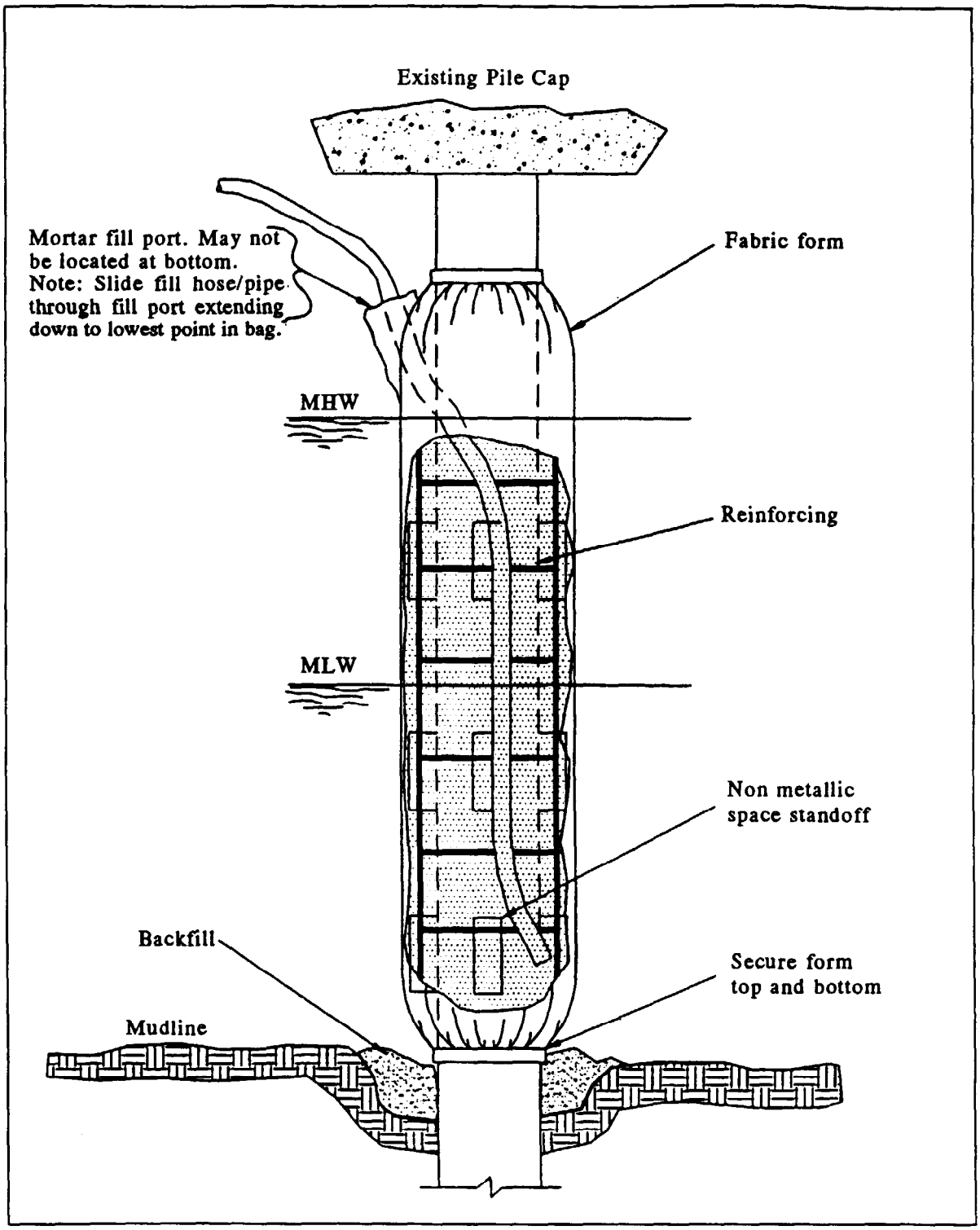



Table 5-21
Figure 1. Flexible form - Closed top.

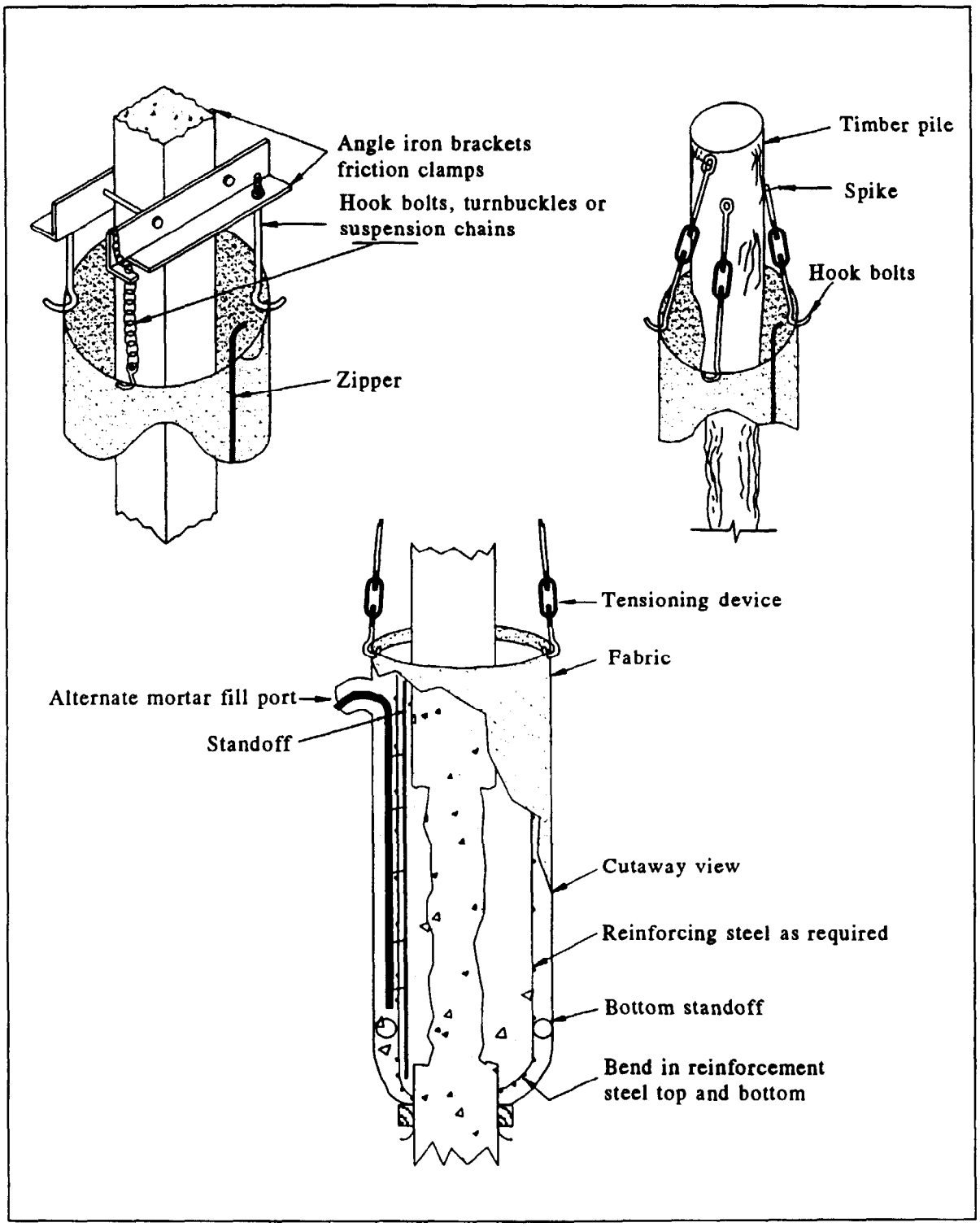



Table 5-21

Figure 2. Open top fabric form. Suspender detail and fabric hanging procedure.

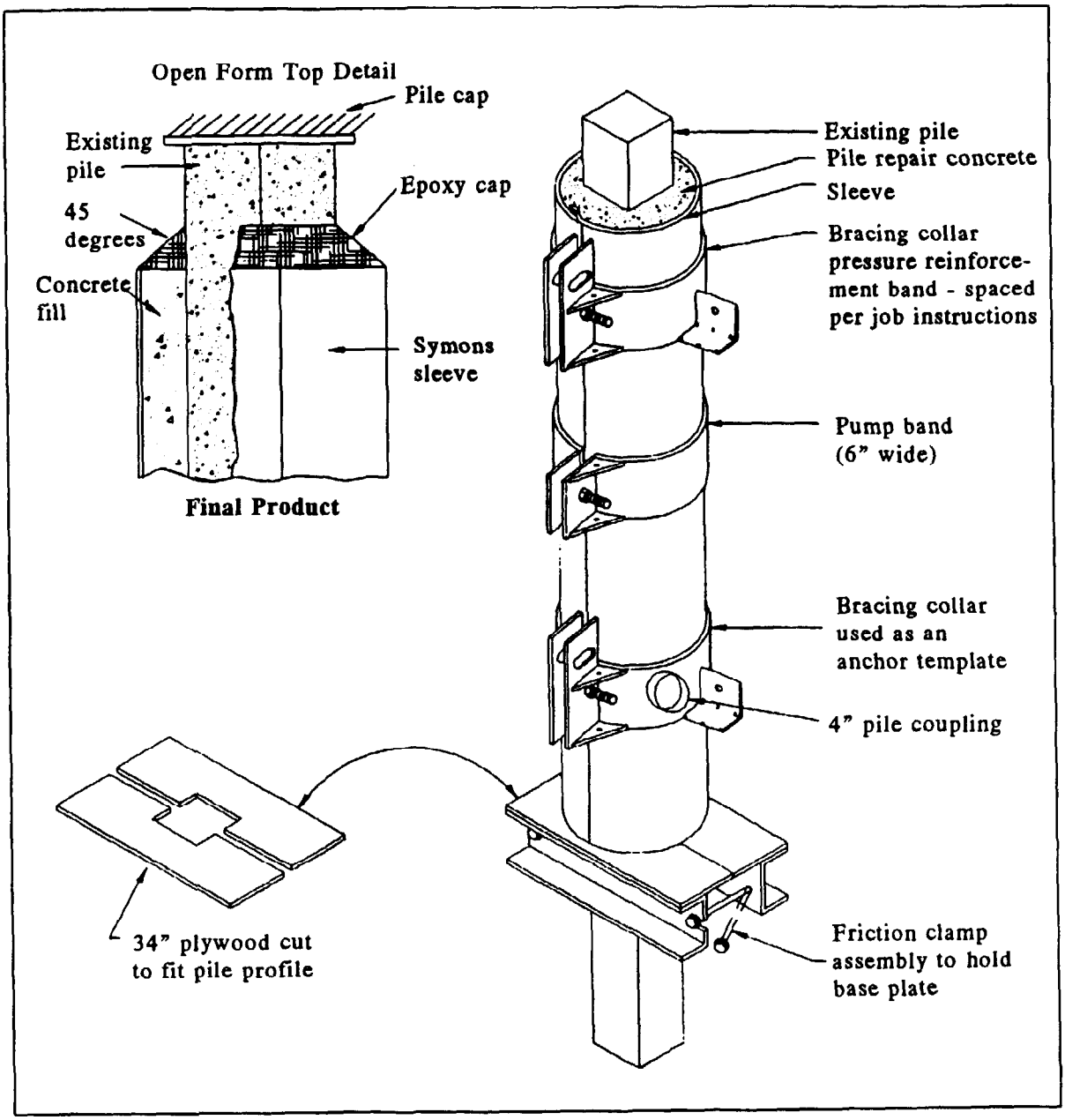



Table 5-21
Figure 3. Commercial rigid form.

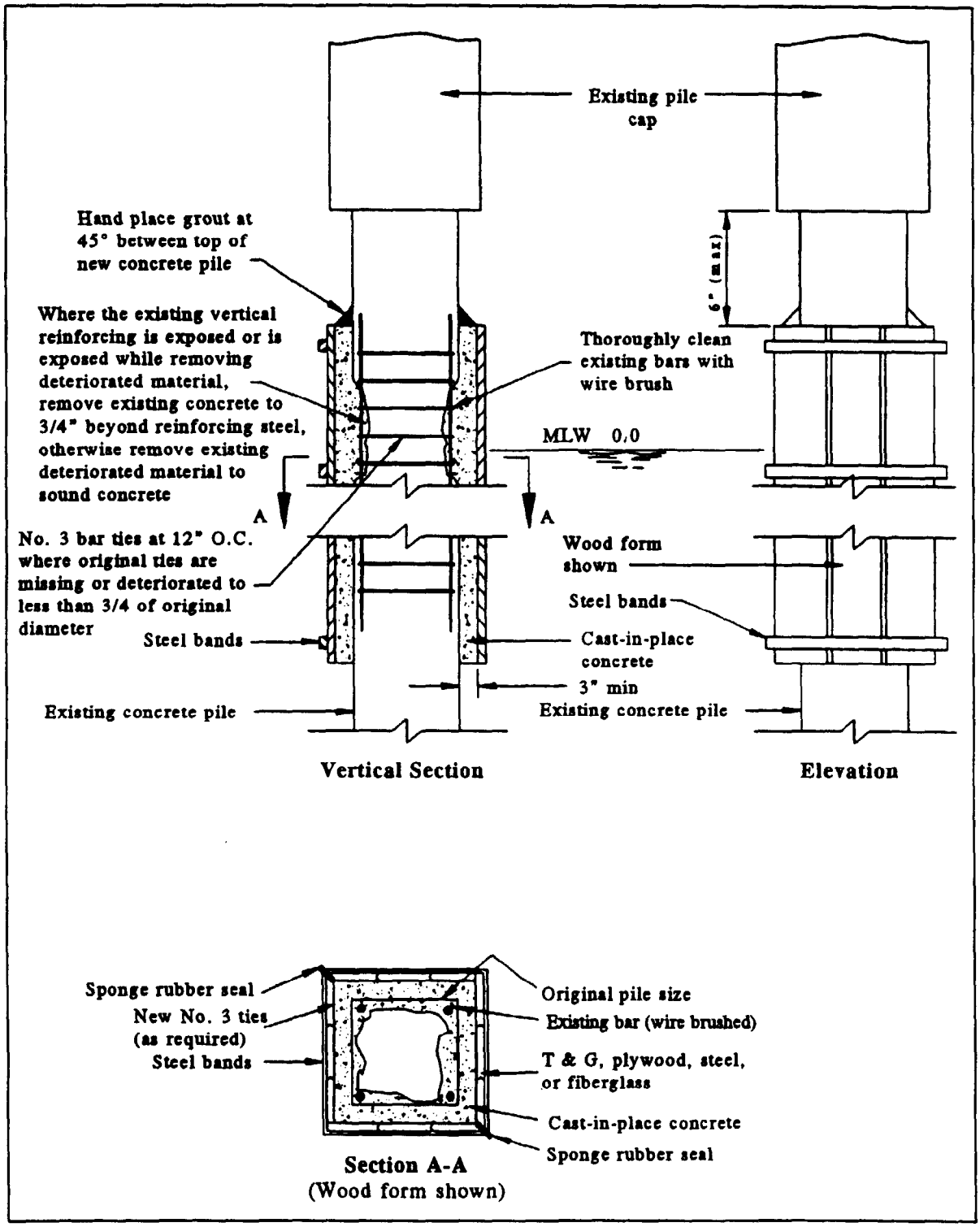



Table 5-21
Figure 4. Conventional T& Gform detail (wood form shown).

Table 5-22
Planning and Estimating Data for Concrete Pile Repair
Using Concrete Encasement

**Description of Task:** Repair a deteriorated concrete pile by installing a concrete encasement from 1 foot above the high waterline to 1 foot below the mudline. The total length of encasement is 20 to 30 feet. Reinforcement of the pile is not required.

**Size of Crew:** Dive station, two laborers.

**Training Requirements:** Familiarity with the jacket to be used, concrete pump operation, jetting or air lifting procedures, and removal of marine growth.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, hydraulic power unit, concrete pump with adequate hose, concrete mixer (if ready-mix concrete is not available), jetting pump and hose, rigging equipment, float stage, scaffolding.

**Productivity of Crew:** 8 hours per pile repair.

**Materials:**

**Form Material** - When using proprietary forms, follow manufacturers' recommendations regarding lengths and diameter of forms, top and bottom closures, spacers, bands, straps, and special fittings. Provide 20 percent extra fittings for breakage if the forms are to be reused. Forms are ordered prefabricated in the required length and diameter. For flexible forms, allowance on the length must be made for extra fabric that may be required around blocking at the top and bottom of the jacket. Some proprietary systems require that different types of forms be used in the tidal and submerged zones.

**Spacers** - A conservative estimate of the number of spacers must be made. In calm water and with vertical piles, relatively few spacers will be required. Rough water and batter piles will require more spacers.

**Wire Mesh Reinforcing** - Usually 6x6-10/10 welded wire fabric is adequate. Calculate the width of wire fabric required based on its circumference, taking into consideration the thickness of the spacers between the pile and reinforcing and allowing a 9-inch overlap of the ends.

**Concrete** - To determine the amount of concrete required to fill the form, be conservative. When using flexible jackets allow for reduction of concrete volume due to loss of water through the permeable fabric, enlargement of the jacket caused by stretching, and waste. Usually an allowance of 10 percent extra concrete over the theoretically calculated quantity is sufficient.

Concrete should be pumped using 15-psi minimum pressure through a suitable pipe or hose which extends down to the lowest point in the form. It is important to start filling with the hose at the bottom and to keep the discharge submerged in concrete during the pouring operation. This procedure will prevent voids forming. Care must be taken when using the hose-tremie method as there is a tendency for the hose to become snagged on the wire mesh reinforcing. Some forms have built-in filling and overflow ports where the lower port is used for filling. Filling from a bottom port is preferred over extending the hose to the bottom of the form.

### 5.7.2 Epoxy Patching/Injection

Epoxy patching is used where localized spalling or cracking occurs. The deteriorated area must be thoroughly cleaned to allow the patch to adhere to the concrete. Once cleaned, the epoxy compound is mixed in accordance with the manufacturer's instructions, forced into the spalled area, and worked smooth by hand. Epoxy will not stick to a wet surface so it must be kneaded to the surface to displace water. The patching epoxy used is described in Section 2.11.1. These epoxy patching compounds should be limited to thicknesses of less than 3/4 inch because of the difference in temperature-related expansion between the epoxy and underlying concrete. Thicker patches will deteriorate when subjected to temperature variations. Portland cement may be substituted for the epoxy grout, but it is more difficult to work with.

Cracks can be repaired by injecting low-viscosity epoxy mortar under pressure into the crack (Figure 5-21) as described in Section 2.11.3. This procedure is summarized in Table 5-23. The first step is to clean the area to be repaired. Plastic fill ports are available from manufacturers of epoxy injection systems. The plastic ports are attached to the crack entrance with an epoxy sealer. The crack surface is also sealed. The epoxy seal is allowed to cure overnight. The next day a low viscosity epoxy resin is injected through the ports to overflowing. After cure, the ports and excess surface materials are removed by grinding.

For deep cracks with wide entrances, fiberglass cloth in conjunction with an epoxy sealer are used to dam the surface. After the dam has cured, holes should be drilled into the crack every 6 inches along its length and used as injection ports so that the epoxy grout extends to the base of the crack. The epoxy grout is injected into the ports, starting at the bottom. After injection is complete, the port holes should be plugged to prevent the epoxy weeping out before setting.

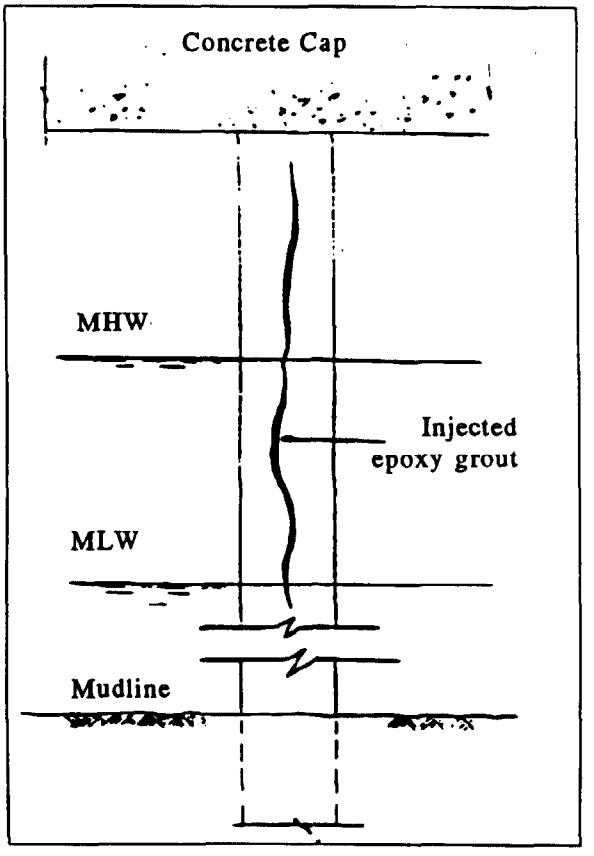



Figure 5-21
Epoxy grouting of concrete pile.

Table 5-23
Concrete Crack Repair by Epoxy Grout Injection

**Problem:** Cracks caused by weathering, deterioration, or reinforcing steel corrosion allow water to penetrate the concrete

**Description of Repairs:** The technique involves forcing a suitable underwater grout to fill voids in cracks and displace existing water (Figure 1). Small cracks can be filled using hand-operated grout gun applicators while large cracks would require pressure grouting. Some epoxy grouts are hand molded into balls and then hand forced into the crack. Underwater grouts will not adhere directly to wet surfaces; the application method should strive to drive off the water at the grout-surface interface. Epoxy grouts adhere better to rough and clean surfaces.

- Thoroughly clean crack and adjacent surface by using waterblaster and mechanical tools - wire brush and scrapers, which will fit into the void. Remove loose material and marine growth. Clean any exposed reinforcing.

- Seal the full length of the surface of the crack using sealing tape or epoxy or similar grout pressed into the crack to form a dam. Use a fiberglass tape with a suitable underwater setting epoxy grout to seal the surface. Allow the seal to cure completely before proceeding.

- After the crack dam has cured, drill 1/2-inch or larger injection holes to the bottom of the crack and along the crack at 6-inch intervals. Size of hole depends injector tip.

- Insert nozzle of grout injector/dispenser into lowest drilled hole and inject flowable grout until it comes out the next higher hole. Proceed up the crack until all holes are filled.

**Note:** It may be necessary to add an extension tip to the nozzle to reach the end of the crack.

**Materials:** Manufacturers are listed in Appendix A.

- Select a flowable, low viscosity epoxy suitable for wet surfaces and underwater application for injection into hole. For temperatures below 55°F, use a polyester resin-based grout.

- For sealing grout, select a fast curing epoxy paste suitable for wet surface and underwater compatible that can be applied by hand or blade.

- Epoxy grout injection gun described in Section 2.11 can be used to dispense two-part epoxy grouts.

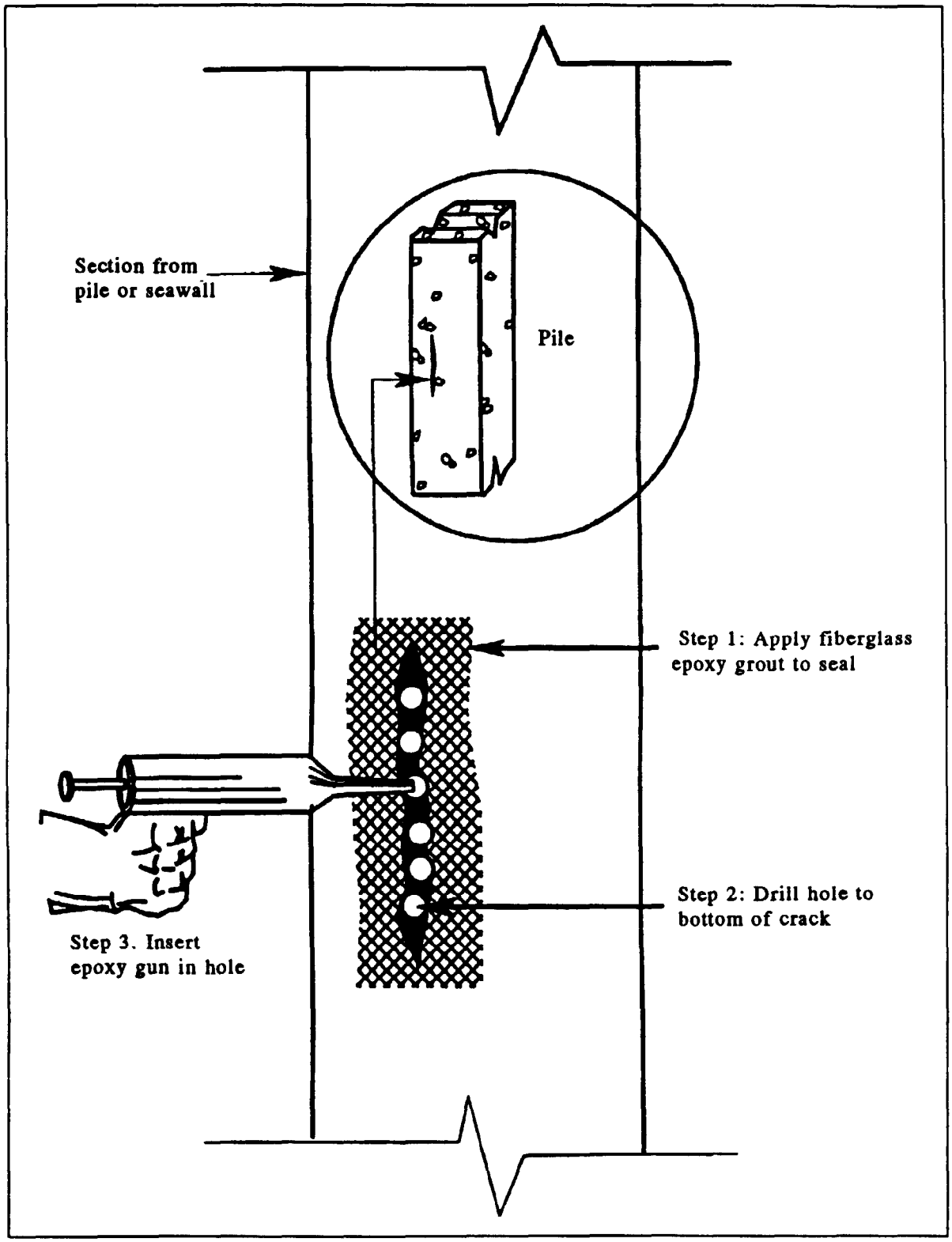



Table 5-23
Figure 1. How to repair concrete cracks with epoxy grout.

Planning and estimating data for repair of concrete piles are provided in Table 5-24 (using epoxy patching) and in Table 5-25 (using epoxy injection).

### 5.7.3 Replacement

A repair technique that may be economical in some situations consists of the replacement of the entire pile. Replacement pile techniques for concrete piles are the same as for steel piles and are described in Section 5.5.3.

Pile replacement techniques require heavy equipment that is not normally available to the UCTs and is usually carried out by others. NMCBs have heavy equipment to carry out pile replacement.

### 5.7.4 Wrapping

Piles wrapped with polyvinyl chloride (PVC) sheet are more resistant to abrasion and pitting by chemical action because there is no direct action by seawater on the pile. Pile wrapping techniques are described in Section 5.9.4.

Table 5-26 provides planning and estimating data for maintenance of concrete piles using wrapping.

## 5.8 CONCRETE SHEET PILE STRUCTURES

As described in Section 3.6.2, there are many causes of deterioration of concrete sheet piles and other precast or cast-in-place concrete structures in the marine environment. There are also many methods for the repair and maintenance of these structures. The repair methods fall into four general categories:

- Replacement/reconstruction
- Epoxy patching/injection
- Tieback system installation/replacement
- Wall load modification

Shotcreting may be used above the waterline, but this method requires special equipment and training and is not normally performed by UCTs.

### 5.8.1 Replacement/Reconstruction

Deterioration that affects the structural integrity of the concrete structure, such as missing lengths of reinforcing steel, should be repaired by replacement or reconstruction of sections of the structure. A method using pumped or tremied concrete is used when holes extend through the concrete section, or are larger than 1 $ft^2$ in area and over 4 inches deep, or are more than 1/2 $ft^2$ in area and deeper than the reinforcing steel. A description of the repair technique is provided in Table 5-27.

- All questionable quality concrete should be removed by hand or power tools.

- The edges of the hole should be square and the top rim should be sloped in the direction of the pour.

- Surfaces of the hole that are above water should be kept continually wet for several hours to allow partial saturation of the old concrete to take place to ensure proper curing of the new concrete.

- Just prior to placement of the new concrete, the holes should be thoroughly cleaned of marine growth.

- Form work should be mortar tight and attached to the existing structure with form ties. Use cotton caulking or similar materials to make tight seal.

Table 5-24
Planning and Estimating Data for Concrete Pile Repair Using Epoxy Patching

**Description of Task:** Repair a deteriorated concrete pile by patching with hand-applied epoxy. Unit area to be repaired is 1 $ft^2$ underwater.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with procedures for removing marine growth and application of epoxy patching compounds underwater.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, protective clothing for personnel handling the epoxy patching compound, float stage or work platform.

**Productivity of Crew:** 30 $min/ft^2$ underwater.

**Materials:**

**Epoxy Patching Compound** - Epoxy patching compounds are usually purchased in two-component kits, with an aggregate additive. A 1-gallon kit might include 1 gallon of each component plus aggregate, resulting in more than a 2-gallon yield. Patching coverage is measured in square feet per gallon. The required patching yield is obtained by taking the square footage to be covered and dividing by the square foot per gallon coverage rate.

**Potential Problems:** If water temperature is less than 60°F, proper adhesion to the pile may not occur. Skin irritation may occur if individual is sensitive to the epoxy material. Use protective gloves while mixing and applying epoxy materials.

Table 5-25
Planning and Estimating Data for Concrete Pile Repair Using Epoxy Injection

**Description of Task:** Repair a 6-inch-deep crack in a concrete pile by injecting low-viscosity neat epoxy grout into the crack. Total length of crack to be repaired is 10 feet.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with procedures for removing marine growth, the use of epoxy grout pump, and the use of injectable epoxy.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, hydraulic impact wrench with masonry bits, high-pressure pump for waterblaster, hydraulic power unit, protective clothing for personnel handling the epoxy compound, epoxy pump, float stage or work platform.

**Productivity of Crew:** 10 to 20 min/linear foot of crack.

**Materials:**

**Low-Viscosity Epoxy Grout** - Commercially available injectable epoxy grouts are usually purchased in two-component kits. Mixing proportions will vary, so manufacturers' instructions should be followed. The volume of the crack must be estimated by taking its length, average width, and average depth. An additional 25 percent should be added to allow for overfilling of the cracks and inaccuracies in estimating the size of the cracks.

**Potential Problems:** If water temperature is less than 60°F, proper adhesion to the pile may not occur. Skin irritation may occur if individual is sensitive to the epoxy material. Use protective gloves when mixing or applying epoxy materials.

Table 5-26
Planning and Estimating Data for Concrete Pile Maintenance Using Wrapping

**Description of Task:** Wrap a concrete pile with commercially available polyvinyl chloride (PVC) wrapping sheets from 1 foot above the high waterline to 2 feet below the low waterline. Total length to be wrapped is 10 to 20 feet.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with procedures for removal of marine growth and with installation procedure for the PVC pile wrap to be used.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, special fastener tools for pile wrapping (dependent on manufacturer), float stage or work platform.

**Productivity of Crew:** 3 hours per pile.

**Materials:**

**Polyvinyl Chloride Pile Wrap Unit** - Commercially available PVC pile wraps are available in many prefabricated sizes to fit various pile sizes and lengths. Some have separate units for splash zone and underwater use, while others are a single unit. Manufacturers' literature should be consulted before ordering.

**Strap and Special Fittings** - Each pile wrap manufacturer has particular fasteners and special fittings. Manufacturers' literature should be consulted before ordering.

**Potential Problems:** Projections or sharp edges on the pile may puncture or tear the pile wrap, so care should be taken to remove such problems.

Table 5-27
Typical Concrete Wall Repair

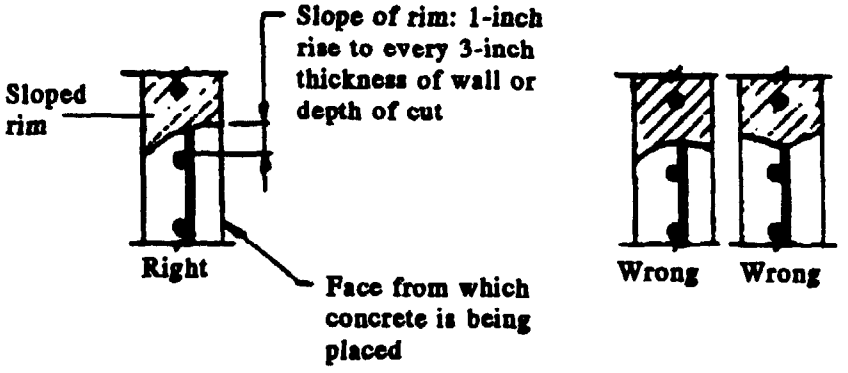
**Problem:** Severely deteriorated areas require replacement with cast-in-place concrete.

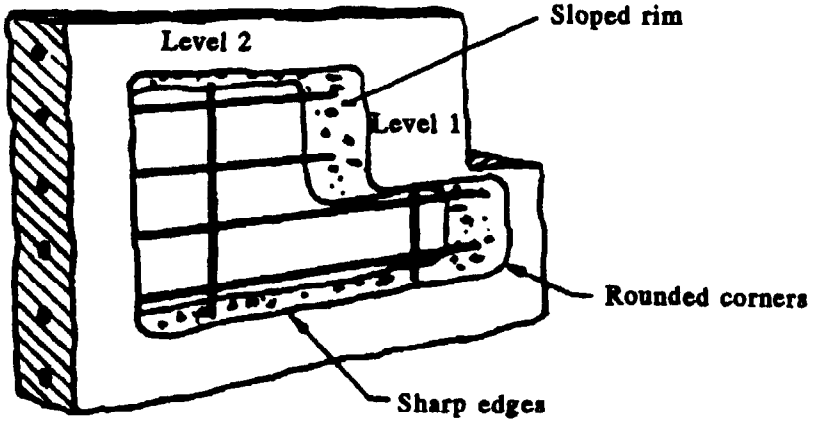
**Description of Repairs:** Defective section of wall is removed, surfaces and reinforcing steel are prepared, formwork constructed, and wall is restored with cast-in-place concrete.

**Materials:** Sand-cement mortar and portland cement concrete as designed by engineer, anti-washout admixture may be added for underwater repairs. Equipment used includes sandblasting and air-water jet cleaning equipment, concrete saw, air chipping hammer, air-suction gun for mortar if available, power vibrator and tamper, and conventional concrete placement tools.

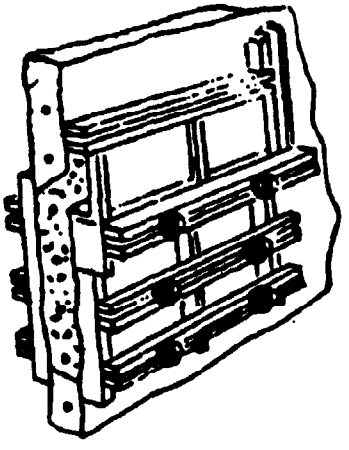
**Preparation:**
- Use air hammer to remove unsound concrete to 3/4-inch minimum depth.
- Cut the top edge of the hole to slope as shown in Figure 1. If necessary to fill the hole from both sides, the slope of the cut should be modified accordingly.
- Cut the bottom and sides of the hole approximately square with the face of the wall. Spalling and featheredges can be avoided by having chippers work from both faces. All interior corners should be rounded to a minimum radius of 1 inch.
- Ensure a minimum of 1 inch clearance around all exposed reinforcing. Remove unnecessary tie wires.
- Clean all surfaces to bond to new concrete with wet sandblasting and water jet. Clean exposed steel with abrasive blasting. Epoxy coat steel where possible. Parallel splice-weld new steel where 25 percent or more of original diameter is lost.

**Repair Procedures:**
- Construct front forms for patches so the concrete can be placed in lifts not more than 12 inches high. The back form can be built in one piece. Fabricate and fit all forms before concrete placement is started.
- Chimneys (accesses) may be required at more than one level. In some cases, a chimney may be necessary on both sides of the wall or beam. In all cases, the chimney should extend the full width of the hole.
- Ensure forms are substantially constructed so that pressure can be applied.
- Ensure forms are mortar tight at all joints between adjacent sections, between the forms and concrete, and at the tie-bolt holes to prevent the loss of mortar. Twisted or stranded caulking cotton, folded canvas strips, or similar material should be placed between the joints as the forms are assembled.
- Surfaces to receive new concrete should be kept wet for several hours prior to placement.
- Immediately before placing the front section of form for each lift, coat the surface of the old concrete with a 1/8-inch-thick layer of mortar. This mortar should have the same sand and cement content and the same water-cement ratio as the new concrete. The surface should be damp, but not wet. The mortar can be applied with an air-suction gun, by brushing, or being rubbed into the surface by hand encased in a rubber glove.
- Place concrete immediately. Ensure thorough compaction by vibration/tamping.
- Forms may be removed the day after placement. If chimneys were used, remove the remaining projections the second day working up from the bottom.
- Thoroughly moist-cure the new concrete.
- Finish with a wood float finish. Tool or chamfer edges and corners as required.

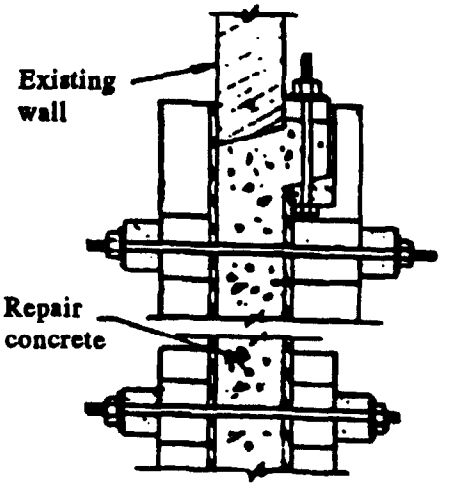



**Preparation of Irregular Area for Typical Wall Repair**



Front form is made up in sections for successive 12-inch lifts




**Formwork for Typical Wall Repair**

Table 5-27
Figure 1. Repair of concrete wall.

- Forms attached to flat surfaces are best supplied with chimneys. Chimneys allow concrete to be poured into the form and also permit the concrete to be forced into the hole by pressure applied to the chimney opening.

Place concrete underwater in accordance with the procedures described in Section 2.10. Remove form work the day after casting unless form removal would damage the newly placed concrete. The chimney projections should normally be removed after the third day, working up from the bottom; working down from the top tends to break concrete out of the repair.

Section replacement using cast-in-place concrete in open-top forms is a simpler operation. No special features are required in the form work, but they should be mortar tight when vibrated and, if possible, should give the concrete a finish similar to the adjacent areas.

Table 5-28 provides planning and estimating data for repairing concrete sheet pile structures using concrete reconstruction.

### 5.8.2 Tieback System Installation/ Replacement

Movement of concrete walls can be arrested by installing a new tieback system or replacing the defective elements of an existing system. This repair/maintenance technique is explained in Section 5.6.4.

Tieback system installation/replacement requires major specialized equipment and is usually carried out by shore-based construction forces.

### 5.8.3 Wall Load Modification

Concrete wall movement can be arrested by changing the in-place loading on the wall, which is discussed in Section 5.6.5.

Wall load modification is usually carried out by shore-based construction forces.

## 5.9 TIMBER PILES

As described in Section 3.7, there are many causes of deterioration of timber piles in the marine environment. There are also many methods for the repair and maintenance of timber piles. **Repair and maintenance methods fall into four categories**:

- Concrete encasement
- Partial replacement
- Complete replacement
- Wrapping

### 5.9.1 Concrete Encasement

Concrete encasement can be used for timber piles that have not deteriorated to less than 50 percent of their cross-section area. The general procedures for repairing timber using concrete encasement are described in Table 5-21. They are essentially the same as for steel piles as described in Section 5.5.1. Planning and estimating data are included in Table 5-29. Some general information is provided below. Refer to the figures in Table 5-21 for an outline of the procedure. The **repair procedure** involves:

- Cleaning the pile
- Installing reinforcing, spacers, and forms about the pile
- Pouring concrete to fill the space between the pile and the form

Nonmetallic spacers are used to maintain a uniform concrete thickness and ensure a minimum (2 inches) distance between pile and reinforcing steel and reinforcing and form. Each form manufacturer provides detailed instructions relating to installing their specific designs.

Table 5-28
Planning and Estimating Data for Concrete Sheet Pile Repair
Using Concrete Reconstruction

**Description of Task**: Repair a severely deteriorated 12-inch-thick concrete sheet pile wall by reconstructing the deteriorated portion with cast-in-place concrete. Unit area to be reconstructed is 10 $ft^2$. Access to the wall is from both sides.

**Size of Crew**: Dive station, two laborers.

**Special Training Requirements**: Familiarity with procedures for removal of marine growth, concrete pump/truck operations, concrete cutting/chipping machine operation, concrete formwork fabrication and installation.

**Equipment Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, hydraulic drill with bits, hydraulic chipping hammer, hydraulic hammer drill with bits, oxygen arc cutting equipment, rigging equipment, float stage or work platform.

**Productivity of Crew**: 40 hours per 10-$ft^2$ patch.

**Materials**:

**Concrete Form Material** - The concrete form is required for casting the repair section. The formwork must exist on both the front and back of the repair section and should extend a minimum of 3 inches over the existing sound concrete. The frontal plus the rear area of the repair plus the form overlap is the required area of formwork.

**Steel Reinforcing Bars** - Steel reinforcing bars must be placed in the repair section to replace those bars that were removed. Estimates can be made by measuring the gaps between sections of sound reinforcing steel. Allow for sufficient lap of new bars with existing bars.

**Concrete** - Concrete quantity is determined by the volume of the area to be filled. A conservative estimate should include an allowance of 10 percent extra concrete over the theoretically calculated quantity for waste and overfill.

**Potential Problems**: There may be difficulty in matching the existing concrete. Care must be taken in removing the forms; removing them too early will result in the concrete sagging at the top and bulging at the bottom. Forms must be dewatered before pouring concrete, if possible, or underwater concrete placement techniques must be used.

Table 5-29
Planning and Estimating Data for Timber Pile Repair
Using Concrete Encasement

**Description of Task:** Repair a deteriorated timber pile by installing a concrete encasement from 1 foot above the high waterline to 1 foot below the mudline. The total length of encasement is 20 to 30 feet.

**Size of Crew:** Dive station, two laborers.

**Productivity of Crew:** 8 hours per pile repair.

**Special Training Requirements:** Familiarity with manufacturers' instructions for the rigid or flexible form used, concrete pump operation, jetting or air lifting procedures, and removal of marine growth.

**Equipment/Materials Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, hydraulic power unit, concrete pump with adequate hose, concrete mixer (if ready-mix concrete is not available), jetting pump and hose, rigging equipment, float stage, scaffolding.

**Form Material** - Either flexible or rigid forms may be used. Follow manufacturers' recommendations regarding lengths and diameter of forms, top and bottom closures, spacers, bands, straps and special fittings. Forms are ordered prefabricated in the required length and diameter. For flexible forms, allowance on the length must be made for extra fabric that may be required around blocking at the top and bottom of the jacket.

**Spacers** - A conservative estimate of the number of spacers must be made. Rough water and batter piles will require more spacers than calm water application.

**Wire Mesh Reinforcing** - Usually 6x6-10/10 welded wire fabric is adequate. Calculate the width of wire fabric based on its circumference, taking into consideration the thickness of the spacers. Allow a 9-inch overlap of the ends.

**Concrete** - Be conservative on the amount of concrete required. Usually an allowance of 10 percent extra for stretching jacket and waste is adequate.

**Form Reinforcing Straps and Special Fittings** - The spacing and number required depend on the type of form and the hydrostatic pressure of the concrete fill. Some types of reinforcing straps are reusable; allow for a loss of 20 percent of the straps each time they are used. In addition to reinforcing straps, closure forms, blocking hangers, pump inlet valves, and clamps will be required, depending on the forming system being used.

Both flexible and rigid forms are available and manufacturers are listed in Appendix A. Forms may also be fabricated from materials on site. Selecting the form depends primarily on availability and choice of the designer or construction crew.

Flexible forms fabricated from a porous fabric are usually left in place. Both open and closed top models are available. Open top fabric forms are usually suspended from the piling using nails or hooks. After filling, the concrete is topped with an epoxy cap or nonshrinking grout at a 45-degree angle as shown in Figure 5-17.

Rigid forms are generally open top and bottom and are removed and reused after the concrete has completely cured. Rigid forms can be fabricated from material found at the construction site. Rigid forms require a bottom seal and base plate to hold the form in place. A temporary friction clamp and base plate conforming to the pile contour can be fabricated and attached to the pile at the bottom of the repair area (Figure 3 of Table 5-21). The rigid form rests on the base plate to form the bottom seal.

The piles must be cleaned of marine growth and rotten wood. Failure to do so would result in poor bond between the concrete and pile. It is also important to ensure that the concrete be poured within 72 hours (or sooner in warmer waters) following cleaning to ensure that new marine growth will not have formed on the pile surface.

Concrete should be pumped using 15-psi minimum pressure through a suitable pipe or hose that extends down to the lowest point in the form. It is important to start filling with the hose at the bottom and to keep the discharge submerged in concrete during the pouring operation. This procedure will prevent voids from forming. Care must be taken when using the hose-tremie method as there is a tendency for the hose to become snagged on the wire mesh reinforcing. Some forms have built-in filling and overflow ports where the lower port is used for filling. Filling from a bottom port is preferred over extending the hose to the bottom of the form.

### 5.9.2 Partial Replacement

The repair of timber pile structures may involve the replacement of sections of the pile members. Sections are typically replaced using one of several posting techniques or by fish plating techniques.

A major drawback to these timber replacement techniques is that the replacement section is susceptible to marine borer attack, particularly at exposed cut ends. This can be minimized by covering the ends with a suitable preservative PVC wrap or encasing in concrete.

**5.9.2.1 Posting Techniques**. Posting a damaged timber pile with a new pile butt post is described in Table 5-30 and illustrated in Figures 1 and 2. A water jet or air lift is used to excavate around the base of the pile. The damaged pile is cut below the mudline through sound wood. A new pile butt is cut to length and the top of the pile is cut to fit the pile cap. Slightly undersized holes for drift pins are bored into the new pile butt section, after which the pile butt is maneuvered into place. Galvanized steel drift pins are driven into the piece of pile remaining in the seabed. Shims are placed between the pile and pile cap and held in place with 1-inch-diameter galvanized steel bolts. The area around the base of the pile is then backfilled.

Planning and estimating data for repairing timber piles by posting to the mudline are provided in Table 5-31 and by fish plating to below the low waterline in Table 5-31.

Table 5-30
Posting of Damaged Timber Piles

**Problem:** Severe damage to pile where greater than 50 percent of the pile cross section is damaged.

**Description of Repairs:** Many different techniques are available for partial restoration of severely damaged timber piles. In the majority of cases these repairs are considered temporary and should only be used as an interim solution until new piles can be installed.

- Cut out the damaged section of the pile to provide upper and lower sections with sound timber.

- Cut a replacement stub to fill the gap and shape end to fit pile and stub cap. A replacement section with the same diameter or cross section is recommended. If similar repair section is not available the bundled (strapped together piles) or larger piles may be used.

- Treat all wood, cut ends, and bolt holes with a suitable preservative.

- Install new pile section and attach to pile butt and pile cap shimming to pile cap for tight fit:

**DOWEL METHOD (Figure 1)** - Drive 1-inch-diameter steel dowel into the old pile stub. Bore hole for dowel in replacement section. Lower and maneuver replacement section in place.

**DRIFT PINS (Figure 1)** - Bore slightly undersized holes (see detail) for the drift pins in new pile section and maneuver into place. Drive galvanized drift pins through holes into old pipe stub.

**PIPE SLEEVE (Figure 2)** - Drill holes in pipe sleeve for 3/8-inch-diameter galvanized spikes and slide pipe sleeve over old pile butt. Maneuver new section into place and slide sleeve up so 1/2 length covers replacement section. Drive spikes through holes into upper or lower section to hold pipe sleeve in place.

**FISH PLATES (Figure 3)** - For joints below water, build two 3/4-inch-thick steel plates 36 inches long and a minimum of 3 inches wider than pile diameter.

**TIMBER SCABS (Figure 4)** - 2-4X12 treated timber scabs (4 if replaced section is longer than 20 feet). Through bolt to pile using 1-inch-diameter galvanized bolts, with nuts and 2 OGEE washers.

**Note:** These methods are typically for temporary repair. Extend useful life by using concrete encasement. Even with X-bracing, weak joints will exist and all splices and holes below water may be subjected to accelerated marine borer attack. PVC pile wrap may be used to prevent borer attack.

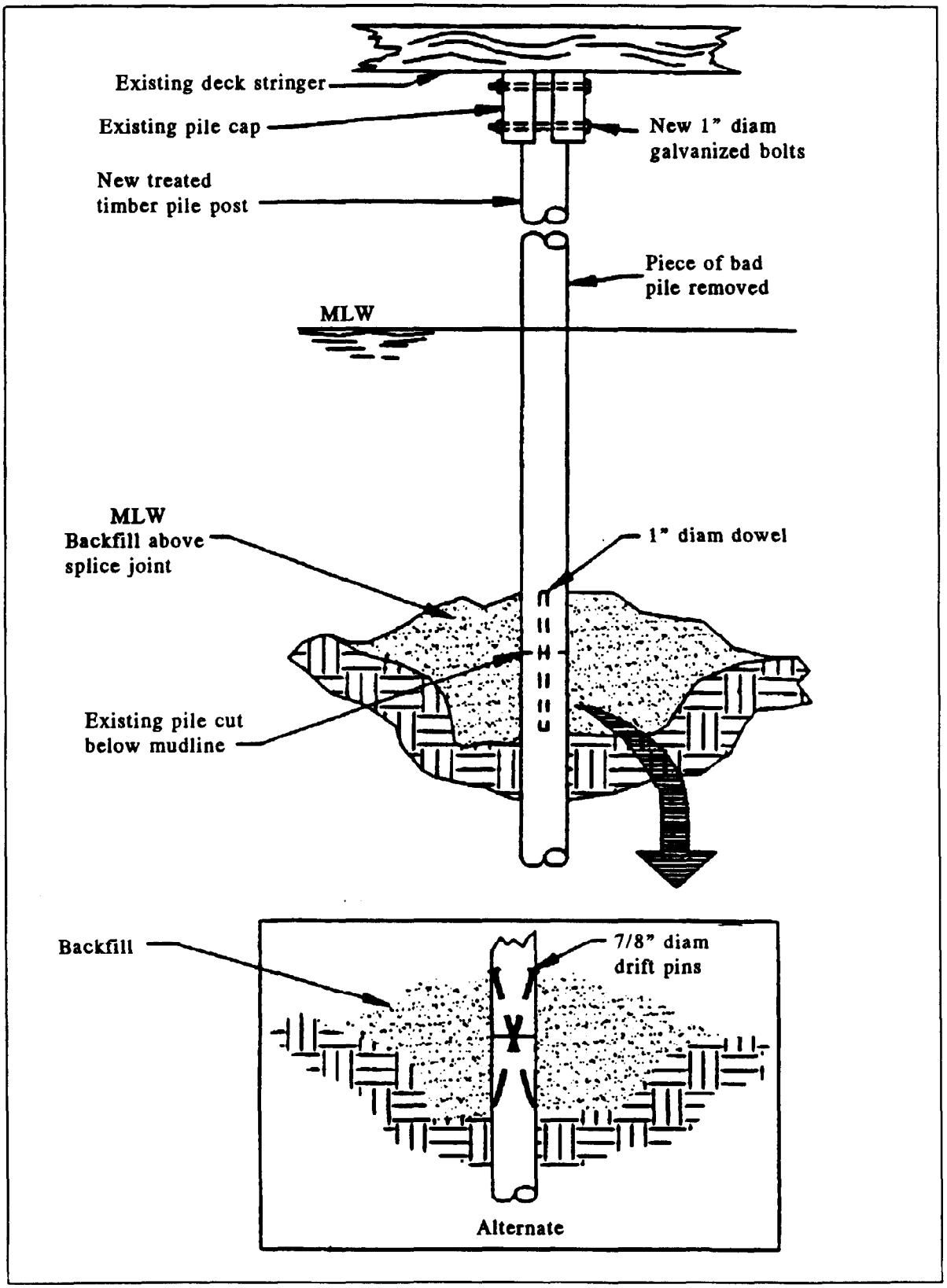



Table 5-30

Figure 1. Typical posting of a timber pile using a dowel or drift pins.
Note: Figure 2 is an alternative method using a pile sleeve.

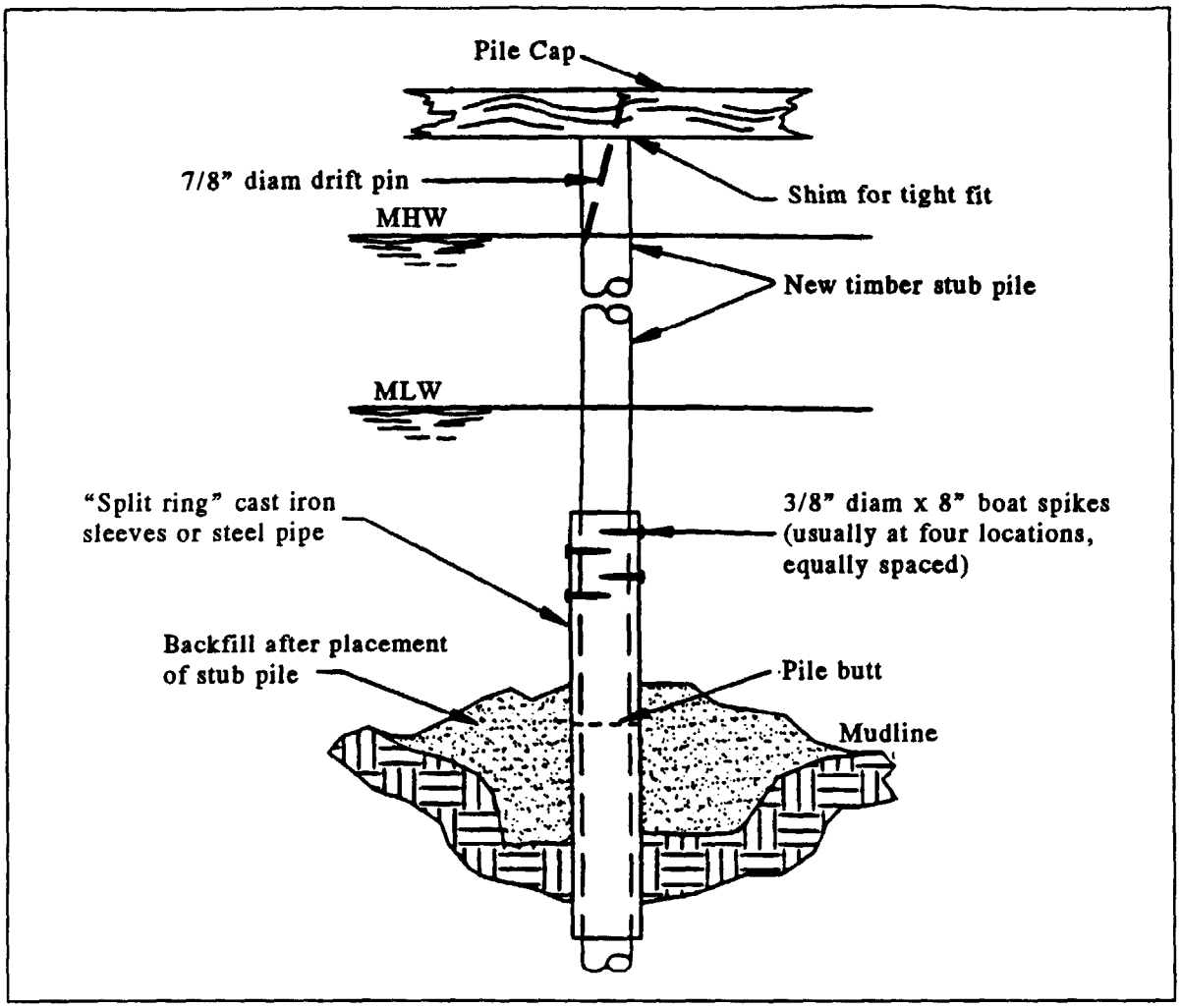



Table 5-30
Figure 2. Typical posting of timber pile using a pipe sleeve.

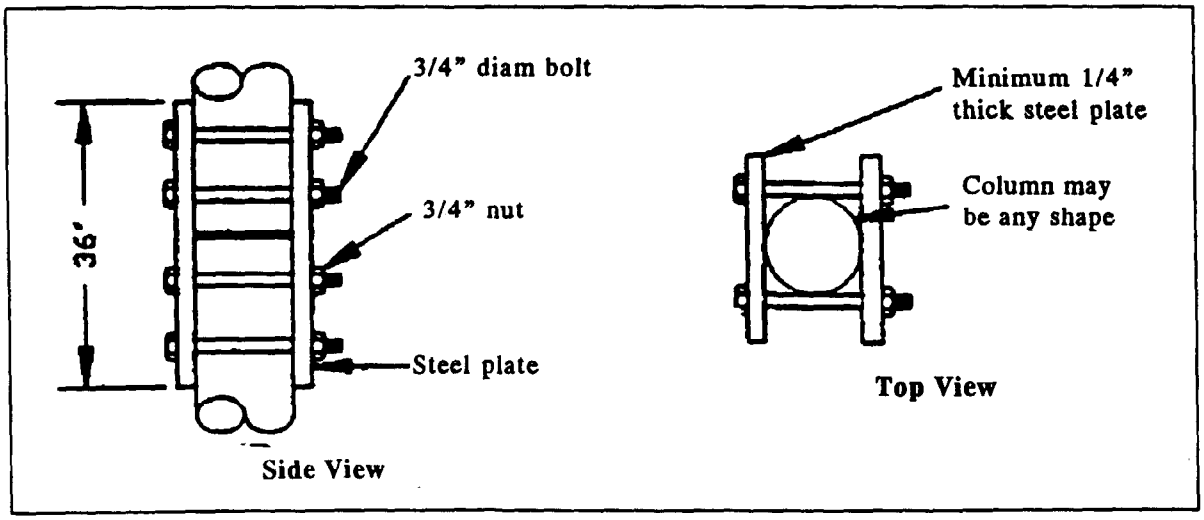
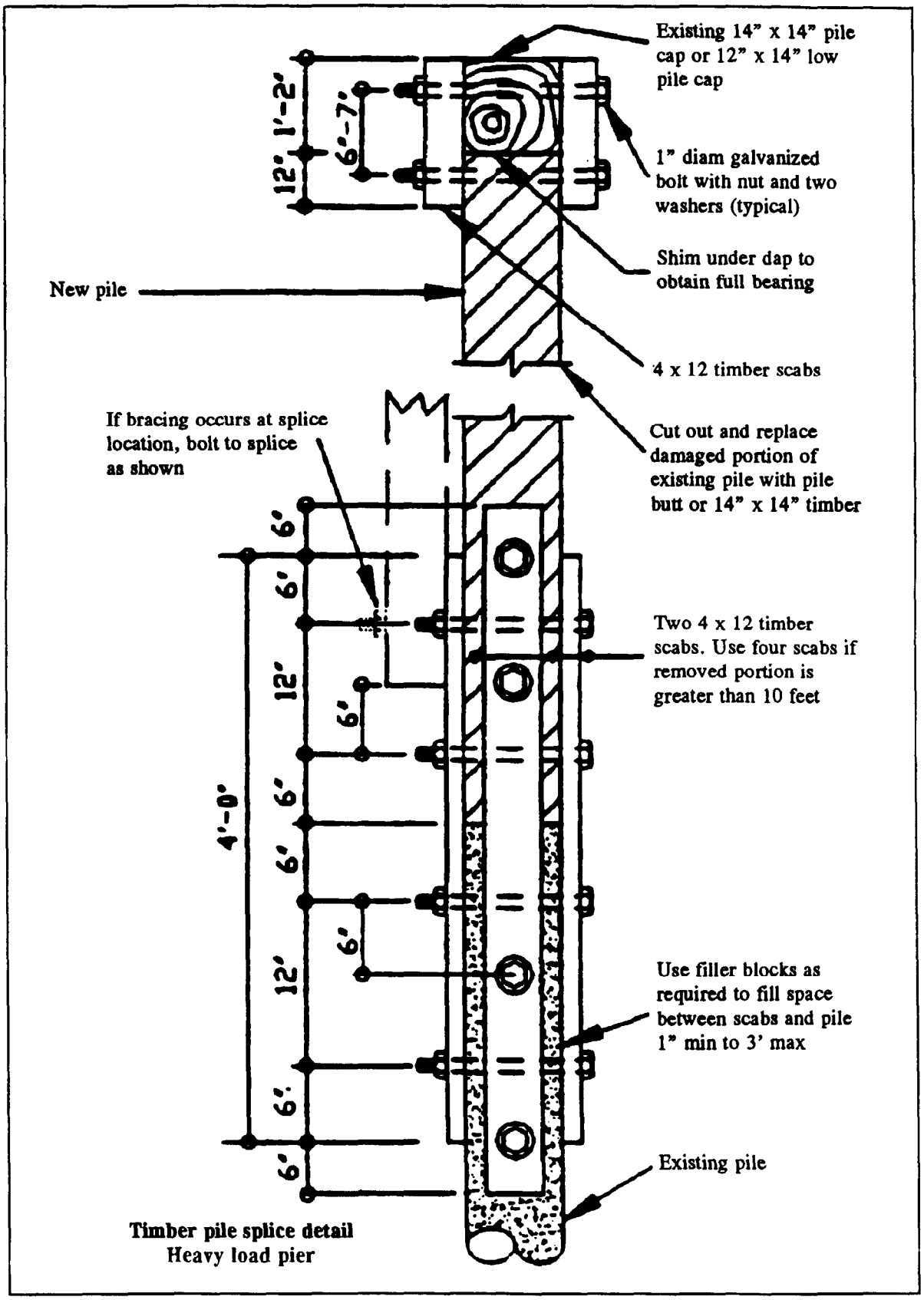



Table 5-30
Figure 3. Fish plates joining "like" diameter piles.




**Timber pile splice detail**
Heavy load pier

Table 5-30
Figure 4. Timber scab detail.

Table 5-31
Planning and Estimating Data
for Timber Pile Repair Using Partial Replacement to or Below Mudline

**Description of Task:** Repair a severely deteriorated timber pile by posting to the mudline with a new pile butt connected with a pipe sleeve at the base of the replacement section. Total length of repair is 20 to 30 feet.

**Size of Crew:** Dive station, two laborers.

**Special Training Requirements:** Familiarity with underwater cutting techniques, procedures for removal of marine growth, jetting or air lifting procedures, underwater lifting procedures, and drilling procedures.

**Equipment Requirements:** High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, hydraulic drill with bits, hydraulic power unit, air lift or jetting pump and hose, rigging equipment, crane or lifting equipment, float stage, oxy-acetylene torch equipment, clamping template for cutting piles, and hydraulic chain saw.

**Productivity of Crew:** 10 hours per pile.

**Materials:**

**Replacement Pile Section** - The replacement pile section should be long enough to span the measured distance between the bottom cut and the top cut on the damaged pile. If replacement is to be performed to the bottom of the concrete deck, allowance must be made for "swinging" room in bringing the pile under the deck and a shim installed to fill the gap.

**Pipe Sleeve** - The pipe sleeve is required to provide a moment resisting connection at the base of the repair. The diameter of the pipe sleeve must be sufficiently large to accept both the existing pipe and the replacement section. The minimum length of the pipe sleeve should be 3 feet.

**Fish Plate** - Fish plates are used in pairs, one on each side of the repair, and are made of 4- by 10-inch treated timber. The minimum length of each fish plate is about 3 feet.

**Connection Hardware** - Connection hardware will depend on the details of the repair. Allow for losses due to dropping.

**Potential Problems:** All load must be removed from the existing pile before it is cut to avoid jamming the saw. Creosote will ruin a wet suit and may cause skin irritation.

Another method of posting uses a pipe sleeve at the bottom joint to develop a moment connection, as illustrated in Figure 2 of Table 5-30. A pipe or split sleeve compatible in diameter with the remaining pile is selected, and the new pile butt post is shaped to fit into the pipe or sleeve. The pile butt and sleeve is placed over the cut off pile and maneuvered under the pile cap. If pipe is being used, one-half of its length is slipped over the pile butt and fastened with 8-inch-long by 3/8-inch-diameter boat spikes. The new pile butt is shimmed tight against the pile cap and secured with a 7/8-inch-diameter drift pin. The area around the base of the pile is then backfilled.

