FHWA-DP-98-1

UNDERWATER EVALUATION AND REPAIR OF BRIDGE COMPONENTS

Demonstration Project 98

Participant Workbook

November 1995

U.S. Department
of Transportation

**Federal Highway
Administration**

SESSION 1

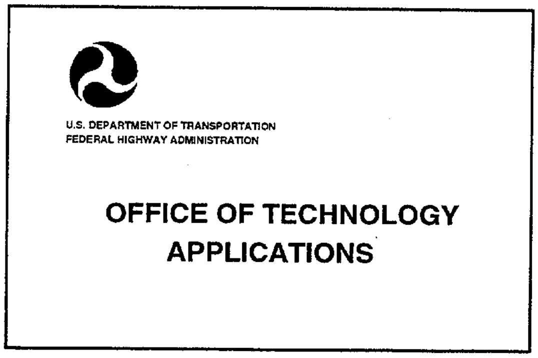
INTRODUCTION

SESSION 1: INTRODUCTION

TOPICS:
REGISTRATION
OPENING REMARKS AND INTRODUCTIONS
PURPOSE AND OBJECTIVES

LESSON PLAN:

DURATION	30 minutes
GOAL	Understanding of the need for underwater evaluation and repair.
OBJECTIVE	Be able to state the objective of the course and the purpose for being a participant.
OUTLINE	I. Registration II. Opening Remarks and Introductions III. Purpose and Objectives



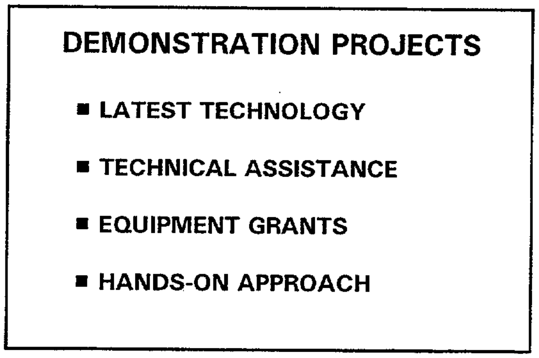
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

OFFICE OF TECHNOLOGY APPLICATIONS

1-1

A. Overview of FHWA's Office of Technology Applications

- Goal is to place latest technology in hands of technical personnel at state and local levels.



DEMONSTRATION PROJECTS

- LATEST TECHNOLOGY
- TECHNICAL ASSISTANCE
- EQUIPMENT GRANTS
- HANDS-ON APPROACH

1-2

One way this is accomplished is through demonstration projects which are provided to states.

- Latest technology includes methods, techniques and hardware.
- Demonstration projects can provide technical assistance to use or install latest technology.
- Can provide grants to states to try and evaluate latest equipment. States are then required to report on their evaluation.
- Where possible, Demonstration Projects provide an actual opportunity to observe and use new technology.

UNDERWATER BRIDGE INTEGRITY PROGRAM

- UNDERWATER EVALUATION AND REPAIR OF BRIDGE COMPONENTS (DP 98)
- SCOUR MONITORING AND INSTRUMENTATION (DP 97)

1-3

The Underwater Bridge Integrity Program consists of two parts as shown in this slide.

The scour monitoring and instrumentation (DP 97) portion consists of a two day course on fixed and portable scour detection and monitoring equipment, such as mechanical systems and sonar.

DP 80

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

BRIDGE INSPECTION TECHNIQUES AND EQUIPMENT

1-4

DP 80, which was presented a few years ago, is also available to the states if requested.

1-5

DP 80 concentrates on underwater inspection of bridges.