**5.9.2.2 Bracing Posted Piles.** When adjacent timber piles have been repaired using either posting or fish plating techniques, it may be necessary to provide some resistance to lateral loads imposed on the structure. This can be done by installing X-bracing between piles, as illustrated in Figure 5-22. Treated timbers are fastened high on one pile and low on the adjacent pile, forming an X pattern. Where the X-bracing crosses, a timber spacer should be bolted between the bracing pieces to shorten the unsupported length of span.

### 5.9.3 Complete Replacement

Piles subjected to severe deterioration may be more economically repaired by complete replacement of the pile. The installation of timber replacement piles is similar to that described in Section 5.5.3 for steel piles.

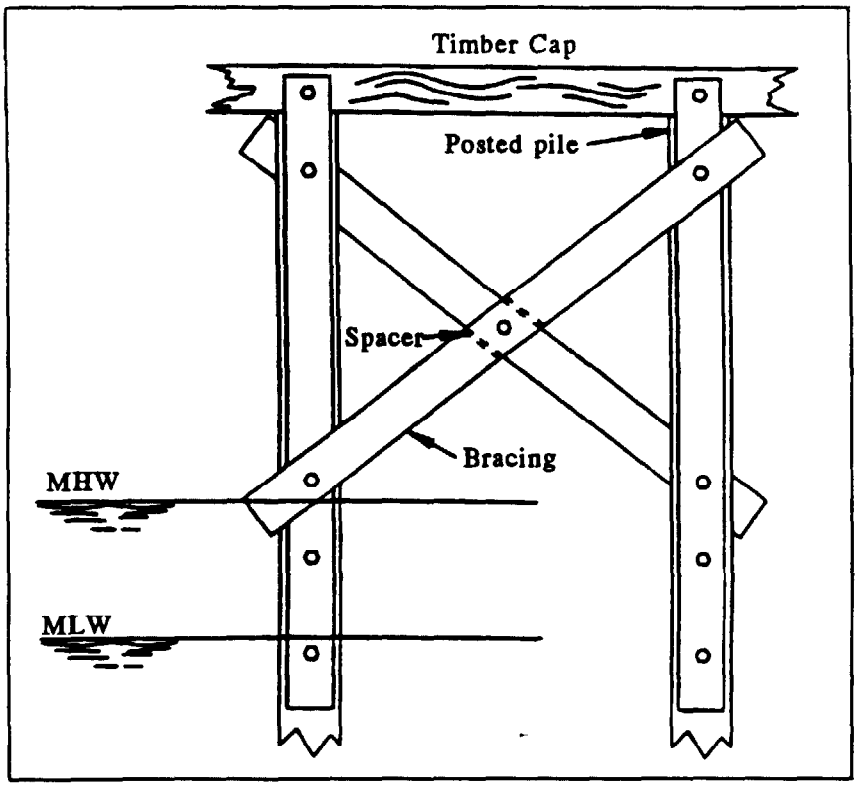



Figure 5-22. Bracing posted piles.

Pile replacement techniques require heavy equipment that is not normally available to the UCTs and would usually be carried out by others. NMCBs and Construction Battalion Units (CBUs) have the heavy equipment required to carry out timber pile replacement.

### 5.9.4 Wrapping

A protection technique widely used for timber pile structures is the application of polyvinyl chloride (PVC) sheets. Wrapping timber piles with PVC sheets is very effective in preventing marine borer attack as well as in destroying borers already existing in the pile. The procedure for wrapping timber piles is basically the same as for wrapping steel or concrete piles and is described in Table 5-32. Planning and estimating data is provided in Table 5-33 for steel and in Table 5-34 for timber piles.

The two-unit pile wrap system, illustrated in Figure 1 of Table 5-32, uses an upper intertidal unit starting at least 1 foot above mean high water and extending to at least 3 feet below mean low water. The lower unsealed unit overlaps the intertidal unit and extends to below the mudline. Polyurethane foam seals are used at each end of the intertidal unit to ensure air and water tightness.

- The PVC sheet is wrapped around the pile and tightened.

- The wrapper is fastened with aluminum alloy bands around the seals and aluminum alloy nails along the vertical joints.

- Do not use aluminum nails on CCA treated piles; instead install bands at 3-foot intervals or use bronze nails.

- The area around the base of the pile is backfilled after the PVC barrier is installed.

- If the timber pile is creosoted, a 6-mil polyethylene liner must be placed between the pile and the PVC sheet in the intertidal zone (check manufacturer recommendations).

Long-term testing has shown that PVC wrappers placed directly over creosoted timber piles lose their plasticity and become brittle and porous. Check with the pile wrap manufacturer for the latest application information. The intertidal wrapping section may be ordered with a polyethylene liner attached to permit a single-step application process.

## 5.10 TIMBER SHEET PILE STRUCTURES

As described in Section 3.7.2, there are many causes of deterioration of timber walls in the marine environment. There are also many methods for the repair and maintenance of timber walls. The repair and maintenance methods fall into four general categories:

- Patching
- Concrete capping/facing
- Tieback system installation/replacement
- Wall load modifications

### 5.10.1 Patching

Localized areas that have deteriorated as a result of marine borer infestation or rot can be repaired by patching with underwater cement as described in Table 5-35.

Table 5-32
Protecting Piles with Polyvinyl Chloride Wrappings

**Problem**: A new, old, or repaired pile requires a covering to protect it from marine borer deterioration. Effective where damage to existing pile is less than 30 percent. Technique can also be used on steel piles to reduce corrosion and on concrete piles to prevent abrasion.

**Description of Repairs**:

- Clean surface of pile by removing all surface growth, deteriorated timber, and protrusions that might strain or puncture the wrap. Unbolt and remove timber bracing as required.
- Follow PVC wrap manufacturer's installation instructions making sure all seal gaskets are properly installed in place. Seal integrity is important to prevent water flushing under pile wrap.
- For steel H-piles, use blocking (Figure 1a) to fill channel voids at top and bottom of pile wrap. Cut styrene blocks slightly larger than inside flanges and force into place. A suitable sealing compound is applied to surface of foam where it contacts pile. For a steel pile, wrap should extend from 1 foot above MHW to 1 foot below the mudline and be sealed at top and bottom.
- Install foam sealing gasket around pile at top and bottom of wrap.
- Wrap the PVC jacket, of proper length, around the pile, cinch jacket tight against pile. Nail the overlap joint at 3-foot intervals using aluminum alloy nails. On steel or concrete piles use plastic straps or banding at 3-foot intervals (Figure 1b).

**NOTE**: For piles treated with CCA (copper chromium arsenic), do not use the aluminum alloy nails. Instead install aluminum bands at the 3-foot intervals. Bronze boat nails can be used in CCA treated piles. Check with corrosion engineer for compatibility of joining materials.

- Install and tighten aluminum bands over top and bottom seals and nail through band clip to secure band in place.
- Replace all previously removed bracing.

**NOTE:** Where pile length exceeds length of pile wrap, overlapping wraps may be used. Wrap from top down with 12-inch minimum overlap (Figure 1c). Rotate joint 90 degrees from upper joint. Where rocks prevent installation of a bottom seal band below mudline, install barrier as low as possible and fill rock voids with hand-packed or tremie concrete.

**Application**: This method is widely used for preventing or arresting marine borer attack, or corrosion of steel piles. The method is more economical than concrete encasement. Standard wraps are available in 60-mil thickness, thicker wraps up to 150 mils can provide abrasion protection in areas where ice and other abrasion is present.

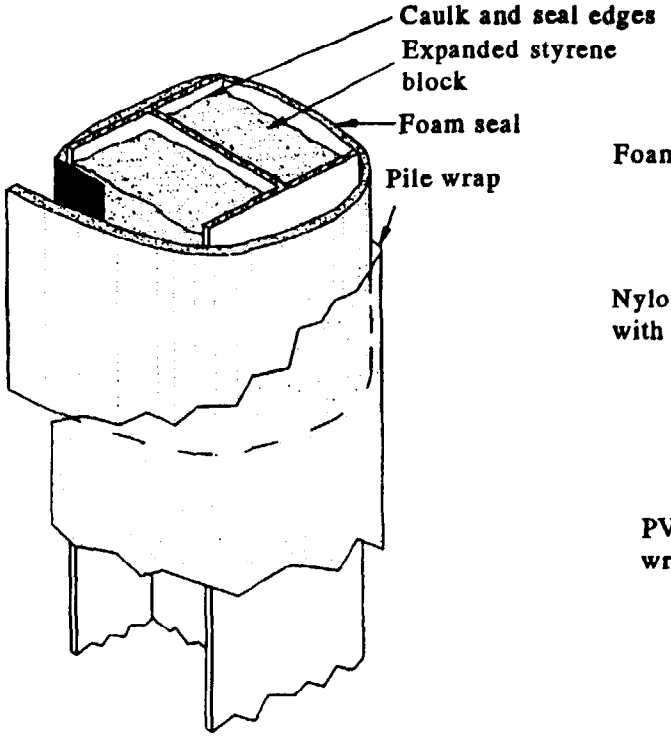



**Figure 1(a) Steel pile**

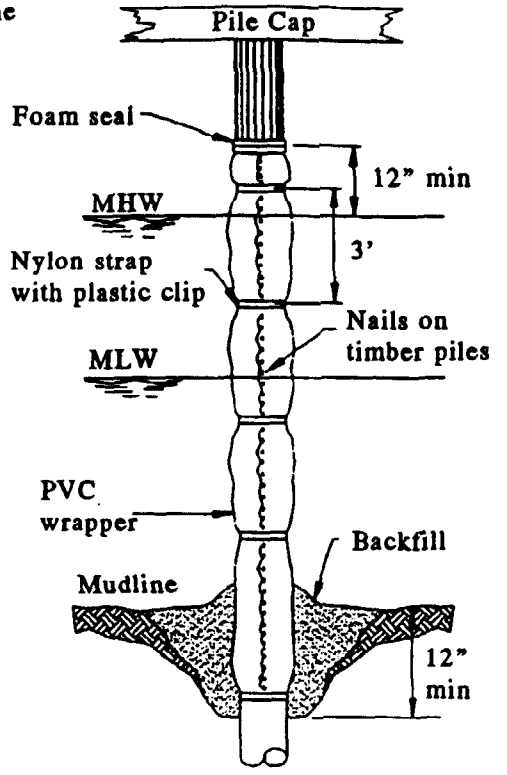



**Figure 1(b)**
**Typical single unit pile wrap on round pile**

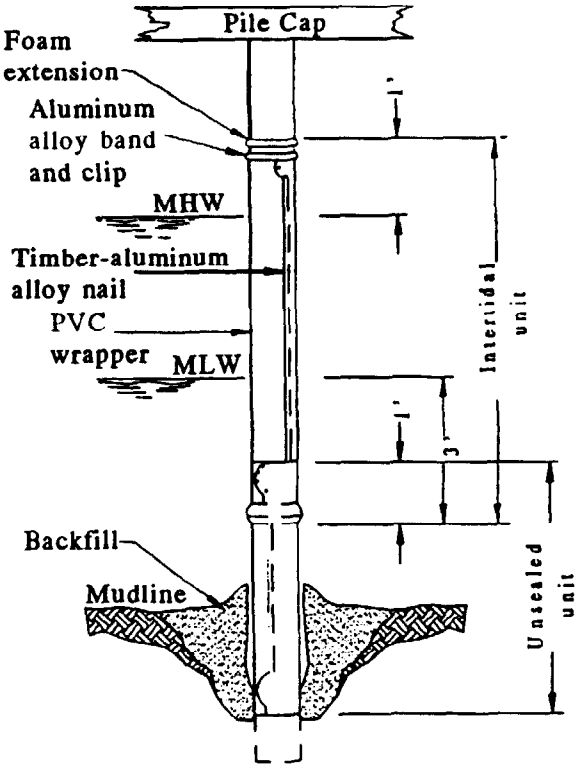



**Figure 1(c)**
**Typical two-unit pile wrap**

**Notes:**

On steel piles, extend 1 ft above MHW to 1 ft below mudline.

Do not use aluminum nails on CCA-treated timber piles.

Use bands or straps at 3-ft intervals on concrete or steel piles.

Table 5-32
Figure 1. Wrap for timber, steel, and concrete piles.

Table 5-33
Planning and Estimating Data for Steel Pile Maintenance Using Wrapping

**Description of Task**: Wrap a steel pipe pile with commercially available polyvinyl chloride (PVC) wrapping sheets from 1 foot above the high waterline to 2 feet below the low mudline. Total length to be wrapped is 10 to 20 feet.

**Size of Crew**: Dive station, one laborer.

**Special Training Requirements**: Familiarity with procedures for removal of marine growth and installation procedure for the PVC pile wrap to be used.

**Equipment Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, special fastener tools for pile wrapping (dependent on manufacturer), float stage or work platform.

**Productivity of Crew**: 4 hours per pile.

**Materials**:

**Polyvinyl Chloride Pile Wrap Unit** - Commercially available PVC pile wraps are available in many prefabricated sizes to fit various pile sizes and lengths. Some have separate units for splash zone and underwater use, while others are a single unit. Manufacturers' literature should be consulted before ordering.

**Foam Seals, Straps, and Special Fittings** - Each pile wrap manufacturer has particular foam seals, fasteners, and special fittings. Manufacturers' literature should be consulted before ordering.

**Potential Problems**: Projections or sharp edges on the pile may puncture or tear the pile wrap, so care should be taken to remove such problems.

Table 5-34
Planning and Estimating Data for Timber Pile Maintenance Using Wrapping

**Description of Task**: Wrap a timber pile with commercially available polyvinyl chloride (PVC) wrapping sheet from 1 foot above the high waterline to 2 feet below the mudline. Total length to be wrapped is 20 to 30 feet.

**Size of Crew**: Dive station, one laborer.

**Special Training Requirements**: Familiarity with procedures for removal of marine growth, jetting or air lifting procedures, and installation procedure for the PVC pile wrap to be used.

**Productivity of Crew**: 4 hours per pile (includes cleaning).

**Equipment/Materials Requirements**: High-pressure waterblaster, hydraulic grinder with Barnacle Buster attachment, high-pressure pump for waterblaster, hydraulic power unit, air lift or jetting pump and hose, special fastener tools for pile wrapping (depending on the manufacturer), float stage or work platform.

**Polyethylene Liner** - The intertidal area on any pile wrapping system should be protected from creosote damage by the placement of a polyethylene liner directly on the timber before placement of the PVC wrapping from 1 foot above the high waterline to 3 feet below the low waterline. Alternatively, some PVC wraps can be ordered with a polyethylene liner attached.

**PVC Pile Wrap Unit** - Commercially available PVC pile wraps are available in many prefabricated sizes to fit various pile sizes and lengths. Consult manufacturers' literature before ordering.

**Foam Seals, Straps, and Special Fittings** - Each pile wrap manufacturer has particular foam seals, fasteners, and special fittings. Consult manufacturers' literature before ordering.

**Potential Problems**: Projections or sharp edges on the pile may puncture or tear the pile wrap, so care should be taken to remove such problems.

Table 5-35
Patching Holes in Timber Sheet Piling

**Problem:** Localized surface areas have deteriorated as a result of rot or marine borer infestation.

**Description of Repairs** (Figure 1): Clean deteriorated areas removing marine growth and deteriorated wood.

**Small Holes:** Drive galvanized nails or bronze boat nails partially into wood in the repair area to provide gripping strength for the patch. Fill holes with commercially available epoxy or cement grout. Use manufacturer's application procedure.

Alternatively, cover area with treated ship's felt, available through local boat yards, and fasten in place by covering with 1-inch-thick treated boards attached with galvanized or bronze nails.

**Larger Areas:** Cover holes with timber or metal patches. Drive pipe casings behind wall and use pressure grout techniques to fill voids behind wall.

Extensive deterioration of the wall may require more extensive repair techniques such as driving new steel sheet pile behind or in front of the deteriorated wall or forming a new concrete face such as described under repair of steel sheet pile.

**Application:** These types of repairs will require engineering analysis to evaluate strength and utility of repaired structure. Extensive deterioration may require replacement with a new bulkhead. Partial repair may be more effective in cold water areas where wood deterioration is generally slower.

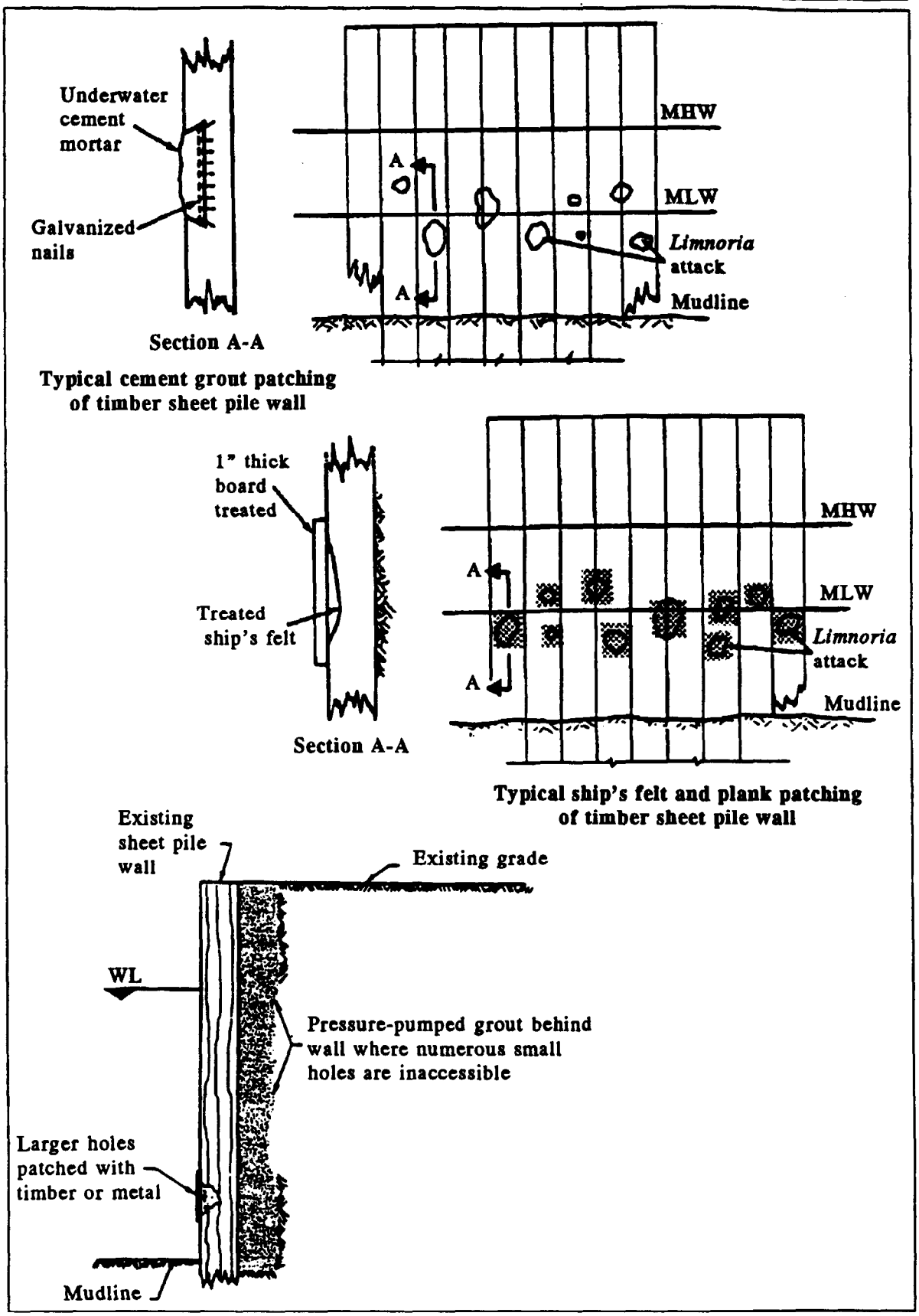



Table 5-35

Figure 1. Repair of timber sheet piling.

The affected area should be thoroughly cleaned to sound wood. Galvanized nails are driven into the wood within the deteriorated areas to provide a mechanical connection for the patch. The holes are filled with commercially available portland cement in the following manner: the mortar is formed into grapefruit-sized balls on the surface, lowered to the diver in a bucket, and pressed by the diver into the hole.

Ship's felt and treated boards can be used to repair localized damage. The deteriorated area is cleaned thoroughly to sound wood. The area is covered with creosoted ship's felt and fastened in place with galvanized roofing nails. The felt is then covered with 1-inch-thick creosoted boards and fastened with galvanized nails.

Planning and estimating data for repair of timber sheet pile structures are provided in Table 5-36 (using hydraulic cement patching) and in Table 5-37 (using ship's felt and creosoted boards).

### 5.10.2 Concrete Capping/Facing

Large-scale deterioration of timber sheet pile structures can be repaired using concrete capping/facing techniques. Concrete capping is used when extensive deterioration has occurred on the top of the timber wall but the remainder of the wall is basically sound. This method is described in detail in Section 5.6.2. All marine growth and unsound wood must be removed before a concrete cap or face is installed.

Concrete capping techniques usually require heavy equipment that is not normally available to the UCTs and would usually be carried out by others.

### 5.10.3 Tieback System Installation/ Replacement

Movement of timber walls can be arrested by installing a new tieback system or replacing the defective elements of an existing system. This repair/maintenance technique is explained in Section 5.6.4.

Tieback system installation/replacement is usually carried out by shore-based construction forces.

### 5.10.4 Wall Load Modification

Timber wall movement can also be arrested by changing the in-place loading on the wall. The technique is discussed in Section 5.6.5.

Wall load modification is usually carried out by shore-based construction forces.

## 5.11 CATHODIC PROTECTION SYSTEMS

Corrosion of steel marine structures is an electrochemical oxidation process where current flows from a more reactive area (the anode) through the seawater electrolyte to a less reactive area (the cathode). This results in the corrosion of the anodic area. Steel is anodic as compared with most other metals that are used in marine structures, but it should also be noted that new steel is anodic to old steel and that highly stressed areas are anodic to nonstressed areas. This illustrates why repairs to steel structures must be protected from corrosion and why bent metal pieces corrode faster than plate metal.

Table 5-36
Planning and Estimating Data for Timber Sheet Pile
Repair Using Hydraulic Cement Patch

**Description of Task:** Repair a deteriorated timber sheet pile wall by patching with hydraulic cement. A 1-ft$^2$ area below the low waterline is to be patched.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with procedures for removal or marine growth and placement of underwater cement.

**Productivity of Crew:** 30 minutes for a 1-ft$^2$ patch.

**Equipment/Materials Requirements:** Hydraulic grinder with Barnacle Buster attachment, hydraulic chipping hammer, hydraulic power unit, float stage or work platform.

**Galvanized Nails** - A sufficient number of galvanized nails must be driven into the wood to provide a mechanical connection for the underwater cement. As a minimum, a nail should be placed every 3 to 4 inches along the outside of the repair and on a 6- by 6-inch grid on the interior of the repair. Allow for losses due to dropping.

**Hydraulic Cement** - The hydraulic cement need not fill the void left by the removed wood but should be at least 2 inches thick. The volume of cement needed is found by taking the area of the patch and multiplying by 2 inches. An allowance of 25 percent should be added for waste and shrinkage of the cement.

**Potential Problems:** Should be used only if a limited number of repairs are to be performed. When large-scale deterioration is observed, other techniques should be used.

Table 5-37
Planning and Estimating Data for Timber Sheet Pile Repair
Using Ship's Felt and Creosoted Boards

**Description of Task:** Repair a deteriorated timber sheet pile wall by patching with ship's felt and creosoted boards. A 1-$ft^2$ area below the low waterline is to be patched.

**Size of Crew:** Dive station, one laborer.

**Special Training Requirements:** Familiarity with procedures for removal of marine growth.

**Productivity of Crew:** 30 minutes for a 1-$ft^2$ patch.

**Equipment/Materials Requirements:** Hydraulic grinder with Barnacle Buster attachment, hydraulic chipping hammer, hydraulic power unit, float stage or work platform.

**Ship's Felt** - The ship's felt must cover the entire hole to be patched as well as extending over the surrounding sound wood. The area of the holes to be patched should be estimated and a 25 percent allowance made for extra material.

**Creosoted Boards** - The creosoted boards must cover the entire hole to be patched as well as extending over the surrounding sound wood. The length and width of the boards should be a minimum of 8 inches greater than the largest length and width of the patched area.

**Galvanized Nails** - As a minimum, four galvanized nails are required to secure the boards. Galvanized roofing nails are required on approximately a 6- by 6-inch grid to secure the ship's felt.

**Potential Problems:** Felt is difficult to handle underwater if the area to be covered is over 4 $ft^2$. Creosote will ruin a wet suit and may cause skin irritation. Check local environmental restrictions on using creosoted materials.

### 5.11.1 Cathodic Protection Mechanism

Cathodic protection systems control corrosion by passing a current onto a steel structure through a seawater electrolyte, making it entirely cathodic and resistant to corrosion. There are two basic systems of cathodic protection, the sacrificial anode and the impressed current systems, both of which are illustrated in Figure 5-23.

The sacrificial anode system uses anodes of highly active metals, usually zinc or aluminum alloys, as the source of generated current. The loss of surface electrons consumes the anodes, so that it is necessary to replace them from time to time. Anodes are commonly cast with embedded steel straps used to attach the anodes to the steel structure to be protected. The anodes are mechanically attached to the structure by welding or bolting them into place. Welding is the preferred method of attachment as it provides both a positive mechanical and electrical connection between the anode and the structure. Bolted connections often do not provide a good electrical connection. The use of lockwashers between the anode and the structure on bolted connections improves the likelihood that a good electrical connection is achieved if bolted attachment is used.

The impressed current system uses low-voltage, high-amperage, direct current from an external power source. The positive side of the circuit is connected through electrical wire to the anodes, which are made of metals that are nonreactive in the marine environment, such as lead alloys and platinum alloys. The negative side of the circuit is connected to the steel surface being protected. The power to the impressed current system is provided from a shore-supplied alternating current (AC) source with controller circuit and converted to direct current (DC) by a rectifier.

The effectiveness of a cathodic protection system can be determined by measuring the electrical potential of the structure being protected. This can be accomplished using an underwater voltmeter as illustrated in Figure 3-23 or by using a portable voltmeter and portable reference electrode or "half-cell" as shown in Figure 3-22. In using the underwater voltmeter, it is important that the area to be inspected be cleaned of all marine growth in order to

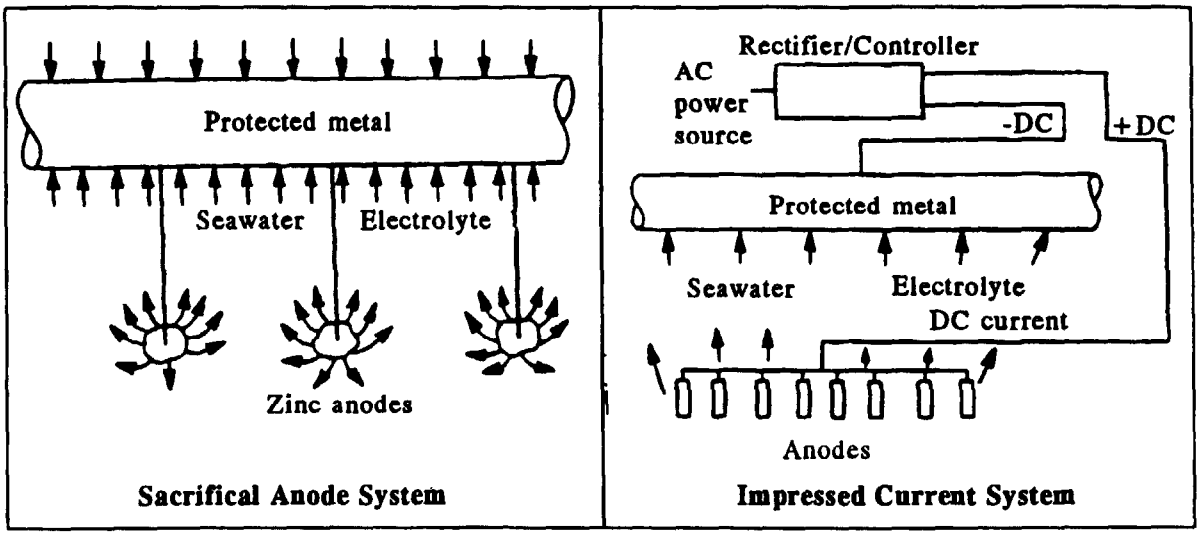



Figure 5-23
Cathodic protection systems.

make a good electrical connection between the probe on the voltmeter and the structure. When using the portable meter and reference electrode, marine growth does not have to be removed, but a solid and dependable connection to the structure must be made. Guidance for the interpretation of the measured potential of steel in seawater is given in Table 3-4. In general, a potential between -0.80 and -0.90 volts referred to a silver/silver chloride reference electrode indicates effective cathodic protection.

### 5.11.2 Anode Replacement

The following discussion is concerned with the cathodic protection of steel waterfront structures. A discussion of the cathodic protection of fleet moorings can be found in Section 5.4.3.

The failure of a sacrificial anode system can be due to the consumption of the anodes or loss of electrical continuity between structure components. Anode replacement simply involves attachment of the new anode by welding or bolting. Lack of electrical continuity between structure components is more serious from a structural point of view because it indicates that the components may not be physically connected. Lack of continuity is also difficult to find and correct. This is usually accomplished by visual inspection and by checking voltage of adjacent members with the underwater voltmeter.

In an impressed current cathodic protection system with multiple members being protected, failure of an electrical connection can result in higher corrosion rates than for an unprotected member. The **failure of an impressed current cathodic protection system** can be caused by:

- A break or poor connection in the wiring to the anodes
- Damaged or missing anodes
- Excessive fouling of the anodes
- Loss of AC power
- Failure of the controller circuit
- Defective rectifier

The repair procedure in this case is simply to replace the missing or defective element of the system, followed by a field test of the system.

## 5.12 SCOUR PROTECTION

One of the most significant forces in the marine environment is that of wave action. Wave action, coupled with strong currents, is the cause of the erosion of seabed material around marine structures. **Protection against scour forces** falls into two general categories:

- Riprap placement
- Sheet pile driving

### 5.12.1 Riprap Placement

An economical method of scour protection is the placement of riprap at the base of the structure or at points where wave/current action is the strongest. Riprap, which consists of stones dumped randomly into place, is quite useful in this application because its mass and surface toughness make it highly resistant to movement under the effects of wave and current action.

Where riprap is not available or suitable, several alternatives may be used. Bags of almost any size made of synthetic fiber woven into water-permeable fabric are commercially available under a variety of

trade names (manufacturers are listed in Appendix A). These bags are placed in the area to be protected and filled with concrete. The bags should be provided with a self-closing inlet valve to accommodate the insertion of the concrete pump hose. Refer to Section 2.10 for a discussion of placing concrete underwater.

When large mass units are not required or other alternatives are not available, cement bags may be used. The stability of the bags may be increased by placing them in interlocking stretcher-header fashion and driving reinforcing bars through them before the cement sets. Further discussion of sacked concrete techniques is given in Section 2.10.4.

On sandy seabeds, a filter fabric may be required under the riprap or bags to prevent scour through the individual units. The materials most commonly used are commercially available, synthetic fiber, nonwoven fabrics, weighing between 8 and 12 oz/yd$^2$. Woven synthetic fiber fabrics weighing between 5 and 7 oz/yd$^2$ also perform well. Figure 5-24 illustrates a scour repair and prevention using fabric bags and a filter fabric.

### 5.12.2 Sheet Pile Driving

The driving of sheet piling, particularly steel sheet piling, in front of a structure subject to scour, is sometimes used as a remedial measure. The increased surface area of the sheet piling diminishes the effect of the wave/current action, and, if necessary, allows any lost foundation material to be replaced in back of the sheet piling. Usually the equipment required to drive sheet piling is not directly available to the UCTs; thus, this type of repair procedure would be carried out in conjunction with other construction groups.

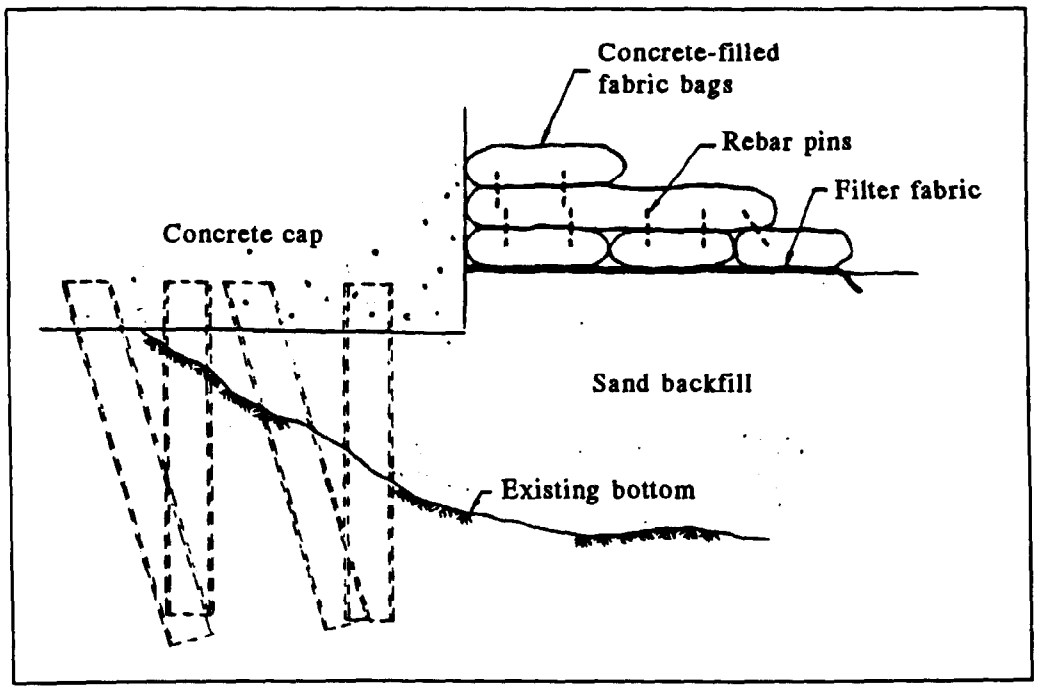



Figure 5-24
Fabric bags/filter fabric scour protection.

# Chapter 6

# UNDERWATER INSTALLATION PROCEDURES

## 6.1 SCOPE

Examples of facilities that the UCTs may be tasked with installing include underwater nearshore cables and pipelines, shallow water ranges, moorings, the Offshore Petroleum Discharge System (OPDS), and aids to navigation. Most other installation operations require heavy construction equipment and are within the scope of other Navy activities. The UCTs will frequently be tasked with assisting other activities on large installation projects requiring diver support.

Techniques for the four installation tasks are described in the following sections:

- Section 6.2 - Cable Installation
- Section 6.3 - Pipeline Installation
- Section 6.4 - Degaussing/Deperming Tube Installation
- Section 6.5 - Offshore Petroleum Discharge System

Each installation task may impose unique circumstances, and the exact techniques used must be determined by the personnel familiar with the situation on a case-by-case basis.

Planning and estimating data are provided in each section. For an operation to be a success, it is essential for the UCT to be aware of the conditions at the site. Section 1.4 lists the information about the site that should be obtained before deployment.

## 6.2 CABLES

### 6.2.1 Installation Methods and Equipment

UCT personnel will generally be involved in assisting with the installation of new cable facilities. Execution plans and planning for the cable installation are normally prepared by NFESC Code ESC55. The primary responsibilities of UCT divers will include assisting in landing the cable from the cable ship to shore and associated work with providing stabilization and protection for the cable. The UCTs may also conduct preinstallation surveys of the proposed cable routes to mark the submerged route and shoreline and to establish navigation guides for the cable landing. In some cases it may be necessary to actually conduct the cable installation. In this case it is usually from a ship of opportunity.

Whether assisting or conducting the installation, it is necessary to understand the general procedures associated with cable installations. Cable installations are extremely complex and require careful planning to ensure that all support craft, materials, support and operational personnel, and technical representatives for splicing and handling of the cable are on hand at the right time. Availability of personnel and vessels must include provisions for contingencies, such as weather and equipment failure.

Every cable installation operation should begin with:

- A survey of the cable route, the detail of which is dictated by the available "as-built" or existing information.

- The required length of cable to be installed.

- The conditions encountered on site.

Detailed information concerning site survey techniques can be found in Chapter 4.

The majority of cable-laying operations in which the UCTs have participated involve cable termination at a facility that is far enough inshore to allow termination in a fixed, dry, protected, and accessible environment. Cable termination to shore cables is typically done in an underground cable vault. An existing cable vault may already be installed, which would require only that new penetrations be made. Otherwise, a new vault must be constructed.

**6.2.1.1 Navigation and Tracking System Stations.** The landing of a cable usually involves a special navigation technique - a pair of range poles. Navigation range poles are essential in cable landing operations. Erecting targets (range poles) onshore for alignment of the cable is required whenever cables are brought into shore from the cable-laying ship. The idea is to provide a pair of range poles, as illustrated in Figure 6-1. They should be visible from the cable layer, and in line with the proposed cable route.

When the cable must follow a prescribed path to avoid underwater obstacles, other methods must be used. Marker buoys placed along the cable route, particularly at turns in the route, will allow the cable-laying vessel to visually line up the proposed route. An alternative is to provide fixed stations ashore that can be used for taking sight angles or ranges to the cable layer as it moves from point to point along its path. The position readout from shore-based theodolite angles may be available either aboard the cable layer or at the shore stations; in the latter case a communications system is essential for transmitting position information to the cable layer. More recently, new global positioning systems that provide satellite position such as

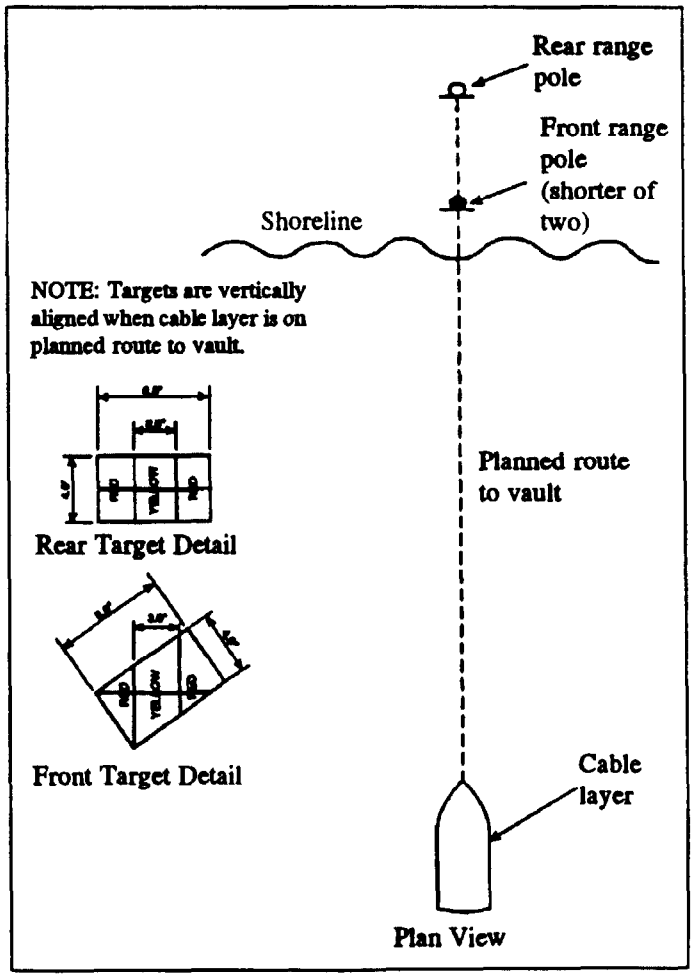



Figure 6.1
Range pole configuration for cable landing.

Global Positioning System (GPS) and Differential GPS are currently in wide use. Other navigation-survey systems such as Super Hydro and the Diver Navigation System (DNS) are also used for cable route surveys. More information on navigation systems can be found in Section 4.4.

**6.2.1.2 Trenching, Rock, and Berm Removal.** During the planning stages a study should be made of the beach area and the effects of winds and waves. The information from this study will be used to determine the requirements for burying the surf and shore sections to provide protection from weather, surface, and local traffic conditions. Generally, cables are brought through the surf zone, beach, and dunes to the inshore termination point. The cable landing area should be selected so that ecological damage is minimized and restoration can be effectively carried out. Environmental permits will be required (see Section 1.4.4).

Berm removal comprises cutting a 50-foot swath through the berm and dunes with a bulldozer to provide ample room for pulling cables to the vault. The cutaway material should be stowed in a convenient area for later replacement.

Cable trenching onshore and in the surf zone can be done with a backhoe. Material that is not easily excavated with a backhoe may require the use of controlled blasting excavation, as discussed in Section 2.7, or other suitable mechanical trenching techniques. The trenches are cut to a minimum depth of 4 feet. The actual depth of protective burial of the cable depends on the changing nature of the beach area and local traffic; high erosion rates or ice scour will require deeper burial. The trench width is determined by the number of cables, the required separation, and the need for a cable protection system.

**6.2.1.3 Cable Stowage.** The handling and stowage problems encountered are related to the physical characteristics of the cable, such as diameter, weight, minimum bending radius, and torsional stiffness. Many cables have a preferred coiling direction. When coiled in the wrong direction, the cable becomes stiff and will not lay flat in the pan. Some cables are torque balanced and are stiff in either direction. They must be handled carefully and coiled in much larger diameter loops.

Stowage of cables on wood or steel reels poses a number of cable-laying problems if the total length of cable to be laid exceeds that which can be stored on a single reel. For longer lengths it is necessary to splice the cable on the bitter end of one reel to the leading end of the next at sea. This method is dependent on the availability of an experienced splicer and splicing equipment.

On cable ships it is customary to carry long lengths of cable in cable tanks. These tanks are specially designed to allow for storage of the cable in concentric circles with dense packing, to get the maximum cable possible into the tank.

Another stowage technique uses portable cable pans set on the decks of barges. Normally the cable pans are loaded at the cable factory and shipped by rail or water to the site. A large crane is required to load the cable pan onto the cable barge. This technique allows cable loading and splicing operations to be performed in port.

As a minimum, electrical continuity checks should be made at the following steps in the loading process:

- Prior to splicing and prior to unreeling
- After each splice is made
- After unreeling each reel and stowing aboard prior to making the next splice

In some cases it may be necessary for UCT personnel to load the cable from reels onto the cable barge. In this case a cable pan can be fabricated using lumber and plywood to cover the available deck space. The dimensions of the pan will depend on the length of cable. A powered cable reel should be used for the shore portion of the cable. The cable is fed over guide sheaves to the center of the cable pan. A crane can be used to hold this sheave in location. The arrangement is shown in Figure 6-2.

As the cable is being transferred from a reel to a cable pan, one complete turn is applied on the cable for each loop in the pan. Therefore, care must be taken to ensure that the cable is sufficiently soft to accept twist and that the cable pan is sufficiently large to reduce the amount of twist in the cable. Otherwise, the cable will form hackles and kinks and the cable transfer cannot be accomplished. The cable is guided by hand to circles in the cable pan. Dunnage is placed over each layer of cable to minimize nicking of the cable between lower layers.

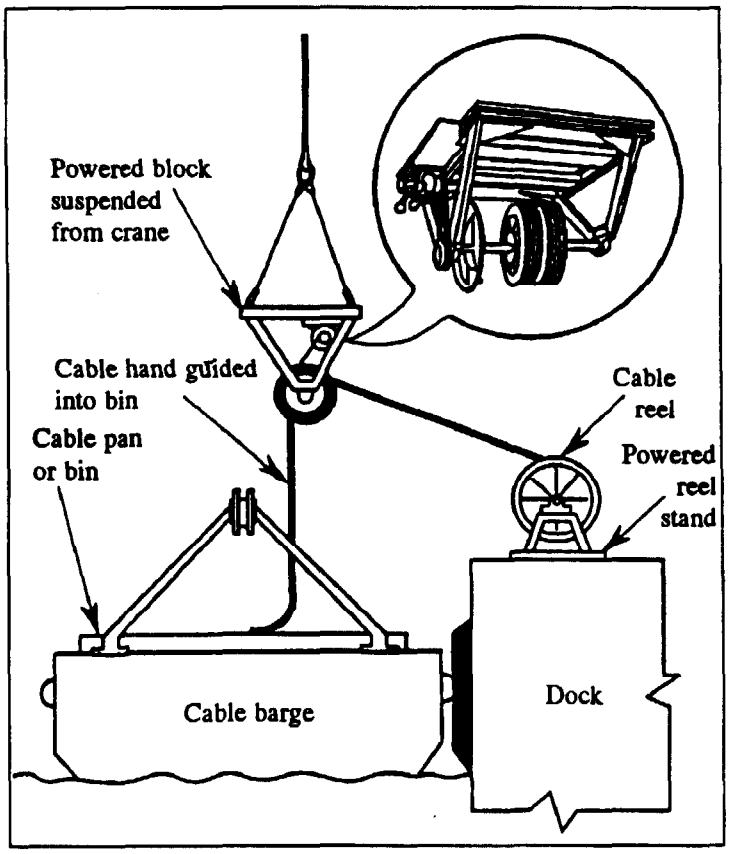



Figure 6-2. Arrangement for loading cables on a barge from storage reel.

**6.2.1.4 Hauling the Cable Ashore.** A very important part of the cable installation operation is bringing the cable ashore from the ship or barge to the cable vault. During this stage of the operation, the cable could be easily damaged by bottom obstructions or excessive hauling forces. One procedure is as follows:

- Using a small inflatable or amphibious vehicle, a hauling line is passed ashore from the cable ship.

- The seaward end of the hauling line is attached to the cable using an in-line swivel and shackles. The swivel allows the cable to rotate freely and release rotational torque, which would be built up from removal of the cable from the storage bins.

- With a strain on the hauling line from shore, the cable is pulled off the cable ship and floated off the bottom using float balloons tied 15 to 20 feet apart on the cable.

- The float balloons are removed after the cable is hauled ashore and secured to the cable vault or deadman anchor.

The cable float balloons reduce the required hauling force and keep the cable from snagging on seafloor obstructions. It is very important to ensure that the cable float balloons (usually called pumpkin floats) are se-

cured using the proper harness arrangement and knots. "D" rings on these floats are NOT designed to carry the load. The correct arrangement is shown in Figure 6-3.

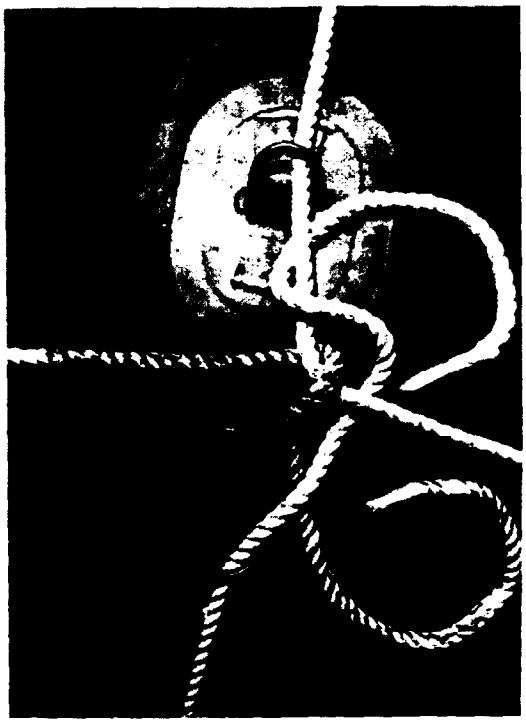


Figure 6-3. Harness arrangement and knots to secure float balloons.

Figure 6-4 shows a typical arrangement for shore landing of a cable. In this case a winch is used for the hauling operation. The hauling force that brings the cable ashore must also be provided by bulldozers, backhoes, tractors, and other heavy machinery. At least two hauling vehicles are required since there is usually not enough room to pull the cable from the ship to the vault in a single pull. When wheeled (not tracked) vehicles are used to provide the hauling force on sandy beaches, traction can be increased by using available roads, runways, and other paved areas.

Directional changes in the hauling route are often necessary to follow a specified trench line, to avoid obstacles, or to allow the hauling vehicle to operate on paved surfaces. The turn can be accomplished using a beach sheave or roller assembly, as illustrated in Figure 6-5. The sheave diameter must be selected to be compatible with the minimum bend diameter of the cable. Care must be exercised to ensure that the beach sheaves are properly rigged and that the deadman anchors are designed to carry the expected hauling loads.

Sometimes the deadman anchor is formed in place by pouring fresh concrete. In this situation, it is important for the concrete to reach a

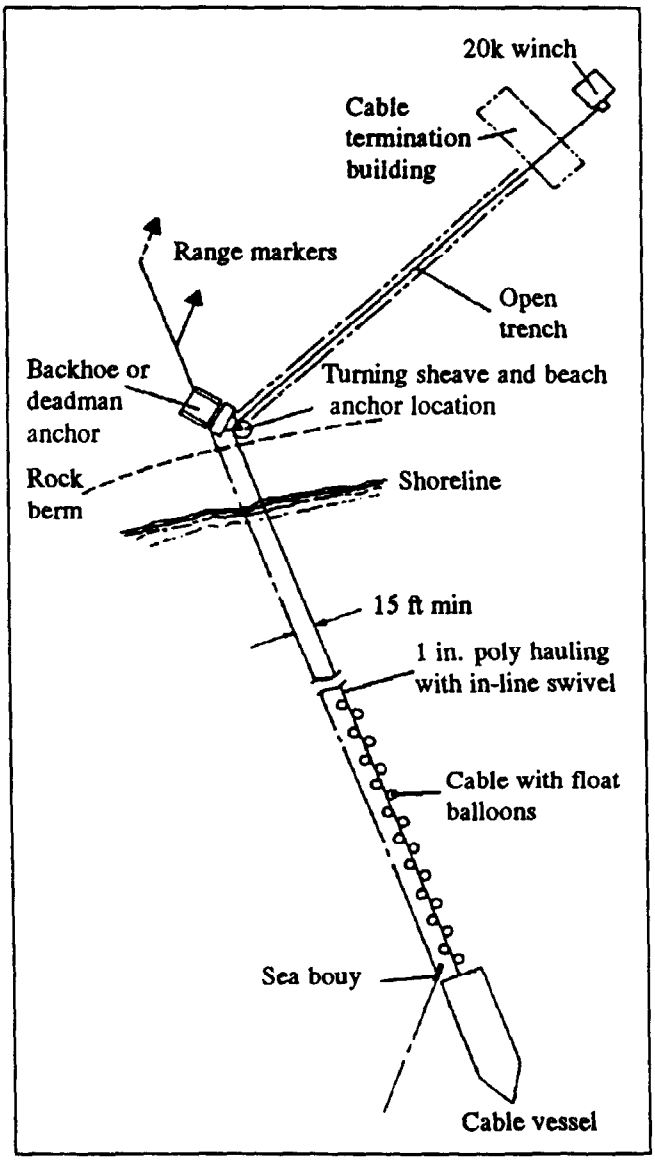



Figure 6-4. Arrangement for hauling cable ashore using a winch.

full strength cure before pulling operations begin. Full strength may require 48 to 72 hours depending on environmental conditions.

The hauling operation is particularly important. From the time the cable leaves the ship, the beach crew must maintain positive control to ensure that the floating cable is straight and that the end of the cable is not, accidently or otherwise, released. If heavy currents or wind forces are present, the floating cable can be assisted into position using small craft with tag lines to the cable.

Any time the cable is not attached to a hauling vehicle and the cable is floating, it is essential that the cable be tied off to a deadman anchor using stoppers. A deadman anchor should also be used when the load is being transferred from one hauling vehicle to another. Again it is important to be sure that the deadman anchor is designed to carry the expected loads of the cable or hauling system.

When sufficient length of shore cable has been pulled in, it should be tied off to a deadman anchor. It should not be released from this anchor until the float balloons have been removed from the cable, and the cable is resting on the ocean bottom.

**6.2.1.5 Laying Inshore Cable from a Cable Ship.** The most efficient way to lay the inshore portion of an undersea cable is from the cable ship. The seaward end of the cable is first deployed and the ship arrives at the transition point for the inshore cable. A line is passed ashore using a small boat secured to a winch or a beach-based vehicle, and the cable end hauled in to the onshore termination point. Float balloons are attached to the cable to keep it off the bottom while it is being pulled ashore. Although the technique is effective, it does pose a number of problems, as follows:

- The shore party and equipment must be available and ready to start landing operations when the cable ship arrives at the inshore cable deployment position.

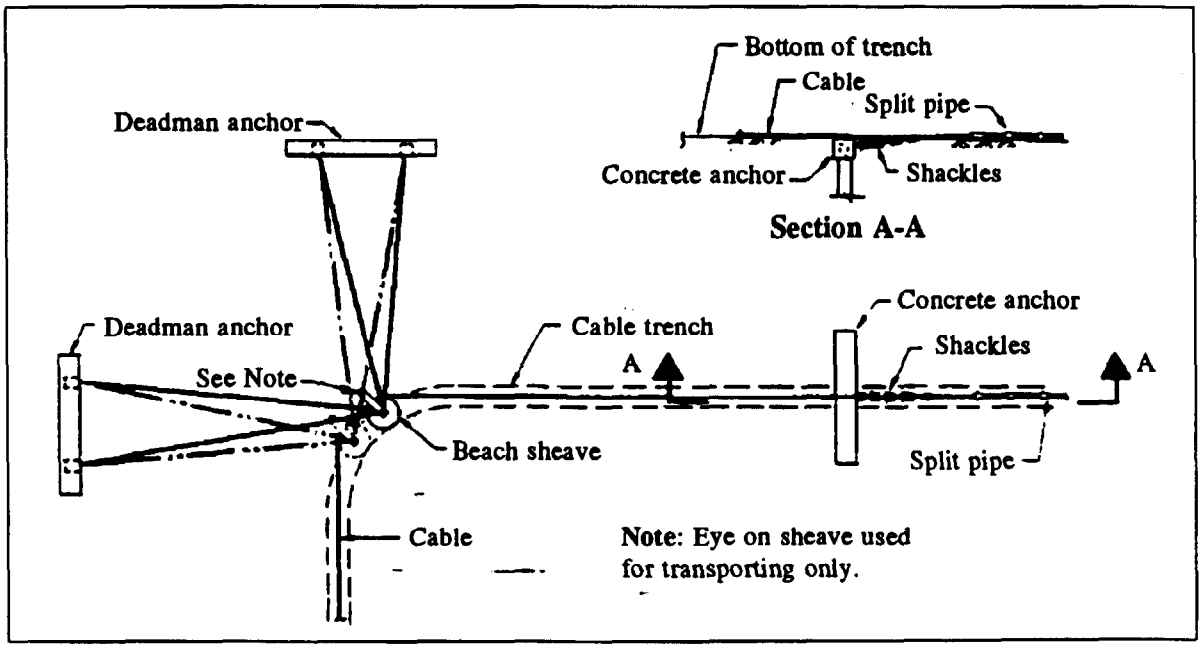



Figure 6-5
Beach hauling equipment.

• Either the length of inshore cable required must be precisely predetermined or the deep-sea cable will have to be cut and spliced to the inshore cable after the inshore cable ship has landed.

• The cable ship will be required to enter into a fixed mooring or to dynamically position itself at the offshore location for as long as it takes to complete the landing and splicing operation.

• Buoying off cable ends and other contingency planning to redeploy the cable ship must be made to provide for weather conditions that would adversely affect any part of the cable landing operation.

When the inshore cable is installed first, the ship is moored offshore of the cable landing site. The inshore cable is then hauled ashore as discussed above. When the inshore cable has reached the prescribed termination point, a wire stopper is attached to the cable and secured to a deadman anchor. The cable ship then breaks the moor and proceeds out to sea, laying the seaward cable.

**6.2.1.6 Laying Inshore Cable from a Barge.** This method involves loading the inshore cable aboard a barge, mooring the barge out beyond the surf zone, connecting the cable to a hauling device onshore with an inhaul line, and pulling the end of the cable to the terminal point onshore. The procedures for hauling the cable are the same as with the cable ship installation.

In addition to the towing vessels, inshore cable installation from a barge requires the services of small craft to carry hauling lines between the cable barge and the shore. The amphibians LARC V and LARC XV, as illustrated in Figure 6-6, are particularly useful, because not only can they carry the end of the hauling line ashore, but they can also move up the beach to assist in cable landing.

After the shore cable has been landed, the moor is broken and the barge is towed out to sea while laying the remainder of the cable. A puller-tensioner winch (illustrated in Figure 6-7) maintains a fixed tension on the cable being paid out. Over the center of the cable pan a sheave is hung from a cable-stayed steel frame or other support that spans the open space. During the laying operation the cable passes from the stowage area, up and over the suspended sheave, through the puller-tensioner device, over the stern, through cable guides, and into the water. An example of the on-deck cable arrangement is shown in Figure 6-8.

**6.2.1.7 Beach Area Restoration.** After the cable-laying operation has been completed, restore the beach and surrounding area to its preinstallation condition. This must be done to minimize the environmental impact of the cable installation. Excavated material set aside during preinstallation operations should be returned to its original location. Landscaped areas should be restored, as should all affected roads, walls, and fences.

### 6.2.2 Protection and Stabilization

A detailed discussion on cable protection and stabilization systems is contained in FPO-1-78(3), Design and Installation of Nearshore Ocean Cable Protection Systems. The reader is encouraged to use this report for the full design philosophy. The information below is summarized from that report.

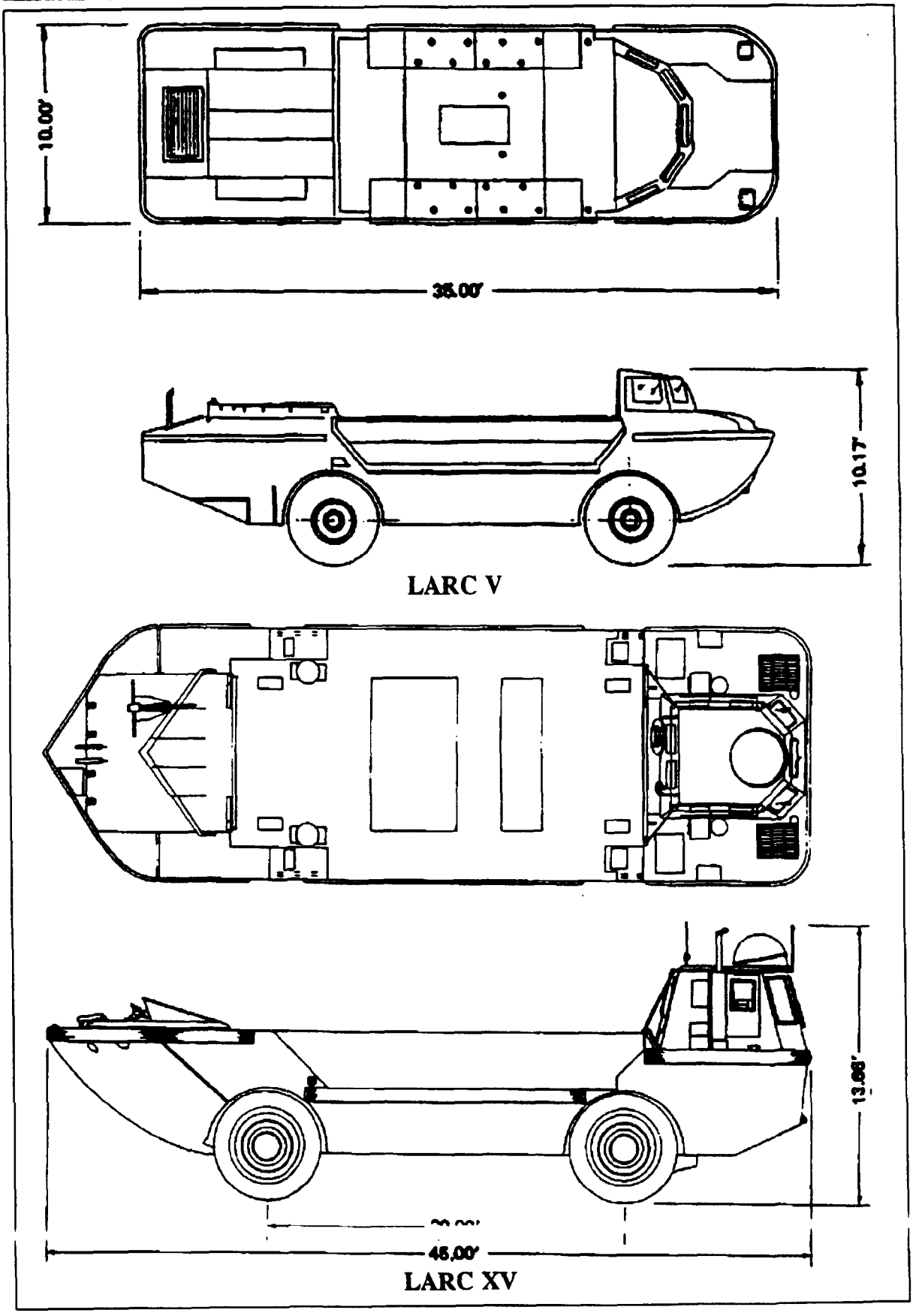



Figure 6-6. Dimensions of LARC V and LARC XV.

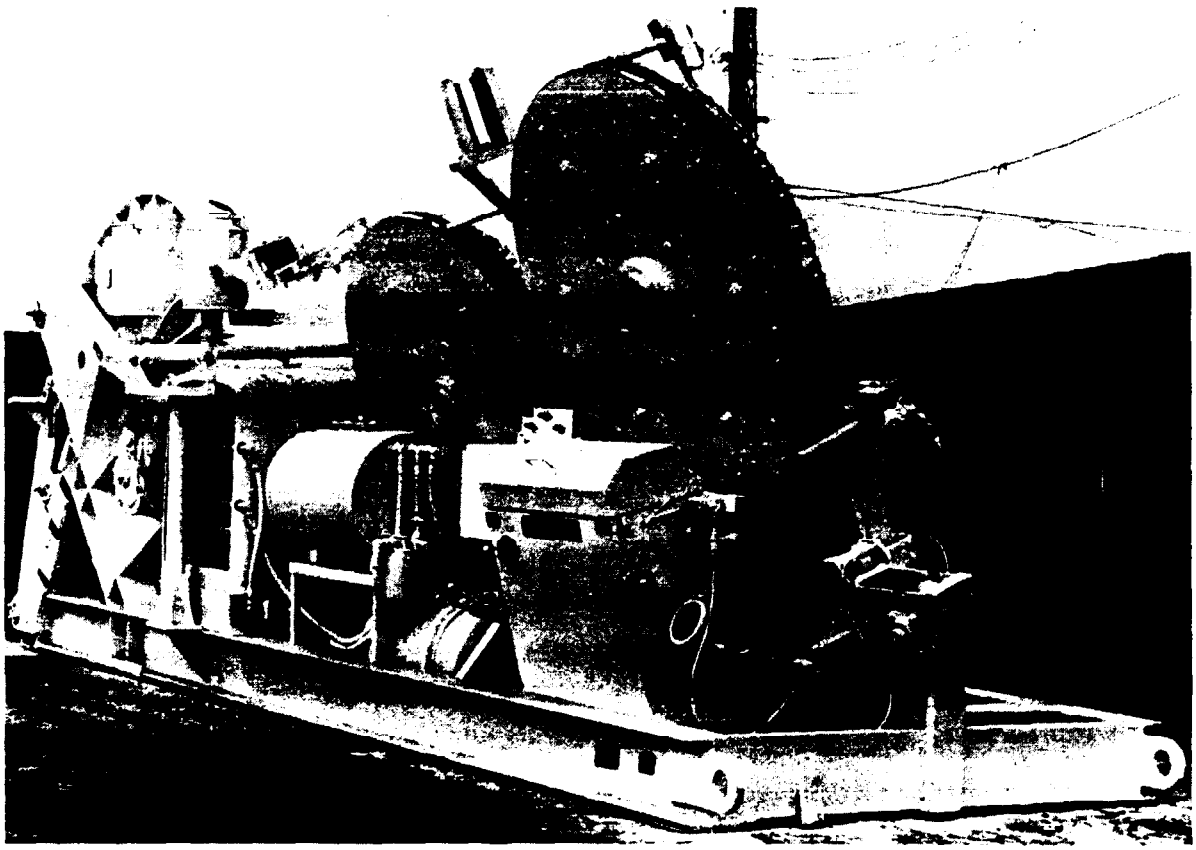


Figure 6-7. OCEI Pengo puller-tensioner winch.