A condensed Demonstration Project 80 - Underwater Inspection is an optional part of this course. If it is presented, it is intended for bridge inspectors or engineers with little or no background in underwater inspection. The course will, as a minimum, cover the following items:

Reasons for underwater inspections
Capabilities and limitations of divers
Managing underwater contracts
Underwater inspection techniques
Documenting underwater conditions
Field Demonstrations

B. Overview of Training Program

The two-day training course is intended for experienced bridge inspectors, and engineers currently involved in bridge evaluation, bridge repair and design of repairs. There are no prerequisites to this course; however, an understanding of bridge repair techniques and an understanding of diving operations is strongly recommended. Conditions underwater can vary greatly at each bridge site, and underwater evaluation and repair methods must be selected in consideration of site and structure conditions. This course is intended to familiarize the participants with the factors which must be considered, and some of the many options which are available to them.

The training course will, as a minimum, cover the following topics:

Status of bridge inspection programs nationwide
Mechanisms of underwater deterioration
Underwater condition surveys (refresher)
Specialized underwater testing equipment
Evaluation of deterioration on structures
Underwater repairs:

    Wet Repairs (Diver)
    Cofferdams
    Diving Equipment
    Topside Support
    Pile Wraps and Jackets
    Rigid Forms
    Flexible Forms
    Concrete Additives
    Underwater Welding
    Epoxies
    Protective coatings

C. Upon completion of the course, the participants should be able to:

1. Recognize underwater deterioration and damage mechanisms.

2. Be able to describe how underwater inspections are conducted.

3. Understand the capabilities and limitations of divers and underwater inspections.

4. Recognize situations where non-destructive and partially destructive testing methods can be employed underwater and understand how the tests are conducted.
5. Understand the effects of damage and deterioration on underwater components of structures and be able to recognize situations where the distress is significant.
6. Recognize considerations in selecting underwater repair methods, including environmental concerns.
7. Understand the capabilities and limitations of underwater construction tools.
8. Recognize the factors to consider in selecting underwater repair methods and materials.
9. Have a basic understanding of cathodic protection systems for structures located in a marine environment.
10. Understand the principles governing the design of scour countermeasures, and be familiar with basic measures currently in use.
11. Understand some of the special considerations necessary for planning and contracting for repairs of components of structures located in water.

D. **Participants should feel free to make notes in this workbook.**

E. **Participants will be requested to evaluate course at the end, and comments are welcome.**

SESSION 2

MECHANISMS OF DETERIORATION

SESSION 2: MECHANISMS OF DETERIORATION

TOPICS: TYPES OF DETERIORATION AND DAMAGE CONCRETE, MASONRY, STEEL, TIMBER

LESSON PLAN:

DURATION	45 minutes
GOAL	Understanding of underwater deterioration and damage mechanisms.
OBJECTIVE	Participant should be able to describe and differentiate between types of structure distress.
REFERENCE	NTSB Pocomoke Bridge Collapse Final Report

OUTLINE

I. Types of Deterioration and Damage
II. Concrete
    A. Scaling
    B. Spalling
    C. Chemical Attack
    D. Cracking
    E. Abrasion-Vessel Damage

III. Masonry
IV. Steel
V. Timber
    A. Abrasion
    B. Freeze-Thaw
    C. Decay
    D. Borers
    E. Insects
    F. Bacterial Degradation
VI. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 2
MECHANISMS
OF
DETERIORATION

2-1

I. TYPES OF DETERIORATION AND DAMAGE

The type of deterioration that will be found near and below the waterline depends on the type of material present in the structure. Each material has its own deterioration mechanism.

The environment at the waterline is very conducive to material deterioration. All mechanisms of deterioration are enhanced and the rate of deterioration may be increased by oxygen, moisture, and salts or other chemicals in the water.

UNDERWATER & WATERLINE DISTRESS

- **MATERIAL DETERIORATION**
  - **CONCRETE**
  - **TIMBER**
  - **STEEL**
  - **MASONRY**
- **EXTERNAL FORCES**
  - **VESSEL DAMAGE**
  - **ABRASION**
  - **ICE FLOES**
  - **SCOUR**
- **MARINE BORERS AND INSECTS**
- **CHEMICALS**

2-2

In addition to the specific types of deterioration to which each material is subject, structures located in the marine environment may also be subject to external agents and forces such as vessel impact damage, ice floes, scour, marine borers and insects, and chemicals.