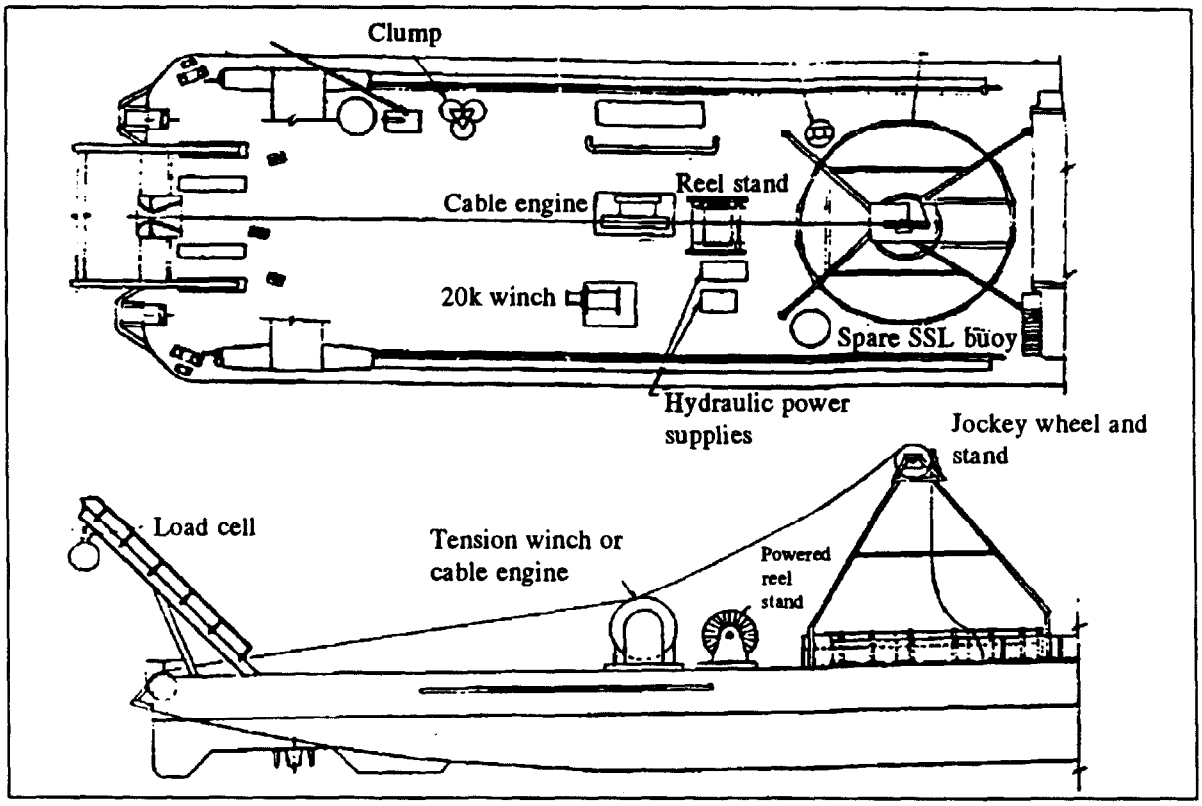



Figure 6-8. Typical deck layout for cable landings.

Environmental factors at the cable installation site may dictate the need for cable protection. Protection is usually provided to prevent impact and abrasion damage and to stabilize the cable against movement from the forces generated by wave and current action. **Protection and stabilization techniques** are separated into four general categories: mass anchor, tiedowns, burial, and tensioning.

**6.2.2.1 Mass Anchor.** Mass anchor stabilization techniques, by virtue of their weight and the resulting friction between the seafloor and the system components, allow the cable to resist environmental hazards. The techniques discussed in this section include: split-pipe, concrete, chain, and oil field pipe.

- **Split Pipe** - A common technique used by the UCTs for stabilizing cables through the surf zone and over rocky bottoms is the use of heavy, nodular cast iron, half-pipe sections, commonly referred to as split-pipe (Figure 6-9). Split-pipe is normally applied from above the high waterline out to a depth where wave and current forces are no longer of significance. Split-pipe performs two basic functions:

- It provides abrasion protection for the cable.

- It increases the cable system density, reducing the system's sensitivity to hydrodynamic forces.

Split-pipe is available in 36-inch-long sections of both 3-1/2-inch ID and 5-inch ID; a 3-1/2-inch-ID pipe half section weighs 75 pounds dry and 64 pounds in water. A 5-inch-ID pipe half section weighs 97 to 102 pounds dry and 85 to 88 pounds in water. Bolted together, half sections of split-pipe produce a ball-in-socket connection arrangement, with an assembled length of 36 inches per set of half sections. Split-pipe in 5-inch-ID can be used for covering spliced sections of cable.

Each ball-in-socket connection allows a 12- to 15-degree bend between sections, which results in a 12-foot minimum turning radius.

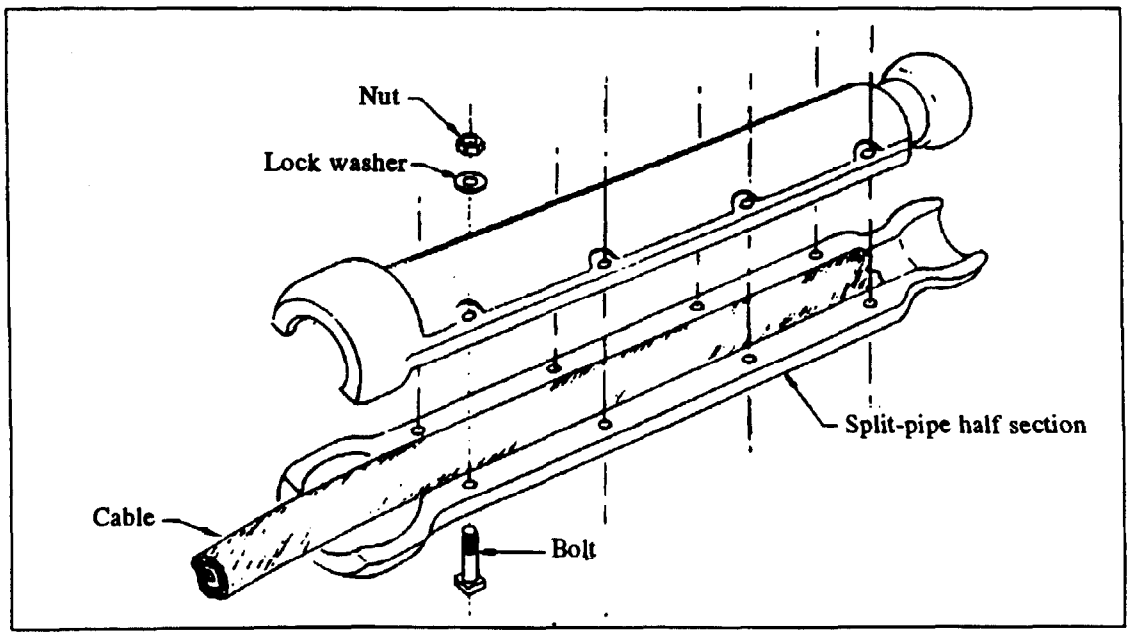



Figure 6-9. Split-pipe protection system.

A section of split-pipe uses eight fasteners, the most common being a 5/8-inch stainless steel bolt, lock washer, and nut assembly. The two fasteners closest to the bell end of the split-pipe provide the strength at the ball-in-socket connection. The remaining fasteners supply additional clamping strength.

Three recently used split-pipe installation techniques are discussed below:

(a) Applying the split-pipe to the cable by divers with the cable resting on the seafloor.

(b) Applying the split-pipe to the cable on the beach and then dragging the piped cable to sea.

(c) Applying the split-pipe to a floating cable from an underrunning vessel.

***a. Diver Split-Pipe Installation.*** The major advantage of diver-applied split-pipe is its simplicity; it does not require sophisticated equipment or a significant amount of coordination with other activities. The technique becomes increasingly difficult as sea conditions become more inhospitable and is only recommended when the application of split-pipe on the surface is not feasible. Best results are usually obtained by staging the split-pipe along the cable route next to the cable before deploying divers. This can be done using surface- or diver-controlled lifting devices, as discussed in Section 2.5. Fasteners and tools should be carried by the divers to the work site. On sandy bottoms, only the split-pipe to be installed that day should be staged to reduce the chance of sand transport burying the sections. Some success has been obtained by placing a 1- to 2-foot-diameter cable reel under the cable or by attaching diver-controlled lift bags to lift the cable off the seabed to make application easier. This technique requires little more than the appropriate fastener tools, divers, and the necessary diving/support equipment. A major disadvantage is that considerable diver time is required.

***b. Beach Split-Pipe Installation.*** Onshore-applied split-pipe calls for landing the shore end of a cable in a normal manner, except that additional cable is pulled ashore. The length of additional cable is equal to the amount of split-pipe protection to be applied. This method is usually practical only if the length of cable to be stabilized with split-pipe is less than about 500 feet. The split-pipe is applied on the beach and the cable ship pulls the cable back out to sea. Upon inhauling the beach end, the cable should be secured to a deadman anchor with a cable stopper directly in line with the incoming cable to minimize cable movement if seaward forces are applied. A quick-release device between the cable stopper and the deadman is used to facilitate release for outhaul. A matting material, typically fiberglass, should be preplaced under the application area to reduce friction between the cable and the beach. This matting, in conjunction with the beach guide, as illustrated in Figure 6-10, allows a smooth transition over the beach into the water. Hauling forces can be reduced by attaching float balloons to the pipe-enclosed cable.

The beach-applied technique is a good approach for handling split-pipe installation through a heavy surf zone, particularly when surf conditions are seldom less than 3 feet. It does have a few drawbacks, however. Hauling split-piped cable back out to sea requires the cable ship to stay on site longer than normal, restricting its use elsewhere. Enough room must be available to

allow the inhauling of additional cable and to allow straight-line split-pipe application on the beach.

*c. Underrunning Vessel Split-Pipe Installation.* Using an underrunning vessel is generally the best technique for applying long distances of split-pipe. An adequate vessel, such as an LCM-6 or the modular construction platform (Appendix B), with an underrunning system installed onboard, is required. Weather conditions must be sufficiently favorable to allow a vessel to remain moored in the application area for long periods of time. In addition, the time required to land the cable must be extended long enough to allow application of split-pipe in the surf zone. This technique, illustrated in Figure 6-11, is applicable for installations requiring more pipe than can be accommodated using the onshore-applied method.

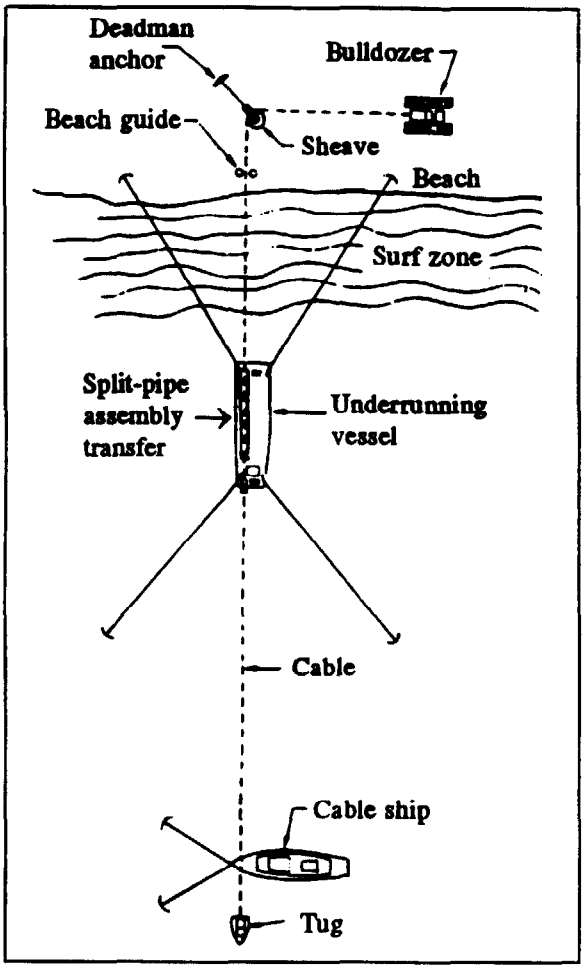



Figure 6-11
Equipment for underrunning vessel technique of applying split-pipe.

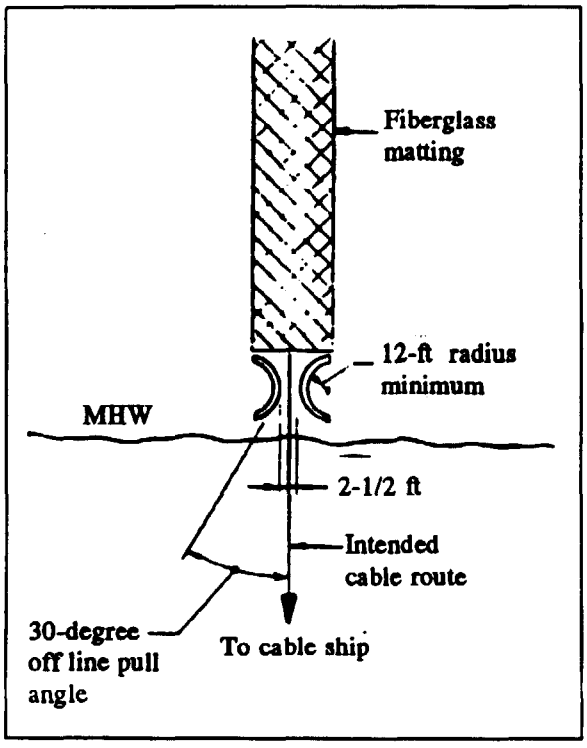



Figure 6-10. Beach configuration for shore-applied, split-pipe installation.

When the proper point reaches the underrunning vessel, inhaul is stopped and the cable is placed in the cable trough. After the cable is secured in place to prevent movement, the float balloons are removed, the split-pipe is attached to the cable, and the float balloons are reattached before the split-pipe is hauled over the cable chute toward the beach. The cable inhaul is then resumed to expose an unprotected section of cable in the trough. This process is repeated until the split-pipe reaches the beach. Additional split-pipe is applied on the underrunning vessel by warping seaward in its moor as the cable is pulled through the trough. Balloons are removed from the

cable, and split-pipe is applied as discussed above until the cable is ready for bottoming.

- **Concrete** - A variety of concreting techniques can be used for stabilizing cables on the seabed:

  (1) Sacked concrete
  (2) Cast-in-place concrete
  (3) Precast concrete

**Sacked concrete** consists of many types of flexible containers, such as burlap, nylon, canvas, or rubber bags, filled with concrete on the surface and positioned over the cable on the seabed. **Cast-in-place** concrete consists of large masses of concrete delivered to the seabed as a wet mix and either allowed to flow unconfined over the cable or pumped into flexible forms that have been placed over the cable. **Precast concrete** elements are blocks of concrete that have been poured and cured on land before positioning over the cable on the seabed. Underwater concreting techniques are discussed in Section 2.10.

- **Chain** - Chain is an appropriate stabilization technique for cable runs with limited life requirements and for stabilizing many cables in a confined area. Chain can be draped across and firmly attached to the cable, laid alongside and attached to the cable, or stretched between large anchors to provide a restraint base for multiple cables. The underwater handling of chain is accomplished using the techniques discussed in Section 2.5.

- **Oil Field Pipe** - The primary protective function of oil field pipe is to provide rigidity to underwater cable to lessen cable abrasion by wave and current action. The use of oil field pipe will decrease the cable system density, requiring the pipe to be immobilized by other techniques. Oil field pipe is a tough pipe that resembles standard pipe and comes in about 20-foot lengths. To facilitate assembly, a pipe assembly machine is used to assemble the desired length of pipe, through which the cable to be protected is run. A protective medium can be placed inside the pipe for additional corrosion protection, or grout can be pumped in to increase the in-water weight.

**6.2.2.2 Tiedowns.** The use of tiedowns is an immobilization technique that physically couples the cable to the seafloor along the length of the cable. This type of protection technique is generally used when the cable or cable/mass anchor system is not heavy enough to remain in place under wave and current action. Tiedown techniques include: screw anchors, grouted fasteners, and rockbolts.

- **Screw Anchors** - Screw/auger anchors, used in sand and clay seabeds to stabilize cables, work on an auger principle. They consist of a rod with a disk that is shaped in the form of a screw. The auger is secured to the cable by either a strap encircling the cable with the auger attached or by installation in pairs with a U-shaped strap straddling the cable, as illustrated in Figure 6-12. Auger anchors are usually embedded with an installation unit consisting of a buoyancy package, a torque motor (either pneumatically or hydraulically operated from the surface), and a framework to hold the components and provide the reaction torque necessary for installation. Commercially available installation units typically weigh about 6,000 pounds, requiring surface-supported lifting capability. Other anchors are discussed in Section 2.8.

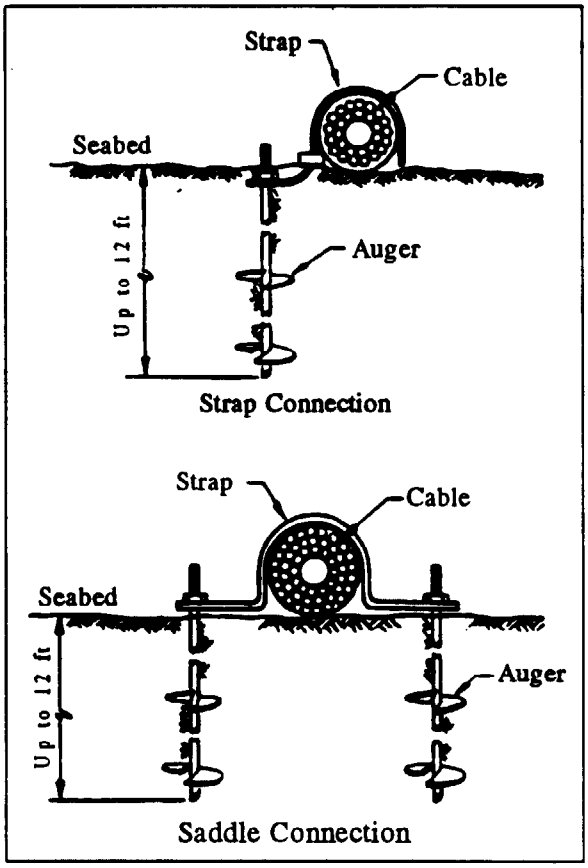



Figure 6-12. Pin anchor fasteners.

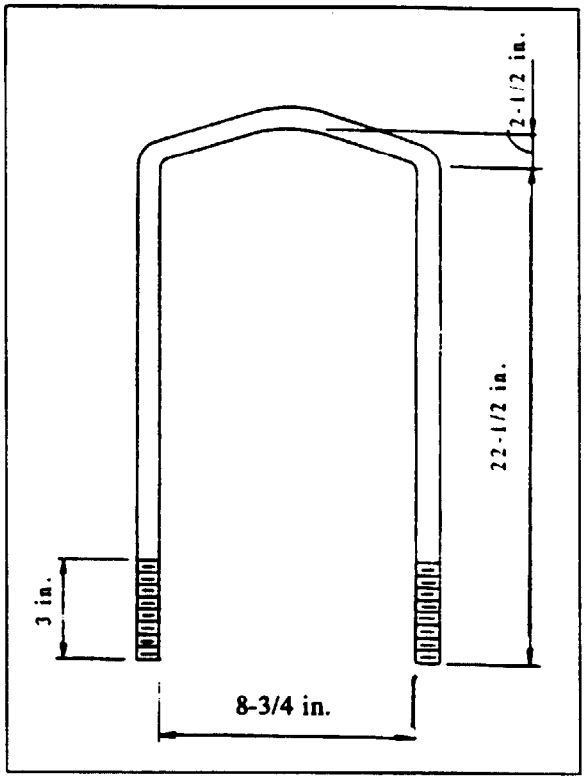



Figure 6-13. U-rod configuration.

• **Grouted Fasteners** - In areas of significant wave and current action, grouted-in copper-nickel or stainless steel U-rods, as illustrated in Figure 6-13, can be used to immobilize split-pipe covered cable. Properly installed U-rods provide an excellent immobilization technique, but require good diving conditions and considerable time. U-rods must be installed tight against the top of the split-pipe or the resulting split-pipe movement and abrasion may lead to failure. Grouted fasteners can develop considerable holding strength in some weak seafloor rock, making them a better alternative than expansion anchors, such as rockbolts. The clearance inside the U is set to just clear the projections on the type of split-pipe used, and the legs should allow a minimum of 10 inches insertion into the grout. The last 3 inches of each leg should be threaded and a nut installed before grouting to provide pullout resistance.

A drill jig, illustrated in Figure 6-14, is normally used to achieve proper spacing and alignment of the U-rod holes. Drilling of the holes, discussed in Section 2.2.3, should allow at least 3/8 inch around the grouted fastener to permit distribution of the grout. The drill rod should be clearly marked to indicate when the hole is deep enough. A hole of insufficient depth will not allow the U-rod to fit snugly over the split-pipe, rendering it useless. The U-rods should then be grouted in place immediately using the techniques discussed in Section 2.11. Once the grout is dispensed in the hole, the U-rod must be pressed firmly against the top of the split-pipe. The grouted hole should be protected against grout washout.

• **Rockbolts** - Nongrouted rockbolts develop their anchoring strength by me-

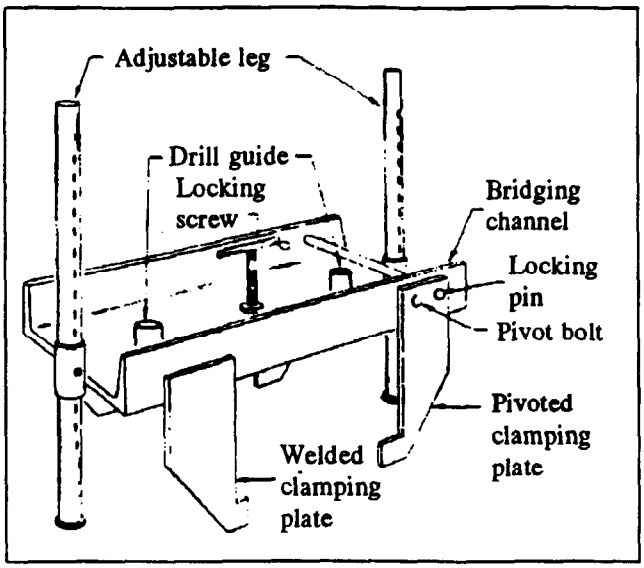



Figure 6-14. U-bolt drill jig.

chanically expanding the down hole end of the bolt, which develops an anchoring force through a combination of friction, adhesion between the anchor and rock, and physical penetration of the anchor into the rock. Rockbolts are classified into two types: drive-set and torque-set.

The drive-set fastener is assembled by placing a wedge into a slotted rod, which has a threaded upper end, and by positioning the rod into a predrilled hole. The anchor is then secured by driving the slotted rod over the wedge that rests on the bottom of the hole, causing the rod to expand into the rock.

A torque-set fastener has a wedge or cone threaded to the bottom of the bolt, and is surrounded by a sleeve. After inserting the bolt into the predrilled hole, torque is applied to the nut, pulling the bolt and cone up through the sleeve, thus securing the anchorage. The torque-set rockbolt is used extensively because of the availability of underwater tools that can supply the required torque.

When rockbolts are used in conjunction with split-pipe, the pipe itself can be used as the clamp. The holes in the flange are used as the drill jig and the rockbolts are installed through the flange into the predrilled hole. This limits the rockbolt size to 5/8-inch diameter, making it suitable only where hard rock seabeds exist. A minimum length of 12 inches is required to ensure that the rockbolt is adequately secured.

If rockbolts are to be used with split-pipe on weak or porous seafloor materials, then a larger bolt is required along with a saddle that spans the split-pipe. Figure 6-15 illustrates such an installation. The same type of rockbolts should be used on both sides of the saddle. If steel rockbolts are used, as shown on the left, sacrificial anodes should be attached to the rockbolt as shown. If titanium rockbolts are used, sacrificial anodes are not required. Titanium rockbolts are not commercially available and must be specially fabricated for the application.

**6.2.2.3 Burial.** Burial provides protection by allowing the cable to be placed below the surface of the seafloor. There are many techniques for cable burial: self-burial, jetting, controlled blasting, dredging and mechanical trenching, and drilled hole.

- **Self-Burial** - Cables lying on sands, silts, and soft clays will be self-burying because of the high unit weight of the cable and the strength reduction and scour of the underlying seabed caused by wave and current action. Sufficient slack must be provided to permit the cable system to follow the seabed surface, and the cable route should not pass over rock that will be exposed at some time during the design life of the system. Self-burial should not be used where damage from dragging anchors may occur. This technique involves no physical work out-

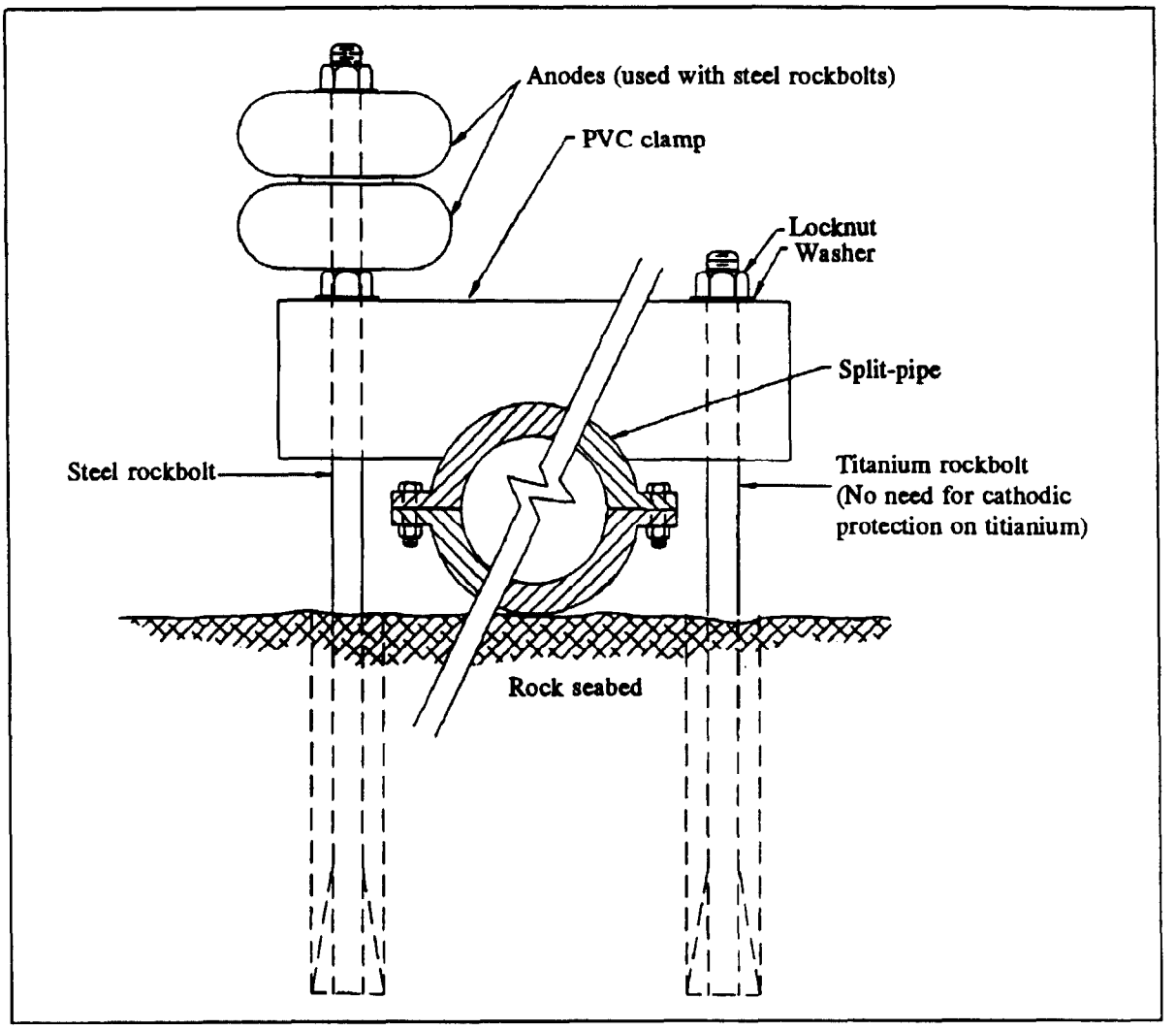



Figure 6-15. Split-pipe installation using rockbolts, using either titanium bolts (shown on the right) or steel bolts with an anode.

side of the cable-laying operation and thus is the first choice where conditions permit. Split-pipe may be applied to provide additional weight to assist in promoting self-burial.

- **Jetting** - Cables can be buried in most noncohesive materials and in many cohesive soils by jetting techniques. These techniques are discussed in Section 2.6.

- **Controlled Blasting** - Successful cable stabilization requires either burying the cable in the seabed or securing the cable to the seabed. Where hard rock or coral seabeds exist, a relatively smooth route must be provided that minimizes bending in the cable and provides adequate support along its length. If not naturally occurring, the route can be prepared by either smoothing a path or trenching and providing a relatively smooth trench bottom. In very hard materials or in extremely rugged terrain, controlled blasting is a viable technique for preparing the route and excavating a trench. Controlled blasting is discussed in Section 2.7.

- **Dredging and Mechanical Trenching** - The burial of cable by a dredge-type

trencher generally requires laying the cable first along the cable route followed by trench excavation and cable insertion by the towed or self-propelled trencher. Trenching in the nearshore zone is usually not performed because wave and current action tends to backfill the trench as soon as it is excavated. Dredging and mechanical trenching are not typically UCT operations.

- **Drilled Hole** - Cables can be installed in drilled holes starting just above the high water mark, running through the nearshore zone at some distance below the seafloor, and emerging from the seabed in deep water beyond the more aggressive environment. This technique requires sophisticated drilling machines and highly experienced personnel and is generally not in the scope of UCT operations. Commercial slant drilling has been successfully used to install pipeline through the surf zone at a distance to 6,000 feet from the shore entry point.

**6.2.2.4 Tensioning.** Tensioning of a cable provides a degree of stabilization by limiting the movement of a cable. The nearshore cable is anchored at either the shore or sea end while it is still supported by float balloons. The cable is then tensioned at the other end and that tension is maintained by a mushroom or clump anchor while the float balloons are removed and the cable is placed on the seabed.

Tensioning is best used as a supplement to other permanent-type cable stabilization techniques to reduce cable displacement produced by wave and current forces while the permanent stabilization is installed.

### 6.2.3 Planning and Estimating Data

The time required to carry out a nearshore cable installation project is highly dependent on the site conditions and varies widely. Bearing this in mind, Table 6-1 has been developed as an example to provide planning and estimating guidance for a nearshore cable installation project. The table is based on a project consisting of the installation of about 18,000 feet of SD List 3 cable. The inshore end is placed in an excavated trench extending from mean low water to a position about 500 feet inland. The nearshore soil is sand. Split-pipe stabilization is provided 300 feet seaward and 100 feet shoreward of the MLW mark. (Installation times for grouted anchors and rockbolts have been included in the table for planning projects with rock or coral seabeds.) The cables are anchored to a precast deadman anchor installed shoreward of the mean low water mark. A sand dune located in the vicinity of the beach will be excavated to provide a 50-foot-wide level access for the cable landing and trenching operation. All trenches, excavations, and sand dunes created or disturbed during project activities will be restored to their original configuration. The cable will be laid to a point where the water depth reaches about 120 feet, assumed to be 3 miles offshore for this example.

Column 1 of Table 6-1 describes the general tasks of the cable installation operation. Column 2 lists the variable factors that affect the time required to carry out each task. Columns 3 and 4 list the low and high estimates of the number of days required to carry out the tasks described in Column 1. The difference in the low and high estimates is caused by variations in site conditions, weather conditions, remoteness of the site, and the skill of the UCT performing the work. These time estimates should be adjusted if the listed variables expected on a particular project are different than those indicated in Column 1 of the table.

Table 6-1
Estimated Time Requirements for Installing Nearshore Cable

| Task Description | Variables | Estimated Time Required (days) | |
|---|---|---|---|
| | | Low | High |
| Onshore cable termination SD List 3 cable | Type of cable | 1 | 2 |
| Berm removal, 500 ft long, 50 ft wide, sand | Distance from MLW mark<br>Local topography<br>Type of soil or rock | 2 | 4 |
| Nearshore trenching, 500 ft long, 5 ft deep, 2 ft wide at bottom, sand | Length, width and depth of trench<br>Type of soil or rock | 1 | 3 |
| Installation of beach hauling equipment, 1 beach anchor, 1 deadman and sheave* | Number of deadmen and sheaves<br>Local topography | 3 | 6 |
| Establishment of navigation and tracking system beacons | Length of cable<br>Number of changes in direction | 1 | 2 |
| Cable stowage, on deck of barge, 18,000 ft of cable | Length and type of cable<br>Type of vessel | 1 | 2 |
| Hauling cable ashore, including mooring the barge 1,000 ft offshore | Hauling distance<br>Weather/sea conditions<br>Type of cable | 2 | 4 |
| Laying inshore cable toward barge, 15,000 ft long | Length of cable<br>Weather/sea conditions<br>Type of vessel | 1 | 2 |
| Beach restoration, 500 ft long, 50 ft wide, sand | Distance from MLW mark<br>Local topography<br>Type of soil or rock | 2 | 4 |
| Protection and stabilization, 300 ft seaward and 100 ft shoreward of MLW mark to be protected | Length to be protected<br>Type of protection<br>Weather/sea conditions<br>Method of installation | | |
| Split-pipe | | 1 | 2 |
| Pin anchors (in sand) | | 2 | 2 |
| U-rods (in rock) | | 10 | 10 |
| Rockbolts (in rock) | | 2 | 10 |
| Jetting (in sand) | | 1 | 1 |

*A freshly poured concrete deadman anchor requires 7 days to fully cure.

Since a number of the tasks listed in Table 6-1 can be carried out simultaneously, the total time required to complete the project is less than the sum of the times for the individual tasks. It is estimated that the total on-site time required to complete the example project is between 15 and 25 days.

## 6.3 PIPELINES

Submarine pipeline technology has evolved rapidly in the last 30 years. The growth in pipeline technology has been driven primarily by the search for offshore oil and gas operations and has evolved from land-based, nearshore operations to dynamically positioned pipeline installation vessels capable of operating in 2,000-foot water depths under very harsh weather conditions. Although the focus of this manual is to support small diameter (8 inches or less) submarine pipelines installed as part of a military facility, the reader should be aware of the wealth of technology and specialized equipment which has been developed as a result of the hundreds of thousands of miles of submarine pipeline which have been installed in the last three decades.

The vast majority of submarine pipelines are oil or gas lines and are constructed of seamless welded steel pipe sections. However, submarine pipelines are employed to transport a variety of products and can be constructed using various combinations of installation procedures, pipeline materials, and joint types. The major considerations governing each of these areas are briefly described in the following sections. Selecting a particular installation procedure, pipeline material, or joint type is made based on a thorough evaluation of site conditions and knowledge of local equipment, personnel, and funding resources. As with any project, a site presurvey (see Appendix C) will be required. Additional planning information unique for pipeline projects, which should also be collected during the presurvey, is listed in Appendix C.

### 6.3.1 Pipeline Design

Submarine pipeline design is a specialized technology which is quite different from the design of land-based pipelines. Technical support for the design and installation of submarine pipelines is available to the reader through the Naval Facilities Engineering Service Center (NFESC). Pipelines that are used to transport hazardous substances or potable water are subject to local and national regulations which govern various aspects of the pipeline design (i.e., burial depth, material selection, wall thickness, etc.). The reader should consult with the NFESC in these situations.

The basic considerations in the design of a submarine pipeline are:

- **Pipeline Hydraulics**: The diameter and operating pressure of the pipe must be sufficient to deliver the required volume of product. This requires evaluation of the pipe system to determine energy losses from the product flow due to changes in pressure, fluid velocity, and pipeline elevation.

- **Wall Thickness Determination**: The pipeline must be strong enough to withstand internal pressure, external pressure, and installation stresses.

- **Hydrodynamic Stability**: The submerged weight of the pipeline must be sufficient to resist movement when subjected to wave and current loads. This evaluation is typically performed for both the installation environment (1-year return period environmental loads and an air-filled pipe) and

the operating environment (20-year + return period environmental loads and a product-filled pipe).

- **Route Selection**: The pipeline route must be selected which will ensure the safety of the pipeline.

- **Installation Procedure Selection**: An installation procedure must be selected which is cost effective, simple, and reliable.

- **Material Selection**: The pipeline material must be selected which will ensure product quality, pipeline safety, simplicity of installation, and cost effectiveness.

- **Pipe Joint Selection**: A jointing procedure must be selected which is compatible with the pipeline product and the selected installation procedure.

- **Internal and External Coatings**: Internal and external coating systems must be selected which will protect the pipeline from corrosion and the product from contamination.

- **Final Inspection, Hydrostatic Testing, and Startup**: The pipeline should be visually inspected, cleaned of any internal debris, hydrostatically pressure tested, and filled before acceptance.

- **Operation, Inspection, and Maintenance**: Operation, inspection, and maintenance procedures should be identified during the design stage and provisions incorporated in the pipeline design (e.g., pressure relief valves, shutdown valves, purge fittings, pig launchers, etc.) to accommodate these requirements.

### 6.3.2 Pipeline Hydraulics

Design procedures for determining liquid flow in a pipeline are based on the Bernoulli theorem (or energy equation). For a simple single product line, the Bernoulli theorem can be used to express pressure losses in a pipeline (shown in Figure 6-16.)

The pressure losses shown in Figure 6-16 are determined by the required throughput, pipe diameter, pipe length, pipeline material, and ancillary fittings. The reader may refer to any standard fluid mechanics text for detailed procedures to calculate pressure losses.

### 6.3.3 Wall Thickness Determination

Factors governing the selection of the pipeline wall thickness are:

- Internal operational pressure
- External installation pressure
- Installation stress
- Submerged weight requirements

Although each of these factors must be analyzed prior to selecting a pipeline wall thickness, the most basic consideration in wall thickness selection is internal operational pressure. This selection forms the starting point for all other analysis.

The required wall thickness of a pipeline may be estimated by:

$$t = \frac{P_i D}{2 \times S}$$

where:

$t$ = wall thickness (in.)
$D$ = pipeline diameter (in.)
$P_i$ = internal operating pressure (lb/in.$^2$)
$S$ = maximum allowable hoop stress (generally 72 percent of yield stress)

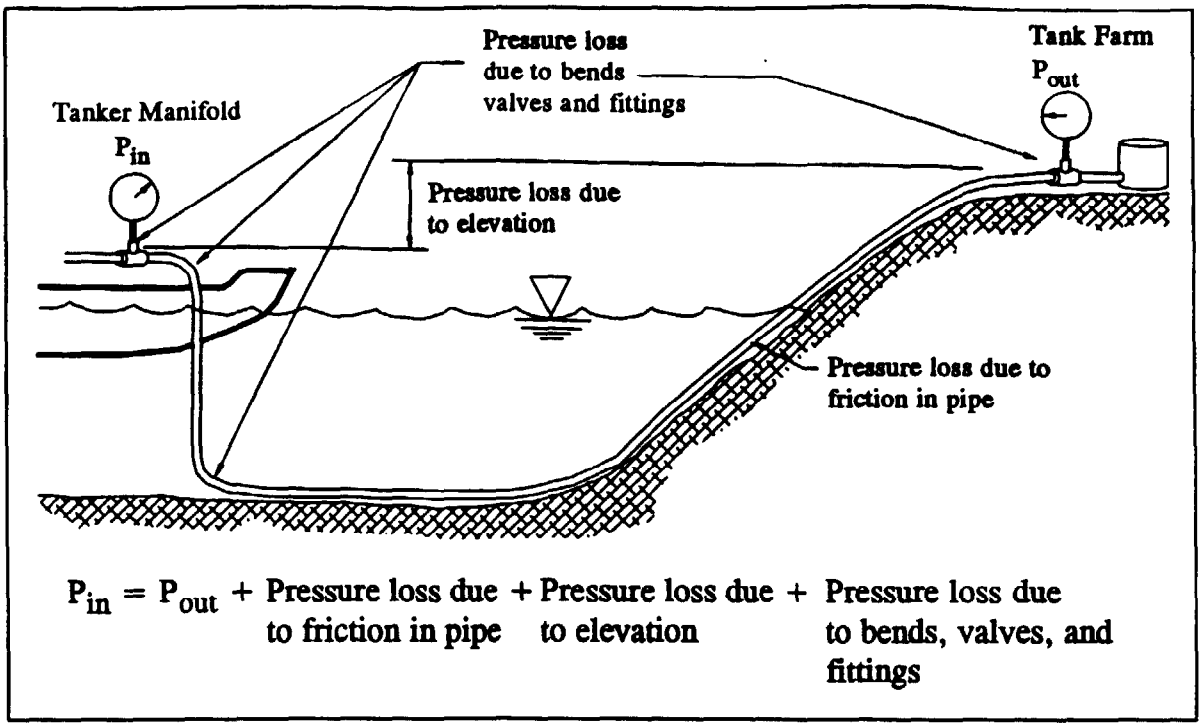



Figure 6-16. Pressure losses in a pipeline.

### 6.3.4 Hydrodynamic Stability

A submarine pipeline is subjected to hydrodynamic forces imposed by currents (steady state or tidal driven) and waves. Wave forces, in particular, can impose substantial loads on a pipeline even at depths of 30 feet or more below the sea surface. Hydrodynamic forces acting on a pipeline are depicted in Figure 6-17.

Determination of the required pipeline submerged weight to prevent movement of the pipeline is achieved by balancing the horizontal and vertical forces imposed on the pipeline. Computer programs are available from both Government and commercial sources to assist in this analysis.

### 6.3.5 Route Selection

Every pipeline installation should begin with a survey of the pipeline route (see Section 4.1). Particular emphasis during both the presurvey and the route selection survey should be placed on identifying manmade and natural hazards along the pipeline route. A final route selection is made after the site investigation and route survey is complete.

Pipeline route selection is a tradeoff between hazard avoidance and installation cost. The first priority in selecting a pipeline route is ensuring the safety of the pipeline. This is accomplished by selecting a route that avoids stationary hazards (e.g., anchorage areas, areas prone to mudslides, suspended spans over faults or rock outcrops, etc.).

Additional protection against movable hazards (e.g., bottom dragging fishing gear, small craft anchors, etc.) is provided to the pipeline by trenching, burial, or providing a riprap cover over the pipeline. Protection against wave and current forces is provided by routing the pipeline perpendicular to the bottom contours and providing additional stabilization (e.g., mechanical anchors, concrete weights, burial, etc.) in areas of high hydrodynamic forces.

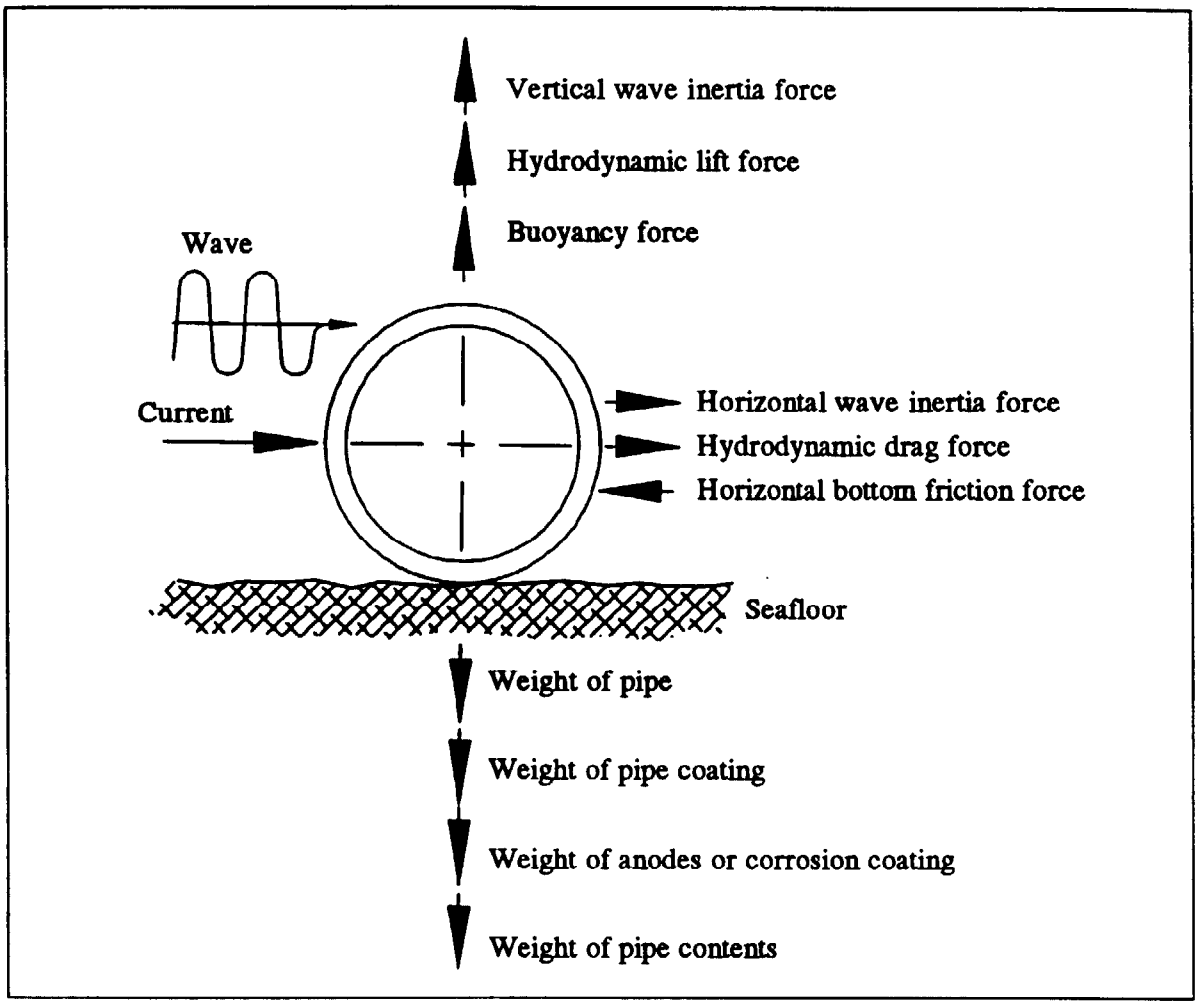



Figure 6-17. Typical forces on a submarine pipeline.

After the risk of pipeline damage has been minimized by obstacle avoidance and cover techniques, route selection then becomes an exercise in finding the least cost (generally, the shortest) distance between the upstream and downstream ends of the pipeline. Whenever possible, shore crossings should be selected that are easily accessible and possess a uniform, gently sloping bottom profile.

### 6.3.6 Installation Methods and Equipment

Submarine pipelines may be installed using a variety of procedures and equipment spreads. Several different installation procedures are often used on a single project. It is quite common to employ one method for installation of the deep water portion of the pipeline and another for the shore crossing and nearshore area. Selection of the installation procedure(s) is determined on a case-by-case basis and is influenced by mission requirements, local site conditions, and the availability of equipment, personnel, and funding resources.

The major methods of submarine pipeline installation are summarized in the following sections and illustrated in Figure 6-18.

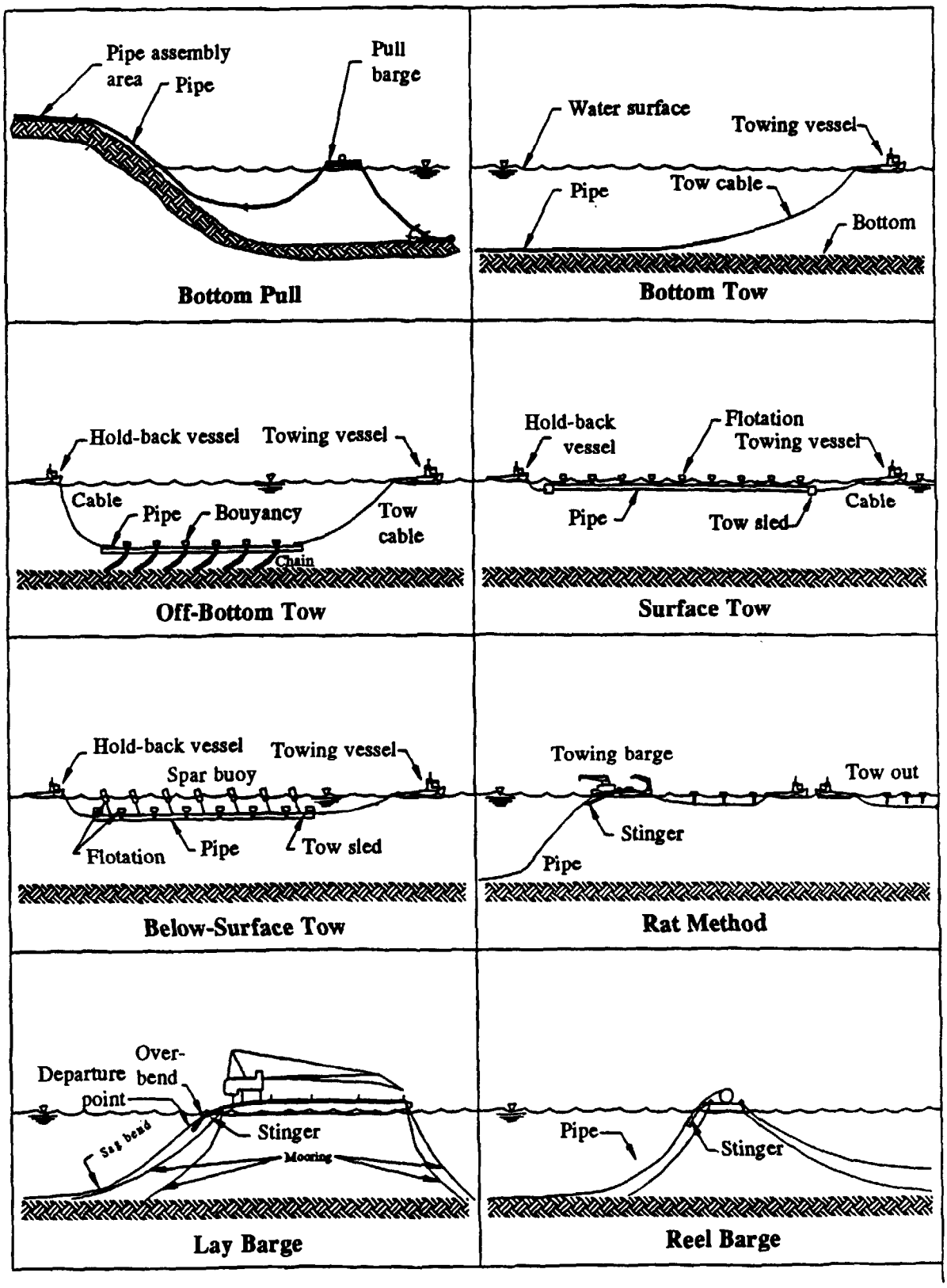



Figure 6-18
Submarine pipeline installation procedures.

**6.3.6.1 Bottom Pull.** The bottom pull installation is ideally suited for the installation of short (10,000 feet or less), small diameter pipelines for ship-to-shore fuel transfer operations. In a bottom pull installation, the pipe is preassembled into short sections (100- to 1,000-foot lengths) at a launch site located adjacent to the shore crossing. A pulling barge is moored offshore of the launch site and along the centerline of the pipeline route. The pulling barge is equipped with a mooring system and a pulling winch. Using its pulling winch, the barge pulls the pipe string offshore one section at a time. A pull-head is attached to the offshore end of the pipeline which seals the offshore end of the pipeline and provides an attachment point for the pull cable. As each section is pulled offshore, a new section is added to the pipeline onshore. The pull barge advances along the pipeline route by pulling on its bow winches while simultaneously paying out on the pipe-pulling winch as the water depth increases. When the pull barge reaches the position of its bow anchors, the anchors are retrieved and repositioned ahead of the barge to begin the pulling cycle again. A separate vessel is used to move anchors.

The bottom pull installation procedure was the method selected for the installation of the now discontinued U.S. Navy Bottom Laid Pipeline Subsystem (BLPS). As utilized in this system, a Side Loadable Warping Tug (SLWT) was employed for the installation vessel. The pipeline was constructed using sections of commercial well casing (steel pipe with threaded ends; both ends joined inside threaded a couplings). Powered pipe tongs were employed to assemble the pipe sections.

If project resources permit, the efficiency of the bottom pull method can be increased by the utilization of a longer pulling cable and high-capacity linear cable pullers. These modifications are quite common for the installation of river crossings by the bottom pull method.

**6.3.6.2 Bottom Tow.** The bottom tow installation method is a variation of the bottom pull method. For tactical pipelines, it is suitable when the pipeline assembly site cannot be located adjacent to the shore crossing. In a bottom tow installation, the pipeline is assembled (in sections) on land. It is then pulled offshore by the tow vessel one section at a time, until the entire pipeline is assembled. The pipeline is then towed to the designated location. For a ship-to-shore POL pipeline, the tow cable is transferred to a pulling winch located at the shore crossing and the pipeline is pulled ashore at the beach crossing.

With the bottom tow method, the pipeline is installed air-filled to reduce the towing forces. If the tow route extends into deep water, the pipeline may also be pressurized (generally with an inert gas) to prevent pipeline buckling or collapse due to hydrostatic pressure.

The bottom tow method can also be employed for longer pipelines (much greater than 10,000 feet) by outfitting each pipe section with alignment sleds and mechanical connectors at the ends of the pipe strings. Each pipe section is then pulled into position and connected with the previously installed section (see Figure 6-19).

Installation of a long distance pipeline by sectional bottom tow is illustrated in Figure 6-19. In this illustration, pipe strings are launched from the mainland assembly site and towed along the pipe route to an offshore island. The first pipe string is pulled ashore upon reaching the island. The second string is then launched and towed into position behind the first string. After arriving at the offshore island, the tow line would then be disconnected from the second string. A diver would then connect a

cable to the second string which would be routed through a receiver sled (installed at the trailing end of the first string) and then up to a surface barge moored above the receiver sled. A deck winch on the barge would be used to pull the leading end of the second string into the receiver sled (Figure 6-20). Mechanical connections are used to join the two pipe strings. The process would be repeated until the entire line is complete.

**6.3.6.3 Off-Bottom Tow.** The off-bottom tow is a variation of the bottom tow procedure. In the off-bottom tow, the pipeline is equipped with drag chains and buoyancy tanks which suspend the pipeline a few feet above the seafloor.

The off-bottom tow is ideally suited for the installation of prepositioned rapidly deployable ship-to-shore POL or potable water pipelines 10,000 to 20,000 feet in length. The advantages of the off-bottom tow method of installation in such an application are:

- Rapidly deployable. A preassembled, pretested pipeline can be operational within 12 hours after the tow vessel arrives on site.

- Minimal land-based equipment and site preparation requirements at the shore crossing.

- Smaller tow forces due to the lack of pipeline contact with the seafloor.

- Smaller pipeline stresses induced by changes in the seabed topography.

- Minimal risk of damage to the pipeline and corrosion coatings due to bottom abrasion.

In a bottom or off-bottom tow, the design of the pull-head is determined on a case-by-case basis. For a shallow-water, small diameter pipeline where the offshore tie-in can be easily accomplished by divers, a simple pull-head arrangement such as that employed in the BLPS (see Figure 6-21) is sufficient. In this case, the pull-head serves only as a bolt-on attachment point for the cable and a simple "padeye" type design is employed.

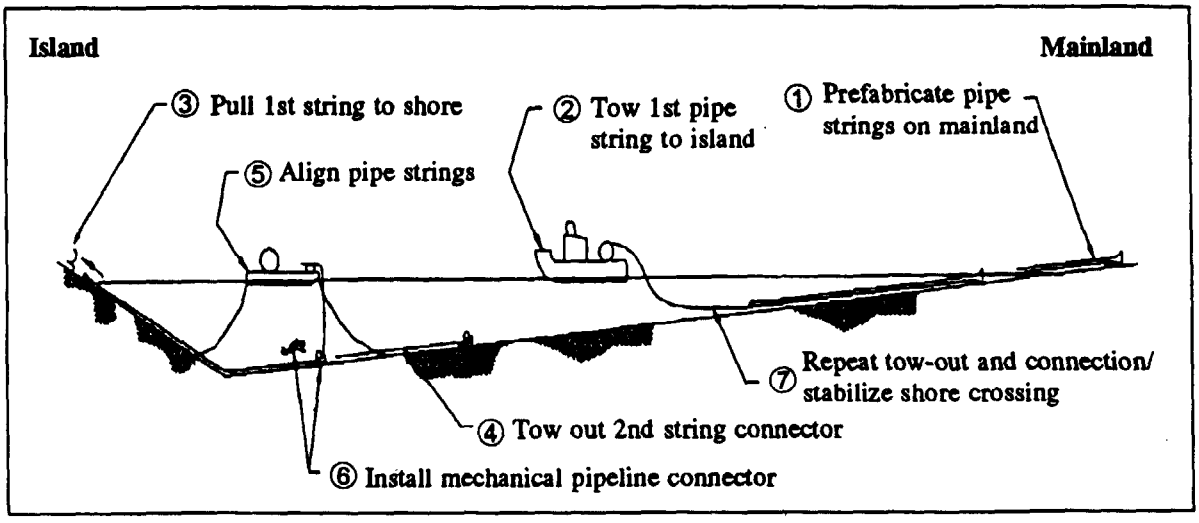



Figure 6-19
Bottom tow installation procedure for long distance pipelines.

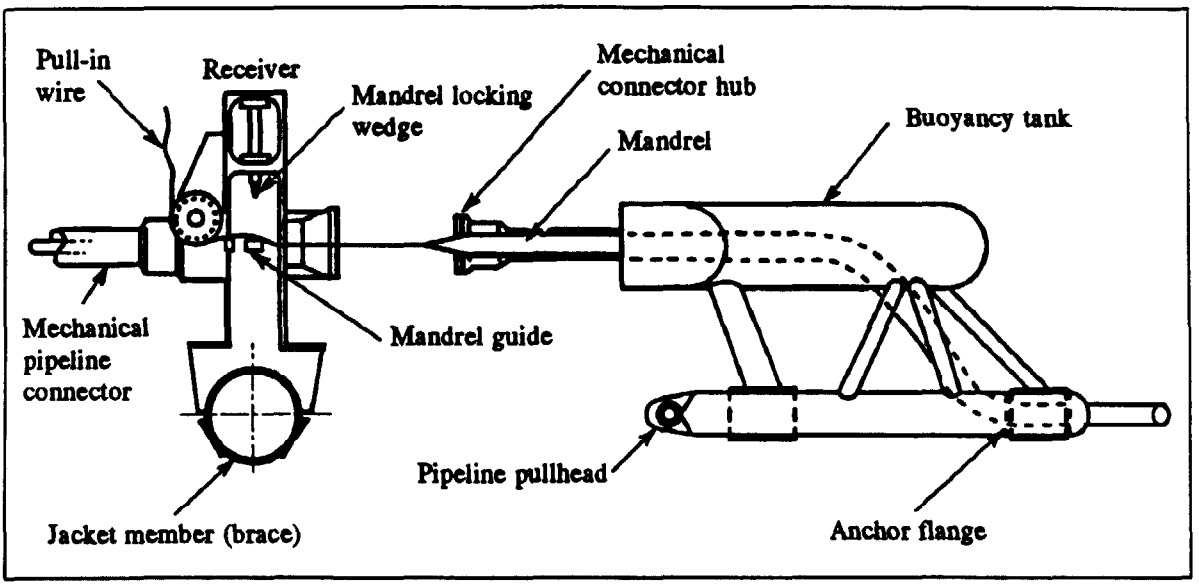



Figure 6-20
Integrated pullhead and pipeline receiver design.

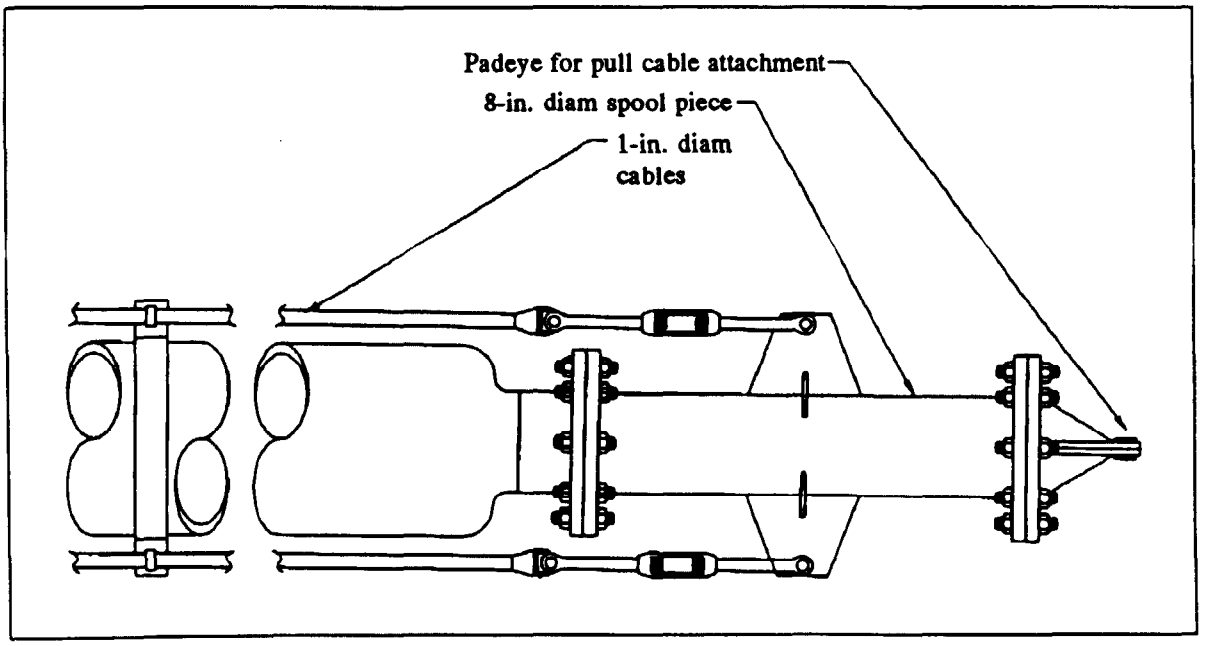



Figure 6-21
BLPS pull-head bottom-laid pipeline.

In deep water, or for longer pipelines, one or both ends of the pipeline will require some form of structure to facilitate subsea tie-ins. In these situations, the pullhead and receiver structure designs are integrated (see Figure 6-20). As tie-in structures can become quite heavy, buoyancy tanks are often used to offset the weight of the tie-in structure. The buoyancy tanks also serve to elevate the leading end of the pipeline above the seafloor. This serves to protect the pipeline against damage during the tow-out due to isolated bottom features or abrupt changes in bottom contour. After the pipe has been pulled into position, the buoyancy tank is flooded. This increases the submerged weight of the receiver sled which is necessary to reduce the pull-in forces during the tie-in operation.

**6.3.6.4 Surface Tow.** The surface tow is suitable for installations where the makeup site cannot be situated at the shore crossing and bottom obstructions preclude a bottom or off-bottom tow. In the surface tow method, pontoons are used to float the pipeline on the surface of the water. During the tow, a hold-back vessel is positioned at the trailing end of the pipeline. The hold-back vessel exerts a tension on the pipeline that serves to limit installation stress and is used to control the position of the tailing end of the pipeline.

A disadvantage of the surface tow procedure is the risk of pipeline damage during the tow-out due to surface wave action.

**6.3.6.5 Below-Surface Tow.** The below-surface tow is a variation of the surface tow and is used when severe seas are expected (or could occur) along the tow route. Like the surface tow, it is suitable where the makeup site cannot be situated at the shore crossing and bottom obstructions preclude a bottom or off-bottom tow. Unlike the surface tow where the pipe floats are attached directly to the pipeline, in a mid-depth tow a pennant is used to secure the float to the pipe, thereby suspending the pipeline below the water surface and protecting the pipeline from wave action.

As with the surface tow, a hold-back vessel is used to limit installation stresses and control the tailing end of the pipeline.

Both the surface tow and the below-surface tow require careful planning and detailed towing procedures to ensure a successful operation.

**6.3.6.6 Reel Boat.** The first pipeline laid from a reel was completed as part of Operation PLUTO (Pipe Line Under the Ocean) during World War II. Fuel lines were laid across the English Channel to supply Allied Forces after the Normandy invasion. Several 3-inch-diameter lines were wrapped onto large floating spools in 25-mile lengths and towed by tugs from an English staging port to the Normandy Coast (Kunzi and Uyeda, 1979).

Reel boats operated by marine contractors range up to 600 feet in length and are capable of installing pipelines up to 16 inches in diameter in water depths up to 1,000 feet. For tactical pipelines with relatively small vessels of opportunity, the reel boat method is suitable for installation of small diameter lines only (approximately 4 inches or less) in water depths of 120 feet or less. Equipment requirements for pipeline above this size preclude installation from Navy vessels. Nonetheless, the reel boat method is a cost effective, simple, and reliable installation.

An overview of the reel boat method is illustrated in Figure 6-22. In this method, prefabricated coils of small diameter pipe are reeled off the installation vessel. Each reel could contain up to 2,500 feet of 3-inch pipe. Stress in the pipeline is controlled

by a slight hold-back tension applied at the pipe reel. When each reel of pipe has been deployed, the end of the pipe is sealed, and the pipe is lowered to the seafloor and marked with a buoy. The reel boat then returns to port and exchanges the empty pipe reel for a full one.

When the reel boat returns, it recovers the end of the previous pipe string and connects the end of the new pipe reel using a flange connection. The process is then repeated until the second end (i.e., island end) tie-in is performed. At the island end, a short length (600 feet) of pipe is floated out to the reel boat. The connection between the last two sections is made at the reel boat. A shore winch then applies a slight tension to the floating pipe string while a diver removes the pipe floats to gradually lower the pipe to the seafloor.

The four point mooring spread is required for the installation vessel during the pipe recovery, tie-in, and abandonment operations. During laying operations, only propellers or thrusters are required for positioning. Stern winch(es) may be employed for additional pull forces if a simultaneous lay/bury operation is used as shown in Figure 6-22.

For a small vessel working 8 hr/day, a production rate of 2,500 ft/day should be easily attainable. Depending on the size of locally available vessels, higher production rates could be attained if several reels could be deployed in sequence from the reel boat.

A typical deck layout for a reel boat installation method is shown in Figure 6-23. The installation equipment has been laid out on the deck plan of a Side Loadable Warping Tug (SLWT) mated to a Non-Powered Causeway Section (CSNP). These are roughly 90- by 22- by 5-foot platforms and serve to illustrate the minimal space requirements for this installation procedure. It is possible to outfit commercial flat-top barges, spud barges, or oil field supply boats with similar layouts.

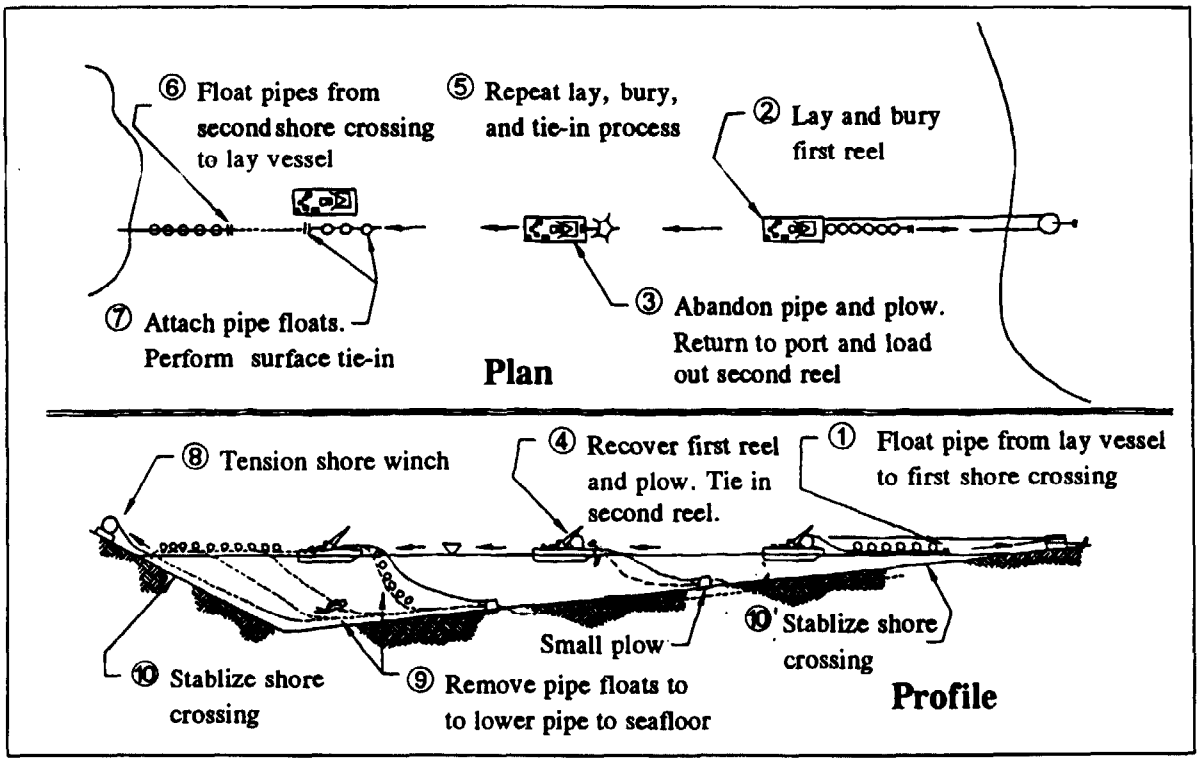



Figure 6-22. Reel boat installation procedure.

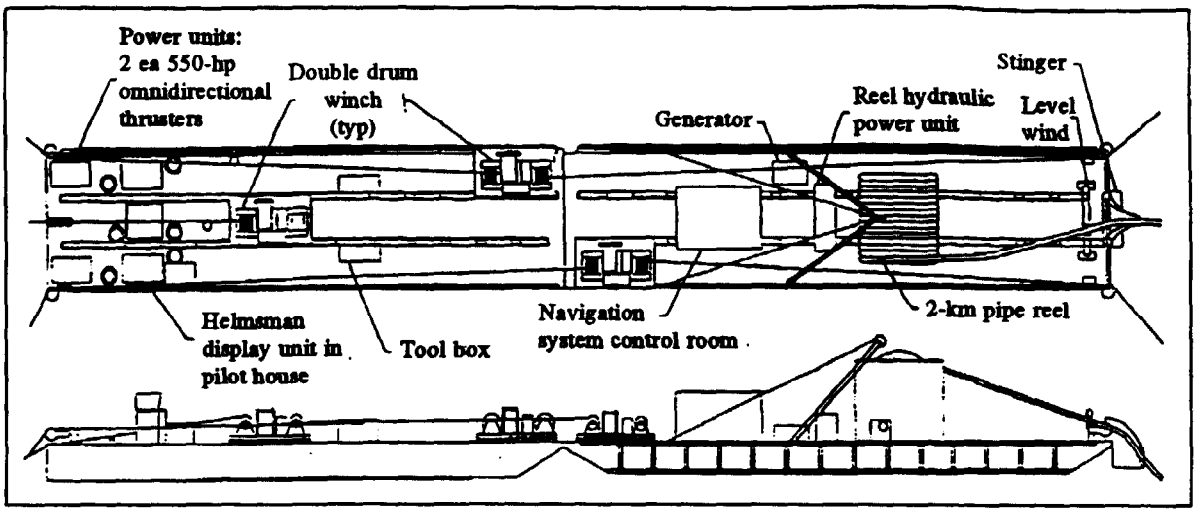



Figure 6-23. Reel boat - typical deck layout.

**6.3.6.7 Lay Barge.** The lay barge procedure is the predominant installation method employed for installation of long distance oil and gas pipelines in deep water. In a lay barge installation, the pipe string is fabricated by joining individual pipe sections on the deck of the lay barge. A curved ramp or "stinger" is used to limit bending stresses throughout the overbend region of the pipe. Bending stresses in the sagbend region (at seafloor) are controlled by a pipe tensioner aboard the lay barge. The tensioner grips the pipe and applies a constant tension to the pipe by pulling against the bow mooring lines.

The lay barge advances along the pipeline route by pulling itself forward on its bow anchors and simultaneously paying out on its stern anchors. During the move-up operation, the pipe is paid out under tension by using the bow winches to overhaul the pipe tensioner. An attendant fleet of anchor handling boats, supply boats, and/or material barges complete the installation spread.

For small diameter pipelines, Navy SLWTs/CSNP/CSP or local vessels can be outfitted to serve as lay barge and support vessels, assuming a fair weather operation.

In a traditional commercial oil and gas submarine pipeline, steel line pipe is employed for the pipeline and joints are welded, coated, and inspected on board the lay barge. For Navy POL pipelines, well casing with threaded connections can be employed. Hydrostatic tests should be performed on each joint after assembly before advancing the barge. The hydrostatic test can be performed by inserting a small diameter pipe with inflatable packers into the last joint on the lay barge. The packers would be inflated to seal the pipe at the joint. Water would then be pumped through the 30-mm pipe to perform a hydrostatic test on each joint as it is added to the pipe string.

**6.3.6.8 RAT Method.** This method was developed by French commercial contractors. The abbreviation RAT stands for: Remourquage (towing), Arboutage (tie-in), and Tension. In this method, long pipe strings are preassembled on land and surface towed to location. A surface tie-in is then performed at an installation vessel which is moored over the previously installed pipe section. The surface vessel is then used to tension the pipeline and lower it to the seafloor.

Although this method is seldom employed in practice, it is suitable for a calm water site and is capable of a high production rate.

**6.3.6.9 Directional Drilling.** Directional drilling for most pipeline installations is a low production, equipment intensive, and highly specialized operation which is generally employed only when unique site conditions are encountered (e.g., for a river crossing of a busy navigated channel). However, for small diameter pipelines (3 inches or less) directional drilling is not unduly equipment intensive and may be suitable for unfavorable site conditions at shore crossing locations (e.g., rock cliff adjacent to shoreline, potential for ice scour, wildlife preserve where shore crossings are prohibited, etc.).

In a directionally-drilled installation, the drill is located behind the shore crossing and a pilot hole is slant-drilled under the river or shore crossing. After the directional bit "daylights," the directional drill bit is then removed and a larger diameter reamer bit is installed. A pipe string is then attached to the reamer bit using a swivel connector. The reamer bit diameter is usually 120 to 150 percent larger than the diameter of the pipe string. The drill string (with reamer bit attached) is then rotated and slowly pulled backward through the pilot hole. As the drill string is withdrawn, the reamer bit expands the diameter of the pilot hole and pulls the pipe string through the shaft. Drilling muds may be pumped through the drill string to lubricate and support the shaft during the pipe pulling operation. If the soil conditions are such that drilling mud will not keep the hole open, a casing is installed from the shore end.

In the case of a river crossing, the pipe string is prefabricated and located on the opposite bank from the directional drill. For a directionally-drilled shore crossing, the pipe string is staged offshore (e.g., reel barge, bottom pull, etc.) and fed into the drilled shaft from the offshore end (Figure 6-24).

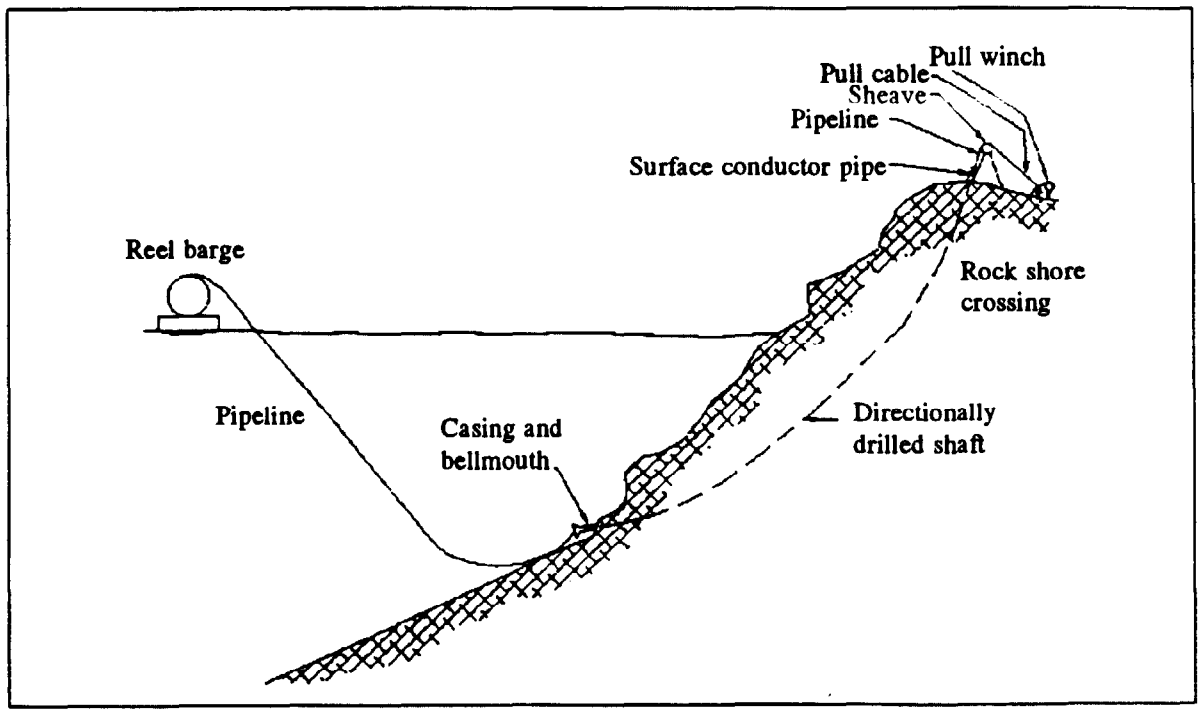



Figure 6-24. Directionally drilled pipeline installation.

Sophisticated guidance systems for directional drilling applications are commonly employed in oil and gas operations. However, less sophisticated equipment is typically employed for small diameter (2- to 4-inch range) pipelines. Irrespective of the sophistication of the guidance system, this procedure requires considerable experience and skill on the part of the drilling crew to maintain the curvature of the drill string along its intended path and to prevent the pipe from becomming locked in the hole.

### 6.3.7 Material Selection

Submarine pipelines may be constructed using a wide variety of materials. Materials commonly used include:

- Steel
- Cast Iron
- Polyvinyl Chloride (PVC)
- High Density Polyethylene (HDP)
- Fiberglass
- Flexible Pipe
- Hose
- Concrete

The selection of any particular material depends on the product type, installation procedure, pipeline operational environment, and maintenance requirements. Material selection criteria for common pipeline materials are summarized in Table 6-2. Additional comments pertinent to specific pipeline materials are provided below. A comparison of pipeline materials for various installation procedures is reprinted as Tables 6-3 through 6-6.

**6.3.7.1 Steel Pipe.** Steel is the predominant material used in the construction of submarine pipelines in the oil and gas industry and accounts for 99 percent of all submarine pipeline mileage installed throughout the world. The many uses to which steel pipe is applied has lead to a wide variety of product classifications. The major steel pipe products used for submarine pipelines are generally produced to API (American Petroleum Institute) specifications and include:

- ***Line Pipe*** - Line pipe is used for the long distance transportation of oil, gas, or water. Most line pipe uses welded joints and is ordered with beveled ends to facilitate a welding. However, line pipe can also be ordered with threaded or flanged ends. It is generally ordered in double random lengths (approximately 40 feet), but is also available in lengths of 10 and 20 feet.

- ***Coiled Tubing*** - Coiled tubing is a continuous length, thin wall, small diameter pipe which was introduced in the late 1960s. Although originally used to service subsea wellheads, it is increasingly being employed for gathering lines in small shallow water oil fields due to its suitability for a low cost reel barge installation. Coiled tubing is produced in diameters ranging from 1 to 3 inches.

- ***Casing and Tubing*** - These are tubular products made specifically for oil, gas, and water wells. Tubing products are employed for the drill string, while casing products are used to line the well. They are furnished with threaded ends and couplings which facilitates rapid joining in the field. Because a welded joint is not employed, casing and tubing products can also be furnished with a polyethylene liner to prevent corrosion or ensure product quality.

Table 6-2. Comparison of Candidate Pipeline Materials

| Material | E (psi) | fy (psi) | p (lb/ft) | Cost[1] ($/lb) | Pressure (psi) | Max Suitable Products[2] | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|
| Steel Pipe: Line pipe (flanged and plain end) | $30x10^6$ | 30 - 60K | 490 | 1.80 | High | All | Highest strength pipe material. Readily available; wide variety of internal and external coating. Most reliable joint techniques. | Corrosion coating or anodes generally required. Internal lining may also be required. Welded joints require high QC/$$ in the field. |
| Coiled Tubing | $30x10^6$ | 30 - 80K | 490 | 1.60 | High | All | See line pipe comments. Excellent for reel boat installation. | See line pipe comments. Residual stress may remain in pipe. |
| Tubing and Casing | $30x10^6$ | 30-80K | 490 | 1.70 | High | All | See line pipe comments. Easily assembled joints. | See line pipe comments. Joints require moderate QC to avoid leaks. |
| Ductile (Cast) Iron | $24x10^6$ | 30-60K | 449 | 1.80 | 250 | PW, NPW | Good strength. Better corrosion resistance than steel. | Brittle; subj to damage due to thermal stress. Subj to attack from acid and alkali soils. |
| Polyvinyl Chloride (PVC) | 400,000 | 4,000 | 89 | 0.70 | 200 | NPW Chem | Excellent corrosion resistance. Lightweight, low cost. | Subj to deterioration in sunlight, fuel, or fuel saturated soil. Strength decrease above 70°F. Requires anchoring underwater. |
| High Density Polyethylene (HDP) | 130,000 | 3,200 | 60 | 0.6 | 200 | PW, NPW Chem | Excellent corrosion resistance. Lightweight, low cost, flexible. | Subj to deterioration from fuel or fuel saturated soil. Requiress anchoring underwater. |
| Fiberglass Longitudinal | $3.0x10^6$ | 35,000 | 113 | 1.55 | 250 | NPW | Lightweight, good strength. | Brittle material, subject to impact and abrasion damage. |
| Flexible pipe | N/A | 12,000 | 156 | 5.00 | High | All | Excellent flexibility and strength. Reliable joint techniques. | Most expensive pipe material, long lead time, custom fabrication process. |
| Collapsible hose | --- | 2,000 | 62 | 1.70 | 150 | PW. NPW, F. Chem | Excellent flexibility, easily installed. | Low design life, low strength, easily damaged, requires anchoring underwater. |
| Reinforced Concrete | $1.4x10^3$ to $5.2x10^3$ | 3-5K comp 300-500 tens. | 145 | 0.10 | 1503 | PW, NPW, Chem | Economical, durable, low maintenance. Excellent material for large diam (36 in. and above), low pressure applications. | Bell and spigot joint has little flexibility, susceptible to leaks, susceptible to sulphate attack and attack by some tropical water crustaceans, may require anchoring underwater. |
| Prestressed Concrete | $1.4x10^3$ to $5.2x10^3$ | 3-5K comp 300-500 tens. | 145 | 0.15 | 1503 | PW, NPW Chem | See reinforced concrete comments. Prestressed construction allows fabrication of larger, longer pipe sections. | See reinforced concrete comments. Post tensioning strands subject to corrosion. |

1. Material prices are indicated of relative price rankings for materials delievere FOB factory excluding any internal and external coating. 2. Product type codes: PW = Potable Water; NPW = Non-Potable Water; F = Fuels; Chem = Good, but limited chemical resistance (consult NFESC for suitability of individual chemical product).
3. Generally 50 psi or less in practice.

Table 6-3. Suitability of Pipeline Materials for Various Installation Methods

| Installation Method | Pipeline Material | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Steel | Cast Iron | Polyvinyl Chloride (PVC) | High Density Polyethylene (HDPE) | Fiberglass | Flexible Pipe | Collapsible Hose | Concrete |
| Bottom Pull | X | X | X | X | X | X | C | C |
| Bottom Tow | X | X | X | X | X | X | C | --- |
| Off-Bottom Tow | X | X | C | C | C | X | C | --- |
| Surface Tow | X | X | C | C | C | X | C | --- |
| Below Surface-Tow | X | --- | C | C | C | X | C | --- |
| Reel Boat | X | --- | C | C | --- | X | C | C |
| Lay Barge | X | X | C | C | C | X | C | --- |
| RAT | X | X | C | C | C | X | C | --- |
| Directional Drilling | X | --- | --- | --- | --- | --- | --- | --- |

Note:
"X" indicates that the pipe material is suitable for use with the listed method.
"C" indicates that extreme care must be exercised in using this combination of pipe material and installation method.

Table 6-4. Coated Steel Pipe Installations

| Item | Installation Method | | | | | |
|---|---|---|---|---|---|---|
| | Bottom Pull/Tow Methods | Reel Method | RAT Method | Directional Drilling | Tow Methods | Lay Barge |
| Special Skills | Pipeline welders<br>Experienced crews<br>Reel operator | Pipeline welders<br>Experienced crews | Pipeline welders<br>Experienced crews<br>Drilling operator | Pipeline welders<br>Experienced crews<br>Divers | Pipeline welders<br>Experienced crews<br>Divers | Pipeline welders<br>Experienced crews |
| Special Equipment | Winches<br>Launchway<br>Pull barge<br>Buoys<br>Tugboat | Barge<br>Tugboat<br>Reel system | Barge<br>Tugboat<br>Buoy system | Drilling machine<br>Drilling fluid | Pipe line-up system<br>Tugboat<br>Buoys | Lay barge<br>Anchor tug<br>Supply barge<br>Tugboat |
| Limiting Site Conditions | Near vertical shoreline<br>Onshore space available | Maximum seas, 6 feet<br>Water depth greater than 20 feet (reel barge draft) | Maximum seas, 2 feet | Maximum seas, 2 feet<br>Water depth greater than 30 feet | Maximum seas, 4 feet | Maximum seas, 6 feet<br>Water depth greater than 20 feet (barge draft) |
| Pipe Diameter Limits (in.) | 4 - 26 | 4 - 12 | 4- 24 | 4 - 24 | 4 - 24 | 4 - 24 |
| Offsite Logistic Support | --- | Pipe delivery<br>Fabrication yard | Fabrication yard | --- | Fabrication yard | Pipe delivery<br>Catering |
| Operational Life | Moderate | Moderate | Moderate | Moderate | Moderate | Moderate |
| Prediction Risk | Low | Low | Moderate | Low | Moderate | Low |

Table 6-5. Flexible Pipe Installations

| Item | Installation Method | | | | | |
|---|---|---|---|---|---|---|
| | Bottom Pull/Tow Methods | Reel Method | RAT Method | Directional Drilling | Tow Methods | Lay Barge |
| Special Skills | Experienced crews | Experienced crews Reel operator | Not applicable for this pipe material | Not applicable for this pipe material | Not applicable for this pipe material | Not applicable for this pipe |
| Special Equipment | Winches Launchway Pull barge Buoys Tugboat | Barge | N/A | N/A | N/A | N/A |
| Limiting Site Conditions | Near vertical shoreline No onshore space | Maximum seas, seas, 6 feet Shallow water less than 20 feet (reel barge draft) | N/A | N/A | N/A | N/A |
| Pipe Diameter Limits (in.) | 4 - 12 | 4 - 12 | --- | --- | --- | --- |
| Offsite Logistic Support | --- | Pipe delivery Fabrication yard | --- | --- | --- | --- |
| Operational Life | High | High | N/A | N/A | N/A | N/A |
| Prediction Risk | Low | Low | --- | --- | --- | --- |

Table 6-6. Plastic Pipe Installations

| Item | Installation Method | | | | | |
|---|---|---|---|---|---|---|
| | Bottom Pull/Tow Methods | Reel Method | RAT Method | Directional Drilling | Tow Methods | Lay Barge |
| Special Skills | Butt fusion machine operator (HDPE) Experienced crews | Butt fusion machine operator (HDPE) Experienced crews Reel operator | Experienced crews | Not applicable for this pipe material | Experienced crews Divers | Not practical for this pipe material |
| Special Equipment | Fusion machine (HDPE) Winches Launchway Pull barge Buoys Tugboat | Fusion machine (HDPE) Reel system Tugboat Barge | Barge Tugboat Buoy system | --- | Line-up system Buoys Tugboat | --- |
| Limiting Site Conditions | Near vertical shoreline No onshore space | Maximum seas, 6 feet Shallow water less than 20 feet (reel barge draft) | Maximum seas, 2 feet | N/A | Maximum seas, 4 feet | Not practical for this pipe material |
| Pipe Diameter Limits (in.) | 4 - 24 | 4 - 12 (HDPE only) | 4- 12 | --- | 4 - 24 | – |
| Offsite Logistic Support | --- | Pipe delivery Fabrication yard | Pipe delivery Fabrication yard | --- | Pipe delivery Fabrication yard | --- |
| Operational Life | Moderate | Moderate | Moderate | N/A | Moderate | Not practical for this pipe material |
| PredictionRisk | Low | Low | High | --- | Moderate | --- |

**6.3.7.2 Cast Iron Pipe.** Cast iron (or ductile iron) pipe is suitable for low pressure water transmission lines. Cast iron pipe contains low carbon and high silicon contents which give this material superior corrosion resistance. However, cast iron is a brittle material which is subject to failure from thermal strains or impact damage. It is normally supplied with bell and spigot type joints which can deflect up to 15 degrees for submarine pipeline installations. It is also available with flange ends. It is generally ordered in lengths of 12 or 18 feet.

**6.3.7.3 Polyvinyl Chloride (PVC).** Polyvinyl chloride pipes provide excellent corrosion resistance and are suitable for the transmission of water and chemical products. PVC pipe can be furnished in continuous lengths for small diameter applications (3 to 4 inches in diameter). Larger diameters are furnished with plain end, flanged end, or mechanical couplings. It is normally furnished in 20-foot lengths when ordered as individual sections. Plain end pipe sections are joined in the field using solvent weld pipe couplings.

**6.3.7.4 High Density Polyethylene (HDP).** High density polyethylene pipe provides excellent corrosion resistance and is suitable for the transmission of water, gas, and chemical products. Polyethylene (PE) pipe can be obtained in continuous lengths (3 to 4 inches in diameter), plain end, flanged end, or mechanical couplings. It is normally furnished in 20- or 40-foot lengths when ordered as individual sections. Plain end pipe sections must be joined in the field using a carefully controlled heat fusion process.

A unique property of PE pipe is that it will attempt to regain its original shape after deformation. Repairs to low pressure transmission line are accomplished by pinching the pipeline to stop the flow while repairs are made. After the repair is complete, the pipe will return to its original shape with no permanent deformation. This property is also used to install PVC liners inside steel pipe products. The PE pipe is compressed and pulled through a steel pipe. After the pulling operation, the PE pipe expands to fill the annular space between the PVC and steel pipe walls.

**6.3.7.5 Fiberglass.** Fiberglass pipe is suitable for water or chemical products and is generally furnished in 20-foot lengths. Flanges and threaded couplings are standard joint types. Field welded joints are also possible using layers of fiberglass impregnated with resin.

While fiberglass is suitable for submarine pipelines, it is seldom employed in practice due to its relative price position. It is much more expensive than PVC or HDD and only slightly less expensive than steel. For a small increase in cost, most projects benefit from the superior strength and performance of steel pipelines.

The advantage of fiberglass is its high strength-to-weight ratio and resistance to chemical and corrosive attacks. It is most suitable in a submarine environment for large diameter pipelines where the ability to limit weight or installation stress is a controlling factor in the material selection process.

**6.3.7.6 Flexible Pipe.** Flexible pipe (see Section 5.3.4.5) is a special product manufactured by a select few manufacturers (e.g., Coflexip, Wellstream, and Simplex) to meet the specific requirements of each particular project. The pipe consists of concentric layers of spiral wound steel reinforcing and HDP extruded coating. The pipe is manufactured in a continuous length and gener-

ally furnished with an end fitting. Interior coatings can be provided to suit any product requirement.

**6.3.7.7 Collapsible Hose.** Collapsible hose is manufactured from neoprene or other rubber-type synthetics. It is most commonly used in military applications for temporary POL and water pipelines such as the Amphibious Assault Bulk Fuel System (AABFS).

**6.3.7.8 Oil Suction and Discharge Hose.** Oil suction and discharge hose is heavy-walled hose manufactured from reinforced rubber or rubber-type synthetics. The hose body is reinforced with high strength textiles and/or steel wire spirals. Oil suction and discharge hose for offshore applications is manufactured in accordance with the Oil Companies International Marine Forum (OCIMF), Hose Standards.

Oil suction and discharge hose is a specialty product manufactured by a few manufacturers (Dunlop, Bridgestone, Uniroyal, Yokohama, Pirelli, Kleber, and Hewitt). Hose sections are manufactured in standard lengths of 30 and 35 feet. It is commonly employed for floating and submarine hose strings at both Navy and commercial offshore oil tanker terminals.

**6.3.7.9 Concrete.** Concrete is traditionally employed for low pressure, shallow water, large diameter (greater than 36-inch) submarine pipelines, primarily for water intake and discharge lines. Concrete pipe sections are normally supplied in 16-foot lengths (up to 34 inches in diameter) or 16- and 32-foot lengths (greater than 34 inches in diameter). All concrete pipe sections use a bell and spigot-type joint.

**6.3.7.10 POL Pipelines.** Suitable materials for submarine pipelines carrying fuel or tanker ballast water include:

- Carbon steel piping material, ASTM A-53-93a, Grade B or API 5L-92, Grade B or superior grades. Pressure temperature rating for all piping valves and fittings shall conform to ANSI B31.3A-93 or B31.4-92 as appropriate. This includes:
  - line pipe
  - coiled tubing
  - tubing and casing
- Heavy duty oil and gas hose conforming to OCIMF, Hose Standards
- Flexible pipe conforming to API RP 17B-88

The collapsible hose system such as that used by the Military Sealift Command's prepositioned ships is considered a temporary system and should not be employed for permanent construction or when the life expectancy exceeds 30 days.

**6.3.7.11 Lined Pipe.** Pipeline materials may also be combined to produce a composite pipe construction. For example, thin-walled polyethylene liners may be pulled through steel well casing to construct a potable water pipeline. In this situation, the steel casing provides strength to withstand high installation and operational stress levels while the polyethylene liner ensures product quality and protects the pipeline against internal corrosion.

**6.3.7.12 Pipe Bundles.** If several pipelines are to be installed as part of the same facility (i.e., separate fuel offloading and ballast water pipelines at a tanker terminal), the individual pipelines may be bundled to allow a simultaneous installation. Figure 6-25 depicts a pipe bundle for

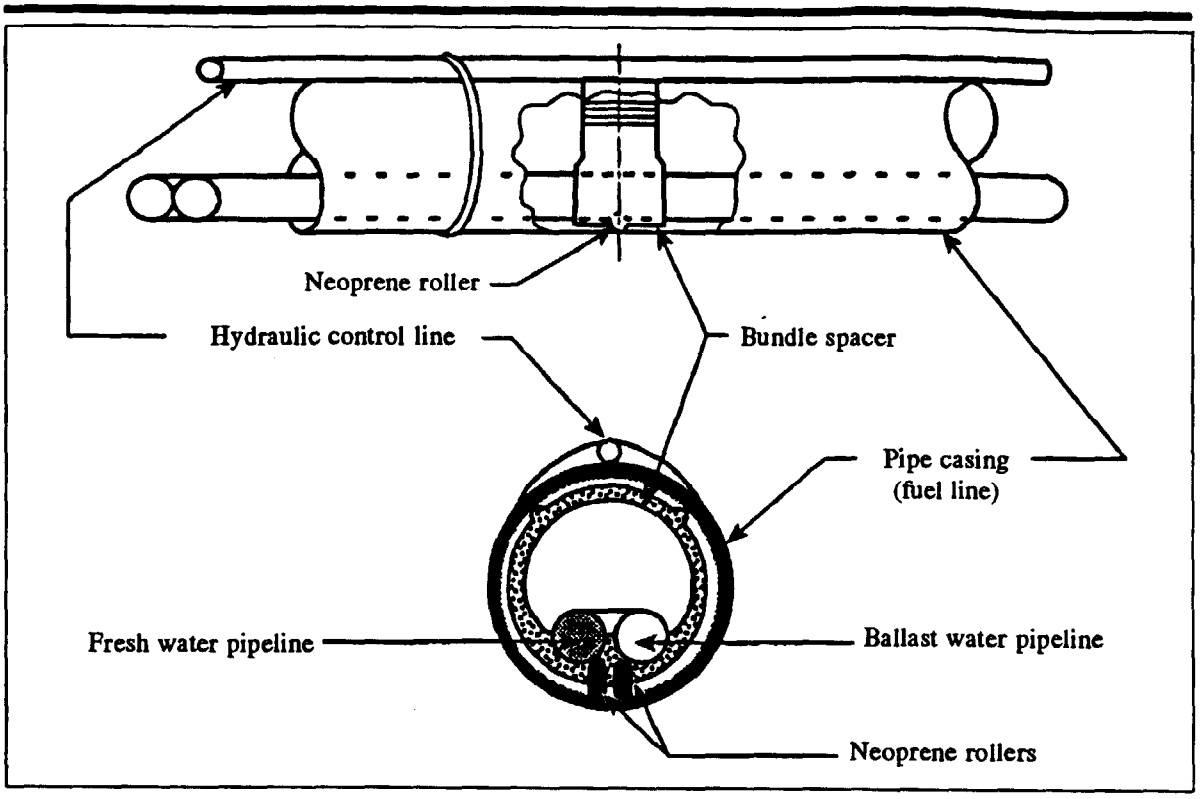



Figure 6-25. Pipe bundle.

a fuel offloading terminal which also includes a hydraulic control line.

### 6.3.8 Pipe Joint Types

The vast majority of submarine pipelines are commercial oil and gas lines and utilize welded steel joints. However, other joint types have also been employed for submarine pipelines. These include:

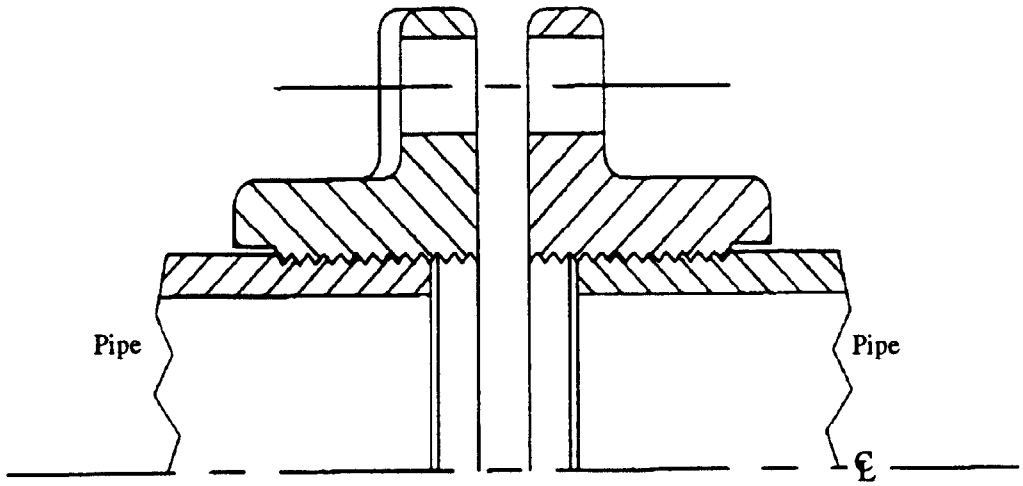
- Pipe flange
- Threaded coupling
- Rigid bell and spigot
- Flexible bell and spigot (ball and socket)

A comparison of common pipe joints for military applications was included in Pannell and Cevasco (1978) and is reprinted as Table 6-7. Illustrations of common mechanical joints employed for submarine pipelines are shown in Figure 6-26. Additional comments are provided below.

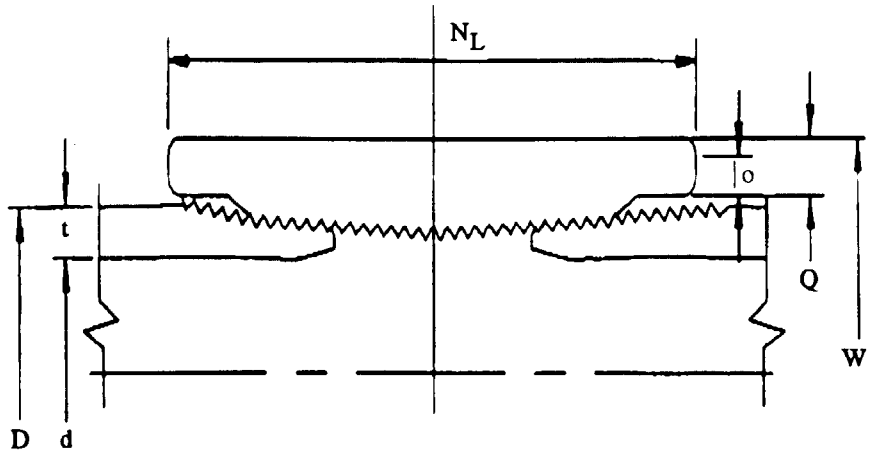
**6.3.8.1 Pipe Flange.** The flanged joint is a very reliable jointing technique but is seldom used for joining individual pipe sections due to (real or imagined) difficulties created by the protruding flanges. The flange projections have a tendency to "hang" on installation equipment and increase passive soil resistance for bottom pull techniques.

Flanged connections are commonly employed for tie-ins of long sections of pipe as well as connecting individual sections of heavy duty (OCIMF) oil and gas hose.

**6.3.8.2 Threaded Coupling.** The threaded coupling is a reliable jointing technique which is ideally suited to military applications. It is rapidly assembled and requires minimal personnel training. However, a

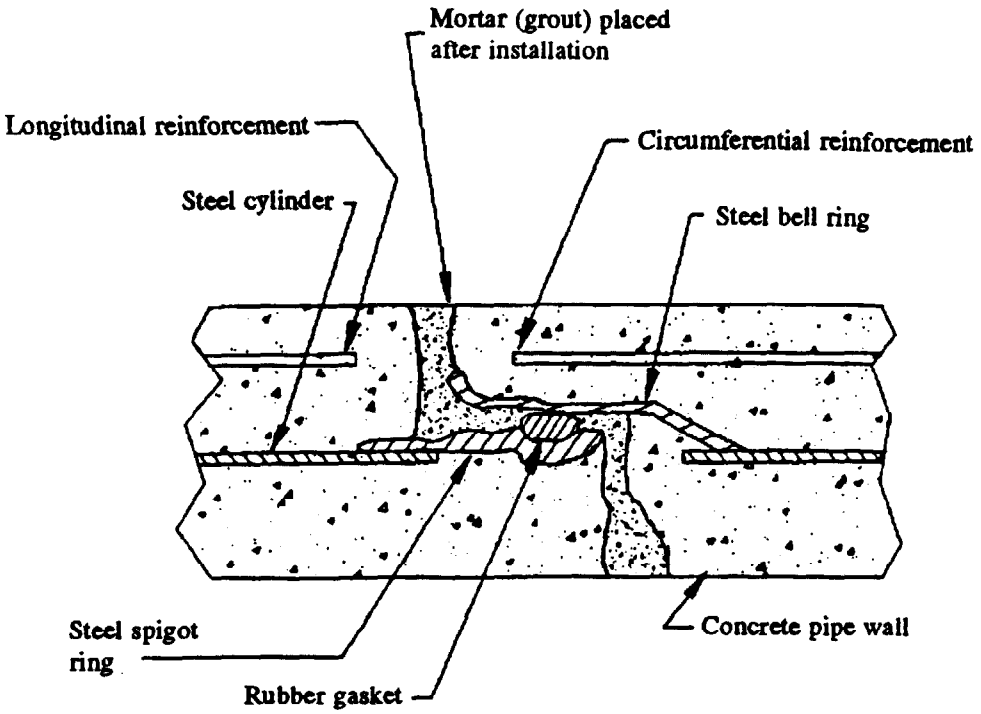



**Pipe Flange**

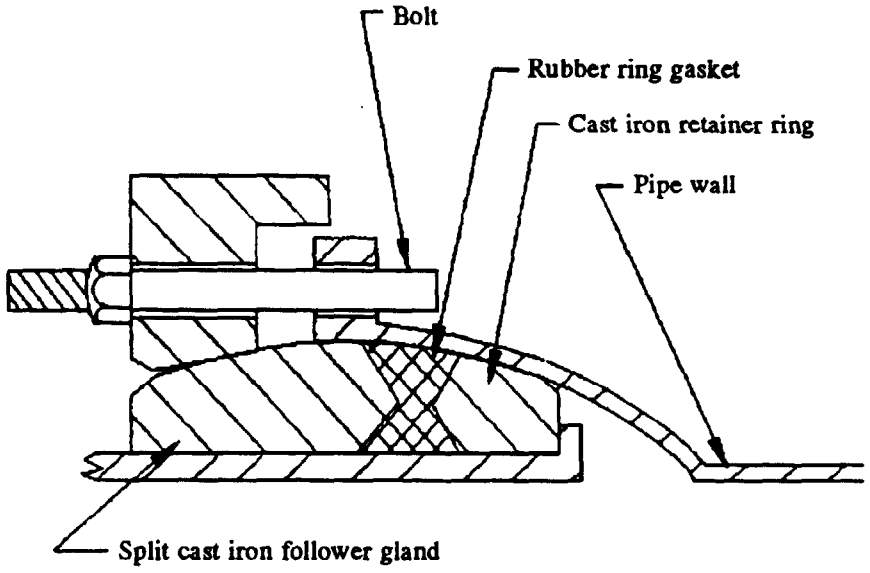



**Threaded Coupling**

Figure 6-26. Common mechanical joints used for submarine pipelines.




**Rigid Bell and Spigot**




**Flexible Bell and Spigot (ball and socket)**

Figure 6-26. Common mechanical joints used for submarine pipelines (continued).

Table 6-7. Pipe Joining Methods

| Joint | Suitability for Use Offshore in Military Applications | Suitability for Troop Use | Extent of Training Required | Adaptability[a] to Training | Indicated Dependability in Offshore Applications | State-of-Art | Reliability and Performance |
|---|---|---|---|---|---|---|---|
| Electric[b] Welded | Excellent | Poor | Extensive | Poor | Excellent | Advanced | Excellent |
| Explosive[c] Weld | Good | Excellent | Intermediate | Poor | Good development | Primarily in | Unknown |
| Threaded[d] Coupling | Good | Excellent | Intermediate | Excellent | Good | Advanced | Good |
| Zap-Lock | Good Questionable | Good -- | Intermediate | Poort | Good development | In use and | Unknown |
| Bolted Flange | Poor | Good | Minimum | Excellent | Good | Advanced | Good |
| Coupled Sleeve (Victaulic) | Unsatisfactory | Excellent | Minimum | Excellent | Very poor | Advanced | Unsatisfactory |
| Other Mechanized Coupling | Unsatisfactory | Excellent | Minimum | Excellent | Poor | Advanced and development | Unsatisfactory |

[a] All methods listed as poor require expenditure of materials and complete removal of joint area at completion of training and for retrieval of pipeline for reuse at another location.

b Electric welded pipeline would require extensive training and practice to maintain proficiency. As such, they are poorly adapted to training.

[c] Explosively welded joints have been under development by industry for some time but have not found widespread use. Therefore, reliability and performance cannot be assessed accurately.

[d] Threaded coupling joints are proven joints. In 4- and 6-inch sizes they have been demonstrated by the Army and Navy as being fully satisfactory for troop use and appear to be satisfactory in 8-inch size. Subitability of threaded couplings in sites greate than 8-inch diameters appear questionable because of the requirement for larger sizes, more powerful equipment, and handling problems.

horizontally-mounted rotary pipe tong is required to assemble the pipe sections in the field. This equipment was previously developed as part of the Navy BLPS and is no longer maintained in inventory. New tongs must be custom designed prior to using this joint for a submarine pipeline project.

Leak prevention in a threaded coupling is also dependent upon pipe dope, a high density compound used to seal the threads in the coupling. Thread compounds should conform to API Bulletin 5A2, Thread Compounds for Casing, Tubing, and Line Pipe. Pipe compounds are subject to aging, however, and this can reduce the useful life of the pipeline from 5 to 10 years.

**6.3.8.3 Rigid Bell and Spigot.** The bell and spigot joint is traditionally employed only for concrete pipelines and is suitable for low pressure, large diameter intake and outfall pipelines. It has limited flexibility and typically can accommodate only 1 to 2 degrees of deflection at the joint. Steel bolts or other longitudinal reinforcement is generally required to increase the resistance of the joint to longitudinal pull-out.

**6.3.8.4 Flexible Bell and Spigot (Ball and Socket).** This joint is traditionally employed for submarine pipelines constructed of cast iron. It provides a reliable seal which can sustain pressures up to 250 psi. The flexible joint allows deflection up to 15 degrees in any direction.

### 6.3.9 Pipeline Stabilization Techniques

In deep water, it is common practice to design the pipeline such that the submerged weight of the pipeline is sufficient to prevent the pipeline from moving when subjected to hydrodynamic loads. In shallow water, the hydrodynamic forces are generally so large that it is impractical to rely strictly on pipeline submerged weight and an additional form of stabilization must be employed to restrain the pipeline. Submarine oil and gas pipeline are traditionally "weight coated" with a layer of high density (up to 200 $lb/ft^3$) concrete when additional submerged weight is required. If additional stabilization is required beyond the weight coating, common techniques include:

- Anchoring:
  -Clump weights
  -Mechanical anchors

- Trenching:
  -Fluidization train
  -Air lift
  -Mechanical trenchers
  -Submarine plow

Anchoring methods are employed only to increase the resistance of the pipeline to motion due to hydrodynamic forces. Trenching methods may be employed either to reduce hydrodynamic loads on the pipe (and thereby increase stability) or as a means of protecting the pipe against impact damage from dragging anchors or fishing gear.

Selecting a stabilization method is done on a case-by-case basis and depends on soil type, hazard type, length of pipeline to be protected, equipment requirements, and cost. Evaluation criteria to be considered when selecting a stabilization method are summarized in Table 6-8. Illustrations of typical stabilization equipment are shown in Figure 6-27.

Table 6-8. Stabilization Method Evaluation Factors

| Item | Anchoring | | Trenching | | | | Notes |
|---|---|---|---|---|---|---|---|
| | Clump Weights | Mechanical Anchors | Fluidization Train | Air Lift | Mechanical Trenchers | Submarine Plow | |
| Soil Type: | | | | | | | |
| Sand | + | + | + | + | + | + | + Effective |
| Clay | + | + | - | - | + | + | - Not effective |
| Rock/Coral | + | + | - | - | - | - | |
| Pipeline Hazard: | | | | | | | |
| Hydrodynamic Forces | + | + | + | + | + | + | + Effective |
| Anchors | - | - | + | + | + | + | - Not effective |
| Fishing Gear | - | - | + | + | + | + | |
| Equipment Requirements | | | | | | | |
| Special Design for Underwater Equipment | N | N | N | N | R | R | N - Not required<br>R - Required<br>D - Deep<br>S - Shallow |
| Water Depth Limitation | D | D | S | S | D | D | |
| Specialized Surface Vessels | N | N | R | N | N | N | |
| Specialized Deployment and Recovery Equipment | N | N | R | N | N | R | |
| Production Rate | - | - | + | + | + | + | + High<br>- Low |
| Day Rate | - | - | + | _ | + | + | + High<br>- Low |

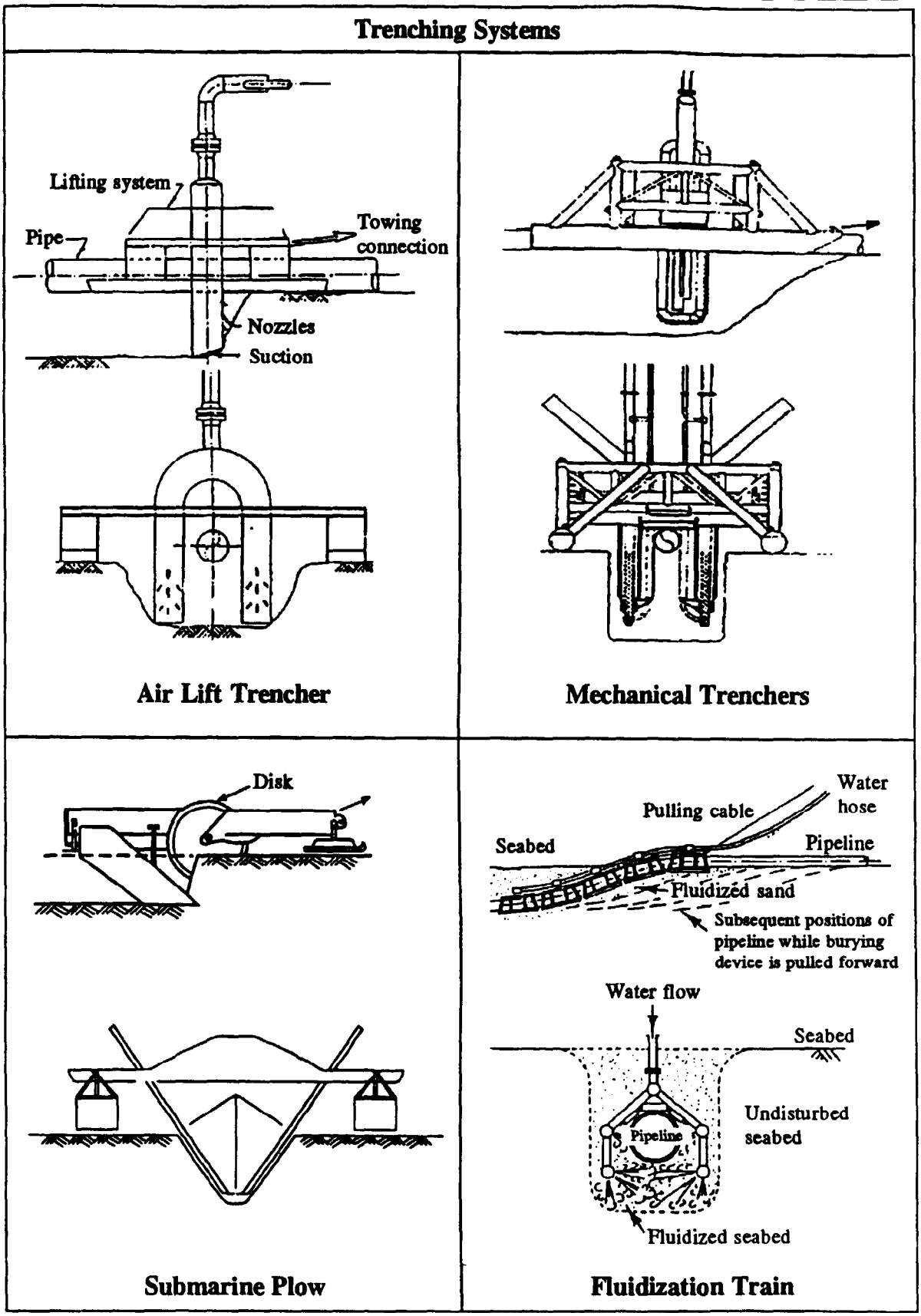



Figure 6-27. Pipeline stabilization equipment.

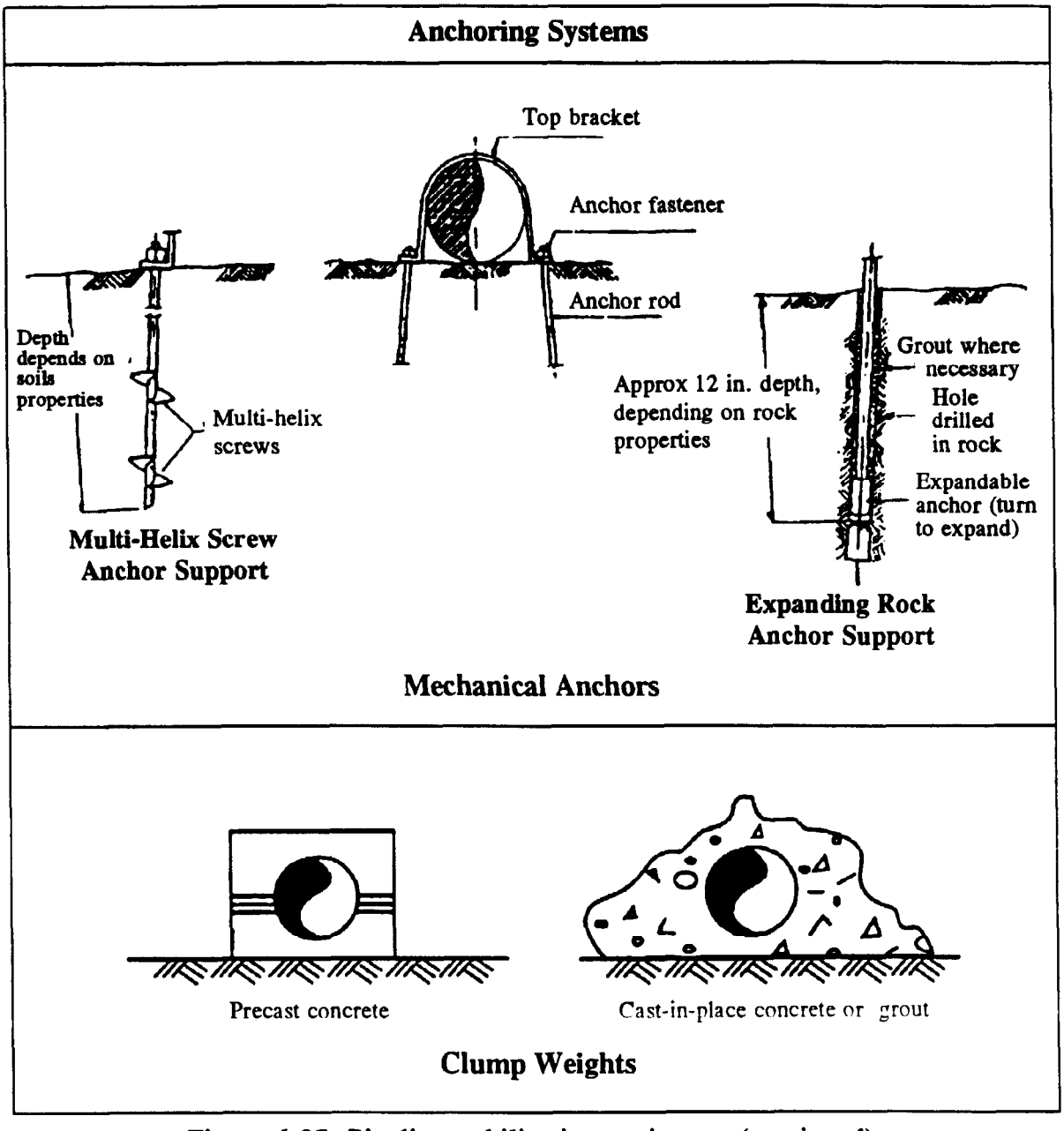



Figure 6-27. Pipeline stabilization equipment (continued).

## 6.4 MAGNETIC SILENCING FACILITIES

Magnetic silencing ranges can be divided into two general categories:

- Degaussing ranges which are designed to measure the magnetic signature of a vessel

- Deperming ranges which are designed to modify the magnetic signature of vessels to within acceptable levels.

Degaussing ranges typically consist of a linear array of magnetometers located across a navigation channel near a Navy installation. These magnetometers, or sensors, are placed inside support structures and are connected to an instrumentation building by cables that provide power and a medium for data transmission. Typically, these support structures consist of fiberglass or PVC tubes embedded in the bottom.

In some cases, more elaborate support structures are employed, depending upon local bottom conditions and facility requirements. Deperming ranges are located either adjacent to a single pier or between two finger piers. Similar to degaussing ranges, sensors are positioned within support structures, usually bottom embedded tubes. Cables connecting the sensors and the range house also supply both power and data transmission. The installation of the support structures for magnetometers is not addressed in this manual due to the extensive engineering support and high degree of accuracy required for their installation.

### 6.4.1 Magnetometer and Cable Installation

There are some variations in the method of installing sensors and sensor cables depending on both the type of range and the type of system that is used at a particular range. Common among all the systems currently in use by the Navy is the fact that a range will consist of sensor support structures (usually tubes), magnetometers, weights suspended from or attached to the sensors, tube caps, and sensor cables. Figures 6-28 through 6-31 illustrate a typical configuration for the different systems. Above water electrical installations are usually not part of the mission assigned to UCT personnel.

**6.4.1.1 Type II System** (see Figure 6-28). Installation of a Type II system is as follows:

- Cut the bronze sensor support cables to the proper lengths and attach them to the sensor with the support collar and to the tube cap as shown in Figure 6-28.

- Pass the sensor cable through the tube top cap and attach it to the sensor.

- Just prior to installing the sensor in the tube, attach the lead weight to the sensor with an appropriate marine grade line. The weight should suspend beneath the sensor approximately 12 to 18 inches.

- Insert the sensor assembly into the tube. The tube top cap sits inside the tube, therefore no fastening devices are necessary. Secure the sensor cable to the outside of the tube with nylon tie wraps. The cable loop protruding from the tube top cap should not exceed the minimum bending radius specified by the cable manufacturer.

- Coil a service loop of cable at the mudline and secure to the tube with tie wraps. Service loop should be of sufficient length to enable servicing the sensor from

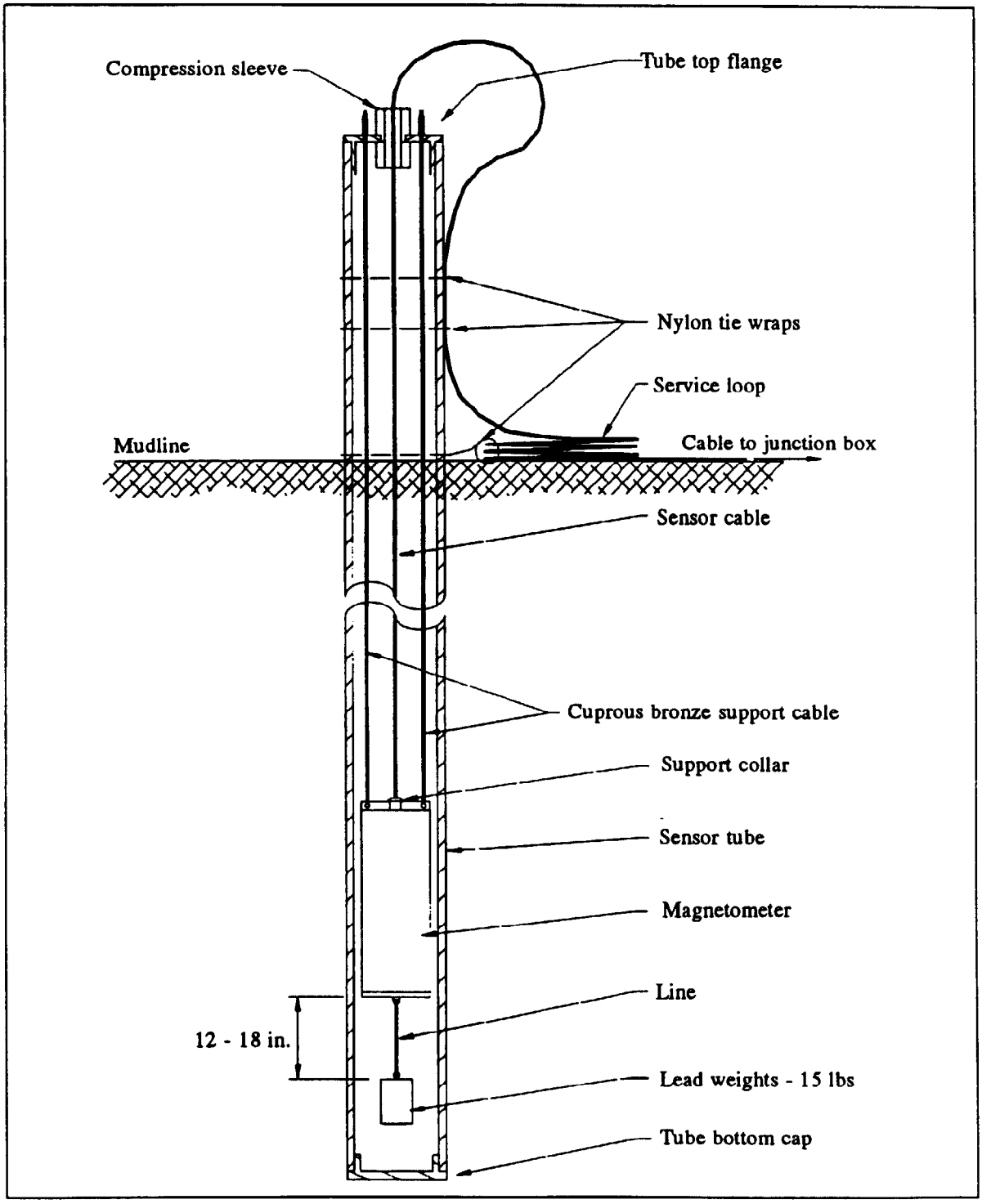



Figure 6-28. Type II sensor assembly.

the surface without disturbing any adjacent cable.

- Each cable should be routed along the bottom to the appropriate junction box(es). Cables are grouped together (usually four to eight) and secured approximately every 10 feet with tie wraps. Cables are routed through protective conduits near the junction box(es) and secured in place.

**6.4.1.2 Type III System** (see Figure 6-29). Installation of a Type III system is as follows:

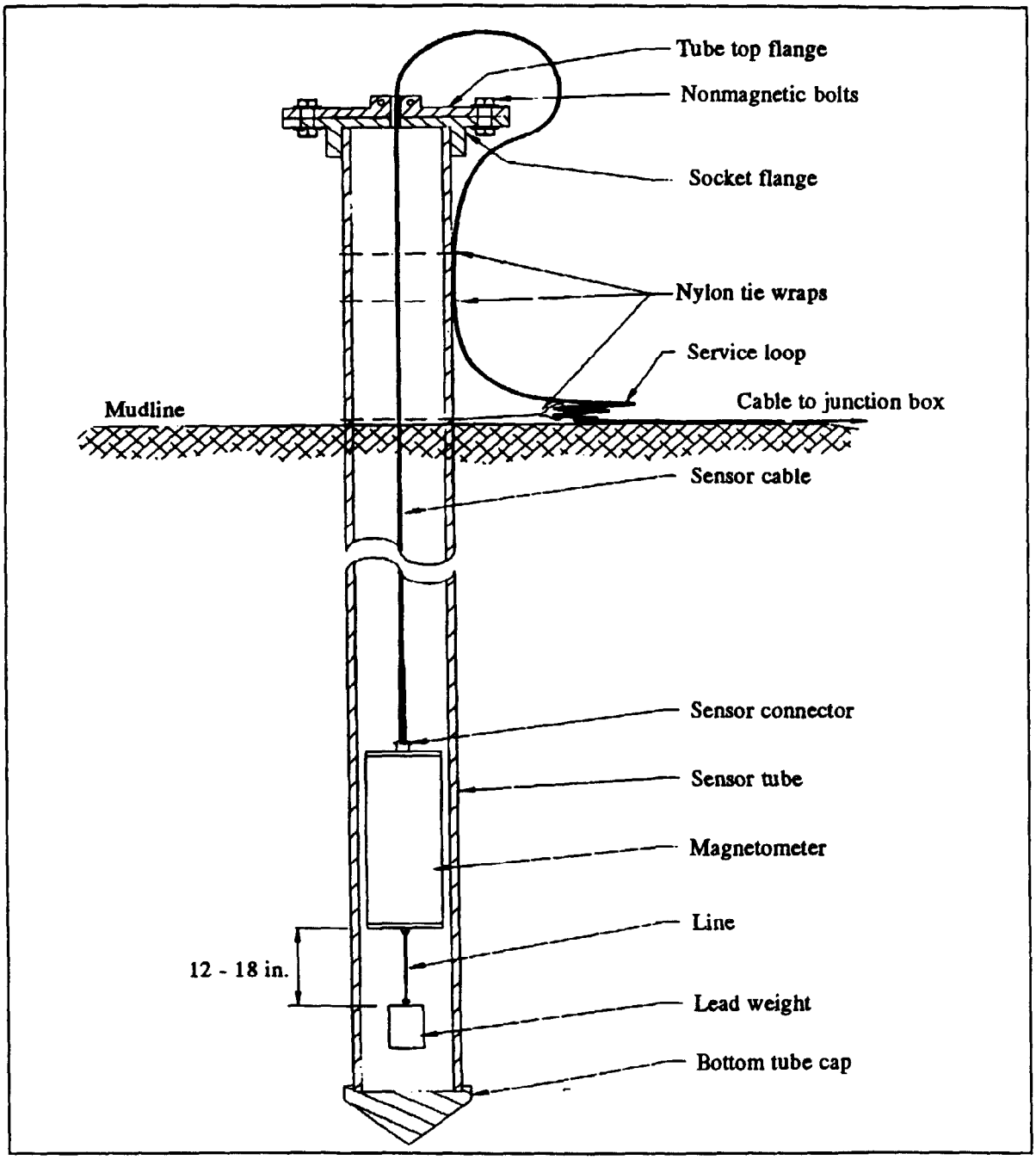



Figure 6-29. Type III sensor assembly.

• Measure on the sensor cable the appropriate length from the tube top flange to the cable connector. Attach the tube top flange to the cable.

• Prior to connecting the cable to the sensor, replace the cable connector O-ring with a new lubricated O-ring.

• Attach a lead weight of approximately 15 pounds to the bottom of the sensor with marine grade line. The weight should suspend from the bottom of the sensor 12 to 18 inches.

• Lower the sensor assembly into the tube, align the tube top flange with the socket flange preassembled on the tube, and secure in place with nonmagnetic bolts.

• Secure the sensor cable to the outside of the tube with nylon tie wraps. The cable loop protruding from the tube top cap should not exceed the minimum bending radius specified by the cable manufacturer.

• Coil a service loop of cable at the mudline and secure to the tube with tie wraps. Service loop should be of sufficient length to enable servicing the sensor from the surface without disturbing any adjacent cable.

• Each cable should be routed along the bottom to the appropriate junction box(es). Groups of cables are bundled together (usually four to eight) and secured approximately every 10 feet with tie wraps. Cables are routed through protective conduits near the junction box(es) and secured in place.