We will look at each of these deterioration mechanisms and external forces in greater detail.

CONCRETE DETERIORATION

- **SCALING**
- **SPALLING**
- **CRACKING**
- **CHEMICAL ATTACK**

2-3

II. CONCRETE

These are the principal types of concrete deterioration: scaling, spalling, cracking, and chemical attack - such as alkali reactions.

Although they are different forms of deterioration, they have much in common and one or more forms can be present at the same time. All of them are influenced by conditions at and below water.

Let's look more closely at each of these types of concrete deterioration.

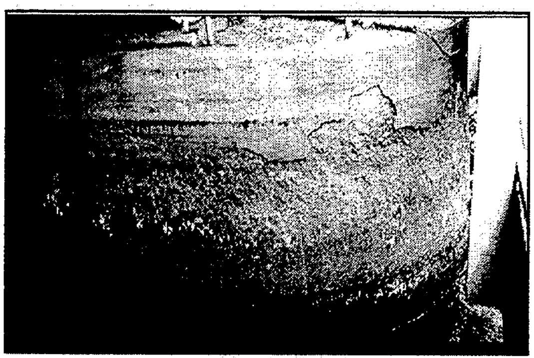
SCALING

2-4

A. SCALING

First, Let's look at scaling.

Most people use the terms scaling and spalling interchangeably to describe any type of concrete deterioration, but they are different phenomena.



2-5

This is scaled concrete. Note that the surface of the concrete appears to be disintegrating. Scaling is the gradual and continuing loss of surface mortar and aggregate from an area. Generally it occurs in the splash zone.

The <u>Bridge Inspectors' Training Manual</u> classifies scaling in the following categories:

(1) Light Scale. Loss of surface mortar; up to 1/4 inch penetration, with surface exposure of coarse aggregates.

(2) Medium Scale. Loss of surface mortar; 1/4 inch to 1/2 inch penetration, with some added mortar loss between aggregates.

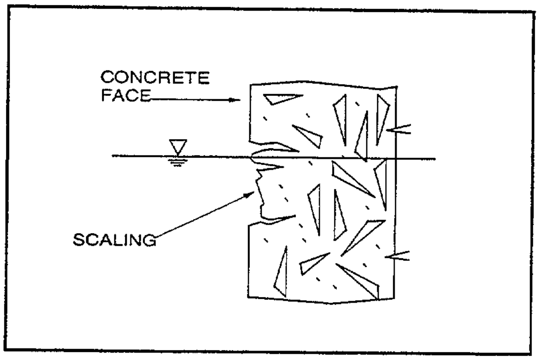
(3) Heavy Scale. Loss of surface mortar surrounding aggregate particles; 1/2 inch to 1 inch penetration. Aggregates are clearly exposed and stand out from the concrete.

(4) Severe Scale. Loss of coarse aggregate particles as well as surface mortar and the mortar surrounding the aggregates. Penetration of the loss exceeds 1 inch.

SCALING

■ **LIGHT**	< 1/4"
■ **MEDIUM**	1/4" TO 1/2"
■ **HEAVY**	1/2" TO 1"
■ **SEVERE**	> 1"

2-6



2-7

Scaling is commonly found at the waterline on piers and piles. It is caused by freeze-thaw action and, therefore, is found in colder climates. Pores and minor surface defects allow water to penetrate and saturate the concrete. When the temperature drops, the water freezes and expands causing the surface of the concrete to "pop-off" or appear to disintegrate. At the waterline, conditions are ideal for scaling to occur.

There are also some studies which show that scaling can occur without freezing due to osmatic pressures which develop as salt solutions migrate from areas of high concentration to areas of lower concentration.

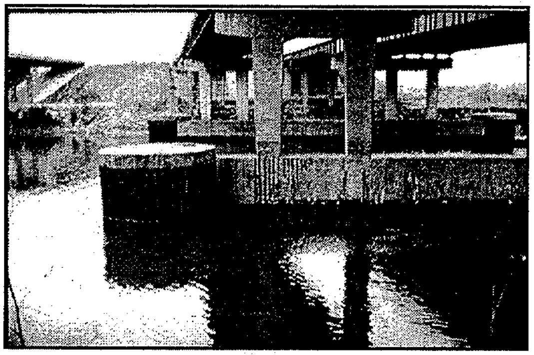
Air voids entrained in concrete either intentionally through the use of air entraining admixtures or unintentionally can allow the concrete to freeze and thaw without damaging the surface.

SPALLING

2-8

B. SPALLING

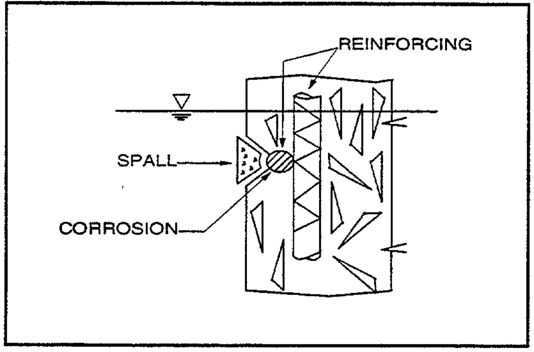
Spalling is similar to scaling in many ways. Both can start with freeze-thaw action, but in spalling you also have corrosion of reinforcing steel.



2-9

The face of this pier wall shows an example of spalling. Note that the reinforcing steel is exposed. This indicates that spalling rather than scaling has occurred.

Spalling is a depression in the surface of concrete which exposes corroded reinforcing steel. It is primarily the result of pressures within the concrete caused by corrosion of the steel. Extensive research has been conducted into the spalling process in bridge decks. Much of this information can be transferred directly to the waterline environment.



2-10

Cracks in concrete over bars near the surface due to shrinkage, cracks due to external damaging forces, and pores that occur naturally in concrete allow moisture and air (oxygen) to reach reinforcing steel near the surface. When the steel corrodes, the products of corrosion occupy up to ten times the volume of the parent material and can produce forces in excess of 5,000 psi.

This slide shows an idealized cross section of concrete in water. This expansive force cracks the concrete and "pops-off" areas on the surface of the concrete member exposing the reinforcing steel to the environment. The process then accelerates until large areas are spalled.

The environment at the waterline of bridges is especially conducive to spalling. Abrasion and constant wet-dry cycles can provide the initial paths for moisture and oxygen to reach the steel. Salt water or water with acidic pollutants makes excellent electrolytes for the corrosion process, and wave and tidal action regularly remove the film of corrosion that develops to provide a new surface for rapid corrosion. In colder climates, water freezing in small cracks also expands and accelerates the spalling process.

At times, spalling can occur over a large area, hidden by the surface concrete. Internal fracture planes may develop below the surface of the concrete. These generally can be detected by the hollow sound produced by striking the surface with a hammer. These areas are sometimes referred to as imminent spalls, or for large areas, delamination.

Reinforcing steel placed with insufficient cover is subject to corrosion, and it is not uncommon to find pieces of reinforcing steel protruding from concrete structures below water. It is also not uncommon to find steel rods used to tie form work together on piers, steel beams used to brace cofferdams, and wire rope lifting loops on concrete piles. Over a period of time, this steel can also corrode, causing spalling of the concrete.

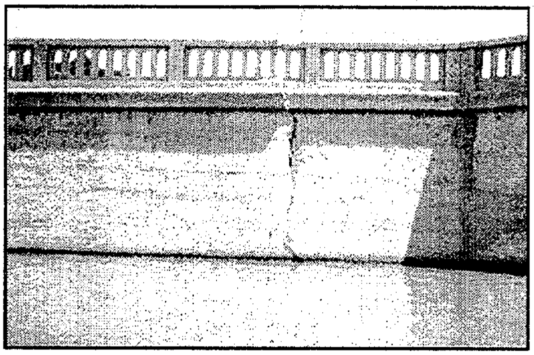
CRACKING

2-11

C. CRACKING

Cracking is an early stage of scaling and spalling. It can also indicate more serious problems such as settlement or design of too much restraint in a structure.