**6.4.1.3 Type IV System** (see Figure 6-30). Magnetic silencing ranges employing the Type IV system differ from early systems in that sensors are connected in series (Daisy Chain) rather than one sensor/one cable as with the earlier Type II and Type III systems (see Figure 6-31). Installation of a Type IV system is as follows:

• Locate the underwater junction box (UJB) and bring it aboard the work platform.

• Terminate to the UJB the sensor cable to the first sensor in the array and the return sensor cable that connects the last sensor in the array.

• Make up the sensor assemblies by attaching the proper length synthetic line between the Viking cap and sensor, pass the sensor cables through the Viking cap, connect the cables to the sensor, and attach the proper Cap Tag to the Viking cap. Check sensor cable connector O-rings prior to mating cable to sensor. Replace any defective O-rings. Ensure ballast (lead weight) is attached to the bottom of the sensor.

• Lower the first sensor in the array along with the UJB to the bottom. Remove the temporary cap, if any, from the sensor tube. Ensure the tube is clear of debris and sediment. Insert the sensor into the first tube. Place the UJB on the Range House side of the first tube. After the Viking cap is placed over the tube, ensure that the clamping ring on the cap is closed and secured. Secure the sensor cable to the side of the tube with tie wraps as depicted in Figure 6-30.

• Install the remainder of the sensors in the array in a similar manner. While installing the sensors, pay out the return sensor cable. As mentioned above, this cable will terminate at the last sensor in the array.

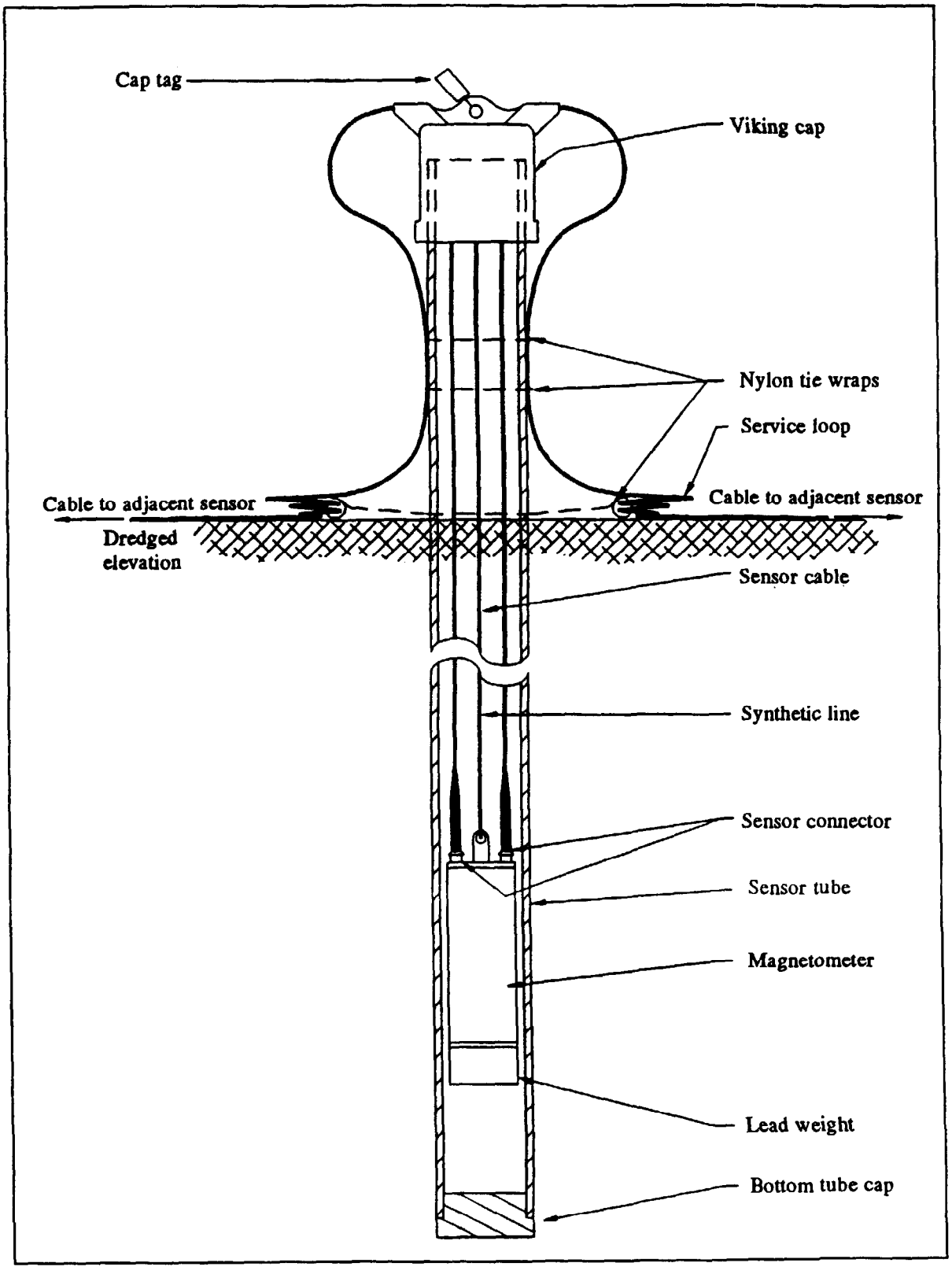



Figure 6-30. Type IV sensor assembly.

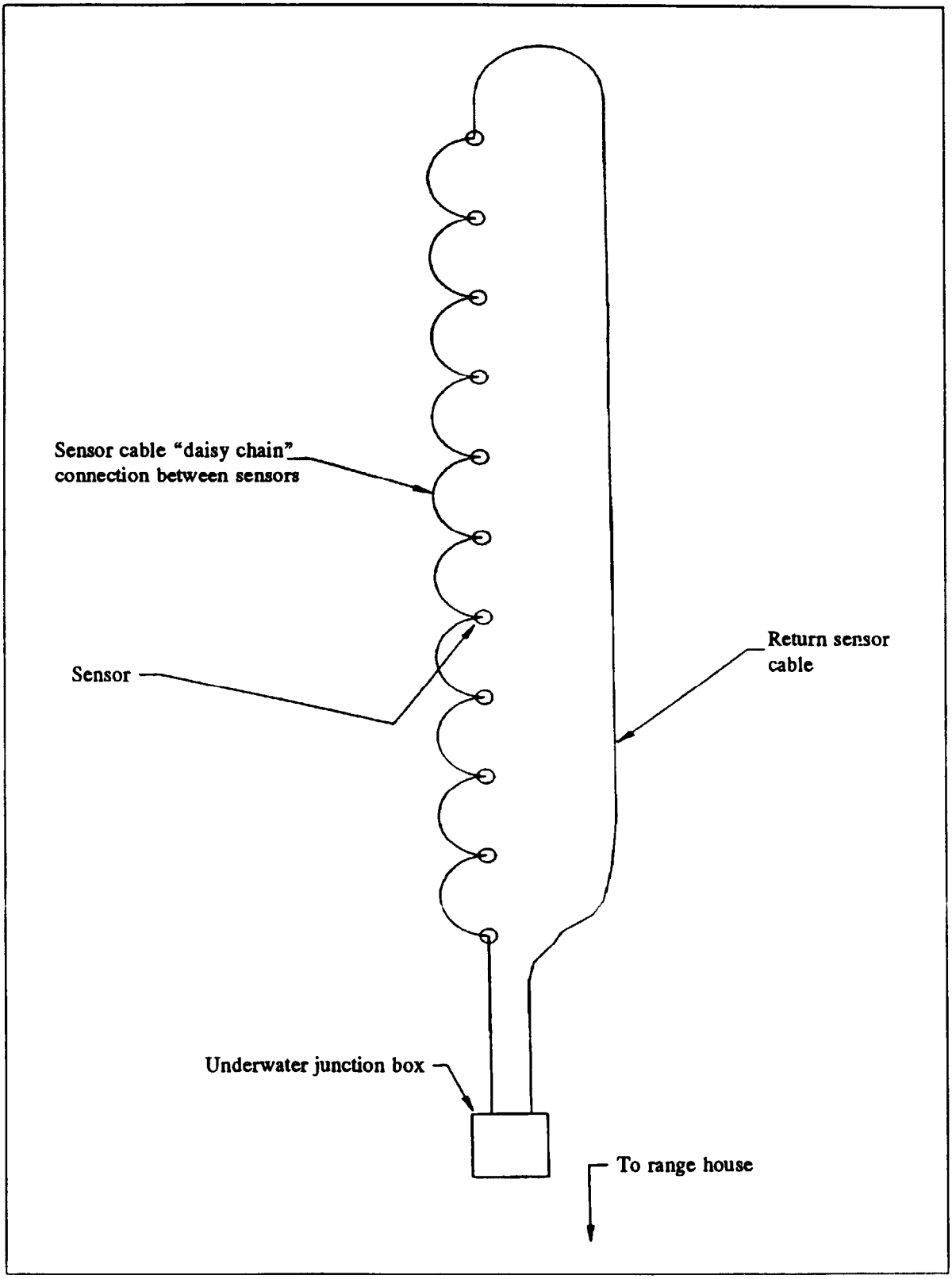



Figure 6-31. Type IV sensor cable configuration.

• As illustrated in Figure 6-30, each sensor has two service loops, placed and secured on either side of the sensor tube. Each service loop should be of sufficient length to allow servicing an individual sensor from the surface without disturbing any adjacent cable beyond the service loop.

**6.4.1.4 Sensor Assembly Replacement.** Numerous magnetic silencing ranges have been installed in dredged cuts that have filled in naturally or were backfilled after installation. When replacing a sensor assembly, it should be necessary to uncover only the tube and service loops of the sensor to be replaced. Once a sensor has been located and brought to the surface, replacement of the assembly follows the same steps listed above. Ensure the service loops are remade and secured in their proper places.

## 6.5 SINGLE ANCHOR LEG MOORING (SALM) DEPLOYMENTS

The Offshore Petroleum Discharge System (OPDS) is a part of the Strategic Sealift's cargo delivery system. OPDS is designed to facilitate the high volume movement of bulk liquid cargo from tanker to shore in support of Fleet Marine Force amphibious operations. Deployment, recovery, and maintenance of the OPDS will be conducted by PHIBCB personnel in conjunction with UCTs. UCT personnel have the responsibility to deploy, retrieve, maintain, and repair parts of the system which require diving support.

OPDS was designed to be installed and carried to the deployment site on a specially designed tanker. It is shown ready for deployment in Figure 6-32 and deployed in Figure 6-33. The OPDS consists of a conduit which delivers the fuel to shore, Single Anchor Leg Mooring (SALM), and towing, handling, and support equipment.

The SALM consists of a steel barge-type base, product swivel, mooring buoys, and associated rigging, piping, and hoses. The steel barge contains 12 internal ballast tanks and associated valves that are used by UCT personnel to control submergence. The base is 155 feet long, 55 feet wide, and weighs over 900 tons when deployed on the bottom. It is designed to be quickly deployed through controlled flooding of the ballast tanks and can be deployed under the following conditions:

| | |
|---|---|
| Water depth minimum/ maximum | 35/200 feet |
| Maximum significant wave height | 5 feet |
| Maximum current | 1.5 knots |
| Maximum wind velocity | 1.6 knots |
| Bottom conditions | Sand, mud, coral (not rock) |
| Seafloor slope | 1:2.5 |

Deployment and maintenance of OPDS requires special skills which are provided to the UCTs in a formal training course. Complete manuals are available to support OPDS operations, and they are listed in Chapter 7. Before deployment, UCT personnel will want to review the following manuals:

• OPDS - SALM, "Deployment and Retrieval Manual"

• OPDS, "Conduit and Conduit Support Equipment Operations, Maintenance, and Storage Manual"

The overall responsibility of UCT personnel will be to support operations involving deployment, recovery, maintenance, and inspection of the SALM, including site selection, stabilization, inspection, and maintenance of the conduit to the beach.

All operations involving the need for divers involve UCT personnel.

The OPDS is complete in that all project equipment necessary to facilitate deployment, maintenance, and operation is contained with the system. Even so, it is imperative that UCT personnel conduct a thorough survey of the equipment to establish presence and operational condition.

On-site camp support will be provided by the PHIBCBs. The UCT detachment will be required to take the organic TOA equipment required to support surface-supported diving operations, including the requirement for surface communications.

Deployment and recovery will require a team of divers working around the clock. Within 7 days of the OPDS tanker arrival, the SALM can be installed. However, weather and site conditions may dictate the need for additional time and effort. Current OPDS plans call for two full detachments to be deployed with each installation.

Due to the around-the-clock nature of the task and other environmental factors such as depth and site conditions, deployment and recovery operations may require deployment of up to two Air Detachments (30 men). The detachment leader will need to carefully evaluate the overall operational situation before establishing the deployment team size.

A brief outline of UCT participation in OPDS deployment is provided in Table 6-9. Detailed procedures and requirements are specified in the manuals.

Deployment of the SALM is expected to take 7 days but could be longer depending on weather, site, and operational conditions.

Following deployment, a UCT inspection and maintenance crew adequate for operating a dive station may be required to remain on site for up to 6 months. Recovery and preparation of the SALM for redeployment can be accomplished in 5 days.

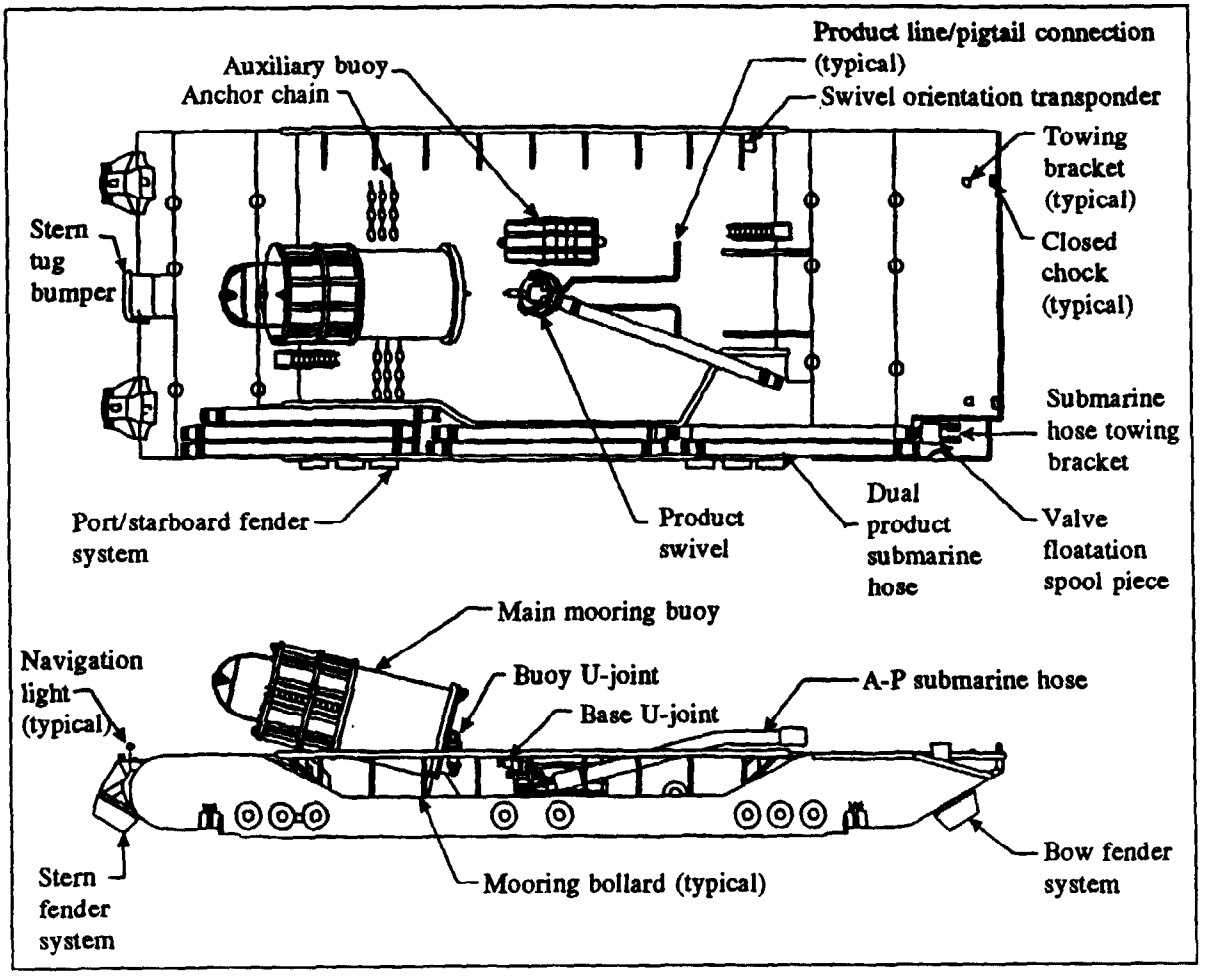



Figure 6-32. OPDS SALM before deployment.

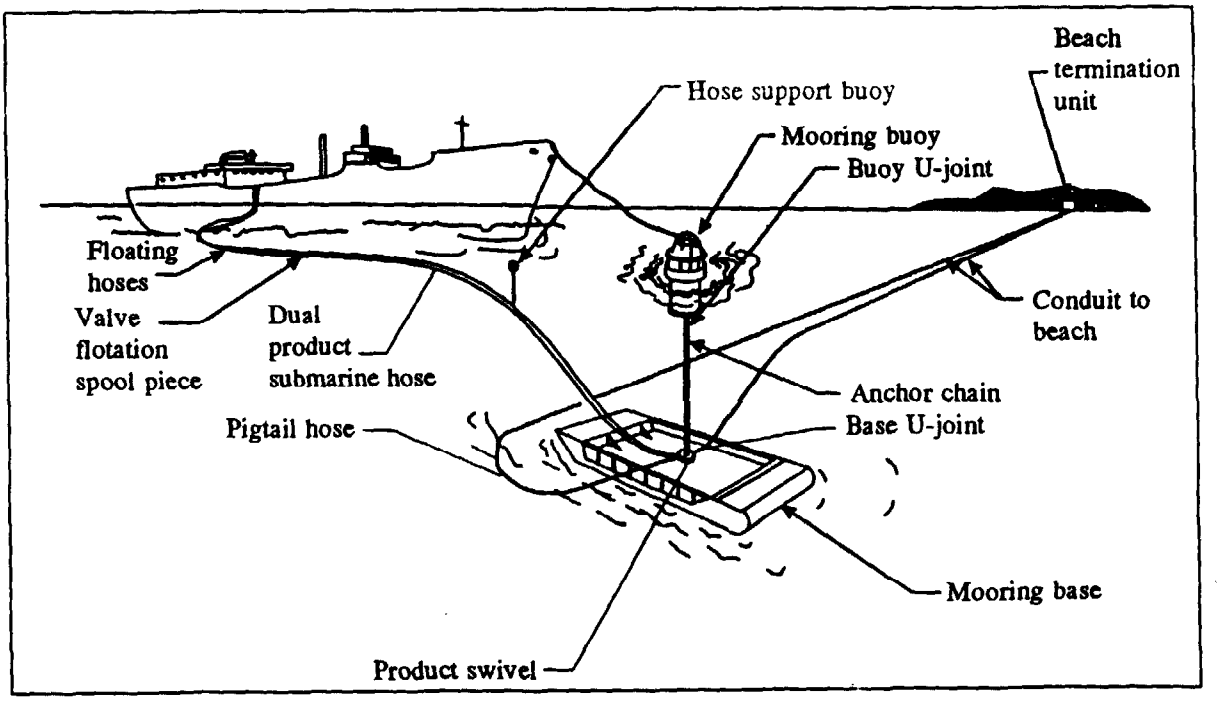



Figure 6-33. Offshore petroleum discharge system.

Table 6-9. Outline of UCT OPDS Participation

I. CONDUCT SALM PREDEPLOYMENT PROCEDURES

1. ON TANKER CHECK OF SALM AND INVENTORY EQUIPMENT
   If possible OPDS inventory and inspection should be accomplished by UCT personnel before tanker deploys to the operational site. All equipment must be on site and in operational condition before deployment is initiated.

2. Installation of dive systems on OPDS dive boat (converted LCM6 boats).

3. SURVEY, SELECT AND MARK INSTALLATION SITES FOR SALM, TANKER MOORING AND CONDUIT ROUTE TO SHORE

4. SURVEY CONDUIT AND INSTALL CONDUIT ANCHORS
   Make sure the conduit, which can be up to 4 miles long, is stable (anchored to the seafloor) and not located where chafing and long suspensions may cause damage and rupture of the line.

5. PREPARE SALM FOR LAUNCH FROM TANKER

6. LAUNCH SALM
   A. Deploy pigtail hoses
   B. Floor tanks in sequence
   C. Deploy submarine hose
   D. On bottom reset valves and inspect hoses and conduit and install mooring hawser

7. RIG FOR TOW TO SITE

8. POSITION SALM AT INSTALLATION SITE

II. DEPLOY SALM

1. DEPLOY SALM
2. INSPECT PIGTAIL HOSE AND CONDUIT ON BOTTOM
3. CONNECT MOORING HAWSER TO MAIN BUOY

III. INSPECTION/MAINTENANCE REQUIREMENTS

1. START-UP INSPECTION/MAINTENANCE

Table 6-9. Outline of UCT OPDS Participation (continued)

III. INSPECTION/MAINTENANCE REQUIREMENTS (continued)

2. TWICE MONTHLY INSPECTION/MAINTENANCE
Submarine hose, floating hose, mooring hawser, remove mud and fouling, and cycle valves

3. MONTHLY INSPECTION
Buoy and auxiliary buoy

4. THREE-MONTH INSPECTION
Mooring base, buoy interior, product swivel, pigtail hose

5. SIX-MONTH INSPECTION
Anchor chain and universal joints

IV. CONDUIT PRERETRIEVAL PROCEDURES

Remove conduit stabilization and assist with pigtail and conduit disconnect

V. RETRIEVE SALM

Disconnect mooring buoy, deballast tanks and retrieve pigtail hose

VI. PREPARE BUOY FOR TOW

VII. PREPARE SYSTEM FOR REDEPLOYMENT

VIII. ASSIST IN RECOVERING SALM ON TANKER

# Chapter 7

# REFERENCES

The references listed below provide additional information on the various subjects covered by this manual. The reader is encouraged to use these references to obtain details of previous UCT operations and further background on specific subjects. The references are categorized in accordance with the organization of Chapters 2 through 6 of this manual. Since a number of the references contain information on more than one topic, they appear more than once in the list.

Copies of all of the references listed are maintained at the Naval Facilities Engineering Service Center and at the headquarters of each of the UCTs.

## CHAPTER 1 - INTRODUCTION

### Section 1.1 SCOPE OF MANUAL

Naval Sea Systems Command (1993). U.S. Navy diving manual, Vol 1 - Air diving. NAVSEA 0994-LP-001-9010, Rev 3.

Naval Sea Systems Command (1991). U.S. Navy diving manual, Vol 2 - Mixed-gas diving. NAVSEA 0994-LP-001-9020, Rev 3.

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Naval Sea Systems Command (1991). U.S. Navy diving manual, Vol 2 - Mixed-gas diving. NAVSEA 0994-LP-001-9020, Rev 3.

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**Section 1.5.4 Materials**

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**Section 1.6 SHIPPING AND HANDLING PROCEDURES**

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**Section 1.7 COMPLETION DOCUMENTATION**

Naval Facilities Engineering Command (1989). Expedient underwater repair techniques. NAVFAC P-991.

## CHAPTER 2 - UNDERWATER WORK TECHNIQUES

**Section 2.2 UNDERWATER TOOLS**

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**Section 2.3 REMOVING MARINE GROWTH**

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# Chapter 8

# GLOSSARY

**Abrasive** - The agent used for abrasive blast cleaning; for example, sand, grit, steel shot, etc.

**Admixture** - A material other than water, aggregates, and cement that is used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing to modify its properties.

**Aggregate** - Granular material, such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form a concrete or mortar.

**Airblast** - The air shock wave created by an explosion.

**Alidade** - A surveying tool consisting of a telescope, supporting post, and straightedge used for measuring horizontal and vertical angles. Typically used in conjunction with a plane table for field compilation of maps.

**Anaerobic Corrosion** - Corrosion caused by anaerobic bacteria, that is, bacteria that can live in an oxygen-free environment.

**Anchorage** - An area designated for ships to anchor in with their own equipment.

**Angle of Repose** - The natural slope that a noncohesive soil will assume.

**Anode** - The consumable component of cathodic protection systems and corrosion cells.

**Anomaly** - A departure from the regular pattern as might be experienced with objects disturbing the earth's magnetic field; an irregularity or defect.

**ANS** - Acoustic Navigation Systems.

**ANSI** - American National Standards Institute.

**API** - American Petroleum Institute.

**Areal** - A type of survey concerned with the general topography/bathymetry of an area rather than with specific details.

**As-Built Drawings** - Drawings that show all deviations from the original design and changes made during construction.

**ASTM** - American Society of Testing Materials.

**AWS** - American Welding Society.

**Azimuth** - An angle measured clockwise from a meridian (such as a baseline) and varied from 0 to 360 degrees.

**Baseline** - A line in a survey that is established between two known points.

**Bathymetry** - The detailed description and analysis of the underwater features of a body of water.

**Bearing** - Measures the angle between a given meridian (such as a baseline) and the line to the object. The angles are from 0 to 90 degrees in four quadrants.

**Benchmark** - A permanently fixed point of known location and elevation used for reference during survey or alignment.

**Berth** - The water area at the edge of a wharf or pier reserved for a vessel.

**Birdcaging** - An expansion of a stranded cable caused by two close sections being pushed together.

**Bitt** - A single- or double-posted steel fitting on a deck of a ship or pier to which mooring lines are secured.

**Block Hole** - A hole drilled into a boulder to allow a small charge to be placed to break the boulder.

**Bollard** - A single- or double-posted steel fitting on a pier or wharf around which mooring lines from vessels are tied.

**BLPS** - Bottom Laid Pipeline Subsystem.

**Borehole** - A hole drilled in rock or other material for the placement of explosives.

**Breakwater** - A substantial structure, located at the outer limits of a harbor or anchorage, to protect the inner waters against the effects of heavy seas.

**Bulkhead** - A retaining wall to prevent sliding of earth or fill into water.

**Buoy** - A float moored to the bottom to mark the position of a shoal, channel, or anchorage limit, or a floating component of a ship mooring.

**Cable** - A flexible rope-like material containing signal transmitting conductors or optical fibers with or without reinforcing outer strength members and jackets.

**Caisson** - A concrete structure with a steel or concrete end closure.

**Cathodic Protection** - An electrical method of controlling corrosion in a conducting medium such as seawater or moist soil where an electrical current is applied to a structure either by the corrosion of an active anode material or an external electrical power supply.

**Cavitation** - The formation of air pockets in a flowing liquid by mechanical forces.

**Charge** - One or more containers or quantities of explosives that are in direct physical contact.

**Chock** - A metal casting with two horn-shaped arms used for passage, guiding, or steadying of mooring or towing lines.

**Cleat** - A metal fitting on the deck of a pier or ship usually with two projecting horns around which a rope may be made fast (as by belaying it).

**Cobblestone** - A naturally rounded stone.

**Cohesive Soil** - A soil, typically clay, that is held together by the mutual molecular attraction of its particles.

**Connecting Wire** - Any wire used in a blasting circuit to extend the length of a leg wire or leading wire.

**Corrosion** - The attack of a metal by electrochemical action.

**Cratering** - The use of explosives in boreholes without adjacent free faces to produce a crater-shaped excavation.

**Crevice Corrosion** - Corrosion of a metal accelerated by a difference in environment between one area on the metal and another area.

**CSNP** - Non-Powered Causeway Section.

**CTD** - Conductivity, Temperature, and Depth.

**Cut/Burnoff Ratio** - Linear inches of metal cut per inch of electrode consumed.

**Cutting Tip** - That part of an oxygen cutting torch from which the gases issue.

**Cutting Torch** - A device used in oxygen cutting for controlling and directing the gases used for preheating and the oxygen used for cutting the metal.

**Deadman** - A block or other heavy item, usually of concrete, buried in the ground to which is attached a steel rod or cable for anchoring objects.

**Deck** - The working surface of a wharf, pier, or vessel.

**Delamination** - A splitting apart into layers.

**Detonation** - The rapid change of an explosive from a solid or liquid form to a gaseous state.

**DGPS** - Differential Global Positioning System: Similar to a GPS except a reference (GSP) station at a known location is used to transmit a correction to a remote GPS on the survey vessel.

**Dissimilar Metals** - Metals with different galvanic potentials when immersed in a conductive medium. These different potentials can cause accelerated corrosion of one of the dissimilar metals if they are electrically connected and exposed to the conductive medium.

**DNS** - Diver Navigation System.

**Dock** - The water area adjacent to a wharf or pier to which a ship can be secured.

**Docking Blocks** - Blocks used to support the keels and hulls of ships, barges, and vessels during overhaul operations.

**Dolphin** - A structure usually consisting of a cluster of timber piles. It is placed at the outward end of piers and wharves, or along shore, to guide vessels into their moorings; to fend vessels away from structures, shoals, or the shore; or to support navigation aids.

**Draft** - Depth of vessel hull or buoy below the waterline.

**Drydock** - A facility for exposing the normally underwater portion of a ship for construction, inspection, repair, or hull maintenance.

**Dynamometer** - A self-contained load measurement device that can be placed either in-line or at the end of a hauling line.

**EDM** - Electronic Distance Meters.

**ELCAS** - Elevated Causeway Section.

**Electrical Potential** - See "Galvanic Potential."

**Electrolyte** - A nonmetallic medium capable of conducting electricity by the movement of ions rather than electrons.

**ERS** - Electronic Ranging Systems.

**ESSM** - Emergency Ship Salvage Material: A Navy maintained pool of equipment used to support emergency ship salvage, ship husbandry, oil spill response, and diving. ESSM pools of equipment are located world-wide and are operated by the Naval Sea Systems Command, Code OOC. ESSM depots are located at Williamsburg, Virginia; Sasebo, Japan; Fort Wainright, Alaska; Stockton, California; and Singapore.

**Explosive** - A chemical substance that rapidly changes into a gas, creating heat and pressure.

**External Charge** - A charge placed external to, and usually in intimate contact with, the material to be blasted.

**Fairlead** - A rigging device such as a pulley which is used to change the direction of a hauling line.

**Fender** - A device, usually of wood, rubber, or rope, to prevent damage to a vessel or shore facility by impact or abrasion.

**Ferromagnetic** - Behaving like iron in a magnetic field.

**Fish Plate** - A timber plate that laps a joint or an area of a piling reduced by deterioration. It is secured to the sides so as to connect the members end to end or to strengthen them.

**Float** - A floating platform used for disembarking from a boat or working around waterfront structures.

**Fouling** - An accumulation of deposits, especially marine biological growth.

**Fracture** - The breaking of rock without movement of the broken pieces.

**Fragmentation** - The extent to which rock is broken into small pieces when blasted.

**Freeboard** - Distance between the deck of a floating vessel or buoy and the waterline.

**Galvanic Corrosion** - An accelerated form of corrosion occurring in an electrolyte when a pair of dissimilar metals capable of acting together as a source of electricity are in contact with each other.

**Galvanic Potential** - A quantity in an electrical field measured (in volts) with reference to some arbitrary level of potential, such as a reference electrode.

**GDOP** - Geometrical Dissolution of Position.

**GFD** - Ground Fault Detector and circuit interrupter: Electrical equipment used to detect the occurrence of electrical leakage in electrical cables and to shut down the power when safe current levels are exceeded. Electrical equipment used by divers underwater must be protected with an approved trip device if the voltage exceeds 7.5 volts for AC and 30 volts for DC. See Appendix D.

**GFI** - Ground Fault Interrupter.

**GPS** - Global Positioning System: A navi-

gation system that acquires ranges from three or more satellites to determine position.

**Granular Soil** - A soil that consists of discrete, easily separable particles.

**Gravity Wall** - A massive structure that obtains stability through its own weight.

**Groin** - A narrow structure projecting out, usually close to right angles, from the shoreline. It is designed to influence offshore currents and wave action in a manner that will minimize erosion of the shoreline.

**Ground Leg** - A distinct portion of the ground tackle system of a fleet mooring.

**Ground Ring** - Steel ring resting at or near bottom at low tide to which riser chain and ground legs of a fleet mooring are secured.

**Ground Tackle** - The anchors, chain, and other supporting equipment used to secure a buoy in a specific location.

**Grout** - Traditionally, a mixture of portland cement and fine aggregate to which is added enough water to make a fluid mixture. Epoxy-resin grouts are also widely available.

**Gunite** - See "Shotcrete."

**Harbor** - In general, a sheltered arm of the sea, easily accessible to maritime routes in which ships may seek refuge, transfer cargo, or undergo repair.

**Hawsepipe** - A cast-iron or steel pipe placed in the bow or stern of a ship or center of a buoy for the anchor chains or tension bar to pass through.

**Hockle** - A tight loop formed in a cable due to twisting or torquing the cable.

**Holiday** - A small hole in a coated surface arising from imperfect application.

**Hose Charge** - A flexible linear charge consisting of a core of explosive surrounded by an outer skin or hose.

**Inclinometer** - A measuring tool for obtaining angles of inclination of mooring chains and tube installations.

**Increment Borer** - A tool for extracting a small plug from a timber element.

**Internal Charge** - A charge placed inside of the material to be blasted, usually by means of boreholes that penetrate into the material.

**Jetty** - A structure (such as a mound or wall) at or near the entrance to a harbor or river constructed to confine the flow of water due to currents and tides and to maintain the entrance free of sandbars.

**Jewelry** - Connecting hardware on a buoy or mooring.

**Kellett** - Weight added to an anchor line to help depress the line and reduce the angle of the line with the seafloor.

**Kerf** - The width of the cut produced during a cutting process.

**Kevlar** - Trade name for DuPont aramid fiber, which is used to make high strength, low stretch rope and fabrics.

**Land Mark** - Any readily available target that can be plotted with a high degree of accuracy.

**LBL** - Long Baseline Systems.

**Line Charge** - A charge with its length much greater than its diameter that, when detonated, acts as if the explosive energy comes from a line rather than a point.

**Magnetometer** - An instrument that can detect magnetic materials.

**Marine Borer** - Any of a number of species of organism in seawater that attacks untreated or poorly treated wood; especially active in warm waters.

**Mass Anchor** - A stabilizing technique that works by virtue of weight and the resulting friction against the seafloor. Typical mass anchors are split pipe, concrete, and chain.

**Mill Scale** - Oxide layer formed on iron and steel when heated for rolling, forging, or other processing.

MLW - Mean Low Water.

**Mole** - A rubble-mound structure that extends outward from shore into the navigable water of a harbor. Generally, the level top is appreciable in area and contains paved roads, railroads, and crane trackage.

**Molten Weld Pool** - The liquid state of a weld prior to solidification as weld metal. Also referred to as puddle.

**Mooring** - System of anchors, chain, buoy, and their accessories used to secure ships temporarily in a fixed location.

**Mound** - An artificial embankment or ridge composed of sand, gravel, and cobbles and constructed on the ocean floor by dumping the material from scows and barges.

**MSL** - Mean Sea Level.

**NDT** - Nondestructive Testing.

**Neat** - A grout formulation without the addition of aggregates.

**NEC** - Navy Enlisted Classification.

**Noncohesive Soil** - A soil that resists deformation by the mechanical interlocking of its particles (gravel, sand, silt).

**Null** - Low or zero scale.

**OPDS** - Offshore Petroleum Discharge System.

**Optical** - Referring to survey methods using instruments aiding sight, such as theodolites and transits.

**OTDR** - Optical Time Domain Reflectometer: An electro-optic instrument used to measure light transmission (attenuation) in fiber optic cables.

**Overbend Region** - For a cable or pipeline deployed from a surface vessel, the transition of the cable from horizontal on deck to near vertical in the water column is called the overbend region.

**Overburden** - Soil that is above another strata of soil or an object.

**Oxidation** - The process of combining with oxygen; burning.

**Oxygen Arc Cutting** - An oxygen cutting process used to sever metals by means of the chemical reaction of oxygen with the base metal at elevated temperatures. The necessary temperature is maintained by an arc between a consumable tubular electrode and the base metal.

**Padeye** - A small, usually round opening that is an edgewise projection of a plate attached to a structure for use as a point of attachment.

**PDP** - Pile-Driven Plate Anchor.

**Pier** - An open- or closed-type structure usually extending perpendicularly from the shore into sheltered navigable water, designed for berthing, loading or unloading cargo, repair, fueling, and general servicing of vessels. It normally provides berthing space on both sides for its entire length.

**Pile** - A long, slender timber, steel, or reinforced concrete structural element driven, jetted, or otherwise embedded into the ground to support a vertical load, to resist a lateral force, or to resist water or earth pressure.

**Plane Table** - A surveying tool consisting of a drawing board mounted on a tripod so that the board can be leveled and rotated horizontally without disturbing the tripod.

**Point Charge** - A charge with its length no more than two or three diameters; when detonated it acts as if the explosion energy comes from a single point.

**Port** - An expanded opening in a crack that allows grout to be introduced into the crack.

**Potable** - Suitable for drinking.

**Probing Bar** - A small diameter steel bar used to penetrate the seabed to locate buried objects.

**Proof Load** - The average force to which an item may be subjected before visual permanent deformation occurs or a force that is applied in the performance of a proof test. Usually the value of proof load is equal to 150 to 200 percent of the rated load value.

**Proof Test** - A term designating a tensile test applied to the item for the sole purpose of detecting injurious defects in the material or manufacture.

**Quarrystone** - A diamond or square cut stone.

**Quaywall** - A heavy structure fronting on navigable water, and parallel to the shore, behind which earth fill is placed. Its function is to act as a bulkhead as well as to provide for berthing of vessels or other service.

**Ramping** - A technique used in underwater or on-land demolition to remove steep vertical cliffs and provide a smooth transition for installation of electrical cables.

**Rated Load Value** - The maximum recommended load that should be exerted on the item. The following terms are also used for the term rated load: SWL," "Safe Working Load," "Working Load," "Working Load Limit," and the "Resultant Safe Working Load." All rated load values, unless noted otherwise, are for in-line pull with respect to the centerline of the item.

**Reference Electrode** - A single electrode that, when immersed in an electrolyte solution, produces a fixed, known electrical potential; it is used as a standard for the measurement of potential differences.

**Retrojet** - A balancing jet used on some underwater high pressure waterjet cleaning nozzles.

**Riprap** - Stones or boulders of miscellaneous size placed without order on the surface of an earthen structure or embankment to act as protection against erosion.

**Riser Chain** - Vertical chain extending from a ground ring upward to a mooring buoy.

**Rope** - A line, a long flexible assembly of steel wires or fiber yarns, twisted, braided, or bundled together to serve as a tensile strength member.

**Rope Charge** - A linear charge made up of a number of small charges, such as dynamite sticks, fastened lengthwise along a piece of rope.

**Rubble** - Rough and uncut stones, irregularly shaped and of various sizes, ranging up to 1,000 $ft^3$ each and up to 90 tons each.

**Sacrificial Anode** - An anode that supplies its own electrons for cathodic protection, thereby consuming or "sacrificing" itself.

**Safety Factor** - An industry term denoting theoretical reserve capability. Usually computed by dividing the catalog stated ultimate load by the catalog stated working load limit and generally expressed as a ratio, for example, 5 to 1.

**Sagbend Region** - For a cable or pipeline deployed from a surface vessel, the transition of the cable from nearly vertical in the water column to horizontal on the seafloor is referred to as the sagbend region.

**SALM** - Single Anchor Leg Mooring.

**Seawall** - A massive gravity-type structure built along, and generally parallel to, the shoreline; designed to protect the shore against erosion resulting from wave action.

**Shackle** - A chain-joining link.

**Shaped Charge** - An explosive charge formed with a conical-shaped cavity at one end designed to increase penetration.

**Sheave** - A wheel with a groove on its perimeter used to guide a rope.

**Ship Heave Compensator** - A large pneumatic/hydraulic spring with sheaves at both ends of the spring to compensate for the effect of ship deck heave motion.

**Shock Load** - A resulting load or force from the rapid change of movement, such as impacting or jerking, of a static load. A shock load is generally significantly greater than the static load.

**Shot** - Fifteen-fathom (90 feet) length of chain.

**Shotcrete** - Shotcrete (or gunite) is a concrete that is pneumatically placed in layers usually from 1 to 2 inches. Water is mechanically added to the dry mixture at the nozzle, that shoots the freshly mixed concrete (really a mortar) at the surface prepared for its reception.

**Sinker** - A weight, usually concrete, attached to a mooring leg to remove direct tension from the anchor, to absorb impact loading, to control chain movement near the anchor, and to localize chain wear.

**Sloughing** - Slippage of the slope of an embankment or excavation.

**Slump** - A measure of the fluid consistency of a concrete sample as measured in a slump test cone. The higher the slump, the wetter the mixture.

**Slurry** - A thin liquid cement.

**SLWT** - Side-Loadable Warping Tug.

**Snake Hole** - A hole drilled or bored under a rock or tree stump for placing explosives.

**Spacing** - The linear distance between centers of boreholes, usually measured along the long axis of the cut.

**Spalling** - Deterioration of a concrete surface usually caused by the expansion of rusting reinforcing steel.

**Spider** - A steel plate or casting with three or more holes to join several chains.

**Stake Piles** - Steel piling anchors driven vertically into a firm bottom.

**Stemming** - Material placed in the top of a borehole to seal off escaping gases and to reduce noise from the detonation of explosives in the hole.

**Stop Log** - A steel plate normally installed across the intake opening of a drydock, providing a secondary seal for the sluice gates inside the flooding tunnel.

**Stringer** - A horizontal framing member used to support a floor or deck.

**Stud** - The center cross bar in a steel chain link.

**Subbottom Profiler** - An instrument used to determine the layering of seabed soils by measuring acoustic echoes.

**Syntactic Foam** - A foam composed of hollow spheres in a resin matrix.

**Tremie** - A steel tube used for depositing concrete underwater, having at its upper end a hopper for filling.

**Triangulation** - A surveying technique for horizontal control based on the geometric proposition that if one side and the angles of a triangle are known, the remaining sides can be computed.

**Trilateration** - A surveying technique for horizontal control based on the geometric proposition that if the three sides of a triangle are known, the three angles can be computed.

**UEFD** - Underwater Electric Field Detector: Hand-held device used by divers to detect the presence of stray electrical field underwater. See Appendix D.

**Ultimate Load** - The average load or force at which the item fails or no longer supports a load.

**Ultrasonic** - Sound with a pitch that is above the upper limit of human hearing. Ultrasonic thickness gage uses ultrasonic sound waves to measure thickness.

**Ultrasonic Testing** - High frequency sound readings to determine voids in landfills, flaws in welds, etc.

**Ultrathermic Electrode** - An electrode used for oxygen arc cutting that is made up of seven small rods within a steel tube. One of these rods will continue to burn after the current is switched off.

**USGS** - United States Geological Survey.

**UTM** - Universal Transverse Mercator.

**UWMT** - Underwater Magnetic Particle Testing: Equipment used to detect the presence of cracks in magnetic materials.

**Wale** - A long, horizontal structural member of timber or steel used for bracing vertical members. Also known as "waler" or "ranger."

**Wharf** - An open-type marginal platform structure, usually parallel to the shoreline, that is used primarily for berthing of vessels. It is usually connected to the shore at more than one point but may also have continuous access along the shore. It ordinarily provides berthing along the outboard face.

# Appendix A

# LIST OF MANUFACTURERS/SUPPLIERS

Most equipment and tools required for UCT operations are available in the UCT Table of Allowance (TOA), the Ocean Construction Equipment Inventory (OCEI), or other Navy sources. However, special equipment and tools, and particularly construction materials and consumables, may have to be acquired from commercial sources. The following list of manufacturers/suppliers is provided only to aid in locating sources of commercial equipment, tools, materials, and consumables. It should not be construed as constituting recommendations for particular companies or products. This list is by no means complete, and there may be any number of additional acceptable sources for any particular item.

The list of manufacturers/suppliers is organized to conform with the sequence of the sections of this manual.

## 2.2 UNDERWATER TOOLS

### *Underwater Hydraulic Tools*

Stanley Hydraulic Tools
3810 S.E. Naef Road
Milwaukie, OR 97222
(503) 659-5660

### *Pipe Cutter*

Wachs, E.H., Co.
100 Shepard Street
Wheeling, IL 60090
(800) 323-8185

## 2.3 REMOVING MARINE GROWTH

### *Cleaning Tools*

Robert C. Collins Co.
(Barnacle Buster)
6772 N.E. 4th Avenue
Miami, FL 33138
(305) 751-0677

The Hotsy Corporation
21-T Inverness Way East
Englewood, CO 80112-5796
(800) 821-6490

## 2.4 THERMAL CUTTING/WELDING

### *Cutting Torches/Rods*

TWECO/Aircair Products
4200 W. Harry
Wichita, KS 67209
(800) 231-9353

Broco Inc.
2824 North Locust Avenue
Rialto, CA 92376-1747
(909) 350-4701

Craftsweld Equip. Corp.
26-28 Jackson Avenue
Long Island City, NY 11101
(718) 784-7346

## 2.5 LIFT BAGS

Crestbury Corporation
d/b/a J.W. Automarine Corp.
#10 Old Road Lane
Mt. Kisco, NY 10540
(914) 241-0297

Mar-Vel Underwater Equipment, Inc.
P.O. Box 654
Camden, NJ 08101-0654
(609) 962-8719

AMRON International
759 West Fourth Avenue
Escondido, CA 92025
(619) 746-3834

Canflex Inc.
505-30th Street
Anacortes, WA 98221
(800) 544-8356

Canflex Inc.
635 Clyde Avenue
West Vancouver B.C. V7T1C6
(604) 925-2003

Subsalve USA
P.O. Box 9307
Providence, RI 02940
(800) 466-6962

### *Winches*

TSE International (Pengo)
5301 Shreaveport Blanchard Highway
Shreaveport, LA 71107
(318) 929-2368 or (800) 825-2402

Continental EMSCO
P.O. Box 1489
Houston, TX 77251
(713) 640-7400

## 2.7 CONTROLLED BLASTING

### *Explosive Charges*

Ensign-Bickford Co.
660 Hopmeadow Street
Simsbury, CT 06070
(203) 658-4411

### *Non-Explosive Demolition Agents (Expanders)*

W.A. Murphy, Inc.
P.O. Box 4607
El Monte, CA 91734
(818) 444-9271

A. J. Harris & Son
250 Stanley Street
P. O. Box 2
New Brittain, CT 06050
(203) 225-7671

## 2.8 ANCHORING

### *Danforth Anchors*

Danforth Anchors
500 Riverside Industrial Parkway
Portland, ME 04103
(207) 797-2791

### *Arrowhead-Plate Anchors*

Cobra Anchor Corp.
504 Mt. Laurel Avenue
Temple, PA 19560
(215) 929-5764

### *Manta Ray Duckbill*

Forsight Products, Inc.
6430 East 49th Drive
Commerce City, CO 80022
(800) 325-5360

*Fortress and General Purpose Guardian Anchors*

NAV-X Corp.
1386 West McNab Road
Ft. Lauderdale, FL 33309
(800) 825-NAVX

*Land-Screw Anchors*

A. B. Chance Co.
210 N. Allen Street
Centralia, MO 65240
(314) 682-5521

Minute Man Anchors
305 W. King Street
East Flat Rock, NC 28726
(706) 692-0256

*Offshore-Screw Anchors*

Anchoring, Inc.
P. O. Box 55263
Houston, TX 77055
(713) 465-8377

## 2.10 CONCRETING

*Flexible Forms*

Sea Form Systems & Mfg., Inc.
116 173rd St. South, Unit No. 9
Spanaway, WA 98387
(206) 535-6080

*Rigid Forms*

Symons Corporation
200 E. Touhy Avenue
Des Plaines, IL 60018
(708) 298-3200

*Fabric Forms*

Construction Techniques, Inc.
P. O. Box 360007
Cleveland, OH 44136
(216) 572-8300

*Concrete Bags*

Construction Techniques, Inc.
P. O. Box 360007
Cleveland, OH 44136
(216) 572-8300

*Concrete Admixtures*

Master Builders
Division of Martin Marietta Corp.
23700 Chagrin Boulevard
Cleveland, OH 44122
(216) 831-5500

Sika Corporation
P. O. Box 297
Lyndhurst, NJ 07071
(201) 933-8800

W.R. Grace & Co.
Construction Products Division
62 Whittemore Avenue
Cambridge, MA 02140
(617) 876-1400

## 2.11 GROUTING

*"Epoxy" Repair, Patch, Grout*

Sika Corporation
P. O. Box 297
Lyndhurst, NJ 07071
(201) 933-8800

Fiberglass Evercoat
6600 Correll Road
Cincinnati, OH 45245
(800) 779-7600

Neptune Research
1683 Latham Road
West Palm Beach, FL 33409
(407) 683-6992

Micro Capsule Engineering
12245 N. E. Whitaker Way
Portland, OR 97230-1101
(503) 256-3455

Tamms Industries
3835 State Road, 72
Kirkland, IL 60146
(815) 522-3394

Ostarr
623 S. LaGrange Road
LaGrange, IL 60525
(708) 482-9712

Permagile Industries, Inc.
101 Commercial St.
Plainview, NY 11803
(800) 645-7546

Hilti, Inc.
P. O. Box 21148
Tulsa, OK 74121
(800) 879-8000

***Repair of Cracks in Concrete***

Ostarr
623 S. LaGrange Road
LaGrange, IL 60525
(708) 482-9712

Permagile Industries, Inc.
101 Commercial Street
Plainview, NY 11803
(800) 645-7546

Tamms Industries
3835 State Road, 72
Kirkland, IL 60146
(815) 522-3394

## 2.12 PROTECTIVE COATING APPLICATION

***Protective Coatings***

Z-SPAR®
A-788 Spash-Zone Compound
Local Marine Stores

Kross Coating, Inc.
146 Flanders Drive
Hillsborough, NJ 08876
(908) 359-1367

Sika Corporation
P. O. Box 297T
Lyndhurst, NJ 07071
(201) 933-8800

Tamms Industries
3835 State Road, 72
Kirkland, IL 60146
(815) 522-3394

PCA Engineering, Inc.
177 Royal Avenue
Hawthorne, NJ 07506
(201) 427-8540

## 3.4 STEEL STRUCTURES

***Underwater Ultrasonic Thickness Indicator***

Cygnus Instruments, Inc.
P. O. Box 6417
Annapolis, MD 21701
(410) 267-9771

Krautkrammer-Branson
50 Industrial Park Road
Lewiston, PA 17044
(717) 242-0327

*Underwater Voltmeter*

Fluid Kinetics
2368 Eastman Avenue, Suite 8
Ventura, CA 93003
(805) 649-5587

*Portable Silver/Silver Chloride Reference Electrodes*

Electrochemical Devices, Inc.
P. O. Box 31
Albion, RI 02802-0031
(401) 333-6112

**4.2 SURVEY CHARTS AND MAPS** - Ordering information (also see Appendix E)

*Ways to order charts*

AUTODIN messages
SF 344s
Letters
Fax
GETAMAP, PC electronic ordering software or available from DMA

***ASGS Maps (For area of interest - East of Mississippi)*** -

U.S. Geological Survey
Earth Science Information Center
507 National Center
Reston, VA 22092
Phone: (303) 236-7477
Fax: (303) 236-1972

***(For area of interest - West of Mississippi)***

U.S. Geological Survey Map Sales
Box 25286
Denver, CO 90225

***DMA Products (For DOD agencies and their contractors)*** -

Director
DMA Combat Support Center
Attn: PMSR, Stop D-17
6001 MacArthur Boulevard
Bethesda, MD 20816-5001
Phone: (301) 227-2495;
(800) 826-0342; or DSN: 287-2495
DSN Fax: 287-2498

*NOAA Products*

Distribution Branch, NCG33
National Ocean Service, NOAA
Riverdale, MD 20737
Phone: (303) 436-6990
Fax: (301) 436-6829

**4.3 BATHYMETRIC SITE SURVEY OPERATIONS**

*Navigational Systems*

Motorola, Inc. (Federal Projects)
7230 Parkway Drive
Hanover, MD 21076
(410) 712-6268

Motorola, Inc. (Non-Federal Projects)
8201 E. McDowell Road
Mail Drop H-3170
Scottsdale, AZ 85252
(602) 441-3033

## 5.3 PIPELINES (Repair)

*Pipe Clamps and Fittings*

Dresser Manufacturing Division
Dresser Industries, Inc.
41 Fisher Avenue
Bradford, PA 16701
(814) 362-9200

Clampette, Inc.
P. O. Drawer 380250
Duncanville, TX 75138
(214) 298-1419

HydroTech Systems, Inc.
11500 Northwest Freeway
Suite 620
Houston, TX 77092
(713) 688-5277

Smith-Blair, Inc.
30 Globe Avenue
Texarkana, AR 75502
(800) 643-9708

Oceaneering Intervention Engineers
P.O. Box 929
Tomball, TX 77377-0929
(713) 351-4499

Plidco International
870 Canterbury Road
Cleveland, OH 44145
(800) 848-3333

Myers Petrochemical
4658 E. Lake Road
Loraine, OH 44054
(216) 949-8195

Rockwell International
400 North Lexington Avenue
Pittsburgh, PA 15208
(412) 247-3338

Big-Inch Marine Systems, Inc.
12235 FM 529
Houston, TX 77041
(713) 460-0003

*Flexible Pipe*

CoFlex and Services, Inc.
7660 Woodway, Suite 390
Houston, TX 77063
(713) 789-8540

Wellstream USA
1700 C. Avenue
Panama City, FL 32401
(904) 769-9471

## 5.9 TIMBER PILES (and other piles)

*Polyvinyl Chloride (PVC) Wraps*

Corrosion Technologies Northwest, Inc.
Splashzone Protection
P.O. Box 581
Kirkland, WA 98083-0581
(206) 682-5554

Ben Meadows Co.
3589 Broad Street
Atlanta, GA 30341
(800) 241-6401

Pile-Gard Osmose Marine Div.
P.O. Box 117
Griffin, GA 30224-0117
(404) 229-1537

Accessible Products Co.
(Zippertubing)
2122 West 5th Place
Tempe, AZ 85281-9990
(602) 967-8888

Denso North America, Inc.
Seashield International
18211 Chisholm Trail
Houston, TX 77060
(713) 821-0084

The Tapecoat Company
P.O. Box 631
Evanston, IL 60204-0631
(708 ) 866-8500

*Kevlar Ropes*

United Ropeworks, Inc.
151 Commerce Drive
Montgomeryville, PA 18936-9628
(215)368-6611

Whitehill Manufacturing Corporation
2540 Green Street
Chester, PA 19013
(610) 494-2378

## GENERAL SUPPLIERS

AMRON International
759 West Fourth Avenue
Escondido, CA 92025-4089
(619) 746-3834

DESCO (Diving Equipment and Supply)
240 North Milwaukie Street
Milwaukie, WI 53202
(414) 272-2371

Ben Meadows Co.
3589 Broad Street
Atlanta, GA 30341
(800) 241-6401

Mar-Vel Underwater Equipment, Inc.
Box 654
Camden, NJ 08101
(609) 962-8719

Aqua Tech Dive Center
1800 Logan Avenue
San Diego, CA 92113
(800) 345-3252

Diving Equipment Co. of America
333 E. Haley Street
Santa Barbara, CA 93101
(805) 564-1923

Diving Systems International
425 Garden Street
Santa Barbara, CA 93101
(805) 965-8538

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# Appendix B

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| To Convert | Into | Multiply By |
|---|---|---|
| Atmospheres | cm of mercury | 76.0 |
| | ft of water (4°C) | 33.9 |
| | fsw | 33.072 |
| | in. of mercury (0°C) | 29.92 |
| | $kg/cm^2$ | 1.0333 |
| | $kg/m^2$ | 10332 |
| | pounds/$in.^2$ (psi) | 14.69 |
| | $tons/ft^2$ | 1.058 |
| Bars | atmospheres | 0.9869 |
| | $kg/m^2$ | 10200 |
| | $kg/cm^2$ | 1.02 |
| | pounds/$in.^2$ (psi) | 14.5 |
| Centigrade | Fahrenheit | (°C x 9/5) + 32 |
| Centimeters | inches | 0.3937 |
| | feet | 0.0328 |
| | yards | 0.01094 |
| Centimeters of mercury | atmospheres | 0.01316 |
| | ft of water (4°C) | 0.4461 |
| | $kg/m^2$ | 136 |
| | $pounds/ft^2$ | 27.85 |
| | pounds/$in.^2$ (psi) | 0.1934 |
| Centimeters/second | feet/min | 1.9685 |
| | feet/sec | 0.03281 |
| | km/hr | 0.036 |
| | knots | 0.01943 |
| | meters/min | 0.6 |
| | miles/hr | 0.02237 |
| | miles/min | 0.0003728 |
| Cubic centimeters | cu. inches ($in.^3$) | 0.06102 |
| | cu. feet ($ft^3$) | 0.00003531 |
| | cu. yards ($yd^3$) | 0.000001308 |
| | gallons (U.S. liquid) | 0.0002642 |
| | liters | 0.01 |
| | ounces | 0.03381 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Cubic feet | cu. cm (cc) | 28320 |
| | cu. inches ($in.^3$) | 1728 |
| | cu. meters ($m^3$) | 0.02832 |
| | cu. yards ($yd^3$) | 0.03704 |
| | gallons (U.S. liquid) | 7.48052 |
| | liters | 28.32 |
| Cubic feet/minute | cu. cm/sec (cc/sec) | 472 |
| | gallons/sec | 0.1247 |
| Cubic feet/second | U.S. gallons/min | 448.8 |
| Cubic inches | cu. cm (cc) | 16.39 |
| | cu. feet ($ft^3$) | 0.0005787 |
| | cu. meters ($m^3$) | 0.00001639 |
| | cu. yards ($yd^3$) | 0.00002143 |
| | gallons (U.S. liquid) | 0.004329 |
| | liters | 0.01639 |
| Cubic meters | cu. inches ($in.^3$) | 61023 |
| | cu. feet ($ft^3$) | 35.31 |
| | cu. yards ($yd^3$) | 1.308 |
| | gallons (U.S. liquid) | 264.2 |
| | liters | 1000 |
| Feet | millimeters | 304.8 |
| | centimeters | 30.48 |
| | meters | 0.3048 |
| | miles (nautical) | O.0001645 |
| | miles (statute) | 0.0001894 |
| Feet of seawater (fsw) | atmospheres | 0.0303 |
| | in. of mercury | 0.9048 |
| | $kg/cm^2$ | 0.03124 |
| | $kg/m^2$ | 312.46 |
| | $pounds/ft^2$ | 64.0 |
| | $pounds/in.^2$ (psi) | 0.445 |
| Feet/minute | cm/sec | 0.5080 |
| | feet/sec | 0.01667 |
| | km/hr | 0.01829 |
| | meters/min | 0.3048 |
| | miles/hr | 0.01136 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Feet/second | cm/sec | 30.48 |
| | km/hr | 1.097 |
| | knots | 0.5921 |
| | meters/min | 18.29 |
| | miles/hr | 0.6818 |
| | miles/min | 0.01136 |
| Gallons (U.S.) | cu. cm (cc) | 3785 |
| | cu. feet ($ft^3$) | 0.1337 |
| | cu. inches ($in.^3$) | 231 |
| | cu. meters ($m^3$) | 0.003785 |
| | cu. yards ($yd^3$) | 0.004951 |
| | liters | 3.785 |
| | pounds of water | 8.33 |
| | gallons (Br. Imp.) | 1.20095 |
| Gallons (Br. Imp.) | gallons (U.S.) | 0.83267 |
| Inches | millimeters | 25.4 |
| | centimeters | 2.54 |
| | feet | 0.08333 |
| | meters | 0.0254 |
| | yards | 0.02778 |
| Kilograms | grams | 1000 |
| | pounds | 2.205 |
| | tons (long) | 0.0009842 |
| | tons (short) | 0.001102 |
| Kilometers | feet | 3281 |
| | miles (statute) | 0.6214 |
| | miles (nautical) | 0.534 |
| | yards | 0194 |
| Kilometers/hr | cm/sec | 27.78 |
| | feet/min | 54.68 |
| | feet/sec | 0.9113 |
| | knots | 0.5396 |
| | meters/min | 16.67 |
| | miles/hr | 0.6214 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Knots | feet/hr | 6080.2 |
| | kilometers/hr | 1.8532 |
| | meters/sec | 0.5144 |
| | statute miles/hr | 1.1516 |
| | yards/hr | 2,027 |
| | feet/sec | 1.689 |
| Liters | cu. cm (cc) | 1000 |
| | cu. meters ($m^3$) | 0.001 |
| | cu. inches ($in.^3$) | 61.02 |
| | cu. feet ($ft^3$) | 0.0353 |
| | cu. yards ($yd^3$) | 0.001308 |
| | gallons (U.S. liquid) | 0.2642 |
| Meters | inches | 39.37 |
| | feet | 3.281 |
| | miles (nautical) | 0.0005396 |
| | miles (statute) | 0.0006214 |
| | yards | 1.094 |
| Meters/minute | cm/sec | 1.667 |
| | feet/min | 3.281 |
| | feet/sec | 0.05468 |
| | km/hr | 0.06 |
| | knots | 0.03238 |
| | mile/hr | 0.03728 |
| Meters/second | knots | 1.934 |
| | feet/min | 196.8 |
| | feet/sec | 3.281 |
| | km/hr | 3.6 |
| | km/min | 0.06 |
| | miles/hr (statute) | 2.237 |
| | miles/min | 0.03728 |
| Miles (nautical) | meters | 1853.248 |
| | kilometers | 1.853248 |
| | feet | 6076.1 |
| | yards | 2025.4 |
| | miles (statute) | 1.1516 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Miles (statute) | centimeters | 160900 |
| | meters | 1609 |
| | kilometers | 1.609 |
| | feet | 5280 |
| | yards | 1,760 |
| | miles (nautical) | 0.8684 |
| Miles/hr | cm/sec | 44.7 |
| | feet/min | 88 |
| | feet/sec | 1.467 |
| | miles/min | 0.0167 |
| | km/hr | 1.609 |
| | km/min | 0.02682 |
| | knots | 0.8684 |
| | meters/min | 26.82 |
| | meters/sec | 0.447 |
| Millimeters | inches | 0.03937 |
| | feet | 0.003281 |
| | yards | 0.001094 |
| Ounces | pounds | 0.0625 |
| Ounces (fluid) | cu. inches ($in.^3$) | 1.805 |
| | liters | 0.02957 |
| | quarts | 0.0313 |
| | gallons (U.S.) | 0.0078 |
| Ounces/$in.^2$ | pounds/$in.^2$ | 0.0625 |
| Pounds | kilograms | 0.4536 |
| | ounces | 16 |
| Pounds/$ft^3$ | kg /$m^3$ | 16.02 |
| Pounds/$ft^3$ | pounds/$in.^3$ | 1728 |
| Pounds/ft | kg/m | 1.488 |
| Pounds/in. | gm/cm | 178.6 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Pounds/ft$^2$ | atmospheres | 0.0004725 |
| | kg/m$^2$ | 4.882 |
| | pounds/in.$^2$ (psi) | 0.006944 |
| Pounds/in.$^2$ (psi) | atmospheres | 0.06804 |
| | feet seawater | 2.250482 |
| | kg/m$^2$ | 703.1 |
| | pascals | 6895 |
| | pounds/ft$^2$ | 144 |
| Pounds of water | gallons | 0.12004 |
| Square feet | sq. mm (mm$^2$ | 92900 |
| | sq. cm (cm$^2$) | 929 |
| | sq. meters (m$^2$) | 0.0929 |
| | sq. inches (in.$^2$) | 144 |
| | sq. yards (yd$^2$) | 0.111 |
| | acres | 0.00002296 |
| Square inches | sq. mm (mm$^2$) | 645.2 |
| | sq. cm (cm$^2$) | 6.452 |
| | sq. feet (ft$^2$ | 0.006944 |
| Square kilometers | sq. miles | 0.3861 |
| | sq. nautical miles | 0.29155 |
| Square meters | sq. feet (ft$^2$) | 10.76 |
| | sq. inches (in.$^2$) | 1550 |
| | sq. yards (yd$^2$) | 1.196 |
| Square miles | sq. kilometers | 2.590 |
| | acres | 640 |
| Square millimeters (mm2) | sq. inches | 0.00155 |
| Square yards | sq. meters (m$^2$) | 0.8361 |
| Temperature (°C) | absolute temperature (°K) | °C + 273 |
| Temperature (°C) | temperature (°F) | 1.8 x °C + 32 |

(continued)

| To Convert | Into | Multiply By |
|---|---|---|
| Temperature (°F) | absolute temperature (°R) | °F + 460 |
| Temperature (°F) | temperature (°C) | 5/9(°F - 32) |
| Tons (long) | kilograms<br>pounds<br>tons (short) | 1016<br>2240<br>1.12 |
| Tons (short) | kilograms<br>pounds<br>tons (long) | 907.18<br>2000<br>0.8929 |
| Yards | centimeters<br>meters | 91.44<br>0.9144 |

Seawater Pressure to Head Conversion (for 64 lb/ft$^3$)

| Gauge Pressure (psi) | Head (ft) | Head (ft) | Gauge Pressure (psi) |
|---|---|---|---|
| 1 | 2.25 | 1 | 0.4445 |
| 2 | 4.50 | 2 | 0.889 |
| 3 | 6.75 | 3 | 1.33 |
| 4 | 9.00 | 4 | 1.78 |
| 5 | 11.25 | 5 | 2.22 |
| 6 | 13.50 | 6 | 2.67 |
| 7 | 15.75 | 7 | 3.11 |
| 8 | 18.00 | 8 | 3.56 |
| 9 | 20.25 | 9 | 4.00 |
| 10 | 22.50 | 10 | 4.45 |
| 15 | 33.75 | 15 | 6.67 |
| 20 | 45.00 | 20 | 8.89 |
| 25 | 56.25 | 25 | 11.11 |
| 30 | 67.50 | 30 | 13.33 |
| 40 | 90 00 | 40 | 17.78 |
| 50 | 112.50 | 50 | 22.20 |
| 60 | 135.00 | 60 | 26.70 |
| 70 | 157.50 | 70 | 31.10 |
| 80 | 180.00 | 80 | 35.60 |
| 90 | 202.50 | 90 | 40.00 |
| 100 | 225.00 | 100 | 44.50 |
| 110 | 247.50 | 110 | 48.90 |
| 120 | 270.00 | 120 | 53.30 |
| 130 | 292.50 | 130 | 57.80 |
| 140 | 315.00 | 140 | 62.20 |
| 150 | 337.50 | 150 | 66.70 |
| 160 | 360.00 | 160 | 71.10 |
| 170 | 382.50 | 170 | 75.60 |
| 180 | 405.00 | 180 | 80.00 |
| 200 | 450.00 | 200 | 88.90 |
| 250 | 562.50 | 250 | 111.10 |
| 300 | 675.00 | 300 | 133.30 |
| 350 | 787.50 | 350 | 155.50 |
| 400 | 900.00 | 400 | 177.80 |
| 500 | 1,125.00 | 500 | 222.20 |
| 600 | 1,350.00 | 600 | 266.70 |
| 700 | 1,575.00 | 700 | 311.00 |
| 800 | 1,800.00 | 800 | 356.00 |
| 900 | 2,025.00 | 900 | 400.00 |
| 1,000 | 2,250.00 | 1,000 | 445.00 |

Note: To find any feet head not in table, multiply psi by 2.25.