All concrete cracks, but where the crack is located and whether it is dormant or active can be important.



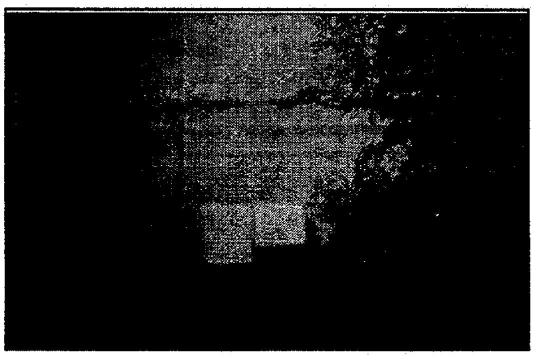
2-12

Cracking can give early warning of developing conditions, but it can also indicate serious hidden problems. This crack extends above water, but the cause of the crack is below water.

2-13

Here are some examples of cracking:

This is a longitudinal crack that allows salt water to come into contact with steel during high tide.



2-14

This is a transverse crack that is much more serious because of its orientation.

It indicates previous stressing of this pile due to lateral force.

The crack did not close tightly when the force was removed, so the internal steel is now vulnerable.

CHEMICAL ATTACK

2-15

D. CHEMICAL ATTACK

Substructures located in water are sometimes subjected to chemicals which attack the concrete. The forms of chemicals vary widely and may be present naturally or due to man-made pollution. Even the type of water (hard versus soft) can affect the concrete.

CHEMICAL ATTACK

- **CHLORIDES**
- **SULPHATES**
- **POLLUTION**
- **ALKALI-AGGREGATE REACTION**

2-16

The penetration of chlorides into concrete can cause corrosion of the reinforcing steel. Chlorides may enter the concrete from deicing agents, saltwater, or admixtures. Chlorides make water an electrolyte. Spalling and cracking of the concrete is likely to occur when chlorides are present.

Sulfates are present in seawater and are common in ground waters, especially when high proportions of certain clays are present. Structures in seawater can suffer sulfate attack in the tidal zone. Sulfate attack is usually detected as a softening of the surface of the concrete. With further deterioration, the surface ravels as material is easily chipped away, and the newly exposed surface is often white in color. When sulfate damage is far advanced, there may also be swelling and cracking of the concrete. Sulfate attack is more common in older structures and those constructed of Type I cement. Type II cement is less susceptible to sulphate attack.

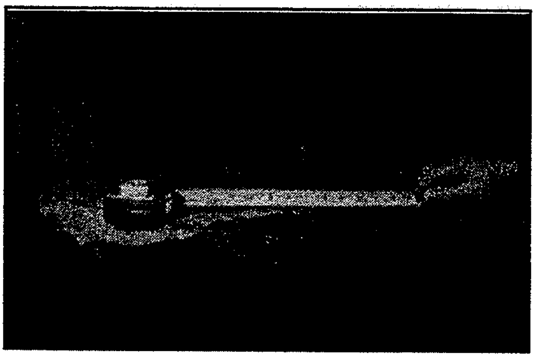
Polluted water can cause various defects depending upon the type of pollution present, but where chemical attack is suspected, it is common to find uniform scaling on the submerged portions of a structure.

Alkali-aggregate reaction deterioration due to the presence of volcanic rock in the aggregate is commonly found in structures built in the late 1920s to the early 1940s. The reaction occurs between the alkalis present in the cement paste and reactive forms of silica contained in certain types of aggregate which, in this case, is volcanic rock. The reaction causes expansive forces which damage the concrete. Factors which control the reaction are the amount, type and size of the reactive silica, the amount of available alkali and water.

2-17

These two slides show examples of Alkali-aggregate reaction and soft concrete, possibly due to sulfate attack or calcium leaching.

This Washington State Bridge is located in salt water.

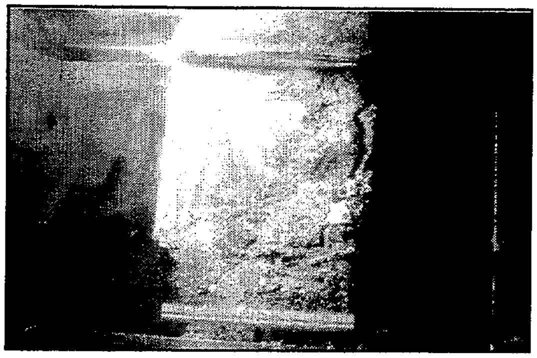


2-18

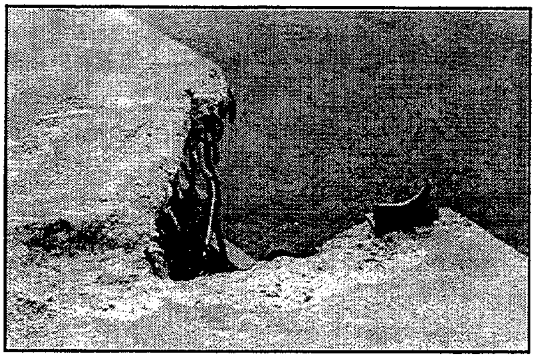
This a bridge in fresh water, very clean water. This possibly may be causing leaching out of calcium.

E. ABRASION-VESSEL DAMAGE

Abrasion damage is due to external forces acting on the surface of the concrete member. Minor abrasion damage resembles scaling, and major abrasion damage may cause gouges, cracks and voids.


2-19

This slide shows a prestressed concrete pile that has been damaged below water, probably by a work boat. Ice can cause severe scaling and abrasion at the waterline. In some rivers, scaling near the mudline is also found due to the abrasive action of bottom material being carried along in a swift current.

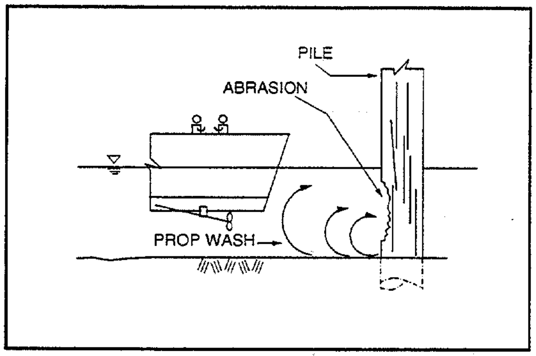

2-20

This shows where a ship hit the deck of a prestressed pile supported structure in a storm.


2-21

This shows the damage below water. The prestressing strand has apparently been stressed enough to crack the concrete, but not permanently yield it.

Cracks, voids, and chipped corners can be caused by vessel impact. Marine traffic or cables used to fasten vessels to structures can also cause abrasive damage.



2-22

Ferry vessels, which repeatedly and rapidly start and reverse their propellers, and tugs maneuvering close to bridges can effectively sand-blast underwater elements, causing severe damage over the long term.

This same condition can occur at bridges near grain loading terminals.

2-23

Prestressed concrete piles generally perform well in the underwater environment, but if the internal steel and prestressing strands are exposed to water, corrosion can occur. This slide shows a lifting loop which had not been cut off and patched properly. This allowed corrosion to begin on the exposed steel and travel into the pile. Even at some distance below water there is enough oxygen for corrosion to occur.