Note: To find psi for any not in table, multiply feet head by 0.4445.

## Fraction-Decimal-Metric Conversion

| Fraction of Inch | Decimal | MM |
|---|---|---|
| 1/64 | .015625 | 0.3969 |
| 1/32 | .03125 | 0.7938 |
| 3/64 | .046875 | 1.1906 |
| 1/16 | .0625 | 1.5875 |
| 5/64 | .078125 | 1.9844 |
| 3/32 | .09375 | 2.3812 |
| 7/64 | .109375 | 2.7781 |
| 1/8 | .125 | 3.1750 |
| 9/64 | .140625 | 3.5719 |
| 5/32 | .15625 | 3.9688 |
| 11/64 | .171875 | 4.3656 |
| 3/16 | .1875 | 4.7625 |
| 13/64 | .203125 | 5.1594 |
| 7/32 | .21875 | 5.5562 |
| 15/64 | .234375 | 5.9531 |
| 1/4 | .25 | 6.3500 |
| 17/64 | .265625 | 6.7469 |
| 9/32 | .28125 | 7.1438 |
| 19/64 | .296875 | 7.5406 |
| 5/16 | .3125 | 7.9375 |
| 21/64 | .328125 | 8.3344 |
| 11/32 | .34375 | 8.7312 |
| 23/64 | .359375 | 9.1281 |
| 3/8 | .375 | 9.5250 |
| 25/64 | .390625 | 9.9219 |
| 13/32 | .40625 | 10.3188 |
| 27/64 | .421875 | 10.7156 |
| 7/16 | .4375 | 11.1125 |
| 29/64 | .453125 | 11.5094 |
| 15/32 | .46875 | 11.9062 |
| 31/64 | .484375 | 12.3031 |
| 1/2 | .5 | 12.700 |
| 33/64 | .515625 | 13.0969 |
| 17/32 | .53125 | 13.4938 |
| 35/64 | .546875 | 13.8906 |
| 9/16 | .5625 | 14.2875 |
| 37/64 | .578125 | 14.6844 |
| 9/32 | .59375 | 15.0812 |
| 39/64 | .609375 | 15.4781 |
| 5/8 | .625 | 15.8750 |
| 41/64 | .640625 | 16.2719 |
| 21/32 | .65625 | 16.6688 |
| 43/64 | .671875 | 17.0656 |
| 11/16 | .6875 | 17.462s |
| 45/64 | .703125 | 17.8594 |
| 23/32 | .71875 | 18.2562 |
| 47/64 | .734375 | 18.6531 |
| 3/4 | .75 | 19.0500 |
| 49/64 | .765625 | 19.4469 |
| 25/32 | .78125 | 19.8438 |
| 51/64 | .796875 | 20.2406 |
| 13/16 | .8125 | 20.6375 |
| 53/64 | .828125 | 21.0344 |
| 27/32 | .84375 | 21.4312 |
| 55/64 | .859375 | 21.8281 |
| 7/8 | .875 | 22.2250 |
| 57/64 | .890625 | 22.6219 |
| 29/32 | .90625 | 23.0188 |
| 59/64 | .921875 | 23.4156 |
| 15/16 | .9375 | 23.8125 |
| 61/64 | .953125 | 24.2094 |
| 31/32 | .96875 | 24.6062 |
| 63/64 | .984375 | 25.0031 |
| 1 | 1.00 | 25.400 |

## Feet to Meters, Meters to Feet

Explanation: The second column of numbers can be referred in either direction. To the left to convert meters into feet, or to the right to convert feet into meters. For example, five lines down: 5 feet = 1.52 meters, and 5 meters = 16.40 feet.

| Feet | | Meters |
|---|---|---|
| 3.28 | 1 | 0.30 |
| 6.56 | 2 | 0.61 |
| 9.84 | 3 | 0.91 |
| 13.12 | 4 | 1.22 |
| 16.40 | 5 | 1.52 |
| 19.69 | 6 | 1.83 |
| 22.97 | 7 | 2.13 |
| 26.25 | 8 | 2.44 |
| 29.53 | 9 | 2.74 |
| 32.81 | 10 | 3.05 |
| 36.09 | 11 | 3.55 |
| 39.37 | 12 | 3.66 |
| 42.65 | 13 | 3.96 |
| 45.93 | 14 | 4.27 |
| 49.21 | 15 | 4.57 |
| 52.49 | 16 | 4.88 |
| 55.77 | 17 | 5.18 |
| 59.06 | 18 | 5.49 |
| 62.34 | 19 | 5.79 |
| 65.62 | 20 | 6.10 |
| 68.90 | 21 | 6.40 |
| 72.18 | 22 | 6.71 |
| 75.46 | 23 | 7.01 |
| 78.74 | 24 | 7.32 |
| 82.02 | 25 | 7.62 |
| 85.30 | 26 | 7.92 |
| 88.58 | 27 | 8.23 |
| 91.86 | 28 | 8.53 |
| 95.14 | 29 | 8.84 |
| 98.43 | 30 | 9.14 |
| 101.71 | 31 | 9.45 |
| 104.99 | 32 | 9.75 |
| 108.27 | 33 | 10.06 |
| 111.55 | 34 | 10.36 |
| 114.83 | 35 | 10.67 |
| 118.11 | 36 | 10.97 |
| 121.39 | 37 | 11.28 |
| 124.67 | 38 | 11.58 |
| 127.95 | 39 | 11.89 |
| 131.23 | 40 | 12.19 |
| 134.51 | 41 | 12.50 |
| 137.80 | 42 | 12.80 |
| 141.08 | 43 | 13.11 |
| 144.36 | 44 | 13.41 |
| 147.64 | 45 | 13.72 |
| 150.92 | 46 | 14.02 |
| 154.20 | 47 | 14.33 |
| 157.48 | 48 | 14.63 |
| 160.76 | 49 | 14.94 |
| 164.04 | 50 | 15.24 |
| 328.08 | 100 | 30.48 |
| 3,280.80 | 1,000 | 304.80 |

1nautical mile = approximately 1.853 km (6,080 ft)

1 statute mile = 1.609 km (5,280 ft)

Weight Equivalents

| Volume | Weight (in pounds) |
|---|---|
| 1 $ft^3$ of seawater | 64 (varies between 63.5 to 64.2) |
| 1 $ft^3$ of freshwater | 62.4 (at 32°F) |
| 1 $in.^3$ of seawater | 0.037 |
| 1 gallon of seawater | 8.55 |
| 1 $ft^3$ of air | 0.0763 (at 60°F, 1 atmosphere) |
| 1 $in.^3$ of steel | 0.284 |
| 1 $ft^3$ of brick (building) | 112-120 |
| 1 $ft^3$ of brick (fire) | 145-150 |
| 1 $ft^3$ of concrete | 120-140 |
| 1 $ft^3$ of earth | 70-120 |
| 1 $ft^3$ of gravel | 90-120 |
| 1 $ft^3$ of wood | 30-60 |

Pressure Conversion

| To Change | To | Multiply By |
|---|---|---|
| Inches of seawater | psi | 0.037 |
| Feet of seawater | psi | 0.4445 |
| Inches of freshwater | psi | 0.0361 |
| Feet of freshwater | psi | 0.4334 |
| Psi | feet of seawater | 2.25 |
| Psi | feet of freshwater | 2.307 |
| Inches of mercury | $lb/in.^2$ | 0.4912 |
| $Lb/in.^2$ | inches of mercury | 2.036 |
| Atmospheres | $lb/in.^2$ | 14.696 |
| $Lb/in.^2$ | atmospheres | 0.06804 |

Density Conversion

| To Change | To | Multiply By |
|---|---|---|
| $Lb/ft^3$ | $kg/m^3$ | 16.02 |
| $Kg/m^3$ | $lb/ft^3$ | 0.0624 |

Power Conversion

| To Change | To | Multiply by |
|---|---|---|
| Horsepower | kilowatts | 0.746 |
| Kilowatts | horsepower | 1.3404 |
| Btu | foot-pounds | 778.3 |
| Foot-pounds | Btu | 0.001285 |
| Btu | horsepower hours | 0.0003927 |
| Horsepower hours | Btu | 2,544.1 |
| Btu | kilowatt hours | 0.0002928 |
| Kilowatt hours | Btu | 3,412.75 |

Prefixes

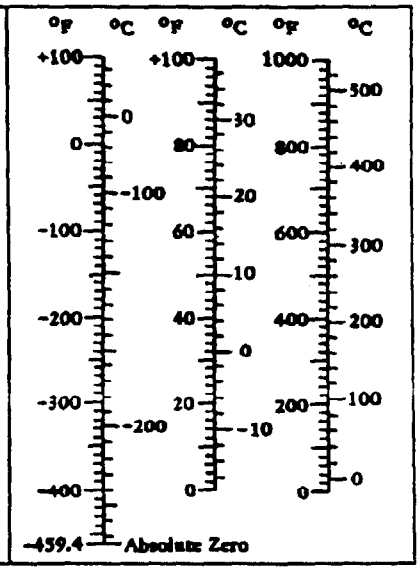
| Prefix | Symbol | Factor by Which Unit is Multiplied | |
|---|---|---|---|
| mega | M | 1,000,000 | $= 10^6$ |
| kilo | k | 1,000 | $= 10^3$ |
| hecto | h | 100 | $= 10^2$ |
| deca | da | 10 | $= 10^1$ |
| deci | d | 0.1 | $= 10^{-1}$ |
| centi | c | 0.01 | $= 10^{-2}$ |
| milli | m | 0.001 | $= 10^{-3}$ |
| micro | μ | 0.000001 | $= 10^{-6}$ |

Temperature Conversion of Fahrenheit to Centrigrade
[For approximate comparisons or conversions from one to the other.]

If exact conversions are required, use:
Deg. Fahr. = (1.8 x deg. Cent.) + 32
Deg. Cent. = 5/9 (deg. Fahr. - 32)

Example:
Convert 477 Centigrade to Fahrenheit:
Deg. Fahr. = (1.8 x 477) + 32 = 890.6

Example:
Convert 2120 Fahrenheit to Centigrade:
Deg. Cent. = 5/9 (2,120 - 32) = 1,160



Approximate Specific Gravities and Densities of Materials

| Substance | Specific Gravity | Average Density ($lb/ft^3$) |
|---|---|---|
| **Metals, Alloys, Ores** | | |
| Aluminum, cast-hammered | 2.55 - 2.80 | 165 |
| Aluminum, bronze | 7.7 | 481 |
| Brass, cast-rolled | 8.4 - 8.7 | 34 |
| Bronze, 7.9 to 14% Sn | 7.4 - 8.9 | 509 |
| Bronze, phosphor | 8.88 | --- |
| Copper, cast-rolled | 8.8 - 8.95 | 556 |
| Gold, cast-hammered | 19.25 - 19.35 | 1,205 |
| Iron, gray cast | 7.03 - 7.13 | 442 |
| Iron, wrought | 7.6 - 7.9 | 485 |
| Lead | 11.34 | 710 |
| Manganese | 7.42 | 475 |
| Mercury | 13.546 | 847 |
| Monel metal, rolled | 8.97 | 555 |
| Nickel | 8.9 | 537 |
| Steel, cold-drawn | 7.83 | 489 |
| Steel, machine | 7.80 | 487 |
| Tin, cast-hammered | 7.2 - 7.5 | 459 |
| Tungsten | 19.22 | 1,200 |
| Zinc, cast-rolled | 6.9 - 7.2 | 440 |
| **Various Solids** | | |
| Cork | 0.22 - 0.26 | 15 |
| Cotton, flax, hemp | 1.47 - 1.50 | 93 |
| Glass, common | 2.40 - 2.80 | 162 |
| Leather | 0.86 - 1.02 | 59 |
| Paper | 0.70 - 1.15 | 58 |
| Rubber goods | 1.0 - 2.0 | 94 |
| **Timber, Air-Dry** | | |
| Ash, white | 0.64 - 0.71 | 42 |
| Cedar, white, red | 0.35 | 22 |
| Chestnut | 0.48 | 30 |
| Cypress | 0.45 - 0.48 | 29 |

(continued)

| Substance | Specific Gravity | Average Density ($lb/ft^3$) |
|---|---|---|
| Timber, Air-Dry (cont'd) | | |
| Fir, Douglas | 0.48 - 0.55 | 32 |
| Fir, eastern | 0.40 | 25 |
| Elm, white | 0.56 | 35 |
| Hemlock | 0.45 - 0.50 | 29 |
| Hickory | 0.74 - 0.80 | 48 |
| Mahogany | 0.56 - 0.85 | 44 |
| Maple, hard | 0.68 | 43 |
| Maple, white | 0.53 | 33 |
| Oak, red | 0.64 - 0.71 | 42 |
| Oak, white | 0.77 | 48 |
| Pine, Oregon | 0.51 | 32 |
| Pine, red | 0.48 | 30 |
| Pine, white | 0.43 | 27 |
| Pine, Southern | 0.61 - 0.67 | 38 - 42 |
| Pine, Norway | 0.55 | 34 |
| Redwood, California | 0.42 | 26 |
| Spruce, white, red | 0.45 | 28 |
| Walnut, black | 0.59 | 37 |
| Willow | 0.42 - 0.50 | 28 |
| Various Liquids | | |
| Alcohol, ethyl (100%) | 0.789 | 49 |
| Alcohol, methyl (100%) | 0.796 | 50 |
| Acid, muriatic, 40% | 1.20 | 75 |
| Acid, nitric, 91% | 1.50 | 94 |
| Acid, sulphuric, 87% | 1.80 | 112 |
| Chloroform | 1.500 | 95 |
| Ether | 0.736 | 46 |
| Lye, soda, 66% | 1.70 | 106 |
| Oils, vegetable | 0.91 - 0.94 | 58 |
| Oils, mineral, lubricants | 0.88 - 0.94 | 57 |
| Turpentine | 0.861 - 0.867 | 54 |
| Water, 4°C, maximum density | 1.0 | 62.428 |
| Water, ice | 0.88 - 0.92 | 56 |
| Water, seawater | 1.02 - 1.03 | 64 |

(continued)

| Substance | Specific Gravity | Average Density ($lb/ft^3$) |
|---|---|---|
| **Ashlar Masonry** | | |
| Granite, syenite, gneiss | 2.4 - 2.7 | 159 |
| Limestone | 2.1 - 2.8 | 153 |
| Marble | 2.4 - 2.8 | 162 |
| Sandstone | 2.0 - 2.6 | 143 |
| Bluestone | 2.3 - 2.6 | 153 |
| **Rubble Masonry** | | |
| Granite, syenite, gneiss | 2.3 - 2.6 | 153 |
| Limestone | 2.0 - 2.7 | 147 |
| Sandstone | 1.9 - 2.5 | 137 |
| Bluestone | 2.2 - 2.5 | 147 |
| Marble | 2.3 - 2.7 | 156 |
| **Dry Rubble Masonry** | | |
| Granite, syenite, gneiss | 1.9 - 2.3 | 130 |
| Limestone, marble | 1.9 - 2.1 | 125 |
| Sandstone, bluestone | 1.8 - 1.9 | 110 |
| **Brick Masonry** | | |
| Hard brick | 1.8 - 2.3 | 128 |
| Medium brick | 1.6 - 2.0 | 112 |
| Soft brick | 1.4 - 1.9 | 103 |
| Sand-lime brick | 1.4 - 2.2 | 112 |
| **Concrete Masonry** | | |
| Cement, stone, sand | 2.2 - 2.4 | 144 |
| Cement, slag, etc. | 1.9 - 2.3 | 130 |
| Cement, cinder, etc. | 1.5 - 1.7 | 100 |
| **Various Building Materials** | | |
| Ashes, cinders | 0.64 - 0.72 | 40 - 45 |
| Cement, Portland, loose | 1.5 | 94 |

(continued)

| Substance | Specific Gravity | Average Density ($lb/ft^3$) |
|---|---|---|
| Various Building Materials (cont') | | |
| Portland cement | 3.1 - 3.2 | 196 |
| Lime, gypsum, loose | 0.85 - 1.00 | 53 - 64 |
| Mortar, lime, set | 1.4 - 1.9 | 103 |
| Mortar, Portland cement | 2.08 - 2.25 | 135 |
| Slags, bank slag | 1.1 - 1.2 | 67 - 72 |
| Slags, bank screenings | 1.5 - 1.9 | 98 - 117 |
| Slags, machine slag | 1.5 | 96 |
| Slags, slag sand | 0.8 - 0.9 | 49 - 55 |
| Earth, etc., Excavated | | |
| Clay, dry | 1.0 | 63 |
| Clay, damp, plastic | 1.76 | 110 |
| Clay and gravel, dry | 1.6 | 100 |
| Earth, dry, loose | 1.2 | 76 |
| Earth, dry, packed | 1.5 | 95 |
| Earth, moist, loose | 1.3 | 78 |
| Earth, moist, packed | 1.6 | 96 |
| Earth, mud, flowing | 1.7 | 108 |
| Earth, mud, packed | 1.8 | 115 |
| Riprap, limestone | 1.3 - 1.4 | 80 - 85 |
| Riprap, sandstone | 1.4 | 90 |
| Riprap, shale | 1.7 | 105 |
| Sand, gravel, dry, loose | 1.4 - 1.7 | 90 - 105 |
| Sand, gravel, dry, packed | 1.6 - 1.9 | 100 - 120 |
| Sand, gravel, wet | 1.89 - 2.16 | 126 |
| Sand or gravel and clay | 100 | 65 |
| Clay | 1.28 | 80 |
| River mud | 1.44 | 90 |
| Soil | 1.12 | 70 |
| Stone riprap | 1.00 | 65 |
| Stone, Quarried, Piles | | |
| Basalt, granite, gneiss | 1.5 | 96 |
| Limestone, marble, quartz | 1.5 | 95 |
| Sandstone | 1.3 | 82 |

(continued)

| Substance | Specific Gravity | Average Density ($lb/ft^3$) |
|---|---|---|
| Stone, Quarried, Piles (cont'd) | | |
| Shale | 1.5 | 92 |
| Greenstone, hornblend | 1.7 | 107 |
| Bituminous Substances | | |
| Petroleum | 0.87 | 54 |
| Petroleum, refined (kerosene) | 0.78 - 0.82 | 50 |
| Petroleum, benzine | 0.73 - 0.75 | 46 |
| Petroleum, gasoline | 0.70 - 0.75 | 45 |
| Tar, bituminous | 1.20 | 75 |

## Properties of Wood

| Wood | Color | Strength | Weight | Density | Ease of Working with Hand Tools | Resistance to Nail Splitting | Base for Finishing | Cost |
|---|---|---|---|---|---|---|---|---|
| Ash, white | grayish brown | high | heavy | hard | hard | poor | medium | medium |
| Cedar, red | red | medium | medium | medium | easy | poor | good | medium |
| Chestnut | grayish brown | medium | light | medium | easy | medium | poor | medium |
| Cypress | yellowish brown | medium | medium | soft | medium | good | poor | medium |
| Elm | grayish brown | medium | medium | medium | hard | poor | medium | medium |
| Fir, Douglas | orange brown | medium | medium | soft | hard | medium | poor | medium |
| Fir, white | off white | low | light | soft | medium | poor | poor | low |
| Hickory | reddish brown | high | heavy | hard | hard | poor | good | medium |
| Magnolia | yellowish brown | medium | medium | medium | medium | medium | good. | medium |
| Mahogany, Honduras | reddish brown | medium | medium | medium | easy | good | medium | high |
| Mahogany, Phillipine | reddish brown | medium | medium | medium | easy | good | medium | medium |
| Maple, hard | light reddish brown | high | heavy | hard | hard | poor | good | high |
| Maple, soft | reddish brown | high | medium | hard | hard | poor | good | medium |
| Oak, red | flesh brown | high | heavy | hard | hard | medium | medium | medium |
| Oak, white | grayish brown | high | heavy | hard | hard | medium | medium | high |
| Pine, eastern white | cream to brown | low | light | soft | easy | good | medium | medium |
| Pine, ponderosa | orange to brown | low | light | soft | easy | good | medium | medium |
| Pine, sugar | creamy brown | low | light | soft | easy | good | poor | medium |
| Pine, yellow | orange to brown | high | medium | medium | hard | poor | medium | medium |
| Redwood | deep reddish brown | medium | light | soft | medium | good | poor | medium |
| Spruce | off white | low | light | sof | medium | medium | medium | medium |
| Walnut | dark brown | high | heavy | hard | medium | me dium | medium | high |

## Adhesives for Bonding Common Construction Materials

| Second Substrate | First Substrate: Wood | Steel | Cloth | Concrete | Glass | Aluminum | Copper/ Brass Bronze | Ceramic Tile | Plastics | Rubber | Asphaltic Concrete |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Wood | phenol/ resorc | epoxies polyimid | casein/ starch aminos | epoxies | epoxies phenol | epoxies polyest | epoxies polyest cyanoacr polyimid | epoxies polyest | phenol/ silicones | neoprene | * |
| Steel | epoxies polyimid | PVAC phenol/ resorc | * | epoxies epox-nit | PVAC cyanoacr anaerob | PVAC cyanoacr anaeorb | epoxies polyest cyanoacr anaerob | epoxies cyanoacr | epoxies PVC | epoxies neoprene | epoxies |
| Cloth | PVAC casein | * | casein/ starch | * | casein/ starch | * | * | * | casein/ starch | * | * |
| Concrete | epoxies | epoxies | * | epoxies polyimid | epoxies polyimid | epoxies polyimid | epoxies epox-am | epoxies polyimid | epoxies | * | epoxies polyest |
| Glass | epoxies phenol/ resorc | PVAC cyanoacr anaerob | casein/ starch aminos | epoxies polyimid | cyanoacr anaerob | cyanoacr anaerob | epoxies cyanoacr | cyanoacr anaerob | PVAC PVC | neoprene | * |
| Aluminum | epoxies polyest | PVAC cyanoacr anaerob | * | epoxies polyimid | cyanoacr anaerob | epoxies polyur cyanoacr anaerob | cyanoacr polyur cyanoacr anaerob | cyanoacr epox-nitr epoxies | PVAC PVC | noeprene | epoxies |
| Copper/ Brass Bronze | epoxies polyest cyanoacr | epoxies polyest cyanoacr | * | epoxies epox-am | epoxies eyanoacr anaerob | epoxies polyur cyanoacr anaerob | epoxies cyanoacr anaerob polyimid | epoxies polyest polyimid epox-nit epox-amid | PVAC PVC | neoprene | epoxies phenol/ |

(continued)

## Adhesives for Bonding Common Construction Materials (cont'd)

| Second Substrate | First Substrate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wood | Steel | Cloth | Concrete | Glass | Aluminum | Copper/ Brass Bronze | Ceramic Tile | Plastics | Rubber | Asphaltic Concrete |
| Ceramic Tile | epoxies polyest | epoxies polyest | * | epoxies polyimid | cyanoacr anaerob | epoxies cyanoacr anaerob | epoxies polyest polyimid epox-nit epox-amid | epoxies polyest cyanoacr | polysulf | epoxies neoprene | * |
| Plastics | phenol/ resorc | eyanoacr | casein/ starch | epoxies | PVAC PVC | epoxies PVC | PVAC PVC | polysulf | polysulf | neoprene | * |
| Rubber | neoprene | neoprene | * | * | * | neoprene | neoprene | epoxies neoprene | neoprene | silicones neoprene | * |
| Asphaltic Concrete | * | epoxies | * | epoxies polyest | * | epoxies | epoxies phenol/ resorc | epoxies | * | * | epoxies polyest polyimid phenol/ resorc |

*No recommendation
anerobics (Loctite Minute Bond 312)
cyanoacrylates (Eastman 910, Permabond, Superglue, Loctite Superbonder)
epoxy-amide
epoxy-nitrile
neoprene/rubber cements (Cabroline F-1 neoprenes)
phenolics/resorcinolics
casein/Elmers glue
polyesters (Bondo, Daubond)
polyimides
polysulfule (Campbell-Odell PS-100)
polyurethanes
PVAC (polyvinylacetate)
PVC (polyvinylchloride)
silicones (GE, Dow Corning)

## Abbreviations

### A

| | |
|---|---|
| A | Ampere |
| ac | Alternating current |
| a,c.-d | Alternating current drop (NDT) |
| acfm | Absolute cubic feet per minute |
| ACU | Atmospheric conditioning unit |
| AF | Audio frequency |
| AFC | Automatic frequency control |
| AGC | Automatic gain control |
| AgCl | Silver chloride (chemical symbol) |
| Ah | Ampere-hour |
| AISI | American Iron and Steel Institute |
| AM | Amplitude modulation |
| ANSI | American National Standards Institute |
| API | American Petroleum Institute |
| ASA | American Standards Association |
| ASME | American Society of Mechanical Engineers |
| ASSY | Assembly |
| ASTM | American Society for Testing Materials |
| ata | Atmospheres (absolute) |
| atm | Atmosphere(s) |
| AVG | Average |
| AWG | American wire gauge |

### B

| | |
|---|---|
| b | Bar (unit of pressure, 1 ata) |
| bbls | Barrels |
| BDV | Breakdown voltage |
| bhp | Brake horsepower |
| BM | Bench mark |
| BOTM | Buoyant off-bottom tow method |
| BSW | British Standard Whitworth |
| Btu | British thermal unit(s) |

### C

| | |
|---|---|
| °C | Degrees Celsius/centigrade |
| cal | Calorie (unit of heat) |
| cath | Cathode |
| CB | Center of buoyancy |
| CCTV | Closed circuit television |
| CD | Chart datum |
| CD | Clearance diver (RN) |
| CDC | Commercial Diving Center (USA) |
| CDJ | Commercial Diving Journal (USA) |
| cfm | Cubic feet per minute |
| cg | Center of gravity |
| CG | Coast Guard |
| clo | Unit of clothing insulation |
| cm | Centimeter |
| $cm^3$ | Cubic centimeter |
| cm Hg | Centimeters of mercury (pressure) |
| cm $H_2O$ | Centimeters of water (pressure) |
| cmil | Circular mil |
| CNS | Central nervous system |
| CO | Carbon monoxide (chemical symbol) |
| $CO_2$ | Carbon dioxide (chemical symbol) |
| CP | Cathodic protection |
| CP | Corrosion potential |
| CPA | Critical path analysis |
| CPR | Cardio-pulmonary resuscitation |
| cps | Cycles per second |
| CRT | Cathode ray tube |
| cwt | Hundredweight |
| CWU | Compression wave ultrasonics |
| cyl | Cylinder |

### D

| | |
|---|---|
| dB | Decibel(s) |
| DB | Derrick barge |
| dc | Direct current |
| DCS | Decompression sickness |
| DDU | Deep diving unit |
| ° | Degree (plane angle) |
| D/F | Direction finding |
| dia., diam | Diameter |
| DIN | Deutsche Industrie Norman |
| DLT | Dead load testing |
| DnV | Det norske Veritas (Norway) |
| DoT | Department of Trade (UK) |
| DOT | Department of Transportation (USA) |
| DP | Dynamic positioning |
| DPV | Diver propulsion vehicle (USA) |
| DRG | Drawing |
| DSL | Deep scattering layer |
| DSRV | Deep submergence rescue vehicle |

| | |
|---|---|
| DSV | Diving support vessel |
| dwt | Deadweight tonnage |
| dyn | Dyne |

## E

| | |
|---|---|
| ECG | Electrocardiograph (heart activity) |
| ECS | Environmental control system |
| ECU | Environmental control unit |
| EDU | Experimental Diving Unit |
| EEG | Electroencephalograph (brain) |
| EHF | Extremely high frequency |
| EHP | Effective horsepower |
| ELF | Extremely low frequency |
| ELCB | Earth leakage circuit breaker |
| EMC | Electromagnetic compatibility |
| EMF | Electromagnetic force |
| EMI | Electromagnetic interference |
| EMT/D | Emergency medical technician/ diver |
| EP | Estimated position |
| ERA | Electrical Research Association |
| ESD | Emergency shutdown |
| ESV | Emergency service vessel |
| ETA | Estimated time of arrival |
| ETD | Estimated time of departure |
| Ex | Exhaust |

## F

| | |
|---|---|
| F | Farad |
| f | Frequency |
| °F | Degrees Fahrenheit |
| fa | Free alongside |
| FAO | For the attention of |
| FAX | Facsimile |
| FCAW | Flux core arc welding |
| FCV | Flow control valve |
| FET | Field-effect transistor |
| ffa | Free from alongside |
| fm | Fathoms |
| FM | Frequency modulation |
| fob | Free on board |
| foq | Free on quay |
| for | Free on rail |
| fot | Free on truck |
| fp | Freezing point |
| fpm | Feet per minute |
| fsw | Feet of seawater |
| ft | Foot |
| $ft^2$ | Square foot |
| $ft^3$ | Cubic feet |
| ft/min | Feet per minute |
| $ft^3$/min | Cubic feet per minute |
| ft/sec | Feet per second |
| ft-lbf | Foot pound-force |
| FW | Flash-butt welding |
| fwd | Forward |
| FX | Forecastle |

## G

| | |
|---|---|
| G | Gauss |
| g, gm | Gram |
| gal | Gallon |
| gal/min | Gallons per minute |
| GEV | Gigahertz |
| GFD | Ground fault detection |
| GMAW | Gas metal arc welding |
| GMT | Greenwich mean time |
| GP | General practitioner (doctor) |
| GPS | Global positioning system |
| gpm | Gallons per minute |
| GRP | Glass reinforced plastic |
| GRI | Gross registered tonnage |
| gr wt | Gross weight |
| GTAW | Gas tungsten arc welding |

## H

| | |
|---|---|
| H | Henry |
| h | Hour(s) (time taken) |
| $H^2$ | Hydrogen |
| HAT | Highest astronomical tide |
| HAZ | Heat affected zone |
| He | Helium (chemical symbol) |
| HE | High explosive |
| Heliox | Helium-oxygen mixture |
| $He/0_2$ | Heliox (gas mixture) |
| HF | High frequency |
| Hg | Mercury (chemical symbol) |
| hi/lo | Butt edge misalignment (welding) |
| HMPC | Hyperbaric Medicine Program Center (SN) |
| hp | Horsepower |
| HP | High pressure |
| HPNS | High pressure nervous syndrome |
| hrs | Hours (24 hour clock) |
| HI | High tension (electrical) |
| HV | High voltage |

| | |
|---|---|
| HW | Hgh water (tides) |
| HYD | Hydraulic |
| Hydrox | Hydrogen-oxygen mixture |
| Hz | Hertz (cycles per second) |

## I

| | |
|---|---|
| IB | In bond |
| IC | Integrated circuit |
| ICAD | Integrated control and display |
| id | Inside (internal) diameter |
| IDS | International diver's symposium (USA) |
| IF | Intermediate frequency |
| IGPM | Imperial gallons per minute |
| ihp | Indicated horsepower |
| IMEP | Indicated mean effective pressure |
| in. | Inch |
| $In.^2$ | Square inch |
| in./s | Inches per second |
| in. Hg | Inches of mercury (pressure) |
| IOD | Institute of Diving (USA) |
| IOE | Institute of Offshore Engineering |
| IOS | Institute of Oceanographic Sciences |
| IP | Indicated power |
| IR | Infra-red |
| IR | Insulation resistance |
| ISIT | Intensified silicon intensified target |
| ISO | International Standards Organization |

## J

| | |
|---|---|
| j | Joile |

## K

| | |
|---|---|
| k | Kilo (one thousand) |
| °K | Degrees Kelvin (absolute) |
| kg | Kilogram (one thousand grams) |
| $kg/cm^2$ | Kilograms per square centimeter |
| kgf | Kilograms force |
| $kgf/cm^2$ | Kilograms force per square centimeter |
| kHz | Kilohertz (one thousand hertz) |
| km | Kilometers (one thousand meters) |
| km/h | Kilometers per hour |
| kn, ki | Knot |
| $kN/m^2$ | Kilonewtons per square meter |
| kV | Kilovolts |
| kVA | Kilovolt amps (thousand volt amps) |
| kW | Kilowatt (one thousand watts) |

## L

| | |
|---|---|
| l | Liter |
| l/s | Liters per second |
| Lat | Latitude |
| LAT | Lowest astronomical tide |
| lb | Pound(s) (weight) |
| LB | Lay barge |
| $lbf/in.^2$ | Pounds force per square inch |
| lbf-ft | Pound force foot |
| LBL | Long baseline (navigation) |
| LED | Light emitting diode |
| LF | Low frequency |
| LICB | Low induction circuit breaker |
| LIM | Line insulation monitor (welding) |
| lm | Lumen |
| ln | Logarithm, natural |
| loa | Length overall |
| Log | Logarithm |
| Lo/Hy | Low hydrogen electrodes (welding) |
| Long | Longitude |
| LOP | Lack of penetration (welding) |
| LS | Locus sigilii (place of the seal) |
| LS | Lump sum |
| LSF | Lack of side wall fusion (welding) |
| LSS | Life support system (USN) |
| LT | Low tension (electricity) |
| LW | Low water (tides) |

## M

| | |
|---|---|
| ---' | Minute (plane angle) |
| μ | Micron |
| μA | Microampere |
| μM | Micrometer |
| m | Meter |
| $m^2$ | Square meter |
| $m^3$ | Cubic meters |
| mA | Milliampere |
| mb | Millibar(s) |
| MB | Motor boat |
| mbar | Millibar(s) |
| MC | Manifold center |
| MCC | Main control console (USN) |

| | |
|---|---|
| MDU | Mobile diving unit |
| MF | Medium frequency |
| mg | Milligrams(s) |
| mH | Millihenry |
| mho | Mho |
| MHW | Mean high water (tides) |
| MHWN | Mean high water neaps (tides) |
| MHWS | Mean high water springs (tides) |
| MHz | Megahertz |
| mi | Statute mile |
| mph | Miles per hour |
| MIG | Machine inert gas (welding) |
| mil | Mil |
| min | Minimum (also minute(s)) |
| MKS | Meter-kilogram-second |
| mL | Milliliter(s) |
| ML | Motor launch |
| MLW | Mean low water |
| MLWN | Mean low water neaps (tides) |
| MLWS | Mean low water springs (tides) |
| mm | Millimeter(s) |
| MMA | Manual metal arc welding |
| mm Hg | Millimeters of mercury (pressure) |
| MΩ | Megaohm |
| MOB | Mobile observation bell |
| MOS | Metal oxide semiconductor |
| MPCP | Magnetic particle crack detection |
| MPI | Magnetic particle inspection (NDT) |
| MRCC | Man-rated chamber complex (USA) |
| ms | Milliseconds |
| MSC | Military Sealift Command |
| MSL | Mean sea level |
| MSV | Multi-function service vessel |
| MSW | Meters of seawater |
| mt | Tonne (metric ton) |
| M/T | "Empty" |
| MTBF | Mean time between failure |
| MTL | Mean tide level |
| mV | Millivolt |
| MV | Megavolt |
| MV | Motor vessel |
| MWL | Mean water level |
| MW | Megawatt |
| Mx | Maxwell |

## N

| | |
|---|---|
| N | Newton |
| $N_2$ | Nitrogen gas (chemical symbol) |
| nA | Nanoampere |
| N/A | Not applicable |
| NASDS | National Association of Skin Diving Schools (USA) |
| NAUI | National Association of Underwater Instructions (USA) |
| NBS | National Bureau of Standards (USA) |
| NDAC | National Diving Advisory Council |
| NDL | No decompression limit |
| NDT | Non-destructive testing |
| Ne | Neon (gas, chemical symbol) |
| NGL | Natural gas liquid(s) |
| NHP | Nominal horsepower |
| Nitrox | Nitrogen-oxygen mixture |
| njj | "No-joint-juice" |
| nm | Nanometer |
| nmi | Nautical mile |
| NMI | No middle initial |
| $N/m^2$ | Newton(s) per square meter |
| NMRI | Naval Medical Research Institute |
| NOAA | National Oceanographic and Atmospheric Agency (USA) |
| NOHD | Nominal ocular hazard distance (lasers) |
| NPS | American straight pipe |
| NPSH | Net positive suction head |
| NPT | American Taper Pipe |
| NPT | National pipe thread |
| NPTF | National pipe thread fine (USA) |
| NRT | Net registered tonnage |
| ns | Nanosecond |
| nt | Net tonnage |

## O

| | |
|---|---|
| $O_2$ | Qxygen (gas, chemical symbol) |
| OBA | Oxygen breathing apparatus |
| OCVR | Open circuit voltage reducer |
| OD | Outside diameter |
| Ohm | Ohm |
| OMB | Mobile observation bell |
| OSHA | Occupational Safety and Health Administration (USA) |
| OTC | Offshore Technology Conference |
| OVB | Over bottom pressure |
| oz | ounce |

## P

| | |
|---|---|
| p, pp | Partial pressure (e.g., $pO_2$) |
| P, PRESS | Pressure |
| Pa | Pascal(s) (unit of pressure) |
| PA | Public address system |
| PADI | Professional Association of Diving Instructors (USA) |
| Pb | Lead (chemical symbol) |
| PBM | Pipe burying machine |
| PCV | Pressure control valve |
| PERT | Program evaluation and review technique (management) |
| pF | picofarad |
| PF | Power factor |
| PFD | Personal flotation device (USA) |
| pH | Acidity/alkalinity, measure of |
| PLS | Prolonged life support |
| PNEU | Pneumatic |
| pp | Partial pressure (e.g., $pO_2$) |
| PPB | Positive pressure breathing |
| PPI | Plan position indicator |
| ppm | Parts per million |
| ps | Picosecond |
| PRR | Pulse repetition rate |
| psi(a) | Pounds per square inch (absolute) |
| psi(g) | Pounds per square inch (gauge) |
| PTC | Personnel transfer capsule (USA) |
| PTFE | Polytetrafluoroethylene |
| PVHO | Pressure vessels for human occupancy |
| PVC | Polyvinylchloride |
| PWM | Pulse width modulation |

## Q

| | |
|---|---|
| Q | Volume flow rate |
| QED | Which had to be proved (from Latin) |

## R

| | |
|---|---|
| r | Radius |
| rad | Radian |
| RBI | Rigid bottom inflatable |
| RC | Resistance capacitance |
| R&D | Research and development |
| RF | Ratio frequency |
| RFI | Radio frequency interference |
| rh | Relative humidity |
| Rh | Rhesus factor (blood) |
| RIV | Rapid intervention vessel |
| RLC | Resistance-inductance capacitance |
| RMS | Root mean square |
| rob | Remaining on board |
| ROV | Remotely operated vehicle |
| rpm or r/min | Revolutions per minute |
| rps | Revolutions per second |
| RSJ | Rolled steel joist |
| RT | Radio telephone |
| RTJ | Ring type joint (flanging) |
| RV | Residual volume (lungs) |

## S

| | |
|---|---|
| SABA | Swimmer's air breathing apparatus |
| SAE | Society of Automotive Engineers |
| SAR | Search and rescue |
| Sat | Saturation |
| SAWS | Single atmosphere welding system |
| SBL | Short baseline (navigation) |
| SBS | Single buoy storage |
| SC | Salvaged charges |
| SCC | Stress corrosion cracking |
| SCC | Submersible compression chamber |
| scfm | Standard cubic feet per minute |
| scfm | Surface cubic feet per minute |
| SCR | Silicon-controlled rectifier |
| Scuba | Self-contained underwater breathing apparatus |
| SD | Ship's diver (RN) |
| SD | Stop depth |
| SDBA | Surface demand breathing apparatus |
| SDC | Submersible decompression chamber |
| ---" | Second (plane angle) |
| SDS | Salvage diving system |
| SDV | Silicone diode vidicon |
| SEIS | Submarine emergency identification signal |
| sg, Sp Gr | Specific gravity |
| SHF | Superhigh frequency |
| shp | Shaft horsepower |
| SI | International system of units |
| SIT | Silicone intensified target (TV) |
| SIT | Spontaneous ignition temperature |
| Sitrep | Situation report |
| SLJ | Surface life jacket |

| | |
|---|---|
| SLR | Single lens reflex |
| SMA | Shielded metal arc welding |
| SNR | Signal-to-noise ratio |
| S/N | Shipping note |
| SOP | Standard operating procedure |
| SPEC | Specification(s) |
| SPM | Single point mooring |
| SPT | Storage production terminal |
| SPU | Swimmer propulsion unit (USA) |
| SRC | Submarine rescue chamber (USA) |
| SRTJ | Swivel ring type joint (flange) |
| SS | Semi-submersible |
| SS | Steam ship |
| SSALM | Submerged single anchor leg mooring |
| SSB | Single side band (radio) |
| SSBA | Surface supplied breathing apparatus |
| SSBL | Super short baseline (navigation) |
| SSDV | Side stone dumping vessel |
| SSS | Side scan sonar |
| SSV | Surface support vessel |
| SSW | Stainless steel spiral wound gasket |
| STD | Standard |
| STP | Standard temperature and pressure |
| SUBMISS | Submarine missing (RN and USN) |
| SUB-SMASH | Submarine accident (RN and (USN) |
| SUT | Society for Underwater Technology |
| SW | Shortwave |
| SWC | Single wellhead completion |
| SWC | Submersible work chamber |
| SWG | Imperial (standard) wire gauge |
| SWL | Safe working load |
| SWR | Standing wave ratio |

## T

| | |
|---|---|
| T | Absolute temperature |
| TBP | Tethered buoy platform |
| TCV | Temperature control valve |
| TDC | Top dead center |
| TDCS | Total diver communication system |
| TDP | Touch down point |
| TIG | Tungsten inert gas (welding) |
| TL | Transfer lock |
| T/L | Total loss |
| TLP | Tension leg platform |
| TLV | Threshold limit value |
| TLV | Tolerance limit value |
| TNT | Trinitrotoluene |
| TP | Test pressure |
| TPI | Threads per inch |
| TPI | Tons per inch (immersion) |
| TSS | Total saturation system |
| TUP | Transfer under pressure |
| TV | Tidal volume (lungs) |
| TV | Television |
| TVD | True vertical depth |
| TVI | Television interference |

## U

| | |
|---|---|
| UD | Upper deck |
| UDTC | Underwater dry transfer chamber |
| UFN | Until further notice |
| UHF | Ultra high frequency (radio) |
| UNC | Unified coarse series |
| UNEF | Unified extra fine series |
| UNF | Unified fine (screw thread) |
| UNS | Unified selective series |
| UPTD | Unit pulmonary toxic dose |
| U/S | Out of service |
| USCG | United States Coast Guard |
| USGPM | United States gallons per minute |
| UT | Ultrasonic test (NDT) |
| UT | Universal time |
| UTM | Universal transverse meridian |
| UTV | Underwater tethered vehicle |
| UUV | Unmanned underwater vehicle |
| UV | Ultraviolet |
| UVS | Underwater vehicle system |
| UWH | Underwater welding habitat |
| UWT | Underwater telephone (also UQC) |

## V

| | |
|---|---|
| V | Voltage, volts |
| VA | Volt ampere |
| VAC | Vacuum |
| VC | Vital capacity (lung) |
| CVO | Voltage out off |
| VDU | Visual display unit |
| VHF | Very high frequency |
| VLF | Very low frequency (radio) |
| Vol | Volume |
| VRU | Vertical reference unit |
| VTVM | Vacuum-tube voltmeter |

| W | | X, Y, and Z | |
|---|---|---|---|
| W | Watt | XIP or XIPS | Extra improved |
| Wb | Weber | | |
| wbs | Without benefit of salvage | | |
| wef | With effect from | yd | Yard (measurement) |
| Wh | Watthour | $yd^2$ | Square yard |
| WOW | Waiting on weather | $yd^3$ | Cubic yard |
| WP | Weather permitting | | |
| WP | Working pressure | Zn | Zinc (chemical symbol) |
| WSP | Work system package | | |
| Wt | Weight | | |
| WT | Wireless telegraphy | | |

## Galvanic Corrosion

Galvanic corrosion will occur whenever two dissimilar metals are connected together electrically and immersed in seawater. The effect of this galvanic corrosion is an increase in the rate of corrosion of one of the metals and a decrease in the rate of corrosion of the other. In order to determine which metal will suffer accelerated corrosion, use the Galvanic Series table.

In the galvanic series, the metals are listed in order of their activity in seawater. The more active metal, the higher it will appear in the series. For example, if mild steel and copper are connected, the steel will corrode at a faster rate and the copper will corrode more slowly than they would if they were not connected.

The rate at which a material galvanically corrodes is dependent on many things. Combinations of metals that are widely separated on the Galvanic Series table tend to be more active than those that are closer together. The relative exposed areas of the different metals are also important. If the exposed area of the metal that is higher in the series is smaller than the exposed area of the metal that is lower in the series, then the acceleration of the attack on the more active smaller area due to galvanic corrosion will be great. If the exposed area of the metal which is higher in the series is larger than that of the metal which is lower in the serles, then the acceleration of the attack due to galvanic corrosion on the large area will be less.

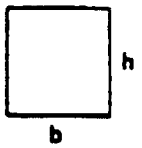
ACTIVE END
(-)
Magnesium
Zinc
Galvanized Steel[a]
6000 Series Aluminum
3000 Series Aluminum
5000 Series Aluminum
Mild Steel (New)
Alloy Steel
Mild Steel (rusted)
Cast Iron
Solder
Lead
Tin
Muntz Metal
Manganese Bronze
Naval Brass
Yellow Brass
Admirality Brass
Aluminum Bronze
Red Brass
Copper
Silicon Bronze
Cupro-Nickel 90-10
Cupro-Nickel 70-30
G-Bronze
M-Bronze
Nickel
Silver Solder
Monel
Stainless Steel
Inconel 625
Hastelloy C
Titanium
Graphite
(+)
INACTIVE END

[a]When zinc is consumed, behaves like mild steel

## Common Area and Volume Formulas

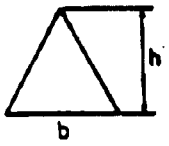
### Square and Rectangle

$A = b \times h$




### Triangle

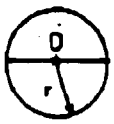
$A = 1/2 \times b \times h$




### Circle

$A = \pi/4 \times D^2$
$A = \pi r^2$

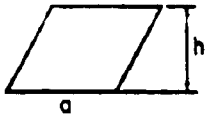
$\pi = 3.14$




NOTE:
Circumference = $\pi D$

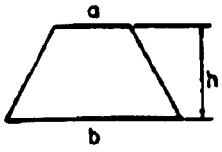
### Parallelogram

$A = a \times h$



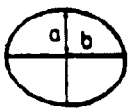

### Trapezoid

$A = 1/2 \times h \times (a + b)$



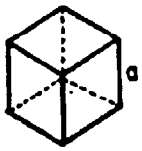

### Ellipse

$A = \pi \times a \times b$



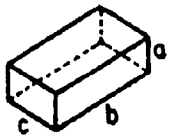

### Cube

$V = a^3$



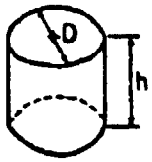

### Rectangular Parallelopiped

$V = a \times b \times c$



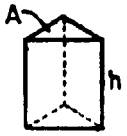

### Cylinder

$V = \pi/4 \times D^2 \times h$



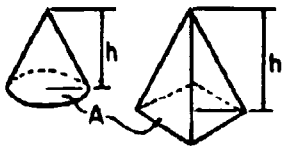

### Prism

$V = A \times h$



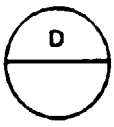

### Pyramid or Cone

$V = 1/3 \times A \times h$




### Sphere

$V = \pi/6 \times D^3$



# Common Trigonometric Calculations

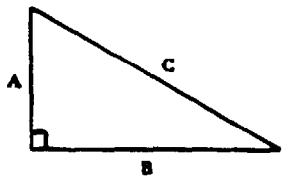
For right triangles only (where two sides of the triangle meet at 90° angles).

1. To find the length of a side when the other two sides are known:

$C = \sqrt{A^2 + B^2}$

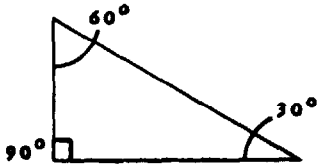
$B = \sqrt{C^2 - A^2}$

$A = \sqrt{C^2 - B^2}$




2. The sum of all the interior angles of a triangle is 180°.

Example: 90° + 60° + 30° = 180°

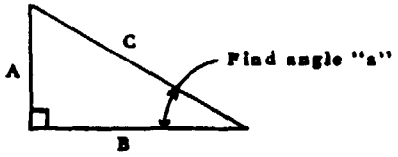



3. Finding the angle between two sides of a right triangle using a hand-held calculator; for example, if you want to find angle a and:

If A and B are known, divide A/B and press ARC TAN (or $TAN^{-1}$).

If A and C are known, divide A/C and press ARC SIN (or $SIN^{-1}$).

If B and C are known, divide B/C and press ARC COS (or $COS^{-1}$).



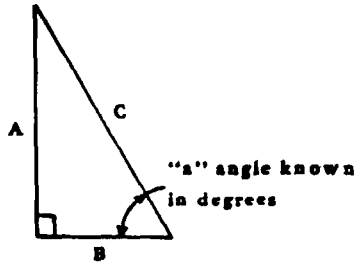

4. Finding the length of the sides of a right triangle knowing at least one side and the angle between two sides, using a hand-held calculator:

<u>To find the length of side C</u>

Knowing B: Divide B by the COS of angle a
Knowing A: Divide A by the SIN of angle a

<u>To find the length of side A</u>

Knowing B: Multiply B by the TAN of angle a
Knowing C: Multiply C by the SIN of angle a




<u>To find the length of side B</u>

Knowing A: Divide A by the TAN of angle a
Knowing C: Multiply C by the COS of angle a

## Common Buoyancy Calculations

1. **Dry weight** of an object such as steel, wood, or concrete:

Weight = density (lb/ft$^3$) x volume (ft$^3$)

$$W = D\,V$$

2. **Buoyant force** (B) is equal to the weight of the water displaced by an object:

$$B = \textit{density of water x volume of the object}$$

3. **Submerged weight** of object in water equals weight of object in air minum buoyant force:

***Definitions***

| | |
|---|---|
| Positively buoyant: | Object rises |
| Neutral buoyancy: | Object floats while submerged |
| Negatively buoyant: | Object sinks |

Submerged Weight = dry weight - buoyant force

$$W_{uw} = W - B$$

4. **Specific gravity** (SG). The density of an object in seawater, in lb/ft$^3$, can be determined by multiplying the specific gravity by 64, or in freshwater by multiplying the specific gravity by 62.4.

5. **Irregular shape volume** is calculated when the dry weight and density are known:

Volume = dry weight (lb)/density (lb/ft$^3$)

$$V = W/D_o$$

where:

| | | | |
|---|---|---|---|
| W | = dry weight | $D_{fw}$ | = density of freshwater |
| D | = density | $D_o$ | = density of object |
| V | = volume | B | = buoyant force |
| F | = force | $W_{uw}$ | = underwater (wet) weight |
| SG | = specific gravity | | |

## Approximate Formulas for Seamanship

1. **Breaking strength** (BS) of:

   - Natural fiber (manila) line = (circumference in inches)$^2$ x 900 lb
   - Nylon fiber line, three strand = (circumference in inches)$^2$ x 2,400 lb
   - 6 x 19 IWRC steel wire rope (WR) = (circumference in inches)$^2$ x 7,500 lb

(**Note**: This formula can be use for other wire ropes as a conservative "rule-of-thumb."

   - Kevlar (aramid) line = (circumference in inches)$^2$ x 7,500 lb

2. **Safe working load** for manila, nylon, polypropylene or steel wire =

   - 1/4 BS for new line or wire rope
   - 1/5 BS if polypropylene
   - 1/6 BS for average (used) condition line or wire rope
   - 1/8 BS for unfavorable applications (i.e., old line or questionable applications, multiple reeving)

3. **Safe working loads** (SWL) in tons:

   - Shackles = (diameter in inches)$^2$ x 3
   - Hooks = (diameter in inches)$^2$ x 2 or 3
   - Open link chain = (diameter in inches)$^2$ x 8

4. **Wire rope (WR) clips:**

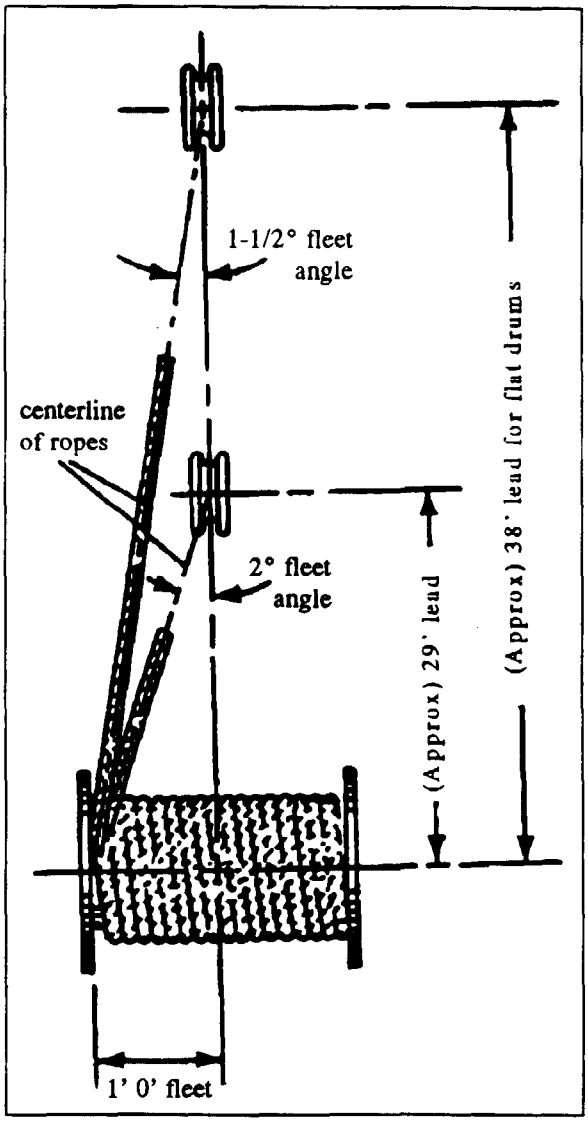
   - Number of clips is 3 x WR diameter + 1
   - Spacing of clips is 6 x WR diameter

## Fleet Angle

A fleet angle is the angle between the rope leaving the sheave and the centerline of the sheave groove. The fleet angle is important when winding a wire rope on a drum. As the rope is being wound on a drum, it wanders from one side of the drum to the other. Make sure the sheave groove is aligned with the center of the drum to minimize the maximum fleet angle. The maximum fleet angle determines the uniformity of the rope wound on the drum. If the fleet angle is small enough, the rope will wind on uniformly. If the fleet angle is too large, it will leave gaps between wraps. These gaps encourage the rope to cut into the underlayers resulting in crushing and pinching of the rope during winching operations. This situation is aggravated by the use of softer synthetic fiber lines. Large fleet angles can also cause excessive abrasion of the rope against the inner surface of the sheave groove and cause the rope to rotate forming hackles and kinks. A levelwind device may be required to ensure uniform winding if a small fleet angle cannot be achieved. This device is usually sold as an option of a deck winch. It consists of a moving sheave mounted on a shaft with diamond-shaped grooves. The shaft rotation is synchronized with the drum rotation such that the diamond grooves push the sheave to align with the wraps on the drum to achieve uniform winding. When using a deck winch with a levelwind, the sheave fleet angle is restricted only by the abrasion and rotation problems mentioned above.

Where space limitations are unrestricted such as on mine hoists, the fleet angle is sometimes as small as 1/2 of 1 degree. This is equivalent to a distance of 115 feet between the drum and the first fixed sheave for each foot of drum width. It represents the minimum below which the rope will not properly wind back from the drum flange after completing one layer.

Most installations do not permit this much distance between the drum and sheave and for average conditions it is considered good practice to keep the fleet angle within 2 degrees for a grooved drum and 1-1/2 degrees for a drum with a smooth face. Two degrees is equivalent to a distance of 29 feet and 1-1/2 degrees is equivalent to 38 feet for each foot of drum width either side of centerline of sheave as illustrated.

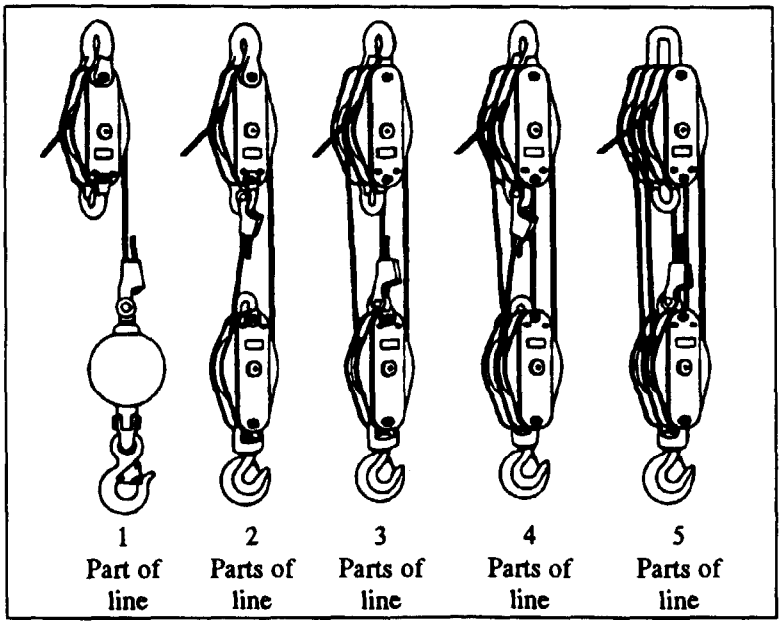


## How to Figure Line Parts

To help figure the number of parts of line to be used for a given load or the line pull required for a given load, the ratio table is provided with examples of how to use it.

**Note**: This table is for wire ropes only, the ratios for aramid ropes are much qreater.

| Number Parts of Line | Ratio for Bronze Brused Sheaves | Ratio for Anti-Friction Bearing Sheaves |
|---|---|---|
| 1 | .96 | .98 |
| 2 | 1.87 | 1.94 |
| 3 | 2.75 | 2.88 |
| 4 | 3.59 | 3.81 |
| 5 | 4.39 | 4.71 |
| 6 | 5.16 | 5.60 |
| 7 | 5.90 | 6.47 |
| 8 | 6.60 | 7.32 |
| 9 | 7.27 | 8.16 |
| 10 | 7.91 | 8.98 |
| 11 | 8.52 | 9.79 |
| 12 | 9.11 | 10.60 |
| 13 | 9.68 | 11.40 |
| 14 | 10.20 | 12.10 |
| 15 | 10.70 | 12.90 |
| 16 | 11.20 | 13.60 |
| 17 | 11.70 | 14.30 |
| 18 | 12.20 | 15.00 |
| 19 | 12.60 | 15.70 |
| 20 | 13.00 | 16.40 |
| 21 | 13.40 | 17.00 |
| 22 | 13.80 | 17.70 |
| 23 | 14.20 | 18.30 |
| 24 | 14.50 | 18.90 |




Using the ratio table ratio formula:

Ratio = Total load to be lifted/Single line pull in pounds

## Wire Rope Sheave Diameter

The radius of bend has an effect on the strength of wire rope. In order to take this fact into account in selecting the size sheave to be used with a given diameter wire rope, the following table can be used as a guide.

| D/d[a] | Strength Efficiency Compared to Catalog Strength (%) |
|---|---|
| 40 | 95 |
| 30 | 93 |
| 20 | 91 |
| 15 | 89 |
| 10 | 86 |
| 8 | 83 |
| 6 | 79 |
| 4 | 75 |
| 2 | 65 |
| 1 | 50 |

[a]Sheave diameter/rope diameter.

**For example**: Using a 1/2-inch-diameter wire rope (d) with a 10-inch-diameter sheave (D), D/d = 10 ÷ 1/2 = 20 and the strength efficiency = 91% as compared to the catalog strength of wire rope.

For long-term or permanent wire rope installations, use D/d as follows:

D/d = 30 (preferred)

D/d = 25 (satisfactory)

D/d = 15 (minimum)

For short term usage, D/d must be 10 or more for safety reasons.

## Definitions

**Proof Load** - The average force to which an item may be subjected before visual permanent deformation occurs or a force that is applied in the performance of a proof test. Usually the value of proof load is equal to 150 to 200 percent of the rated load value.

**Proof Test** - A term designating a tensile test applied to the item for the sole purpose of detecting injurious defects in the material or manufacture.

**Rated Load Value** - The maximum recommended load that should be exerted on the item. The following terms are also used for the term Rated Load: "SWL," "Safe Working Load," "Working Load," "Working Load Limit," and the "Resultant Safe Working Load." All rated load values, unless noted otherwise, are for in-line pull with respect to the centerline of the item.

**Safety Factor** - An industry term denoting theoretical reserve capability. Usually computed by dividing the catalog stated ultimate load by the catalog stated working load limit and generally expressed as a ratio, for example, 5 to 1.

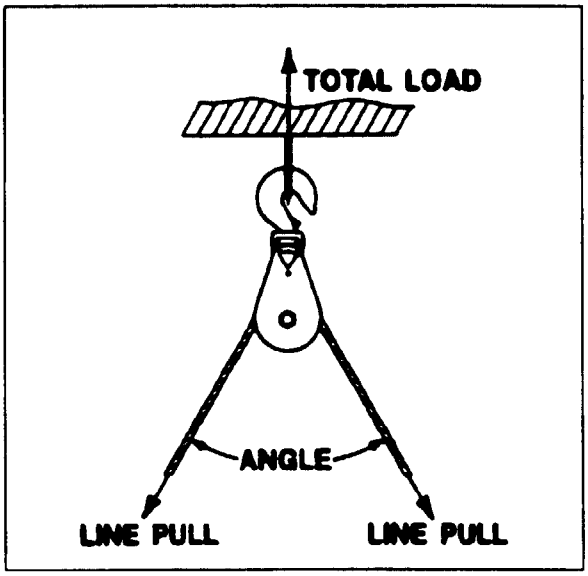
**Shock Load** - A resulting load or force from the rapid change of movement, such as impacting or jerking, of a static load. A shock load is generally significantly greater than the static load.

**Ultimate Load** - The average load or force at which the item fails or no longer supports a load.

## Sheave Loads for Fairleading or Lifting and Lift Loads for Bridles or Slings

A single sheave block that is used to change direction of a load line can be subjected to total loads **GREATLY DIFFERENT** than the weight being lifted or pulled. The amount of total load changes with the angle between the incoming and departing lines to the block.