MASONRY DETERIORATION

- STONE CRACKING
- STONE DELAMINATION (SCALING)
- POINTING FAILURE

2-24

III. MASONRY

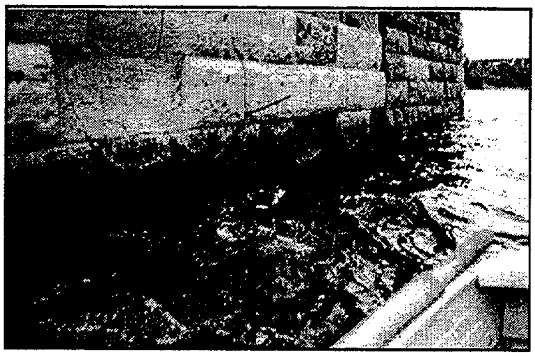
Masonry is not now commonly used in bridge construction, although it is sometimes used as an ornamental facing. Many older bridges, however, have piers and abutments constructed of masonry. The types of stone commonly found are granite, limestone, and sandstone. Problems commonly found in masonry structures include cracking, scaling and deteriorated pointing.

Masonry is a naturally porous material and, although it is generally more durable than concrete, it is susceptible to deterioration by freezing and thawing. The stone may fracture and break off in small pieces and the man-made mortar deteriorates like concrete. More rapid deterioration, such as cracking along bedding planes, may also occur in stone of lower quality.

Masonry mortar joints near the waterline are usually most susceptible to freeze-thaw damage. It is not uncommon for the stone masonry to be in good condition, and for the mortar to be completely missing from several courses of stone near the waterline.

The abrasive action of sand in moving water may cause the masonry below water to experience losses in both the masonry and the pointing.

Older masonry structures may have been repaired using masonry or concrete. The condition of the repairs should also be noted.



2-25

This slide shows typical damage to masonry and pointing. Note the popped-off areas and the deterioration of the pointing, especially near the centerline. The pier is constructed of two different types of stone and the level of deterioration is dependent on the quality of stone.

STEEL DETERIORATION

- **CORROSION**
  - **ELECTRO-CHEMICAL**
  - **BACTERIAL NODULAR**

2-26

IV. STEEL

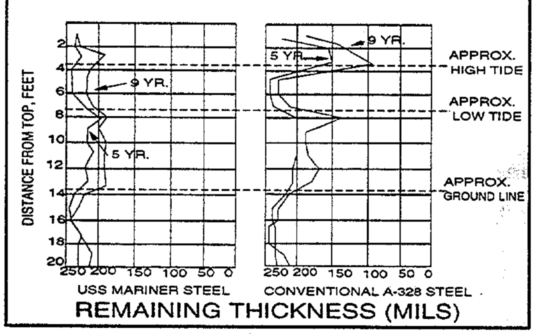
Steel is used as a structural material and as external protective cladding on concrete foundation elements. The primary cause of damage to steel is corrosion. Corrosion is most prevalent in the splash and tidal zones, but can occur both above and below water.

FACTORS INFLUENCING CORROSION

- **OXYGEN**
- **MOISTURE**
- **CHEMICALS**
- **ELECTRICAL CURRENTS**
- **WATER VELOCITY**

2-27

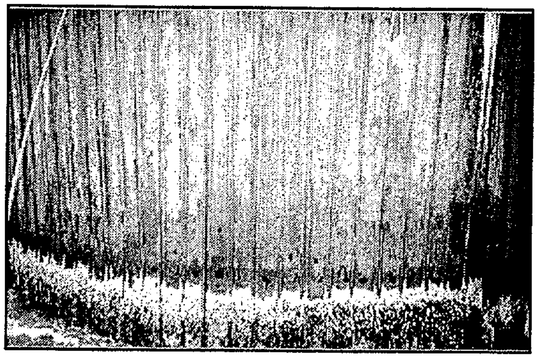
Steel foundation elements located in water, commonly H-piles, pipe piles, or sheet piling, can suffer distress in the form of corrosion. The corrosion can be especially severe when the bridge is located in salt water or brackish water. The most important factors influencing and producing corrosion are the presence of oxygen, moisture, chemicals, pollution, stray electrical currents, and water velocity.