The following chart indicates the factor that is multiplied by the line pull to obtain the total load on the block.




| Angle (deg) | Factor |
|---|---|
| 0 | 2.00 |
| 10 | 1.99 |
| 20 | 1.97 |
| 30 | 1.93 |
| 40 | 1.87 |
| 45 | 1.84 |
| 50 | 1.81 |
| 60 | 1.73 |
| 70 | 1.64 |
| 80 | 1.53 |
| 90 | 1.41 |
| 100 | 1.29 |
| 110 | 1.15 |
| 120 | 1.00 |
| 130 | 0.84 |
| 135 | 0.76 |
| 140 | 0.68 |
| 150 | 0.52 |
| 160 | 0.35 |
| 170 | 0.17 |
| 180 | 0.00 |

## Di-Lok and Stud Link Anchor Chain Dimensions and Test Requirements[a]

| Chain Size | Link Length A | Link Width B | Length Over Six Links C | Links per 15 Fathom Shot | Approx Weight per 25 Fathom Shot | Wrought Iron | | High Strength Steel | | Di-Lok | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Proof Test (lb) | Break Test (lb) | Proof Test (lb) | Break Test (lb) | Proof Test (lb) | Break Test (lb) |
| 1/2 | 3 | 1- 13/ 16 | 13 | 535 | 340 | 10,300 | 15,400 | 15,900 | 22,300 | 22,100 | 34,000 |
| 9/16 | 3-3/8 | 2 | 14-5/8 | 475 | 358 | 13,000 | 19,450 | 19,950 | 27,900 | 27,900 | 42,400 |
| 5/8 | 3-3/4 | 2-3/16 | 16-1/4 | 427 | 385 | 15,680 | 23,560 | 24,560 | 34,380 | 32,300 | 52,200 |
| 11/16 | 4-1/8 | 2-7/16 | 17-7/8 | 389 | 425 | 19,040 | 28,560 | 29,400 | 41,160 | 41,300 | 61,800 |
| 3/4 | 4-1/2 | 2-5/8 | 19-1/2 | 357 | 505 | 22,680 | 33,880 | 34,680 | 48,550 | 48,000 | 75,000 |
| 13/16 | 4-7/8 | 2-7/8 | 21-1/8 | 329 | 600 | 26,600 | 39,872 | 40,430 | 56,600 | 56,000 | 86,500 |
| 7/8 | 5-1/4 | 3-1/8 | 22-3/4 | 305 | 700 | 30,800 | 46,200 | 46,630 | 65,280 | 64,000 | 98,000 |
| 15/16 | 5-5/8 | 3-5/16 | 24-3/8 | 285 | 795 | 35,392 | 53,088 | 53,280 | 74,590 | 74,000 | 113,500 |
| 1 | 6 | 3-9/16 | 26 | 267 | 900 | 40,320 | 60,480 | 60,360 | 84,500 | 84,000 | 129,000 |
| 1-1/16 | 6-3/8 | 3-3/4 | 27-5/8 | 251 | 1,020 | 45,472 | 68,096 | 67,850 | 94,990 | 95,000 | 145,000 |
| 1-1/8 | 6-3/4 | 4 | 29-1/4 | 237 | 1,140 | 50,960 | 76,440 | 75,770 | 106,080 | 106,000 | 161,000 |
| 1-3/16 | 7-1/8 | 4-1/4 | 30-7/8 | 225 | 1,275 | 56,840 | 85,120 | 84,120 | 117,770 | 118,000 | 179,500 |
| 1-1/4 | 7-1/2 | 4-1/2 | 32-1/2 | 213 | 1,415 | 63,000 | 94,360 | 92,910 | 130,070 | 130,000 | 198,000 |
| 1-5/16 | 7-7/8 | 4-3/4 | 34-1/8 | 203 | 1,560 | 69,440 | 104,160 | 102,090 | 142,930 | 143,500 | 216,500 |
| 1-3/8 | 8-1/4 | 4-15/16 | 35-3/4 | 195 | 1,705 | 76,120 | 114,240 | 111,660 | 156,330 | 157,000 | 235,000 |
| 1-7/16 | 8-5/8 | 5-3/16 | 37-3/8 | 187 | 1,865 | 83,160 | 124,600 | 121,720 | 170,430 | 171,000 | 257,500 |
| 1-1/2 | 9 | 5-3/8 | 39 | 179 | 2,035 | 90,720 | 131,488 | 132,190 | 185,060 | 185,000 | 280,000 |
| 1-9/16 | 9-3/8 | 5-5/8 | 40-3/8 | 171 | 2,195 | 98,336 | 137,536 | 143,050 | 200,270 | 200,500 | 302,500 |
| 1-5/8 | 9-3/4 | 5-7/8 | 42-1/4 | 165 | 2,345 | 106,400 | 148,960 | 154,310 | 216,030 | 216,000 | 325,000 |
| 1-11/16 | 10-1/8 | 6-1/16 | 43-7/8 | 159 | 2,530 | 114,800 | 160,720 | 165,960 | 232,360 | 232,500 | 352,500 |
| 1-3/4 | 10-1/2 | 6-3/16 | 45-1/2 | 153 | 2,720 | 123,480 | 172,760 | 178,000 | 249,210 | 249,000 | 380,000 |
| 1-13/16 | 10-7/8 | 6-1/2 | 47-1/8 | 147 | 2,925 | 132,440 | 185,360 | 190,430 | 266,620 | 267,000 | 406,000 |
| 1-7/8 | 11-1/4 | 6-3/4 | 48-3/4 | 143 | 3,125 | 141,680 | 198,240 | 203,250 | 284,540 | 285,000 | 432,000 |
| 1-15/16 | 11-5/8 | 7 | 50-3/8 | 139 | 3,335 | 151,200 | 211,680 | 216,430 | 303,000 | 303,500 | 460,000 |
| 2 | 12 | 7-3/16 | 52 | 133 | 3,525 | 161,280 | 225,792 | 230,000 | 322,000 | 322,000 | 488,000 |
| 2-1/16 | 12-3/8 | 7-7/16 | 53-5/8 | 129 | 3,750 | 171,360 | 239,904 | 243,930 | 341,510 | 342,000 | 518,000 |
| 2-1/2 | 12-3/4 | 7-5/8 | 55-1/4 | 125 | 3,975 | 182,000 | 254,800 | 258,240 | 361,530 | 362,000 | 548,000 |

(continued)

## Di-Lok and Stud Link Anchor Chain Dimensions and Test Requirements[a]

| Chain Size | Link Length A | Link Width B | Length Over Six Links C | Links per 15 Fathom Shot | Approx Weight per 25 Fathom Shot | Wrought Iron | | High Strength Steel | | Di-Lok | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Proof Test (lb) | Break Test (lb) | Proof Test (lb) | Break Test (lb) | Proof Test (lb) | Break Test (lb) |
| 2-3/16 | 13-1/8 | 7-7/8 | 56-7/8 | 123 | 4,215 | 192,920 | 269,920 | 272,910 | 382,060 | 382,500 | 579,100 |
| 2-1/4 | 13-1/2 | 8-1/8 | 58-1/2 | 119 | 4,460 | 204,120 | 285,600 | 287,930 | 403,100 | 403,000 | 610,000 |
| 2-5/16 | 13-7/8 | 8-3/16 | 60-1/8 | 117 | 4,710 | 215,600 | 301,840 | 303,320 | 424,630 | 425,000 | 642,500 |
| 2-3/8 | 14-1/4 | 8-9/16 | 61-3/4 | 113 | 4,960 | 227,360 | 318,304 | 319,050 | 446,660 | 447,000 | 675,000 |
| 2-7/16 | 14-5/8 | 8-3/4 | 63-3/8 | 111 | 5,210 | 239,456 | 335,160 | 335,130 | 469,180 | 469,500 | 709,500 |
| 2-1/2 | 15 | 9 | 65 | 107 | 5,528 | 252,000 | 352,800 | 351,560 | 492,190 | 492,000 | 744,000 |
| 2-9/16 | 15-3/8 | 9-1/4 | 66-3/8 | 105 | 5,810 | 261,408 | 365,960 | 368,340 | 515,670 | 516,000 | 778,500 |
| 2-5/8 | 15-3/4 | 9-7/16 | 68-1/4 | 103 | 6,105 | 270,816 | 379,120 | 385,440 | 539,620 | 540,000 | 813,000 |
| 2-11/16 | 16-1/8 | 9-11/16 | 69-7/8 | 99 | 6,410 | 280,224 | 392,280 | 402,890 | 564,040 | 565,000 | 849,000 |
| 2-3/4 | 16-1/2 | 9-7/8 | 71-1/2 | 97 | 6,725 | 289,634 | 405,440 | 420,660 | 588,930 | 590,000 | 885,000 |
| 2-15/16 | 16-7/8 | 10-1/8 | 73-1/8 | 95 | 7,040 | 298,816 | 418,320 | 438,760 | 614,260 | 615,000 | 925,000 |
| 2-7/8 | 17-1/4 | 10-3/8 | 74-3/4 | 93 | 7,365 | 308,224 | 431,480 | 457,190 | 640,070 | 640,000 | 965,000 |
| 2-15/16 | 17-5/8 | 10-9/16 | 76-3/8 | 91 | 7,696 | 317,408 | 444,360 | 475,940 | 666,310 | 666,500 | 1,005,000 |
| 3 | 18 | 10-13/16 | 78 | 89 | 8,035 | 326,592 | 457,184 | 495,000 | 693,000 | 693,000 | 1,045,000 |
| 3-1/16 | 18-3/8 | 11 | 79-5/8 | 87 | 8,379 | 335,552 | 469,728 | 514,380 | 720,130 | 720,500 | 1,086,500 |
| 3-1/8 | 18-3/4 | 11-1/4 | 81-1/4 | 85 | 8,736 | 344,400 | 482,160 | 534,060 | 747,680 | 748,000 | 1,128,000 |
| 3-3/16 | 19-1/8 | 11-1/2 | 82-7/8 | 85 | 9,093 | 353,248 | 494,480 | 554,050 | 775,670 | 776,050 | 1,169,000 |
| 3-1/4 | 19-1/2 | 11-11/16 | 84-1/2 | 83 | 9,460 | 361,984 | 506,688 | 574,340 | 804,070 | 804,100 | 1,210,000 |
| 3-11/16 | 19-7/8 | 11-15/16 | 86-1/8 | 81 | 9,828 | 370,496 | 518,560 | 594,920 | 832,890 | 833,150 | 1,253,000 |
| 3-1/8 | 20-1/4 | L2-1/8 | 87-3/4 | 79 | 10,210 | 378,840 | 530,320 | 615,800 | 862,130 | 862,200 | 1,296,000 |
| 3-7/16 | 20-5/8 | 12-3/8 | 89-3/8 | 77 | 10,599 | 386,960 | 541,632 | 636,970 | 891,770 | 892,100 | 1,339,550 |
| 3-1/2 | 21 | 12-3/8 | 91 | 77 | 10,998 | 395,136 | 553,056 | 658,440 | 921,810 | 922,000 | 1,383,100 |
| 3-5/8 | 21-3/4 | 12-15/16 | 94-1/4 | 73 | 11,607 | 410,253 | 570,688 | 702,755 | 983,850 | 1,021,000 | 1,566,000 |
| 3-3/4 | 22-1/2 | 13-3/8 | 97-1/2 | 71 | 12,626 | 425,370 | 588,320 | 747,070 | 1,045,900 | 1,120,000 | 1,750,000 |

All dimensions in inches. To convert to millimeters, multiply inches by 25.4.

Note: Do not exceed 3: 1 factor on breaking strength for temporary installations, and 6: 1 for long term or permanent installations.
Example: Divide chart value of breaking strength by 3 or 6 as required for the maximum safe working load.

## Efficiencies of 3-Kip (3,000-lb) Drag Anchors with Chain in Cohesionless and Soft Cohesive Soils[a]

| Anchor Type | Efficiency | |
|---|---|---|
| | Cohesionless (Sand) | Soft Cohesive Mud |
| Stockless | | |
| 48-deg fluke angle | 5 | 2.6 (5[b]) |
| 35-deg fluke angle | 9 | --- |
| Danforth | 17 | 9.5 |
| G.S. | --- | 9.5 |
| Type 2 | 17 | --- |
| LWT | 17 | 9.5 |
| Stato with 30-deg fluke angle | 27 | 22 |
| NAVMOOR | 29 | 22 |
| Moorfast, Offdrill II with 34-deg fluke angle | 8 | 9.5 |
| Moorfast, Offdrill II with 28-deg fluke angle | 13 | 9.5 |
| Stevin | --- | 15b |
| Stevfix | 36 | 21b |
| Flipper Delta | --- | 13 |
| Stevdig | 36 | 15 |
| Boss | --- | 21 |
| Hook | 11 | 21 |
| Bruce Cast | 32 | 3.7 |
| Bruce Twin Shank | | |

[a]After Handbook for Geotechnical Engineering, March 1985, NCEL.
[b]For fixed fully opened flukes.

Holding Capacity (TM) = Efficiency (e) x Anchor Air Weight (WA)

Note: Holding capacity is with chain level with the seabed.

## Static Bollard Pull Formula

Static bollard pull is a measurement of the amount of force a tug is capable of **applying** to a tow under certain conditions. It may be approximated by multiplying the brake horsepower by 1.3 and dividing by 100, with the answer in tons, as in the formula below:

$$T = 0.013 \times BHP$$

where T is the static bollard pull

This is an approximate formula only; estimates may also be made as follows:

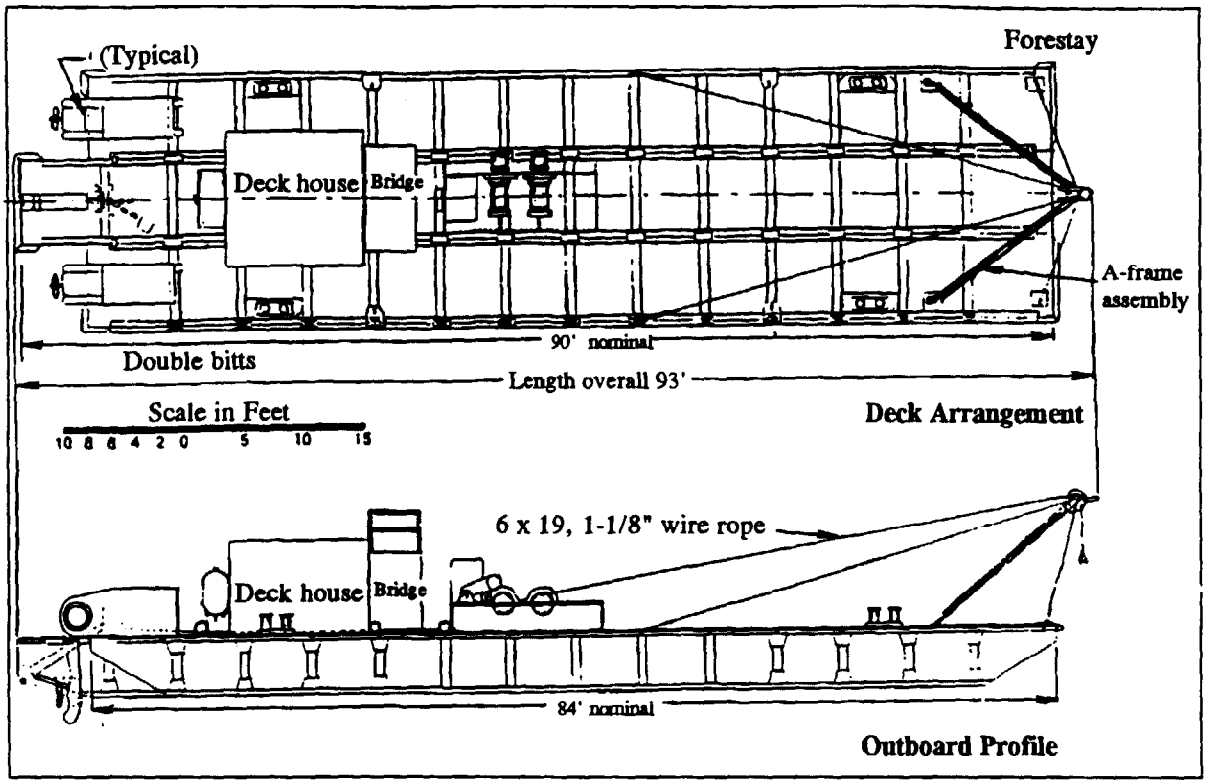
**Standard hull:** Approximately 4,400 pounds plus 23.5 pounds per bhp for open-blade propellers

**Hydroconic tugs of double chine construction:** Approximately 36 pounds per bhp

Kort-nozzle tugs: Approximately 39 pounds per bhp

**Voith-Schneider tugs:** Approximately 25.5 pounds per bhp, which is somewhat less than for conventional propellers

## 3 x 14 Standard Warping Tug Operations Platform




### Propulsion Machinery

Propulsion power for the warping tug is provided by two harbormaster marine tractors installed on the sterns of the two outboard rows of pontoons. Although many different types and sizes of these outboard propulsion units are available in Navy stock, it would appear from drawings and data furnished that the units shown are Model 0-A62, rated at 180 horsepower, each. Propellers are 5-foot-diameter by 4-foot pitch turning at 308 rpm at maximum available engine power and at about 250 rpm at rated power. Each propulsion unit can develop a dead pull thrust of up to 5,000 pounds if the propeller is adequately submerged. Each propeller can rotate about its vertical shaft through 360 degrees and can be elevated to a horizontal position by a hydraulic system powered by the engine; hydraulic reverse gears are also provided, a 32-volt electric starting system is installed in each engine. Steering, elevating, and engine operating controls are installed directly on the after side of the engine allowing the operator a clear forward view for maneuvering. Each unit is fitted with a heat exchanger for cooling and each unit weighs about 16,700 pounds. A 275-gallon fuel tank is installed on the centerline of the warping tug just forward of the two propulsion units.

### Outfit and Mission Support

The primary mission of the warping tug is to handle the pontoon causeways used in making up an LST to the beach. It tows the pontoons into position, secures them together, plants any required anchors, and then maintains tension on the system out from the beach until the LST is in position for make up. The outfit furnished to sup-

port this mission capability comprises a sheave mounted in an A-frame overhanging the bow, a double drum winch amidships, and a 2,500-pound anchor housed in a readily releasable stowage position at the stern. Four pairs of double bitts are installed for alongside towing, a deck house is installed for stowing equipment, and a small bridge structure is erected from which operations can be directed. The anchor cable passes through tunnels in these two structures along the deck centerline. All deck equipment over 4 inches in height between the launching angle and the centerline of the tug must be removed when preparing for side loading on an LST. The outboard propulsion units are used primarily for positioning and towing.

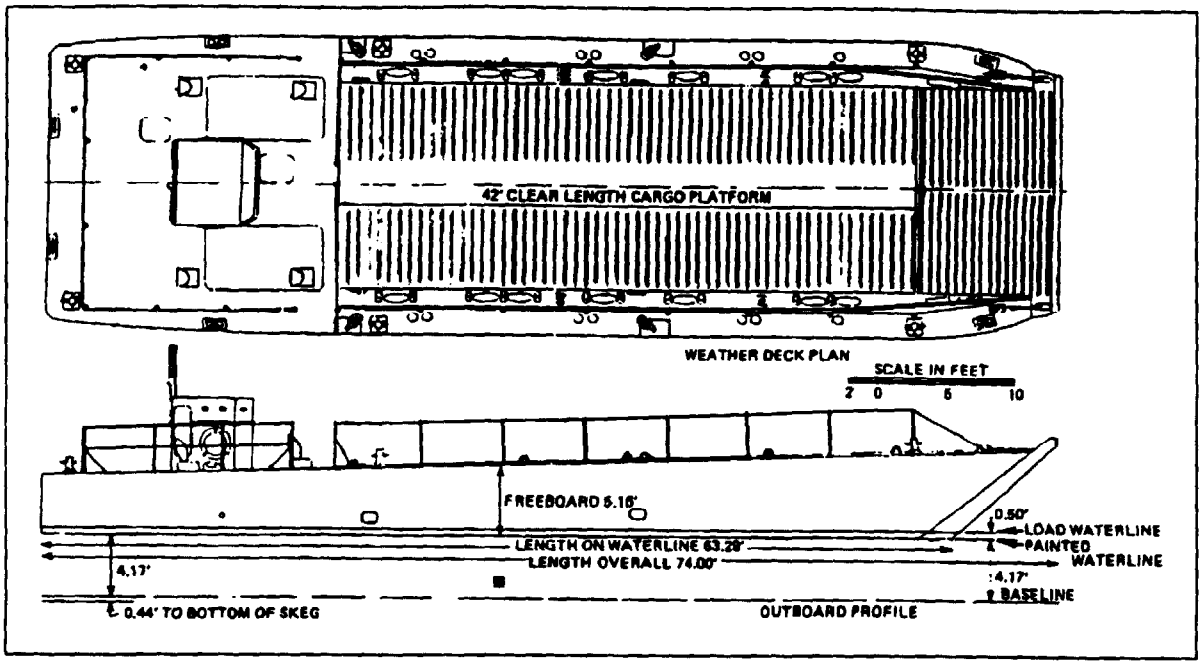
### Geometry and Hydrostatics

Warping tugs designed by the Naval Facilities Engineering Command are configured from the NL Equipment P-Series pontoons. They employ 37 of the NL P-1 rectangular pontoons and 6 of the N.L. P-2 trapezoidal pontoons used as bow and stern rake ends. The NL P-1 pontoons are 5 by 5 by 7 feet; three of these units are fitted the long dimension athwartships giving a total beam for the tug of 21.25 feet including connecting hardware. The two outboard pontoon assemblies each comprise 12 P-1 pontoons, with a P-2 pontoon at the bow and at the stern, for a total length, including hardware, of 84.25 feet. The centerline assembly has 13 P-1 pontoons with a P-2 pontoon fore and aft for a total length of 89.96 feet. This is the overall length of the basic hull, excluding fenders. Each pontoon, including its connection hardware, weighs approximately one long ton; the P-1 pontoons, with their 35 $ft^2$ waterplane area, draw about 1 foot of water. Thus, the mean draft of the assembled warping tug, before the addition of deck house, bridge, A-frame, propulsion units, and winch is very close to 1.00 foot. In this condition, the tug has a metacentric height of 46.60 feet.

### Structure

Each P-1 pontoon is constructed of 3/16-inch steel plate with 3- by 3- by 3/16-inch vertical angle stiffeners spaced 1.75 feet along the 7-foot length and 1.67-foot angle along the 5-foot dimension. These stiffeners and all joints are completely welded throughout and gussets and are provided at the corners both for securing side and deck framing and for preventing racking of the assembled unit. The P-2 pontoons are similarly constructed except that the sloping plates, used for bow and stern fairing, are 3/8 inch thick. At the four corners of the deck and at the four corners of the bottom, recessed weldments are fitted in to provide for bolts and nuts used in securing contiguous pontoons to the connecting hardware. This hardware, or "jewelry" comprises 6- by 6- by 1/2-inch steel angles and 8- by 8- by 1/2-inch steel angles, bolted to the pontoon's top and bottom, and to each other by 3/4-inch steel bolts and nuts. The entire assembled structure of the warping tug has adequate strength to withstand launching from the side of an LST and to withstand many years of exposure to the marine environment. Although this pontoon series has been discontinued, the units are still available in many military stock centers.

## LCM-8 Operations Platform




### Geometry

The LCM-8 (Model 1, Mark VIII) is a box-shaped landing craft with machinery space and propulsion aft and an open cargo well forward terminating in a ramp at the bow. Overall length, including the ramp in the stowed condition, is 74 feet. The hull length is 71.56 feet, and the load waterline length is 63.29 feet. The extreme beam is 21.05 feet and the load waterline draft is 4.50 feet above the baseline. The twin skegs aft extend 0.44 feet below the baseline giving a maximum draft at the stern of 4.94 feet. The main deck at the transom is 8.50 feet above the baseline and rises to a height of 10.75 feet above the baseline at the forward end of the hull proper; depth amidships is 9.33 feet. The cargo flat rises from 5.19 feet above the baseline aft to a maximum height of 5.93 feet above the baseline forward. The cargo well is 42 feet long by 15 feet wide.

### Hydrostatics

Displacement to the load waterline is 266,000 pounds saltwater, cargo capacity is 134,400 pounds, and the weight of the craft, fully fueled and provisioned, is 131,600 pounds.

### Structure

The basic structure is of all-welded steel, although later models have been constructed of welded aluminum which saves approximately 22,000 pounds in hull weight. Transverse frames are spaced at 1.5 feet with a transverse watertight bulkhead every fourth frame; transverse floors are installed halfway between bulkheads, longitudinal framing consists of bottom stringers and longitudinal deck girders spaced every 1.5 feet off the centerline. A longitudinal truss runs the entire length of the hull along the centerline and additional

trusses run the length of the cargo compartment, 4.58 feet off the centerline port and starboard to give the cargo flat the capacity to carry the concentrated loading of an M-48 or an M-60 tank (approximately 48 tons) of the distributed load of 60 tons of cargo. The wing walls running along the length of the cargo compartment are divided into eight watertight tanks port and starboard.

### Machinery

Main propulsion comprises two twin Detroit diesel engines, Model 12005A starboard and 12005B port. These are six cylinder engines with a bore of 4.25 inches, a stroke of 5 inches, and a displacement of 425 $in.^2$ per engine. All four engines are rated at 300 horsepower each at 1,800 rpm with the starboard engine having right-hand rotation and the port engine, left-hand rotation. Both pairs of engines are fitted with an Allison hydraulic transmission. They are started either electrically or hydraulically. The main engines are freshwater cooled by 9-gallon per engine capacity systems which in turn are cooled by seawater pumped through a pair of heat exchangers. All pumps are driven off the main engines. The LCM-8 is fitted with a hydraulic steering system which operates the two rudders in tandem.

### Outfit

The bow ramp is both raised and lowered hydraulically by a pair of winches located below the cargo flat forward of the engine compartment. These winches may be operated individually or in tandem to achieve greater hoist speed. Emergency lowering by gravity is provided together with emergency raising by means of a chain hoist. A 75-pound anchor with 3/8-inch chain has to be manhandled overboard when required. On some models, a portable canopy cargo cover is provided. Lifting eyes, cargo lashing fittings, bitts, and cleats are provided. The vessel is equipped with a remote magnetic heading system, static isolation equipment, and four radio sets: AN/GRC-106, AN/SRC-32, AN/VRC-46, and AN/VRC-47.

### Speed and Propulsion

The craft is fitted with two, 3-bladed 34-inch-diameter by 24-inch pitch propellers, right-hand on the starboard shaft and left-hand on the port shaft. Each propeller is designed to absorb 600 horsepower at an engine speed of 1,800 rpm. Maximum speed in the loaded condition is 9 knots. Fuel capacity is 864 gallons and range at cruising speed is about 150 nautical miles in the loaded condition.

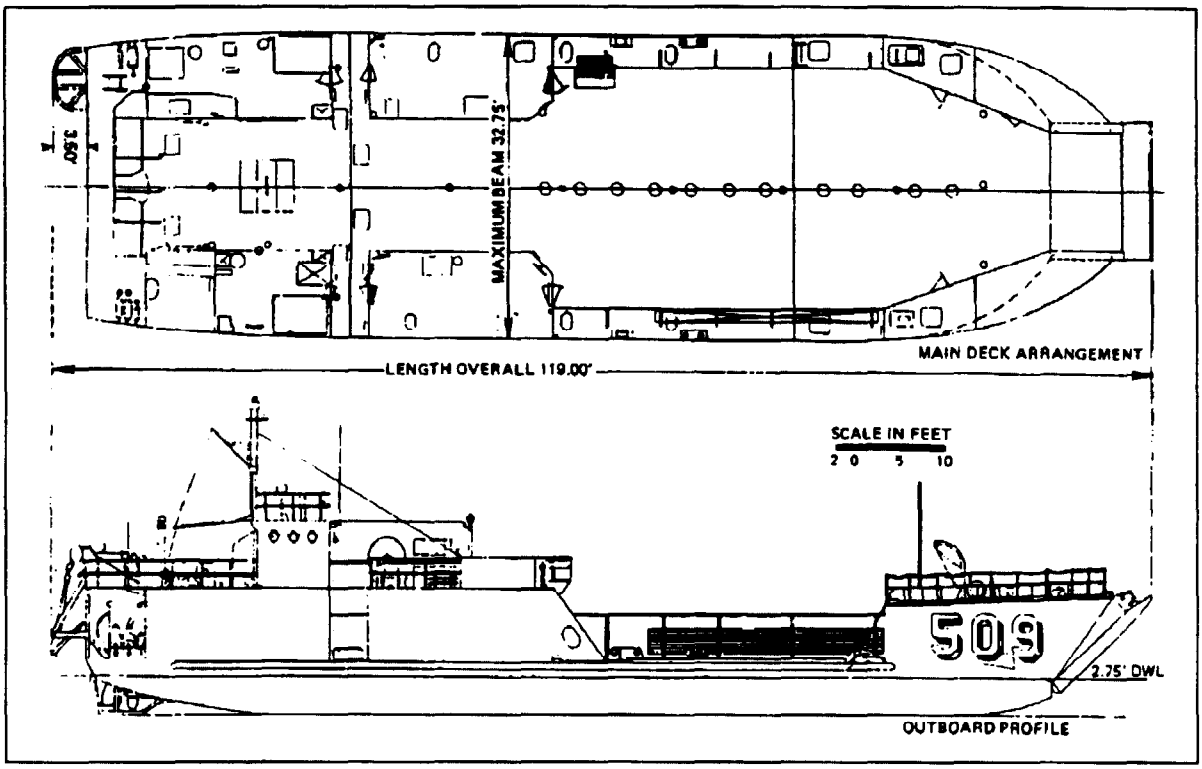
### Maneuvering and Control

Engine starting, speed, and rotation direction of both twin engines are controlled from the pilot house. A pair of handles activates linkages that operate clutches, throttles, and reverse gears in sequence with fore and aft motion of the handles. A steering wheel on the control sand, through a hydraulic telemotor system, operates pistons that actuate rudder motion for steering. Rudders, approximately 3-$ft^2$ each, are directly behind the two propellers giving good ahead maneuvering control. Astern maneuvering control is most effectively accomplished by altering rotation direction of the port and starboard propellers.

**Mission Support**

The LCM-8 landing craft is designed to transport cargo, troops, and vehicles from ship-to-shore, shore-to-shore, or in retrograde movements. It may be used for lighterage and utility work in harbors. It is intended for use in rough or exposed waters and is capable of operating through breakers and grounding on a beach due to the stiffening and slope of the forefoot. Propellers and rudders are protected from bottoming stresses by skegs. A bow ramp with traction treads is provided for offloading vehicles to a beach. The cargo deck is also fitted with traction treads and is adequately structured to support live loads. Provision is made for securing cargo and protecting it from seaway motions.

## LCU-501 Class Operations Platform




### Geometry and Hydrostatics

The LCU-501 class of utility landing craft were originally rated as landing craft, tank (LCT(6)). In 1949, they were redesignated as utility landing ships (LSU) to reflect varied employment. In 1952, the designation was changed to utility landing craft (LCU) and they were classified as service craft. There are presently 23 active utility landing craft in the LCU-501 class series, the LCU-509, which was reclassified as YFU-54 in March of 1966, is typical of this class. The total overall length including the stern anchor brace is 119 feet. The actual hull length is 114.5 feet. The length between perpendiculars is 105 feet. Extreme beam is 32.75 feet and the depth to the vehicle deck amidships is 5.5 feet, with a bulkwark extending up to 10 feet above the baseline. The mean design draft is 3.75 feet to the molded baseline. Height to the top of the forward anchor light mast from the design waterline is 21.17 feet and the height to the top of the main mast from the design waterline is 44.08 feet. When the mast is stowed on deck, the highest point is the T.C.S. antenna atop the pilot house. The height of the top of this antenna from the design waterline is 27.08 feet. Light displacement is 140 tons saltwater and load displacement is 310 tons saltwater. Quarters are provided for the 2 CPOs and 11 crew members in three 3-tier berths and two 2-tier berths.

### Structure

The vessel is constructed of all welded steel. Transverse frames are spaced 2 feet from the fore perpendicular through frame 52 which is 1 foot forward of the transom. The structural support for the cargo deck is provided by eight transverse bulkheads.

Nontight longitudinal bulkheads, 3.5 feet off centerline, run the entire length and watertight bulkheads, 10.75 feet off centerline, run 82 feet through the engine room to the fore peak tank. These ships were constructed in three sections for transportation to advance bases. The forward section extended 30 feet from the fore perpendicular to frame 15, with the bow ramp in the raised position, the total length of this section is 39.5 feet. The midsection extended from frame 15 to frame 39 for a total length of 48 feet. The after section extended from frame 39 to the transom with a total length over the anchor brace of 31.5 feet. It is probably that the joints between sections are permanently welded on all existing vessels of this class.

**Outfit**

The stern anchor is stowed over the port side of the transom for ready release and retrieval during beaching operations. The anchor winch is located on the poop deck port side above the crews quarters. The bow ramp is lowered by gravity and raised with a block and tackle arrangement using a hand ramp hoist on the starboard side or a powered ramp winch on the port side. A lever arm, similar to a gaff boom, is welded to the base of the main mast and extends aft where a stay connects the end to the upport part of the mast and a cable runs down to a hand winch mounted on the poop deck, starboard side, that is used for lowering the mast to a horizontal position along the pilot house top. A forestay and braces are fitted to support the mast when it is cranked up to the vertical position. A grating walkway at poop deck level connects the port and starboard deck houses for athwartship access. This walkway can be removed for moving vehicles along the main deck aft.

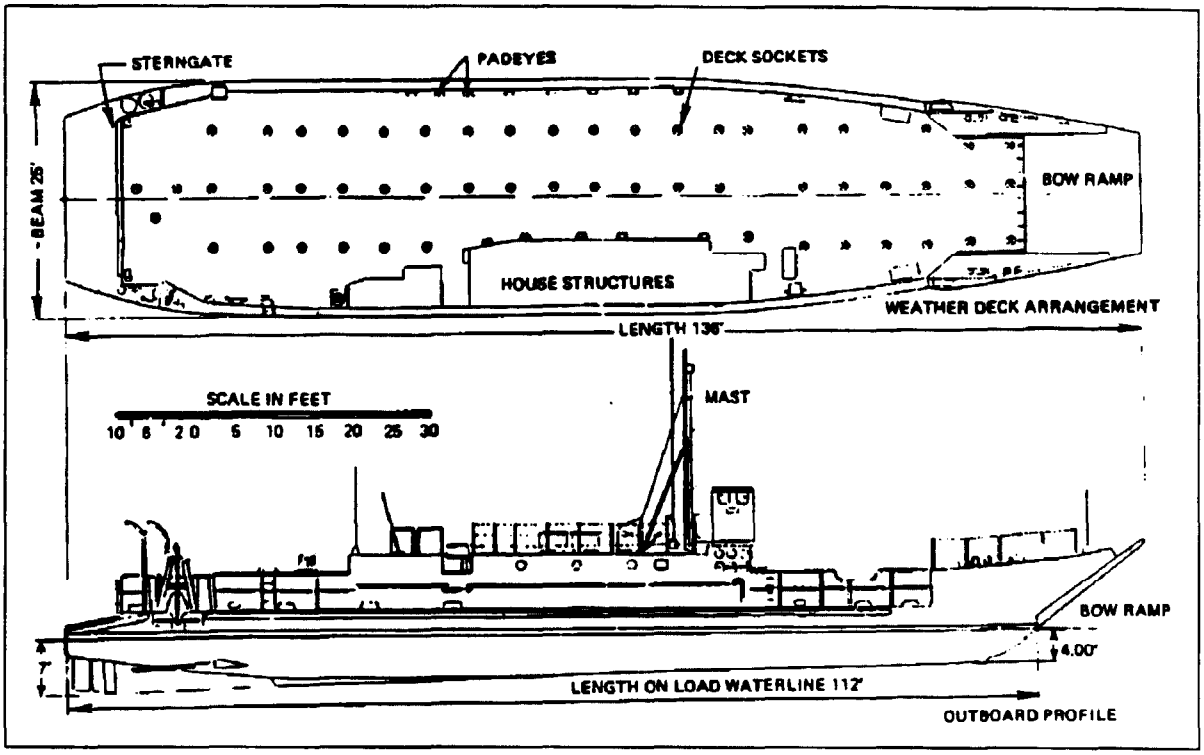
**Machinery and Propulsion**

The LCU-501 class landing craft are propelled by three 225-brake-horsepower gray marine diesel engines. The propulsion system drives the ships at a maximum speed of 9 knots. At a cruising speed of 7 knots, the 11.12-ton fuel capacity gives a range of 700 nautical miles.

**Mission Support**

The LCU-509, which is typical of the LCU-501 class series, is a light but extremely rugged vessel designed for direct "on the beach" loading and unloading. The nature of the vessel also permits loading and unloading at the stern. Having a light draft, it is ideally suited for operation on inland waterways, or on any other shallow water. Equipped with a bow ramp, cargo such as vehicles and livestock can be driven directly from the beach onto the craft. The vessel is capable of transporting a maximum of four tanks or 200 tons of cargo. The bottom is especially designed for "beaching" with a resulting minimization of danger from snags and sandbars. Docking facilities are not required.

## LCU-1610 Class Operations Platform




### Geometry and Hydrostatics

There are some 47 active utility landing craft in the LCU-1610 series; four others have been reclassified as YFBs and seven as YFUs. These ships have an overall length of 136.25 feet and a length between perpendiculars of 134 feet. Beam is 29 feet and depth to the vehicle deck amidships is 8 feet with a bulkwark extending up to 12.5 feet. Landing displacement, carrying three T-43 tanks, is 374 tons which gives a draft forward of 3.92 feet and a draft aft of 7.13 feet. Light displacement is 193 tons. The ships are fitted with both a bow ramp and a stern gate to allow through passage of vehicles; all house structure is on the starboard side only. Maximum height to the top of the mast is 34.13 feet above the design waterline. When the mast is stowed on deck, the highest point is the radar atop the pilot house which is 20.63 feet above the waterline. Berths are provided for two CPOs, a crew of four, and eight transients.

### Structure

The vessel is constructed of all-welded steel (except for LCU-1637, which is aluminum) with transverse frames spaced at 1.75 feet throughout the entire length. Fourteen transverse bulkheads provide structural support for the cargo deck; each bulkhead is stiffened with tee-beams spaced at 1.75 feet. There are no longitudinal structural bulkheads within the hold but 12-inch-deep web-plate keelsons and longitudinal deck girders run the entire length of the ship, 4.5 feet off centerline port and starboard. These are supplemented by hull and deck longitudinals spaced 1.75 feet to give adequate support for carrying 60-ton tanks on the cargo deck.

## Outfit

Lifesaving equipment includes one 15-man inflatable lifeboat and four life rings. Cleats, chocks, and bitts are installed along the deck edge port and starboard sufficient for line handling. The stern anchor is stowed hanging from an A-frame on the starboard side aft at frame 70; the anchor line runs through fairleads to the anchor windlass compartment in the hold where the winch drum is on the centerline between frames 64 and 65. The stern gate is handled by a pair of deck winches and a pair of davits located just forward of the gate on the cargo deck port and starboard. The bow ramp winch is located in the ramp handling machinery compartment in the hold forward with cables passing through the port and starboard void spaces between the cargo deck and the forecastle deck. Ramp raising and powering controls are located on the starboard side forward.

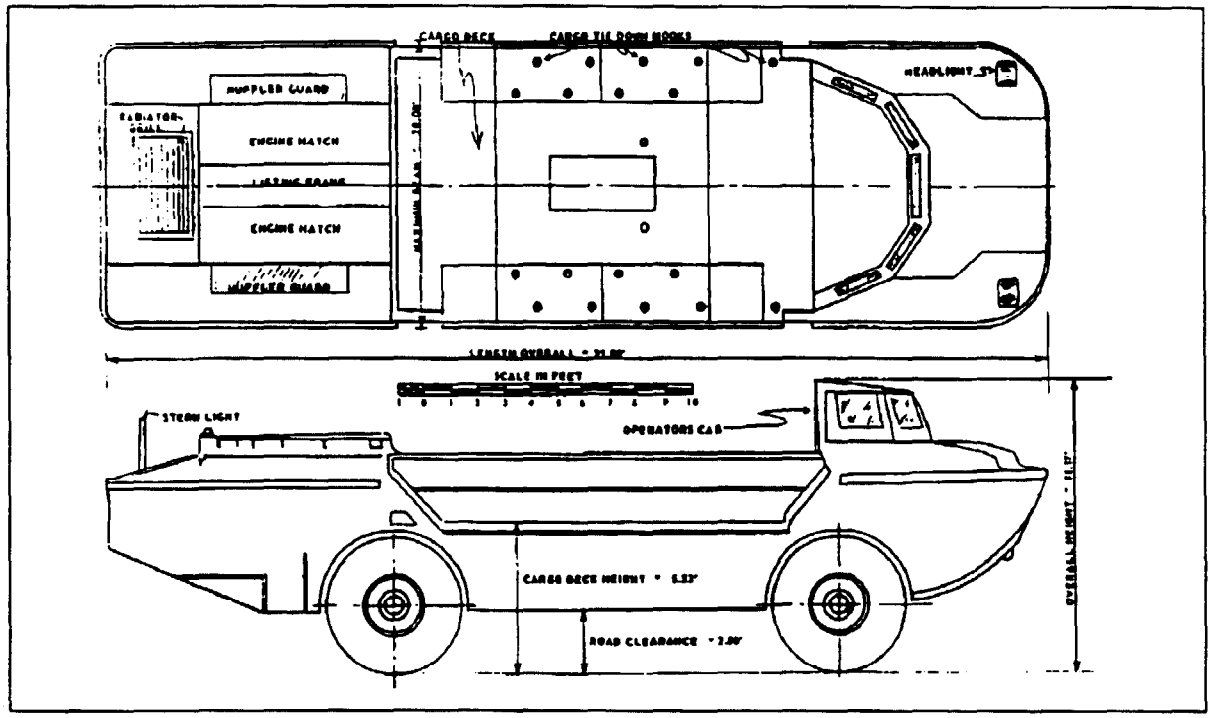
## Machinery and Propulsion

The conventional ship of this class is propelled by four 250-brake-horsepower diesel engines coupled through reverse-reduction gears to two shafts. The 3.5-foot-diameter propellers are housed in 4.5-foot-diameter Kort nozzles to increase dead pull performance, with conventional rudders abaft each propeller. The design shown in the accompanying drawings is powered by the two 500-bhp engines that are used on a few ships of this class and also has a pair of flanking rudders forward of each main screw for improved maneuvering performance in the astern mode of operation. In all ships, engine throttle and reverse controls are actuated on the bridge from the main steering stand. This propulsion system drives the ships at a maximum speed of 10.2 knots. At a cruising speed of 8 knots, the 3,840-gallon fuel capacity gives a range of 1,200 nautical miles. Electric power is provided by two diesel-generators, one located in the forward engine room and one in the after engine room, together with the corresponding power distribution switchboards.

## Mission Support

With the stern gate and bow ramp up, in the seagoing condition, the clear length along the cargo deck is 112.75 feet. Ahead and astern of the deck house structure the clear deck width is 22 feet and abreast of the deck house structure it is 18 feet. The bow ramp width is 14.5 feet and the stern gate is 19 feet wide. Throughout this area, deck sockets are spaced every 5 feet fore and aft and in three parallel rows, 7 feet apart athwartships. In addition, bumper sockets are installed along the rail, port and starboard, and numerous padeyes are provided for lashing down heavy cargo. These vessels are so constructed that they can be cut into three separate sections for overseas transport with field cutting lines between frames 27 and 28, just forward of the deck house, and between frames 49 and 50, at a break in the deck house structure. Although the basic mission of the LCU-1610 class is as a logistics platform with beaching capabilities, this class of vessels can readily be converted to serve in a number of ocean construction work platform capacities, particularly those requiring clear deck space and through passage, fore and aft.

## LARC V Operations Platform




### Geometry and Hydrostatics

The LARC V (lighter amphibious resupply cargo) is a vehicle capable of being operated on both land and water. The amphibious lighter has an overall length of 35 feet, a maximum width over the fenders of 10 feet, and a maximum height to the top of the cab of 10.17 feet. The total net weight, dry, is 19,000 pounds, while the total gross weight is approximately 30,000 pounds. The cargo deck, which is capable of transporting a maximum payload of 10,000 pounds, is 16 feet long, 9.75 feet wide, and 2.42 feet deep. There is a loaded clearance of 2 feet between the hull and the ground. An overhead clearance of 10.33 feet is required for the transportation of the LARC V.

### Structure

The vehicle is constructed with an aluminum frame supporting an aluminum hull, deck, and cab. The lighter is mounted on four rigidly supported wheels and the structure is designed to support the total craft weight on diagonally opposite pairs of wheels over the range of vertical accelerations that may be encountered. An aluminum canopy can be installed to cover the cab in case of inclement weather. The flush deck has a high center of gravity which facilitates the self-bailing feature.

### Outfit

The vessel requires a crew of two persons for its operation. The cargo deck is fitted with ten cargo tiedown hooks and four load centering devices. There are two headlights located at the front of the vehicle and one stern light. To provide access to the engine, the vehicle has two engine hatches, two muffler guards, four engine hatch handles, and one lifting frame. Two manual bilge pumps are incorporated for use if the three hydraulic bilge pumps fail. A marker

buoy locates the light if it should sink in less than 100 feet of water. Four 18 x 25 tires with a 12-ply rating are used to support the vehicle. Pressures of 9 and 18 psig are recommended for the front tires for soft and hard terrain, respectively, while 14 and 22 psig are recommended for the rear tires on soft and hard terrain, respectively. Four dry-charged, 12-volt, 100-ampere-hour batteries are used. The two fuel tanks have a capacity of 72 gallons each.

**Machinery and Propulsion**

The engine is an industrial gasoline engine of 270 gross horsepower at 3,200 rpm of which 30 horsepower is consumed in the auxiliary equipment leaving 240 horsepower for propulsion. For water propulsion, a 30-inch-diameter, 30-inch pitch propeller is used which is located in a housing at the rear of the craft with a road clearance of 1.33 feet. The lighter is capable of traveling at a maximum speed of 30 mph on land and 10 mph in the water. The high range operating radius with no load on land is 250 miles and is 40 miles in water. For a full load, this operating radius is decreased to 200 miles on land but remains 40 miles in the water. Speed loss due to wave action is to be expected and is different only in degree between the amphibian and a vessel of similar dimensions. For the LARC V, speed losses compared to still-water speed at 225 propeller horsepower are 2 percent for 1.2-length wave, 16 percent for the 2-length wave, and 7 percent for the 4-length wave. The critical wave length for the LARC V is 200 feet.

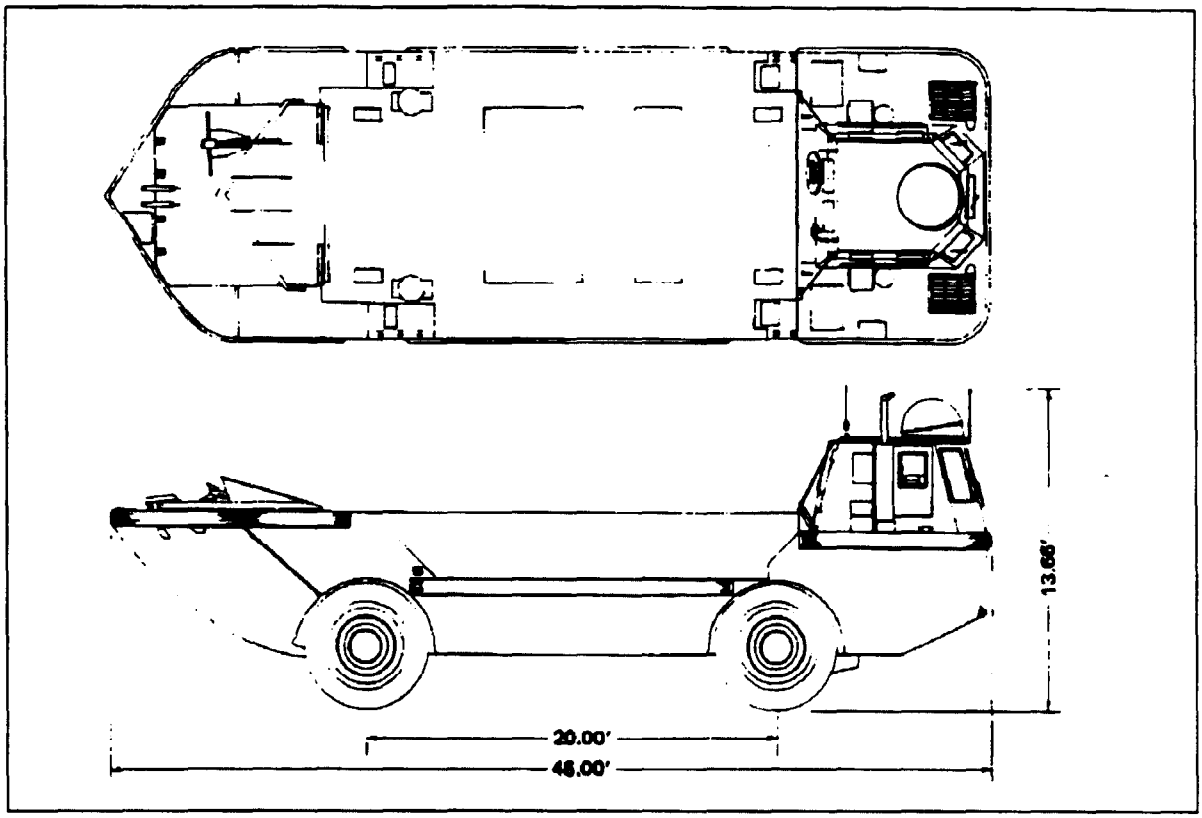
**Maneuvering and Control**

The power steering system on the amphibious lighter will permit relatively easy steering. Basically, the steering on land is accomplished by full hydraulic power and in water by the rudder. The type of terrain (sand, mud, or hard roads) will affect land steering as with any automotive vehicle. Under ideal conditions such as hard smooth surfaces, the outside turning radius is 35.6 feet while the inside radius is 26.5 feet. The turning radius will increase as the terrain becomes softer. The lighter is capable of being steered if the hydraulic power should be lost but much more steering effort will be required; in water the steering wheel will turn the front wheels and the rudder at all times. Broaching in seas is possible. The operator must shift to wheel drive in following seas. The amphibious lighter is capable of going up extremely steep grades as high as 60 percent. The vehicles have an angle of approach of 31 degrees and an angle of departure of 28 degrees.

**Mission Support**

The aluminum amphibious lighter is used to carry cargo from an offshore supply ship to a beach for advanced base supply with a total cargo capacity of 10,000 pounds. It also serves as a dive boat or power supply for underwater work. It also can be used for moving personnel and equipment across both land and water from a base to a construction site.

## LARC XV Operations Platform




### Geometry and Hydrostatics

The LARC XV (lighter amphibious resupply cargo) is a vehicle which is capable of being operated on both land and water. The amphibious lighter has an overall length of 45 feet, a maximum width of 14.5 feet, and a maximum height to the top of the cab of 13.7 feet. The total weight is approximately 75,000 pounds. The cargo deck, which is capable of transporting a maximum payload of 30,000 pounds, is 24 feet long, 13.5 feet wide, and has a depth of 3.2 feet. There is a loaded clearance of 1.5 feet between the hull and the ground. Freeboard is 15 inches.

### Structure

The vehicle is constructed with an aluminum frame supporting an aluminum hull, deck, and cab. The lighter is mounted on four rigidly supported wheels and the structure is designed to support the total craft weight on diagonally opposite pairs of wheels over the range of vertical accelerations that may be encountered. The flush deck has a high center of gravity which facilitates the self-bailing feature.

### Outfit

The vessel requires a crew of two persons for its operation. The cargo deck is fitted with cargo tiedown hooks. There are two headlights located at the front of the vehicle and one stern light. The vehicle has engine and driveline hatches. Manual bilge pumps are incorporated for use if the hydraulic bilge pumps fail. Four 24 by 29 tires with a 16-ply rating are used to support the vehicle. On soft or hard terrain, deflate the

bow tires to 18 psi and the stern tires to 25 psi. For snow or mud, deflate the bow tires to 12 psi and the stern tires to 20 psi. Four dry-charged, 12-volt, 100-ampere-hour batteries are used. The diesel fuel tanks have a total capacity of 360 gallons.

### Machinery and Propulsion

The engine is an industrial diesel engine of 300 gross horsepower at 3,000 rpm. For water propulsion, a 4-bladed propeller with Kort nozzle is used. The lighter is capable of traveling at a maximum speed of 30 mph on land and 9.5 mph in the water. The high range operating radius with no load on land is 200 miles and is 120 miles in water. Speed loss due to wave action is to be expected and is different only in degree between the amphibian and a vessel of similar dimensions.

### Maneuvering and Control

The power steering system on the amphibious lighter will permit relatively easy steering. Basically, the steering on land is accomplished by full hydraulic power and in water by the wheels and the rudder. The type of terrain (sand, mud, or hard roads) will affect land steering as with any automotive vehicle, under ideal conditions such as hard smooth surfaces the outside turning radius is 55 feet. The turning radius will increase as the terrain becomes softer. The lighter is capable of being steered if the hydraulic power should be lost but much more steering effort will be required; in water the steering wheel will turn the wheels and the rudder at all times. The amphibious lighter is capable of going up extremely steep grades as high as 40 percent. The vehicles have an angle of approach of 22 degrees and an angle of departure of 30 degrees. The LARC XV can negotiate 12-foot surf.

### Mission Support

The aluminum amphibious lighter is used to carry cargo from an offshore supply ship to a beach for advanced base supply with a total cargo capacity of 30,000 pounds. It also serves as a dive boat or power supply for underwater work. It also can be used for moving personnel and equipment across both land and water from a base to a construction site. Bollard pull in water is 7,700 pounds.

## Modular Construction Platform

The Modular Construction Platform (MCP) is a mobile and floating work platform designed to support UCT ocean construction operations where sea support vessels are not available. It is powered by two marine outboard propulsion units. Deck equipment on the platform includes an articulating knuckle boom crane, a single-drum winch, and an A-frame.

The modular construction platform provides diver support and transportation for inspection, construction, and repair operations. The MCP may be quickly assembled and launched for use in contingency operations. Missions include cable and small pipeline installation, inspection an repair, site surveying, and underwater and waterfront pier and structure repair.

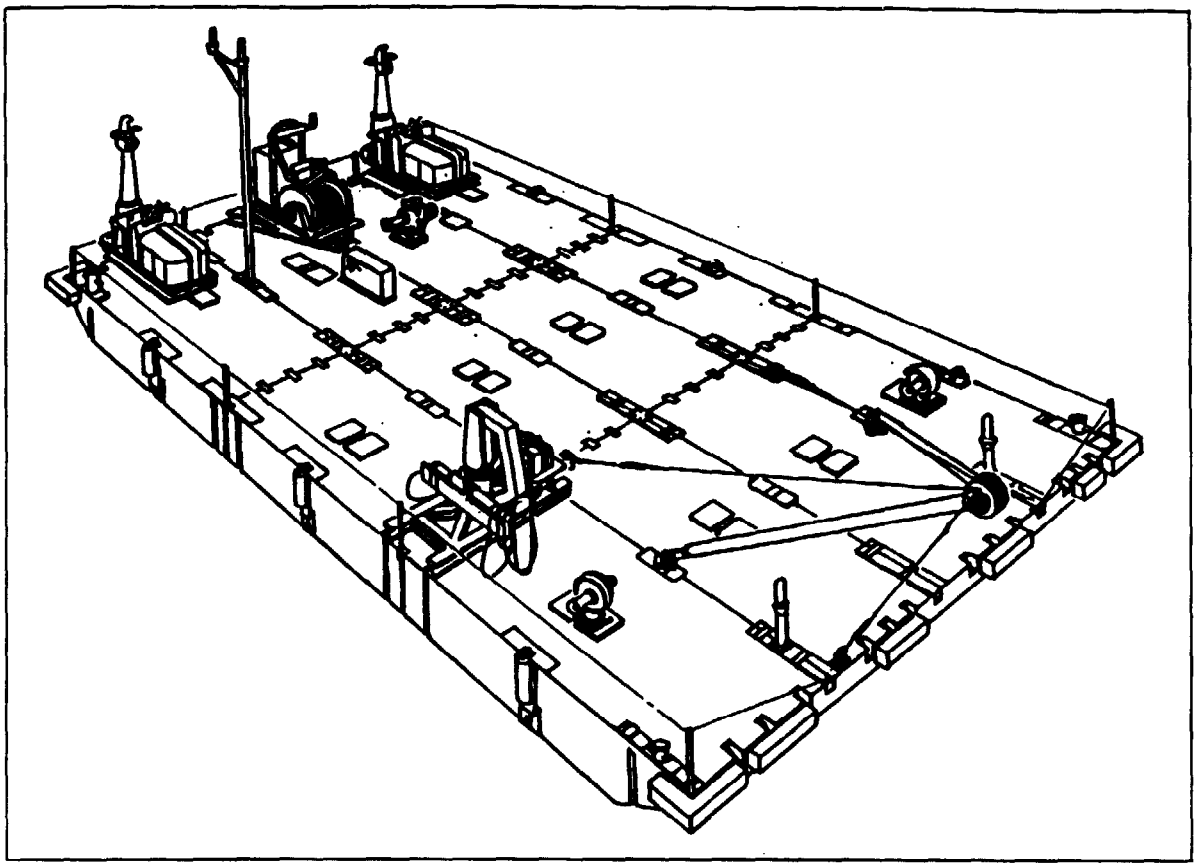
The basic platform shown in Figure B-1 is composed of 12 pontoons. There are four box-end pontoons (NA-P20XX), each weighing approximately 13,000 pounds, and eight raked-end pontoons (NA-P20RX), each weighing approximately 12,500 pounds. These 12 ISO-compatible pontoons are connected together to form a single 32- by 60-foot barge.

The modular construction scheme allows the MCP components to be transported by conventional means and assembled on site into a large work vessel. Assembly is best accomplished in a calm harbor or bay. A team of UCT personnel together with support equipment can assemble and prepare the basic MCP in 8 hours. The MCP can also be assembled on a beach and hauled out to sea using anchors and winches. However, on-land assembly is difficult and requires special equipment to move and align pontoons.

The basic characteristics of the MCP are provided in Table B-1.

Table B-1. Modular Construction Platform Characteristics

| Item | Dimension |
|---|---|
| Overall length | 60 feet |
| Beam | 32 feet |
| Overall depth | 4.6 feet |
| Weight | 158,000 pounds |
| Deck area | 1,920 square feet |
| Load capacity | 135,000 pounds |
| Tons per inch immersion | 4.9 TPI |
| Draft | 17 inches |
| Water depth (for mooring) | 0 to 250 feet |
| Assembly time | 120 man-hours |
| Operational sea states | |
| Moored survival | SS6 |
| Moored diving | SS3 |
| Underway | SS5 |
| Stability beaching | SS5 |
| Speed | 4 knots |
| Range (round trip) | 40 nautical miles |



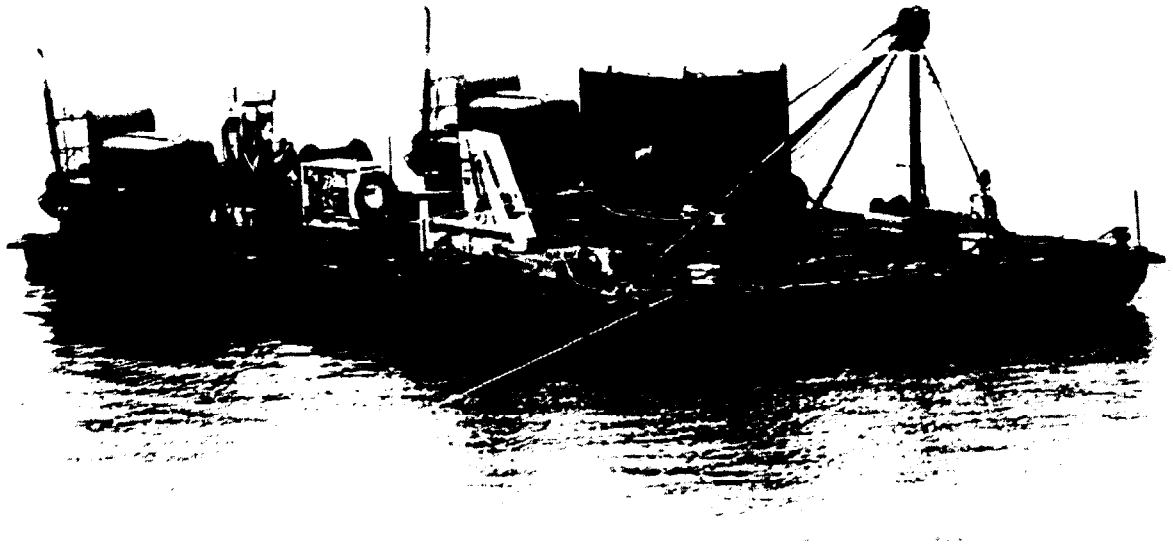


Figure B-1. Modular construction platform.

The 12 steel pontoons provide the basic floating structure for the 60- by 32-foot MCP. Pontoons are equipped with end and side connectors that allow the user to tailor the configuration of the MCP to suit the application. For example, one or two center pontoons can be left out to form a "moon pool" for diving or deploying materials. Or, nine pontoon units can be joined together with connectors to form a 60- by 24-foot platform.

The pontoons are equipped with International Standards Organization (ISO) shipping container corner fillings to permit handling with standard equipment and intermodal transport capabilities.

Connection of pontoons side by side and end to end is accomplished with two types of connectors: pontoon and pontoon link, which are inserted in the connector slots. Vertical pins at the bottom ends of the connectors engage in holes in jaws at the bottom of the slots while the tops of the connectors are held by horizontal shoot bolts along each side and end of the pontoon where the connectors can fit; however, only two connectors along each side and end are required for strength. The unused connector slots are used to mount the crane, winch, A-frame, deck fittings, etc.

The pontoon connectors fit into any full length connector slot of a pontoon and are used to join together pontoons side by side and end to end. Each connector has, at the bottom, one fixed pin and one movable pin which can be raised or lowered to make the bottom connection of adjoining pontoons. The movable pin is locked in position by lowering the handle below the top surface of the connection. The top connection is made by passing a shoot bolt of each adjoining pontoon through a hole in the connector. A hole in the side of the connector facilitates access to a swivel joint comprising a bolt and nut securing the movable pin to the operating rod and handle. The handles must be wired down before the MCP is lifted.

**Available Machinery and Propulsion**

Calculations indicate approximately 200 horsepower is required to drive the platform at 6 knots. Two diesel engine powered marine outboard drive units were chosen as the basic propulsion for the MCP. The propulsion units are bolted to a mounting frame that is welded to the deck of the pontoons. Several manufacturers offer alternative deck-mounted propulsion units in a range of horsepower ratings, which could be mounted on the MCP.

The knuckle boom crane allows lifting of heavy objects on or off the MCP. The crane is mounted to the pontoons using modified pontoon connectors and outboard anchors that fit in the connector slots. When not required for lifting, the crane folds into a compact arrangement for storage. Lift capacity is rated at 2,000 pounds at the maximum boom extension (25 feet(land capacity)). Hydraulic power for the crane is supplied by a hydraulic power supply using an air-cooled diesel engine.

**Fuel/Potable Water Storage**

1. **A-Frame** - The A-frame aboard the MCP is used in conjunction with the deck winch to lift heavy objects. The A-frame maximum load capacity is 50,000 pounds. It is mounted straddling two pontoons using foot assemblies that fit in the pontoon connector slots. The wire rope stays are shackled to D-rings on removable twist locks that fit into the ISO corner fittings.

2. **Deck Winch** - Lifting drag and clump anchors is the primary function of the deck winch on the MCP. Its full drum line pull

is 11,000 pounds and its line speed is 23 feet per minute. It is also mounted in a modular fashion to the pontoons using foundation anchors that fit in the connector slots. The winch is hydraulically operated with its own diesel engine powered hydraulic power supply.

The mooring capabilities of the MCP have been demonstrated using components of the modular mooring system that were provided from the Ocean Construction Equipment Inventory. This mooring provides the crafts with the ability to operate as a self-sufficient platform at predeployed sites.

## Sea State Description

| | |
|---|---|
| SS1 | SMOOTH SEA<br>Ripples, no foam. Wind*: light air, 1 - 4 knots. Beaufort 1. Not felt on face. |
| SS2 | SLIGHT SEA<br>Small wavelets, no foam. Wind*: light to gentle breeze, 4 - 10 knots. Beaufort 2 - 3. Felt on face, light flags wave. |
| SS3 | MODERATE SEA<br>Large wavelets, crests begin to break. Wind*: gentle to moderate breeze, 7 - 15 knots. Beaufort 3 - 4. Light flags extended. |
| SS4 | ROUGH SEA<br>Moderate waves, many white caps, some spray. Wind*: moderate to strong breeze, 14 - 27 knots. Beaufort 4 - 6. Wind whistles in rigging. |
| SS5 | VERY ROUGH<br>Sea heaps up, with spindrift and foam streaks. Wind*: Moderate to fresh gale, 27 - 40 knots. Beaufort 6 - 8. Walking resistance high. |
| SS6 | HIGH SEA<br>Sea begins to roll, dense streaks of foam and much spray. Wind*: Strong gale, 40 - 48 knots. Beaufort 9. Loose gear and light canvas may part. |
| SS7 | VERY HIGH SEA<br>Very high waves with overhanging crests. Sea appears white as foam scuds in very dense streaks. Visibility reduced. Wind*: Whole gale, 48 - 55 knotts. Beaufort 10. |
| SS8 | MOUNTAINOUS SEA<br>Very, very high rolling breaking waves. Sea covered with foam. Very poor visibility. Wind*: Storm, 55 - 65 knots. Beaufort 11. |

*Correlation between sea state and wind description is highly variable and dependent on fetch and wind duration. For seas not fully arisen wind speeds may be much higher than indicated.

# Appendix C

# USEFUL INFORMATION FOR SITE SURVEYS

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## Table C-1
## General Site Investigation Checklist for Overseas Projects

**Contacts**

Names, address, phone, fax, telex nos.
Interpreters

**General Project Information**

Design drawings
Material take-offs
Design basis (environmental design criteria, facility design requirements, system data, etc.)

**General Site Information**

Pocket local language(s) and tourist guides
Nautical charts (NOAA, Defense Mapping Agency, local hydrographic/topographic agencies, satellite/aerial photographs from NOAA, Defense Intelligence Agency or civilian contractors)
Sailing directions (en route & planning guide), coastal pilot, tide and current tables, wind directions and magnitude, etc.
Road maps
Yellow pages/contractor/business directories/related newspaper and magazine articles (National Geographic, general ocean and construction industry publications, etc.)
U.S. and local government military bases
Military intelligence brief on local political and security conditions
Local population and labor force; social and religious practices

**Weather and Climate Data**

Wind, wave, current, temperature, humidity, fog, rain, snow
Summary of seasonal climatology
Optimum construction season

**Legal**

Import duties, fees, custom bonds, local taxes for imported material and temporary equipment
Port duties, storage and handling fees
Sales and use tax
Currency and exchange rates
Right of way acquisition: application procedures, fees, payments
Local construction permit requirements
POCs at consulates and government agencies
Other agencies with site jurisdiction

**Site Logistics for Personnel and Materials**

Transportation services (marine, rail, air, auto-truck: capacities, schedules and rates)
Military air service capacities, schedules and locations
Commercial airline passenger schedules, freight capacities, airport locations
Passport, Visa, Health, Immigration, and Customs agency requirements
Local ports of import: photographs, location, maximum draft, dockage and anchorage availability
Port facilities: services, pilot, tug, fuel, water; fuel cargo handling capacities, storage areas, port and cargo charges
Local agents for clearing materials through customs at ports of entry
Rail service: location, length, distance, loads and clearance limits for nearest rail siding
Inland freight haulers: capacities, rates, etc.
Site storage area for materials
Site materials handling equipment: capacities, rates, etc.
Local vendors/marine equipment suppliers
Local service facilities: machine shops, marine repair yards, steel fabricators, casting yards, etc.
Site accommodations, messing, laundry, and transportation for jobsite personnel
Local water supply quality
Medical, health precautions for site personnel
Local communications: phone/fax/radio locations and communications procedures
Security/personnel clearance requirements
Location, staffing, and transportation arrangements for local recompression chambers
Local road conditions to site (clearance and load limits, new road construction requirements
Other work in general site vicinity

**General Site Conditions**

Site plan and photographs
General description of soil conditions, boring and core locations, bearing capacity, etc.
General description of shore crossing and nearshore areas
Drainage patterns and water table depth
Existing structures and obstructions
Existing availability and ownership

**Construction Material Supply (Availability, Price, Delivery)**

Fuel suppliers (gasoline, vehicular diesel, marine diesel, aviation fuel)
Utility supply (air, water, electric power, sewage)
Location of borrow, fill, or spoil areas
Aggregate/sand/cement/concrete/ready mix/concrete block/form lumber
Steel: structural, reinforcing, sheeting

**Construction Material Supply (Availability, Price, Delivery) (continued)**

Explosives: availability, transportation, security, and storage requirements
Project specific suppliers (i.e., diving equipment suppliers, pipeline, cable, etc.)

**Local Military Equipment and Marine Contractors**

Marine equipment: deck plans and specs
Diving equipment and contractors
Marine and land survey equipment and contractors
Dredging equipment and contractors
Pipeline equipment and contractors
Local military construction units
Local civilian union/labor practices for offshore work (labor categories, rates, working hours, overtime pay, holiday and health benefits, transportation, meal and travel time practices)

**Horizontal and Vertical Control**

Detailed topographic and bathymetric maps
Local grid description
Locations and datum for local survey control points
Extent of GPS coverage for project site

**Installation Environmental Conditions (1 year return interval)**

Maximum, minimum water depth
Maximum surface current
Maximum bottom current (3 feet off bottom)
Maximum wave height
Maximum significant wave height
Maximum significant wave period
Maximum wind speed
Tidal data:
- Type
- Datum
- Extreme high water
- Mean high water
- Mean tide level
- Mean low water
- Extreme low water

Monthly means of air temperature and precipitation
Monthly means of seawater temperature
Monthly means and maximum of windspeed and directions
Monthly means and maximum wave height
Bottom conditions (soil types, vertical profiles, boring data, soils reports, etc.)

## Table C-2
## Site Investigation Pipeline Project Information

**Product Data**

Product type
Physical properties: density, kinematic, viscosity, absolute viscosity, maximum and minimum operating temperature

**Pipeline System Data**

How is product currently supplied/delivered at proposed site?
Required flowrate (possibility of future increase?)
Tie-in locations, length, and size of connecting lines
Operating pressure
Storage tank or tank farm locations, elevations, and capacities
Pump locations, capacity curves
Product quality specifications
Pipeline maintenance and inspection requirements

**Shore Crossing Descriptions**

Plan views
Beach profiles
Soil profiles
Location of existing pipeline or other utilities
Stable or migratory sediment cover
Ownership/rent/ROW acquisition
Onshore or offshore obstructions
Blasting, clearing, and grading requirements
Debris disposal requirements
Restoration requirements
Access roads, walkway, utility, drainage, lighting, fencing, and security requirements

**Site Data Sources** (Contact local data sources for pipeline hazard identification)

Local Navy base
Local port authority
Local pipeline operators
International oil companies
Local pilots and commercial fishermen
Local cable and pipeline operators
Local marine contractors

## Suggestions for Bathymetric Surveys

The following suggestions for performing bathymetric survey work are from UCT experience gained in various worldwide work sites. The survey team must consider the following suggestions and decide how to apply this information to the particular job. A recommended reference for surveying is the Hydrographic Manual, Publication 20-2, U.S. Coast and Geodetic Survey, Department of Commerce, 1980.

### The Survey Plan

The survey plan should be laid out so that track lines cross bottom contours at a 90-degree angle whenever possible. For steeply sloping bottoms the track lines should cross bottom contours at about a 45-degree angle.

In general, the line system layout is governed by the type of control used and the configuration of the area. A system of widely spaced cross or tie lines parallel to the coast should also be included in the survey plan to verify the accuracy of the soundings taken along the track lines. If any suspected shoal areas are discovered while running the survey, they should be fully defined by running additional short, closely spaced lines over the area. When surveying navigation channels the survey plan is normally arranged so that the limits of the channel are first defined by a series of cross lines perpendicular to or diagonally across the channel axis. Later, the channel is fully defined by a system of closely spaced lines parallel to the axis of the channel. To align successive boat runs, an EDM or a second transit should be used, assuming steerage by transit or range markers. Landmarks such as towers, piers, build ings, etc. can serve as aids in aligning adjacent survey boat runs.

### Field Plotting

The rough and smooth survey plots should be completed before leaving the detachment site. This will help in identifying any obvious errors in the information. The final prints must be reviewed with the facility customer before departure to ensure that the results are suited to the needs of the particular facility.

### Survey Drawing Completion

A blueprint number should be obtained from the local facility Public Works representative. The callout "UCT-1" or "UCT-2," as applicable, must be included in the title block to clarify who performed the survey. List the surveyor's name, rate, and rank with the "DV" designation in the "drawn by," "checked by," and "approved" blocks. Recording of work into the facility drawing system is essential to ensure that anyone needing the information in the future can find it.

### Drawing Approval

Survey drawings should be reviewed and approved by one of the UCT's Registered Professional Engineers if the facility is to use the survey results as a basis for project budgeting or specifying a contract. The UCT Commanding Officer and Executive Officer are usually registered and can review and approve. Inaccurate bathymetric

surveys can result in high material and labor cost overruns. If the facility is reviewing a working copy before the drawings are signed, the drawings should be marked "Preliminary."

### Datum

There are several "datums" or zero elevation levels depending on the use of the information. The POIC should personally review local datum information with the lead surveyor and the facility customer. The survey should be referenced to the particular datum the facility requires. The datum must be clearly described in a general note on each sheet of the survey drawings. The Navy generally uses Mean Lower Low Water (MLLW) in areas with large inequalities in the height of successive high or low tides (such as the Pacific Coast) and Mean Low Water (MLW) where the successive high or low tides are nearly equal (such as the Atlantic Coast). This pattern may be different when the worksite is overseas. Many elevation benchmarks are referenced to Mean Sea Level (MSL). The datum to be used should be discussed and agreed to prior to the job to ensure that both the tide and depth readings will be proper. The datums should be checked when the survey results are compared with previous soundings.

### Benchmarks

Existing USGS, NOAA (USC&GS), U.S. Army Corps of Engineers, State, or Navy benchmarks must be used or tied into even if only remotely available. If not available, a clear and detailed written description must be prepared for each benchmark installed, including how to reach the mark from a prominent location, the type of mark, the type of foundation, the information stamped on the benchmark, and the distance and direction to the mark from at least three permanent objects and any previous marks. A sketch should also be prepared showing the tide gage, all benchmarks used in the survey, and the objects used in the benchmark description. Photographs of the benchmarks and surrounding areas are valuable if accompanied by a description of where each shot was taken and which direction the camera was aimed.

### Transits

The transit positions must be set up to give reasonable crossing angles, such as approximately between 45 and 135 degrees. Intercept errors are unacceptably large when lines of bearing approach are nearly parallel. If necessary, the transit positions must be relocated to give good intercept angles for the nearshore and offshore portions of the survey.

### OIC Checks of the Surveyor's Work

Survey errors may invalidate the entire project. Survey work requires a double check by someone other than the surveyor and his assistants. The OIC or Detachment Officer may perform this check even if not an experienced surveyor. The lead surveyor (EA, BU, or other) should walk the checker through the computation steps, looking for obvious ommissions, reversed direction, or other errors. The survey drawings should be checked to see if the shapes, directions, distances, and position of landmarks make sense. This step may help point out incorrect numbers that have been improperly added or subtracted. The mathematics must be checked for calculation errors, especially those that form the basis of elevations, tide

levels, and lane angles. Math errors in any of these will cause all data to be incorrectly plotted.

**Recording Details of the Survey**

All UCT land and bathymetric surveys must be reproducible. Future surveyors must be able to read the UCT survey drawings and determine the following:

(1) The location of benchmarks

(2) How to reconstruct baselines

(3) How to reconstruct all angles, distances, and elevations

All numbers and descriptions necessary to reproduce the survey should be included on the final drawing, without relying on the field book notes. Supporting information or background explanations contained in the field book notes should be shown on the drawings. Any reference in the drawing notes to the field book should be by date, number, etc.

**Feet and Inches Versus Feet and Tenths**

All measurements with their units of measure and any conversions between inches and tenths of feet must be clearly recorded. Readable measurements are mandatory for correct calculation and survey recheck. Errors due to incorrect units may require rework of all or part of the entire survey.

## Suggestions for Fathometer Operation

### Fathometer Testing

Refer to the manufacturer's instructions.

### Testing Precautions

1. Follow the troubleshooting guide in the O&M manual.

2. Never energize the transmitter without the transducer plugged in.

3. Never energize a transducer unless it is submerged in water to prevent heat buildup.

4. The zero mark will be seen for the transducer draft and speed of sound even if the recorder or transducer is not properly transmitting or receiving.

5. A strong print of the transmitter pulse may exist even though the transducer is not working.

6. A power cutoff case switch automatically deenergizes the fathometer when the top case is opened. Check the switch if the unit is inoperable.

### Fathometer Controls and Adjustments

**Read the Manual**. Review the setup, test, and operating instructions. ollow the proper sequence since adjustments may affect each other. The UCT Raytheon DE-719s and CHESDIV OCEI DE-719Bs are adjusted identically although the manuals are different. The adjustment of other makes of fathometers will vary.

**Zero Adjust Scale and Range**. The X-1 Range is normally used. X-2 doubles the depth readings.

**Sensitivity**. Normally the sensitivity (signal strength) control is not pegged. If the control is pegged, or if the signal trace fades for no apparent reason, the gain control circuitry is suspect. Follow the troubleshooting sequence in the O&M manual. Turn off the entire unit whenever disconnecting power or reconfiguring the unit.

**Tide and Draft**. This control represents two critical variables:

a. **Draft**. The depth of the transducer below the water level can be determined by direct measurement or by marking the rod supporting the transducer with depth marks. The initiation pulse is adjusted to this depth using the tide and draft control. The measured depth is noted alongside the strip chart trace. This becomes the basis for comparison of all runs that follow in that sounding session. An additional draft correction due to settlement and squat while the boat is underway must be made if the depth of the transducer below the water surface changes significantly while running at the surveying speed. The amount of this correction can be easily checked by deploying a marker buoy with a short scope and comparing fathometer readings taken while at rest beside the buoy and running it at surveying speed. All personnel and equipment expected to be onboard during the actual survey should be onboard during this test.

b. **Tide.** Applying a tide correction to the measured reading is essential. Corrections may be obtained from official tide tables for general route surveys, anchor placements, or "rough" depth surveys where precision is not essential. Assume that the tide tables are good to the nearest foot as long as the proper reference station and local correction factor are used, and the worksite is not a bay or inlet that may experience a tidal bore or time delay effects. When conducting a record survey such as predredging or post-dredging, or when confirming available water depth along piers, wharves, or approach channels, etc., it is most correct to use a tide gauge.

Many harbors have existing tide gauges which may be read directly. A simple tide gauge may be installed if none is convenient. A wooden staff or board of adequate length to cover the maximum range of expected tide can be marked off in feet and inches or feet and tenths. If a benchmark of known elevation is in the area, the tide gauge should be set to the local zero datum. If there is no vertical control benchmark, the tide gauge may be set to the depth and time of the locally predicted high or low tide. A series of tide readings can later be compared with the predicted tide profile to determine differences in range and time. The tide gauge is read and recorded every 15 or 20 minutes when taking soundings. The readings are expanded to cover several high and low cycles when not working from a known elevation.

All tide readings should be retained as a part of the survey data and turned over to the facility in the final survey package. Tide corrections for rough surveys may be drafted into the sounding by adding the value of the tide correction to the draft adjustment. Both should be listed on the strip chart header. In this manner, depth may be read directly. If the tide correction is known in advance and with confidence, the above approach is suitable. The chart must be well labeled with all information. A plus (+) tide height must be subtracted from observed water depth. A minus tide results in an addition to the water level. This approach allows direct reading of the depth with respect to the datum. However, the tide level must be checked at the end of each line and the correction adjusted accordingly.

When performing precise surveys, the preferred approach is to apply the tide correction after completing the sounding run. The correction is added to, or subtracted from, the recorded depth. This approach minimizes the opportunity for field adjustment errors. Recording the depth uncorrected for tide does require an additional mathematical step but is the method recommended by the Army Corps of Engineers to preclude future survey confusion and possible legal claims.

**Speed of Sound.** The speed of sound in water is affected by temperature and salinity. Bar checks are the standard method used to compensate fathometer readings for variations in the speed of sound with depth and from one area to another. The bar may be any reflecting surface such as a length of 2- or 3-inch-diameter pipe, a wide metal bar, or a weighted board which can be lowered to a known depth below the transducer. The overall length of the bar should be at least several feet and carefully marked lines should be attached to each end for lowering and holding the bar below the transducer. Bar checks should be made at the beginning and end of each day's survey work. An additional check should be made during the middle of the day when performing record surveys, particularly in harbor and estuarine areas where the speed of sound can change significantly over a tidal cycle.

Bar checks should be made in a protected area with minimal currents so that the target can be held directly beneath the transducer. Readings should be taken at several evenly spaced intervals over the range of depths expected in the survey area. Ensure that the boat is balanced on an even keel while taking the readings. Adjust the speed of sound knob until the target appears at the exact premeasured depth. The bar check records should be saved and given to the facility customer as part of the project data.

**Data Entries.** All information needed to identify and correct the run must be recorded on the strip chart paper. There is no set format for a legend or title block. The OIC or crew leader should have a title block convention for the duration of the project. A proper title block is also essential on the bar check strip chart and record. The following information should appear:

***Sounding Trace*** - Time, Date, Run Identification Number or Letter, Depth Range, Scale (X-1 or X-2), Chart Speed, Boat Speed or rpm, Time of Calibration Bar Check, Draft Correction, and Tidal Height (if adjusted into the reading; if no tide correction, so state).

***Bar Check*** - Time, Date, "BAR CHECK" at Depth," Depth Range, Scale (X-1 or X-2), Fathometer Model and Number, and location where the check was conducted. A tide correction is not applied to a bar check.

A sample title block for the sounding trace and bar check follows.

<table>
<tr><td colspan="2">Run No.</td><td colspan="2">Time</td></tr>
<tr><td colspan="2">Depth Range</td><td colspan="2">Date</td></tr>
<tr><td colspan="2">Scale Setting X-1 X-2</td><td rowspan="2">Fathometer</td><td>Model</td></tr>
<tr><td colspan="2">Chart Speed</td><td>Serial No.</td></tr>
<tr><td colspan="2">Boat Speed or RPM</td><td colspan="2" rowspan="4">PROJECT</td></tr>
<tr><td colspan="2">Time of Cal. Bar Check</td></tr>
<tr><td colspan="2">Draft Correction</td></tr>
<tr><td colspan="2">Tidal Height<br>(if corrected)</td></tr>
<tr><td colspan="2" rowspan="2">Check block if not<br>corrected for tide</td><td colspan="2">Sounding Operator</td></tr>
<tr><td colspan="2">SOUNDING TRACE DATA BLOCK</td></tr>
</table>

| | | | |
|---|---|---|---|
| Bar Check Location | | | |
| Depth | | Fathometer | Model |
| Depth Range | | | Serial No. |
| Scale Setting X-1 | X-2 | PROJECT | |
| Time | | | |
| Date | | | |
| Bar Check Operator | | | |
| | | BAR CHECK DATA BLOCK | |

**Fathometer Setup**

**Transducers.** Both the DE-719 and DE-719B are designed to use 208-kHz transducers with a connecting cord of a premeasured length and known electrical characteristics. The existing units are equipped with the 2445 AD (or 200 T5D) narrow beam transducer. The 2445 AD's 8-degree half-power beam angle results in the beam covering a lane on the seafloor approximately one-sixth of the water depth. The optional 7245 208-kHz very narrow beam transducer has a 2.5-degree half-power beam width. The more narrow the beam width, the more precise the depth reading, especially in very deep water or steeply sloped areas. The wider beam width offers the advantages of "seeing" a greater proportion of the seafloor to locate obstacles or high points. The 2445 AD is quite adequate for our survey work. Replacement 2445 AD transducers are very expensive. The 719 and 719B will work with other transducer types as long as they have the same electrical characteristics. The 200 T5D is a generic replacement. When ordering replacements, be sure to specify the slug style Cannon J12-3 and connecting sequence, Red, Black, White. An alternate 50-kHz wide-beam transducer will see a seafloor lane approximately equal to the water depth. The wider beam makes precise depth readings difficult but would penetrate the seafloor surface slightly.

> NOTE
> **Do not use a 50-kHz transducer for record surveys.**

Recording units are generally tuned to a specific transducer element and cable. The unit should be test-operated far in advance of the job when switching transducer types or frequencies in order to determine the need for internal adjustments. Transducers of the same style are interchangeable.

**Transducer Mounting.** The transducer should be firmly mounted as suggested in the O&M manual. The transducer head should be at least a foot below the surface

to avoid it becoming airborne if the boat pitches. The following conditions must exist with the boat on an even keel or the same list that will exist during the survey:

(1) Transducer mast vertical to prevent reading a slant distance for depth

(2) Transducer head tilted backward about 1 degree from vertical to maintain smooth water flow over the transducer face without cavitation

(3) Transducer mast mounted for a fixed depth

**Recorder.** The recorder must be protected from water spray. The unit may be enclosed in a plastic bag with the bag opening facing aft. The operator can read into the bag to open the recorder door and write on the paper while still protecting the unit.

### Fathometer Operations Tips

**Stylus Problems.** Stylus wear, breakage, or loss of spring tension can affect both the black line trace darkness and the location where the trace is burned into the paper.

**Stylus Belt Problems.** A loose set screw on either of the stylus drive belt wheels will result in the belt slipping off. A tired, weak, or worn stylus belt sponge will result in the stylus wire not tracking properly. If the sponge is too loose, the stylus wire will either fall out of its retaining clips or will alternately track and then underride the support plate for the electrical contact wire. This last condition will tend to shear the top end of the stylus and will result in double-struck, unintelligible marks. Field repairs to the sponge can be performed by gluing a small replacement sponge to the belt with contact cement. A soft synthetic sponge or a piece of yellow foam earplug will work satisfactorily.

**Paper Creep.** A misaligned takeup platen will cause the paper to creep up or down on the recorder table. The symptoms are as follows:

(1) Drifting zero mark at draft mark.

(2) Paper buckling on the top or bottom edge as it runs against the plastic alignment guides.

(3) Stylus marking the top edge of the paper above the zero mark (this is caused by the stylus physically marring the tops of the folds of the buckling pressure-sensitive paper). Correct for paper creep by adjusting the slot screw holding the axle arm for the paper takeup reel.

**Reconstructing Readings for a Drifting Zero Due to Paper Creep.** It may be discovered after recording a number of runs that the paper has crept up and down on the recording due to an improperly aligned takeup platen. A misaligned trace can be corrected mathematically. If the error was the same for the whole trace, add or subtract the correction as appropriate. For a gradually increasing or decreasing error, divide the trace into equal sections about 6 inches long and use an average correction for that 6-inch strip by interpolation. Determine different corrections for each 6-inch section.

# Appendix D

# ELECTRICAL SAFETY FOR DIVERS

## SCOPE

Electricity can be used safely underwater by divers provided they are protected from electrical shock hazards. Electrical power is used underwater by divers for lighting, remotely-operated vehicles (ROVs), video equipment, inspection equipment, communication equipment, and other electrical devices. Diver electrical shock hazards occur from:

1. Carelessness or comlacency
2. Ground faults in the power system
3. Electric fields in the water

Diver electrical safety can be achieved by common sense, education, preventive maintenance, properly designed underwater electrical equipment, and by the use of ground fault detection and interruption (GFI) devices designed specifically for underwater electrical power systems. An underwater electric field detector (UEFD) is available to warn the divers of stray electric fields originating from underwater electrical equipment.

## SAFETY CRITERIA

Divers can be exposed to shock hazards that can be more dangerous than those on land. ***The most dangerous electrical shock hazard for a diver is at the air and water interface.*** In this condition, the lower part of the diver's body is in the water (generally from the chest down) and the upper part (generally the arms, neck, and head) is out of the water, in air. If a diver comes in contact with an electrical circuit out of the water by grabbing electrical equipment handed to him from the surface or grabbing a faulted cable or conduit, a ground fault electrical current would enter the body at the contact point and flow through the diver's body and into the water. The resulting electrical shock would be severe to lethal.

The diver's skin contact resistance is substantially reduced by water absorption, particularly in highly conductive saltwater. This decrease in skin resistance reduces the voltage across the body required to create a fatal current flow. The voltage can be applied to the diver directly by physical contact with an energized circuit or by the presence of a strong electric field in the water.

The Navy Bureau of Medicine (BUMED) has adopted the Association of Offshore Diving Contractors (AODC) Code of Practice for the Safe Use of Electricity Under Water (Ref D-1). The AODC code deals with the various hazards which may arise from the use of electricity underwater, and describes practices aimed at minimizing the risk associated with the use of electricity underwater.

## SAFE BODY CURRENT

Factors that determine the severity of the electric shock effects are:

1. The duration of the electrical shock
2. Magnitude of the current
3. Magnitude of the voltage
4. Frequency of the current
5. Path through the body

The human body's response changes between an individual's skin contact and electrical path. For example, a 3-milliampere shock for 1 millisecond through the heart or brain can cause death or paralysis for some individuals. Researchers have used a large number of subjects to arrive at average values and safety levels for the most susceptible. Table D-1 presents some typical responses to various levels of electrical shock. These responses were derived by Dalziel and discussed in "Effects of Electric Shock on Man" (Ref D-2). Table D-1 provides a basis for electrical safety on land, but **NOT** safe operating levels for divers in water.

Figure D-1 shows safe body current levels for divers as adopted by the AODC and BUMED, and defines the maximum current/time relationships to which a diver may be exposed. Based on research and uncertainties relating to underwater use, the values used for worst case, limb-to-limb contact resistance on a diver in the water are:

- 750 ohms for voltages up to 50 volts
- 500 ohms for voltages over 50 volts
- 100 ohms at any voltage for possibility of a front to back of the chest contact path

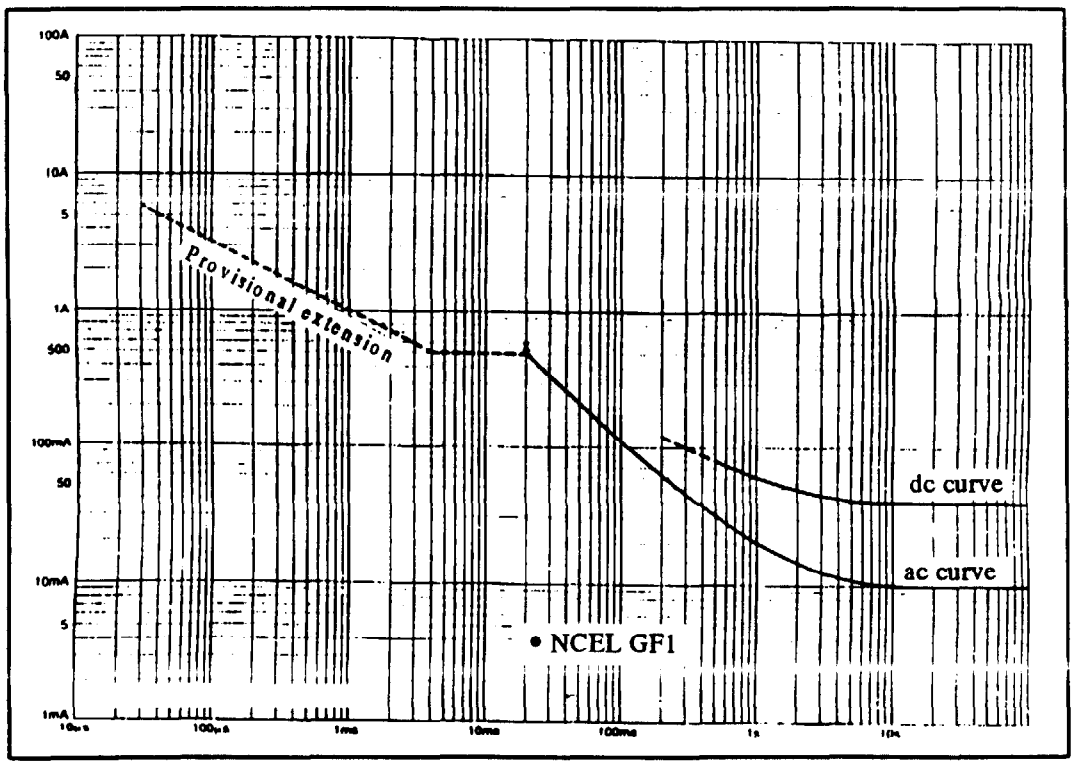



Figure D-1. Safe body current levels.

Table D-1. Electrical Safety on Land

| Effect | Milliamperes (1,000ths of an ampere) | | | |
|---|---|---|---|---|
| | Alternating Current 60 Cycles | | Direct Current | |
| | Men | Women | Men | Women |
| No sensation on hand | 0.4 | 0.3 | 1 | 0.6 |
| Slight tingling - perception threshold | 1.1 | 0.7 | 5.2 | 3.5 |
| Shock - not painful and muscular control not lost | 1.8 | 1.2 | 9 | 6 |
| Painful shock - painful but muscular control not lost | 9 | 6 | 62 | 41 |
| Painful shock - let go threshold | 6 | 10.5 | 76 | 51 |
| Painful and severe shock - muscular contractions, breathing difficulty | 23 | 15 | 90 | 60 |
| Possible ventricular fibrillation from short shocks: | | | | |
| Shock duration 0.03 sec | 1,000 | 1,000 | 1,300 | 1,300 |
| Shock duration 3.0 sec | 100 | 100 | 500 | 500 |

## DIVER ELECTRICAL SAFETY

There cannot be too many precautions taken to eliminate underwater shock hazards. Common sense, training, and good equipment maintenance play a critical role in preventing electrical accidents.

### Common Sense

Common sense rules for the use of electricity by divers are the best means of ensuring diver safety. Most cases of electrical shock result from human error. There is no substitute for attention to details of connections, acceptable conditions of equipment, tagging out switches, and so on. As in terrestrial situations, inattention or carelessness is a greater hazard than the equipment or environment.

### Training

Training on the use of electrical equipment underwater is essential. Training should provide the diver with an understanding of the use of the equipment, the potential hazards, and how to avoid them.

The training should provide information that will put the diver in control of his own safety around electrical equipment. This self-reliance is crucial underwater because the conductive seawater medium prevents the buddy diver from coming to the aid of the first, since this would place both divers at risk. In addition, the primary treatment for electric shock is mouth-to-mouth resuscitation, which cannot be effectively administered underwater. There cannot be too many precautions taken to eliminate underwater electrical shock hazards.

### Maintenance

Maintenance of electrical equipment used underwater must be carefully accomplished. In addition to visual inspections, insulation should be checked regularly for resistance to ground. Line cords should be checked for frayed or worn insulation and loose connections. Careful maintenance and inspection records are an essential part of an underwater electrical safety program.

## RECOMMENDED ELECTRICAL SAFETY PRACTICES FOR DIVERS

By strict adherence to a few basic electrical safety practices, injury from electrical shock hazards can be avoided.

**REMEMBER**
**Electricity seeks the path of least resistance.**

Divers must avoid the condition where they become the path of least resistance.

*1. Never hand a diver an electrical tool or a device while the diver is at the water surface (Figure D-2).* Always allow the electrical tool or device to enter the water first. If an electrical fault exists or occurs, the electrical current will flow through the water and not through the diver's body. The circuit breaker or ground fault detector will trip to notify surface support personnel that a problem exists. After the tool or device is submerged, the diver can grab the equipment.

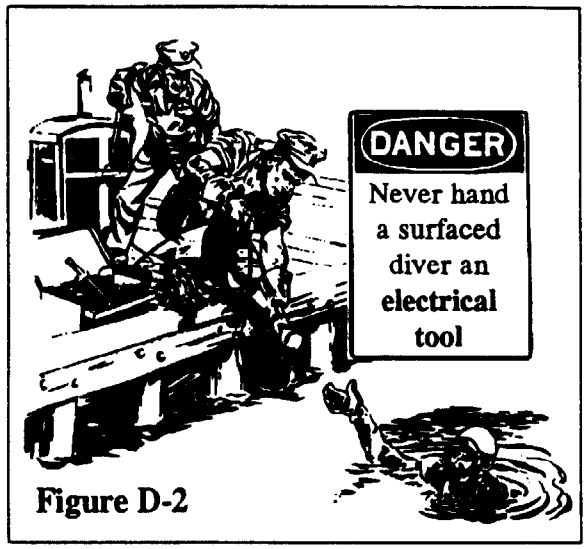
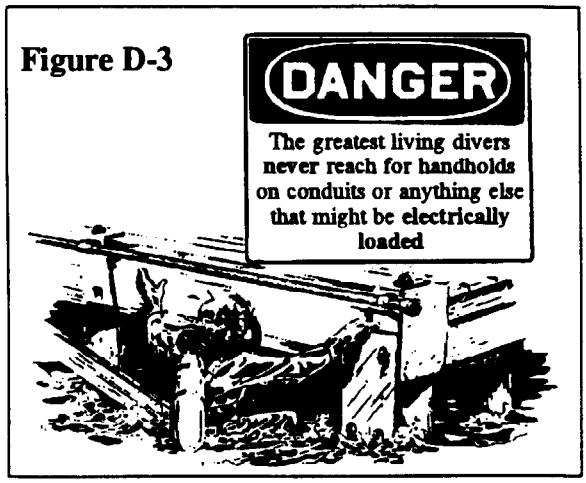


Figure D-2

*2. Never reach out of the water for handholds on conduits, cables, or anything that might be electrically powered while still partially submerged in the water (Figure D-3.* If an electrical fault exists, deadly electrical currents can flow through the diver's body and into the water. Use a rope or handholds made of wood or other nonconductive material to exit the water or to assist in staying afloat.

Figure D-3



*3. Always connect underwater electrical devices to a ground fault detector and interrupter and not directly to the power source (Figure D-4).* The ground fault detector/interrupter (GFI) will monitor the electrical circuit and shut it down if an electrical ground fault occurs. A good practice is to install GFIs on all electrical power sources used in wet locations or if a potential for a ground fault is great, such as in inclement weather. Be sure that the GFI is designed for use with underwater electrical equipment.

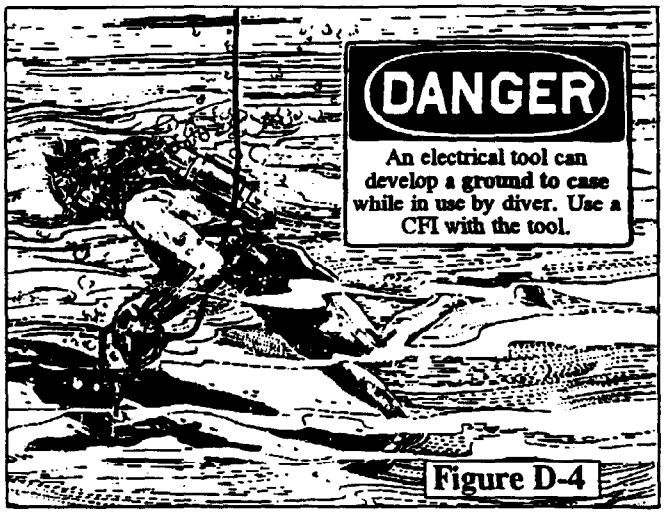


Figure D-4

*4. Never bypass any circuit protective device, and always use the correct rated protective devices.* The circuit protective devices are installed to protect the electrical equipment from an overload that can damage insulation and create an electrical shock hazard. If the protective device continues to trip the circuit, a condition exists that must be investigated and corrected.

*5. When possible, use electrical tools or equipment that use inherently safe voltage and current levels.* For example, 12-volt battery packs are inherently safe because the voltage cannot generate harmful electrical currents to a diver. The AODC Code of Practice for the Safe Use of Electricity Underwater (Ref D-1) presents safe voltage levels for various types of electrical equipment. An underwater flashlight powered by a 6-volt lantern battery is an example of inherently safe electrical equipment.

*6. When possible, survey the dive site for stray electrical fields (Figure D-5).* Dangerous electric fields may be present in cathodically protected areas such as a harbor or around a pier. The cathodic protection is a corrosion preventive system that induces electrical currents in the water to protect metal parts in the water. Some systems may develop underwater electric fields that can cause dangerous electrical currents to flow through a diver who inadvertently dives or swims into the field. Ensure such systems are shut down before and during a dive. An electric field detector can be used to monitor electric fields in the water and provide an alarm if dangerous fields exist.

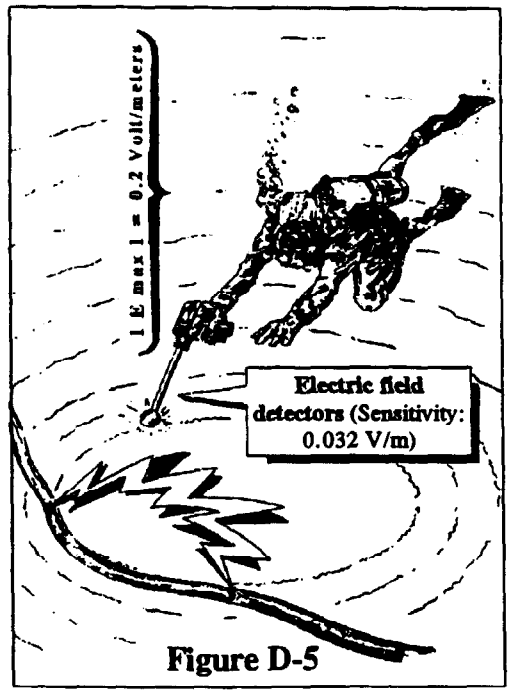


Figure D-5

## GROUND FAULT PROTECTION TECHNIQUES

Protection methods for preventive electrical shock hazards can be categorized as passive or active protection.

**Passive Protection**

The insulation on electrical wire that prevents contact with the energized wires is an example of passive protection. The passive protection methods provide no warning and do not shut down power in the event of a ground fault. Other methods of passive protection are:

- **Double Insulation** - Provides two layers of insulation with no conductive medium between the insulations.

- **Shielding** - Encloses the entire electrical circuit inside an enclosure made of conductive material. The enclosure is grounded so that any electrical fault would be directed to ground rather than to a diver making contact with the equipment.

- **Grounding** - Grounding of all electrical equipment provides a first level of protection. However, it is difficult to ensure that all grounds are in place and that their resistance to earth is low. If there is a problem with the grounding, the ungrounded equipment becomes a hazard without the operator being aware of it.

- **Isolation** - In an isolated system, power is supplied to the load by way of the secondary winding of an isolation transformer. No part of the load circuit is grounded. If a ground occurs in an isolated system, no fault current can flow because a return path is not provided. A second fault is required for a hazard to develop.

- **Diver Education** - A diver training program should include information on the physiology of electric shock, preventive measures, and personal awareness of electrical safety. The information must be continuously reinforced to assure that the protection afforded by a training program is not circumvented by diver carelessness.

**Active Protection**

An example of active protection in the home is the ground fault circuit breakers that protect the bathroom electrical outlets and are now required by most local building codes. Active protection methods fall into three general classes:

- Residual Current Device (RCD) or Earth Leakage Circuit Breakers (ELCB)
- Ground continuity monitors
- Insulation monitors

1. **Residual Current Devices (RCDs) or Earth Leakage Circuit Breakers (ELCBs)** detect a difference in the current flowing to and from the load and respond by tripping a circuit breaker which interrupts the supply. An example is a device that uses a differential transformer that monitors the line current. When current in the hot line is different than current in the neutral line, an imbalance in the magnetic flux in the core of the differential transformer develops and a voltage is generated in the secondary winding. This voltage causes a circuit breaker to trip. This type of device is adequate for on-land use, but when used on long cables or cables underwater, operation may not be reliable due to the capacitance of the cable's insulation. The cable capacitance will cause nuisance tripping of these devices.

2. The **ground continuity monitor** works in conjunction with the passive protection method of grounding all system components. In practice, the ground return path is broken at the power source, and a current is impressed on the ground. If the

ground circuit opens, the current flow stops, and a circuit breaker opens the power circuit. This system provides no protection underwater if a diver comes in direct contact with a line conductor.

3. The **insulation monitor** is the preferred type of protective system for diver electrical safety. This device monitors the insulation resistance of a circuit. The system operates by having the load connected to the supply by way of an isolating transformer that has a center tapped secondary winding. A DC voltage is applied to the power circuit at the center tap. Should a ground develop, any leakage current flowing would be DC, and would flow through a reference resistor. The voltage developed across this resistor is monitored by a control circuit. When the voltage exceeds a preset voltage level corresponding to the minimum acceptable ground resistance, the control circuit opens the output circuit breakers and fires a triac (an electronic switch) to short circuit the output power leads. If the circuit breakers fail to open, the short circuit induced by the triacs will blow the input fuses to the supply, and open the circuit.

## UNDERWATER ELECTRIC FIELDS

Underwater electric fields can be generated from an undetected ground fault in the pier power system, a powered cathodic protection system, or a fault in the lighting and inspection devices carried by the diver. Divers performing underwater inspection of piers and offshore structures can swim near hazardous electric fields. The shock hazards to the diver who swims into an electric field are the same as described earlier in this text, but no contact with any part of the electrical equipment is necessary. If a diver swims into an electric field, his/her body will be exposed to a potential (voltage) equal to the difference in field intensities of the point closest to and furthest from the fault or source. Tests conducted on human volunteers have shown that electric field strengths of approximately 0.5 V/ft can result in currents as high as 5 ma through the chest. Higher field strengths could result in loss of muscular control or, in the worst case, ventricular fibrillation.

## ELECTRICAL SAFETY EQUIPMENT

The most common item associated with electrical safety is the Ground Fault Interrupter (GFI) found on electrical outlets in bathrooms and areas where water is present. These GFIs designed for terrestrial use may not be adequate for use with electrical equipment used by the divers. There are two types of electrical safety devices specifically designed for diver applications. They are the **2.5-kVA Ground Fault Detector (Standard and Arctic versions) and the Underwater Electric Field Detector (UEFD).**

### • 2.5-kVA GFD (Standard and Arctic Version)

A GFD and shutdown system is available to protect divers from electric shock hazards. Shown in Figure D-6, the GFD monitors the insulation resistance of the load circuit being used by the diver. When the ground fault resistance drops to a predetermined level, a trip signal within the unit is sent from the control unit to a circuit breaker and all power to the output is shut off from the load in 10 msec or less. This same signal is delayed a few milliseconds and then fires an electrical circuit that places a short circuit across the output. This delay allows the circuit breaker to open under normal current loads. When the triacs

fire, they provide a short circuit path to dissipate any stored energy in the load circuit, such as energy stored in a long cable due to cable capacitance.

There are two versions of the GFD available, the standard and the arctic version. The following is a brief specification of the GFDs:

| Standard Version | Arctic Version |
|---|---|
| 2.5-kVA output power | Same |
| 115 VAC, 60 Hz | Same |
| 20 amperes max output current | Same |
| Shutdown time in 10 msec or less | Same |
| Weight (pounds): | |
| 78 | 43 |
| Dimensions (inches): | |
| 10.9 x 7.6 x 14.4 | 10.6 x 8.0 x 14.3 |

Both units incorporate the same design. The arctic version uses components that can operate at a temperature range of -40 to +140°F. The standard version operates in a temperature range of +30 to +95°F. The arctic version is also lighter because it uses a lightweight isolation transformer. Both units meet the AODC safety standard for allowed fault currents and shutdown times and are approved for Navy use.

**NOTE**
**The output connection of the GFD is critical to ensure proper operation.**

The NFESC 2.5-kVA GFD system is an insulation monitoring device. Hence, a good ground connection is extremely important to ensure proper operation. If there is no ground wire in the plug to the GFD, a separate ground wire must be connected from the GFD grounding terminal to the water. When using the arctic GFD on the ice, a ground wire must be connected from the GFD to the water. Failure to provide a good ground path will cause the GFD to be inoperative for ground faults, jeopardizing the diver's safety.

**CAUTION**
**Certain types of electrical equpment will not operated with the GFD, or the GFC may damage the equipment connected to it.**

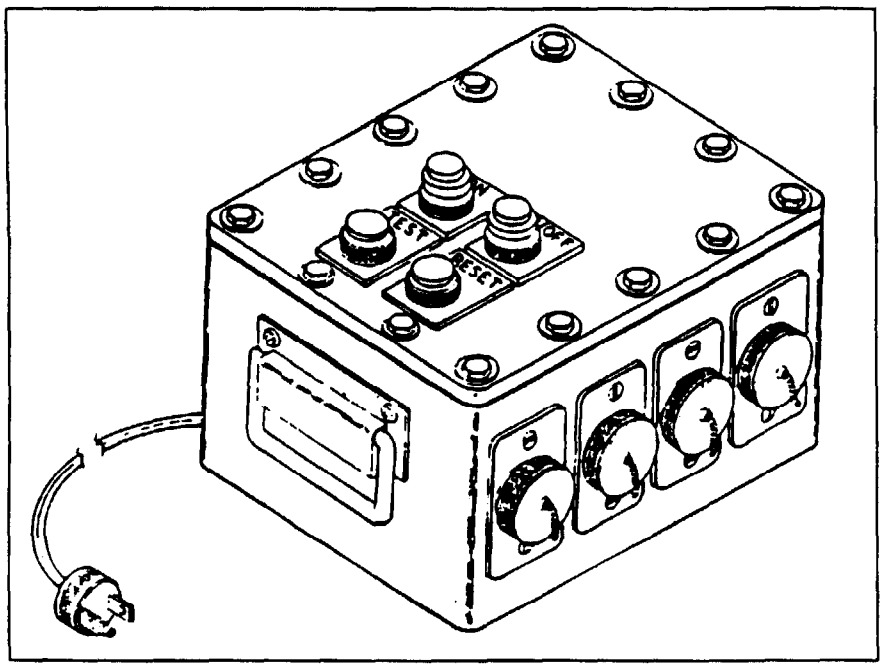



Figure D-6. 2.5-kVA ground fault detector.

Certain types of equipment such as a remotely-operated vehicle (ROV), video camera, communications equipment, or special electronic devices may have electrical circuits that could cause the GFD to become inoperative or damaged. Electrical equipment with isolation transformers at the input or built-in electronic leak detectors in the circuit, can cause the GFD to malfunction or not provide monitoring capability. Consult with a qualified electronics/electrical engineer/technician to review the circuit diagram for potential problems.

### Underwater Electric Field Detector

The UEFD was designed to be carried by, and provide a warning to, a diver swimming into an electric field. The UEFD is shown in Figure D-7. The UEFD senses the voltage across three pairs of electrodes (x, y, and z) exposed to the water. The signal to warn the diver of the presence of an electric field is generated from the sum of x, y, and z signals. The UEFD is calibrated to detect and warn the diver of a weak field and a strong field. They are:

- The weak field signal is to warn the diver that an electric field of 0.1 V/ft is present and to proceed with caution.

- The strong field signal is to warn the diver that an electric field strength of 0.2 V/ft is present and to swim away or stay away, or get out of the water. A field

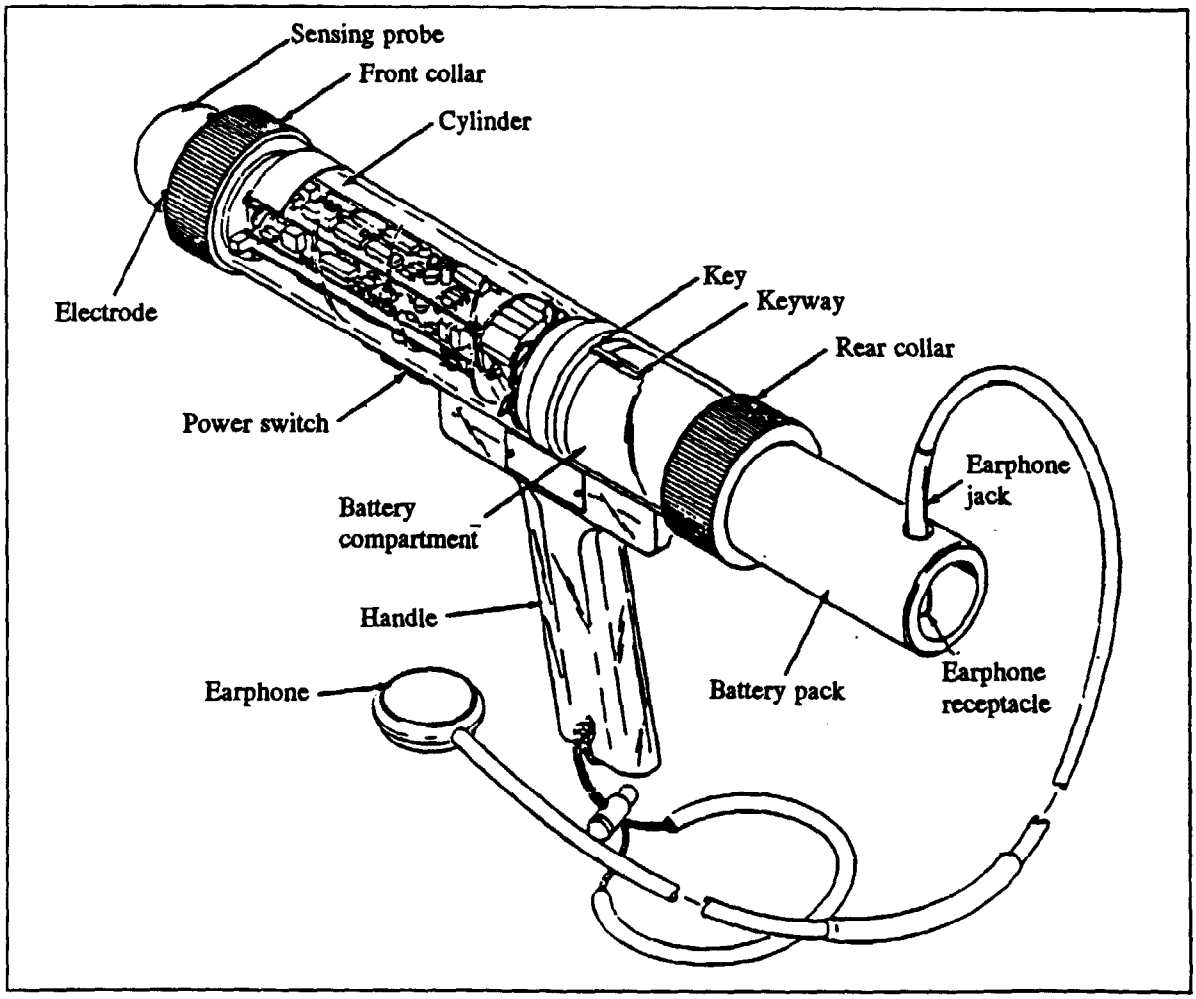



Figure D-7. Underwater electric field detector.

strength of 0.2 V/ft is not fatal to the diver but the electric field will be perceptible and may be uncomfortable.

The UEFD ***does not*** protect the diver after he or she swims into a dangerous electric field. For example, if a strong electric field is present around a pier and the diver unknowingly jumps into the water and the electric field, the UEFD will not help. If the UEFD is used to test the water before a diver enters, then the UEFD will detect the electric field and provide a warning.

## REFERENCES

D-1. Association of Offshore Diving Contractors (AODC). Code of practice for the safe use of electricity underwater. London WCIA 2HN, England, Sep 1985.

D-2. C.F. Dalziel. "Effects of electric shock on man," IRE Transactions on Medical Electronics, May 1956, pp 44-6.

# Appendix E

# NOAA BATHYMETRIC MAP PRODUCTS

The following information was obtained from the NOAA computer Bulletin Board:

**Catalog 5: United States Bathymetric and Fishing Maps**

This catalog provides a graphic index of all published bathymetric mapping products together with a listing of titles, map scales, and ordering information. The free catalog is published annually.

*Bathymetric Maps*

Bathymetric maps are topographic maps of the seafloor and do not include navigational information. They are designed for multipurpose use by a variety of users engaged in diverse ocean activities. These maps provide detailed information on the size, shape, and location of significant underwater features. Bathymetric maps are at 1:250,000 scale and carry an overprint of the Minerals Management Service lease block information.

*Loran-C Overlays for Bathymetric Maps*

Users may obtain mylar overlays with 2 or 3 Loran-C rates for their bathymetric maps. Specific ordering and pricing information appears in Catalog 5.

Loran-C overlays are ordered by sending a written request with payment to:

External Affairs (N/CG22x2)
Charting and Geodetic Services
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2729

*Bathymetric Fishing Maps*

Bathymetric fishing maps, produced at 1:100,000 scale, are tailored to the needs of commercial and sport fishermen. The maps identify and portray the distribution of bottom sediment types and known bottom obstructions, in addition to the basic information found on the standard bathymetric map. They are intended to aid fishermen and other users in the identification of seafloor features, the location of potential fishing grounds, and the location of wrecks or obstructions that might cause gear damage. These maps are overprinted with Loran-C rates to allow operators of fishing boats to fix their positions relative to the fishing areas.

*Topographic-Bathymetric Maps*

While bathymetric maps portray only seafloor characteristics, topographic-bathymetric maps graphically depict the relief of the seafloor and adjacent land areas. These maps, a joint product of NOAA and the U.S. Geological Survey, are available at

scales of 1:24,000, 1:100,000, and 1:250,000. They are of special interest to individuals and agencies involved with scientific, environmental, or engineering studies dealing with the coastal zone. The 1:250,000 scale maps are only available with overprints of the Minerals Management Service lease block information.

### *Regional Bathymetric Maps*

These maps are ideally suited for a wall-mounted general overview of the seafloor topography over large areas. They may be used in classrooms to illustrate geology, plate tectonics, and related scientific topics. The maps are published at 1:1,000,000 scale, and have been compiled from 1:250,000 scale maps to ensure that mapped features are accurately represented.

### *Plotting Sheets for General Bathymetric Chart*

The plotting sheets for the General Bathymetric Charts of Oceans (GEBCO) are a series of plotting sheets of the North Pacific Ocean that were produced by NOAA under the auspices of the International Hydrographic Bureau (IHB). These plotting sheets contain only numerical bathymetric information. Users include the U.S. Department of Defense, U. S. Coast Guard, and commercial fisheries and engineering firms needing to fix position with respect to bottom features. A plotting sheet index is included in NOAA Catalog 5.

### *Nonpublished Bathymetric Products*

NOAA can provide bathymetric information for some areas where maps have been compiled, but are not yet published. NOAA will provide, on special request, black line ozalid prints of compilation manuscripts for bathymetric maps that are in the production process, and are sufficiently developed to include accurate bathymetric data.

These products are identified in Catalog 5 as Black/White for the 1:250,000 scale maps. For the 1:100,000 and 1:24,000 maps, a dagger in front of the map name indicates the availability of those maps in only an ozalid copy format.

Copies of these maps can be obtained from:

Robin Warnken
National Geophysical Data Center
NOAA/E/GC3
325 Broadway
Boulder, CO 80303-6338

Additional information on map products appearing in Catalog 5 can be obtained from:

Carl Fefe
New Products and Procedure Section
(N/CG224)
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2693

### *Geophysical Maps*

These specialized maps are used for research and geophysical prospecting. They consist of a set of three or four sheets: a base bathymetric map, a magnetic anomaly map, a gravity anomaly map, and, where available, a sediment overprint. There are two series of geophysical maps:

1. The 1:250,000 scale series contains geophysical data for the Continental Shelf and Slope

2. The SEAMAP series at a scale of 1:1000,000 covers geophysical data gathered in the deep-sea area.

Geophysical maps are identified in the map indexes of Catalog 5.

Users of these maps include the U.S. Department of Defense, energy and mineral prospectors, commercial fisheries, foreign governments, and selected waterborne commercial vessels.

### *Ocean Survey Sheets*

These are plotting sheets published at twice the scale of U.S. Navy plotting sheets, but otherwise conform to the U.S. Navy Bathymetric Sheets used for bathymetric surveys. These plotting sheets are typically used by Federal and State agencies and private companies engaged in mapping the seafloor.

For orders and information, write or call:

Data Control Section (NCG/243)
Hydrographic Surveys Branch
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2709

### *Offshore Mineral Leasing Area Maps*

This is a series of nautical charts overprinted in red to show offshore mineral leasing areas and blocks. The series is used in offshore mineral leasing plans and programs. Users include the U.S. Department of Defense, U.S. Coast Guard, Federal planning and regulatory agencies, commercial fishermen, and private engineering firms.

### *Marine Weather Services Charts*

This series of 16 charts shows National Weather Service radio stations and broadcasting areas in addition to other vital information concerning weather reporting. Coverage includes the U.S. coastal waters and Puerto Rico.

### *Out-of-Print Charts*

NOAA retains some file copies, and in certain cases press copies, of charts it has published and printed over the years. Many of these charts represent the only record of historical coastlines and are uniquely valuable as a source for studies or research relating to these coastlines. For more information contact:

Physical Sciences Services Section
(N/CG3341)
National Ocean Service, NOAA
Riverdale, MD 20737
Telephone: (301) 436-5766

### *U.S. Coast Pilot*

This nine-volume series of books covers contiguous stretches of the coastline. Volumes are sold individually, allowing users to purchase only those covering their intended cruising area. These books provide detailed information to supplement nautical charts, particularly for mariners cruising unfamiliar waters. Useful information includes location of fuel piers, repair and haul-out facilities, local navigation regulations including, for example, hours of drawbridge operation, descriptions of natural and cultural shoreline features, tides and tidal currents, local weather conditions, and navigational hazards.

The nine volumes cover the coastal margins of the conterminous United States, the Great Lakes including the St. Lawrence River, Puerto Rico, the Virgin Islands, Hawaii, and the Alaskan coast. All volumes are published annually except for the two Alaska volumes which have a biennial schedule.

Each of the nine volumes is also available on 9-track magnetic tape. To order these tapes, please contact:

External Affairs (N/CG22x2)
Charting and Geodetic Services
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2729

### *Tables of Distances Beween United States Ports*

This publication assembles under one cover the separate distance table found in each of the Coast Pilot volumes. The distances shown are the shortest distances that safe navigation permits. The tables are useful for trip planning to determine the time allowed for passage. Users of these tables include: recreational boaters and yachters, commercial boat operators and shipping companies, boater service organizations, and commercial fishermen.

### *Digital Shoreline Data*

The use of automated systems in the production of NOS nautical charts has resulted in the creation of a database of digital shoreline coordinate data. This database is available in part or in whole on 9-track magnetic tape, and provides an excellent source for use in coastal research, planning and engineering efforts, and by those developing an automated cartographic capability, such as digital graphics-supported marine navigation systems.

The coordinate data represent the shoreline as collected from the largest scale nautical chart coverage published for a given area, and is available either as varied large-scale or uniform 1:250,000 small-scale data sets. The small-scale coordinate data are derived from the large-scale digitized data and do not represent a specific NOS chart.

Shoreline for the conterminous United States, Puerto Rico, the U.S. Virgin Islands and Hawaii, and Alaska (partial coverage) is available. Shoreline for the Pacific Trust Territories and the Great Lakes is not available at this time. Although the database is not routinely maintained with contemporary changes that are portrayed on the latest published NOS charts, future maintenance is being considered.

For a brochure describing the shoreline data and pricing, please contact:

External Affairs (N/CG22x2)
Charting and Geodetic Services
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2729

### *Digital Aids to Navigation*

NOS maintains a database of aids to navigation information as part of its nautical chart production procedure. Information contained in the database is periodically updated from Weekly and Local Notices To Mariners and other sources used to revise nautical charts. Included are fixed and floating aids to navigation, landmarks, and some marine hazards. The database is available in part or in whole on 9-track magnetic tape. A brochure describing the database is available from:

External Affairs (N/CG22x2)
Charting and Geodetic Services
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2729

**Digital Cartographic Computer Programs**

Many digital computer programs are available from NOAA that support the analysis of geographic data. Two that are useful for the analysis of NOAA nautical data are:

**General Integrated Analytical Triangulation Program (GIANT).** Computes a triangulation net using a least squares technique to solve for ground coordinates from image points measured on two or more aerial photographs. It is used in support of photogrammetric mapping, and is extremely flexible with respect to the data formats it can read and the value ranges associated with camera and ground station parameters.

**General Cartographic Transformation Package (GCTP).** Calculates transformations between geographic coordinates and rectangular coordinates for 20 separate types of map projections, and calculates transformations between any two projections. The software package contains parameter lists for computing on either the 1927 or the 1983 North America Datum.

For further information about these programs contact:

National Geodetic Information Branch
(N/CG174)
National Ocean Service, NOAA
1315 East-West Higway
Silver Spring, MD 20910
Telephone (Voice): (301) 713-3242

**Possible Sources of Wreck Information, Pamphlet #8**

This educational pamphlet is designed to assist persons seeking information on charted wrecks. It provides a bibliography of source material and instructions on how to obtain and use this information. The pamphlet is of special interest to scuba divers, boat operators, fishermen, salvagers, classroom instructors, and researchers.

**Automated Wreck and Obstruction Information System (AWOIS) and AWOIS User's Guide**

This guide contains information on submerged wrecks and obstructions in areas within U. S. coastal waters that have been researched or investigated by NOAA. Each wreck or obstruction has latitude and longitude, position accuracy codes, survey status, and historic and descriptive information keyed to a nautical chart by chart number and type of wreck. Users may purchase standard area or special area hard copy printouts from the database. A free AWOIS User's Guide for this file is available that provides information for interpreting the data on the printout. The guide also explains the use of the system as a basic research tool. Costs and specific ordering instructions are contained in the AWOIS User's Guide.

This product is particularly popular with scuba divers, researchers, and commercial salvagers and is a useful source for historical research on shipwrecks. It also provides important information to sport and commercial fishermen.

To order the AWOIS User's Guide or to purchase specified printouts, contact:

Operations Section (N/CG241)
Hydrographic Surveys Branch
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2702

**Aerial Photography**

Prints of aerial photographs dating from 1927 to the present that comprise part of NOAA's chart compilation holdings are available to the public. These holdings include panchromatic, color, black and white infrared, and color infrared images depending on the date and purpose of the photography. Photograph indexes are keyed to latitude and longitude on 1-degree by 2-degree plots and are available at a nominal charge. Basic photograph sizes are 9x9 inches, but enlargements up to four times original size are made available by special request.

There is coverage of most of the coastlines represented on NOAA nautical charts, and these photographs are an exceptionally valuable source material for coastal studies and engineering projects. A free brochure that describes the photography and ordering procedures is available by contacting:

Photogrammetry Branch (N/CG2314)
Nautical Charting Division
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2675

*Digital Hydrographic Database*

The NOAA Hydrographic Database constitutes the most accurate and extensive digital bathymetric data available for the coastal waters of the United States, Alaska, Hawaii, and Puerto Rico. This database contains the source for most of the soundings, bottom characteristics, and navigational hazards symbolized on the NOAA charts. The database includes values gathered during the surveys, and provides more detailed information compiled for the same area. For this reason, it is an excellent database for research-extensive knowledge of sea bottom conditions. This database is not intended for use in navigation and is not updated by Notice to Mariners.

These data are contained on 9-track magnetic tape and in plot form on microfiche and paper. For a free descriptive brochure, order Data Announcement 87-MGG-12. This brochure and information regarding other geophysical data sets are available from:

National Geophysical Data Center
NOAA E/CG3
325 Broadway
Boulder, CO 80303
Telephone: (303) 497-6338

*Hydrographic and Topographic Surveys*

Hydrographic surveys are detailed, large-scale plots of surveyed depths of both charted and uncharted water areas. These surveys provide the hydrographic detail for nautical charts. Data for land detail are gathered from a variety of sources and are compiled on plots known as Topographic Surveys. NOAA has compiled these surveys since 1834 and they represent a unique and comprehensive record of our coastline and adjacent waters, showing conditions that existed at the date of the survey. They provide, in many areas, a detailed record of the changes that have occurred from both natural and manmade sources.

These surveys are used extensively by the public and government agencies for research, engineering, and development pur-

poses. They are often referred to in property disputes where the shoreline represents a boundary, and certified copies are frequently presented as evidence in the court.

Survey descriptive reports describing the conditions under which each hydrographic or topographic survey was conducted can be obtained as companion information to most surveys. The reports discuss the factors that influence the accuracy and completeness of surveys, and provide additional information significant to understanding the survey results. Information concerning hydrographic surveys, topographic surveys, and their companion descriptive reports can be obtained by contacting:

Data Control Section (N/CG243)
Hydrographic Surveys Branch
National Ocean Service, NOAA
1315 East-West Highway
Silver Spring, MD 20910
Telephone: (301) 713-2709

**The following products are generally available where National Oceanic and Atmospheric Administration (NOAA) charts are sold:**

*Tidal Current Charts*

These charts graphically represent tidal currents in selected bays and harbors of the United States. Each series consists of a set of 12 or 13 charts that depict, by means of arrows and figures, the direction and speed of the tidal current for equal intervals of the tidal cycle.

*Tidal Current Tables*

The tidal current tables list predicted times of minimum and maximum tidal currents and current velocities for each day of the year at 54 places located along the Atlantic and Pacific coasts of North America and the Pacific coast of Asia. The tables also provide the conversion factors for predicting tidal currents at 2,400 subordinate stations in these areas.

*Tide Tables*

Tide tables list the predicted times and heights of high and low waters for each day of the year for about 200 of the most important harbors throughout the world. The tables also contain conversion factors for tidal predictions at thousands of subordinate stations.

*Delaware River and Bay Atlas*

This new information product is designed to provide, under one cover, all the tables and charts necessary to predict water levels and currents in the Delaware River and Bay. Computer-generated graphics enable tidal height and current predictions to be made throughout the estuary. This initial publication will be followed by similar atlases covering the Columbia RIver, Charleston Harbor, and Long Island Sound.

NOAA

**Where to get the products described above?** Unless otherwise specified above, nautical products are available from:

NOAA Distribution Branch (N/CG33)
National Ocean Service
Riverdale, MD 20737
Telephone: (301) 436-8301

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