2-28

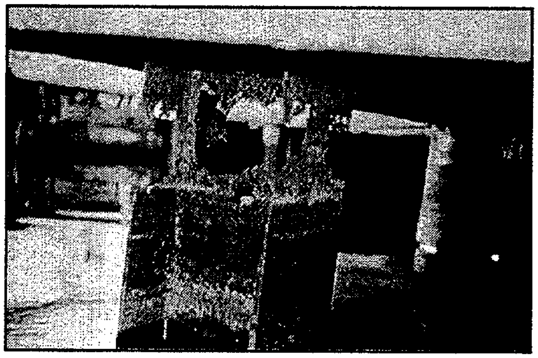
This chart depicts the rate of deterioration of steel in seawater. Note that this chart shows two different steels. Though the high nickel (Ni) steel shows less corrosion overall, the corrosion pattern is similar for both steels.

Corrosion is the conversion of the metallic ion, through electrochemical reactions, into a compound form (rust). In the electrochemical process, there must be a current flow. This current flow can be caused by external forces, or as the result of differences in potential between different metals. Bridges in industrial areas, where there may be many stray electrical currents, may experience severe corrosion problems.



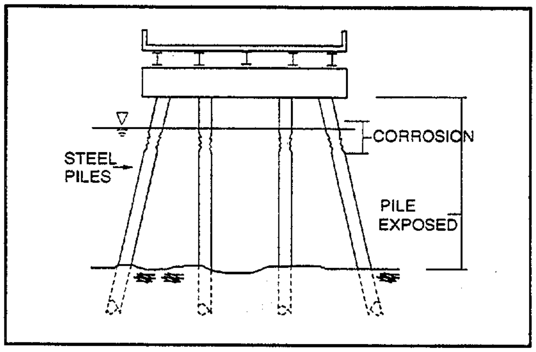
2-29

For bridge elements located in water and not protected from the water, the water acts as an electrolyte. Salt water or those waters that contain significant amounts of sulfur or chlorides are more acidic and make better electrolytes so that the corrosion rate is much greater than in fresh water. In the splash zone, caused by waves and tides, and in areas of high velocity flow, the corrosion rate is also much greater than in still waters. The moving water provides more wet-dry cycles, carries more oxygen to the metal, and tends to remove the initial film of corrosion which would normally retard further deterioration. If there are abrasive materials in the water, these can also remove the initial film of corrosion and increase the rate of corrosion. Corrosion rate is also generally greater in warm waters than in cold waters.



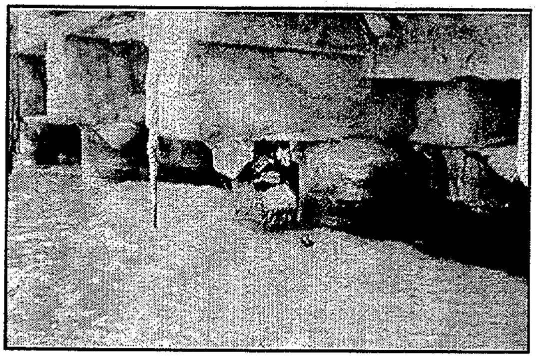
2-30

Corrosion of steel H-piles in saltwater and brackish water can be severe. In a typical bridge configuration, relatively lightweight piles driven into a massive soil channel bottom support a massive/concrete deck system. These two massive end conditions act as cathodes and the exposed slender metal pile acts as an anode, giving up electrons which go into solution.



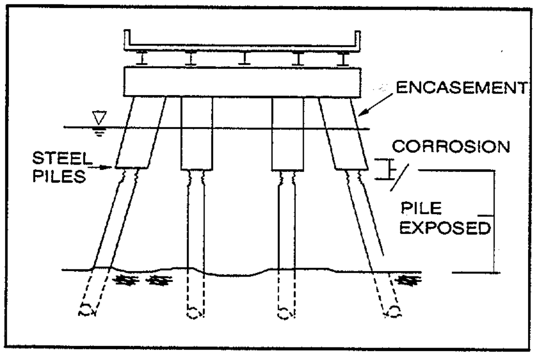
2-31

Often the most severe corrosion occurs near the waterline. This condition is shown pictorially in this slide.



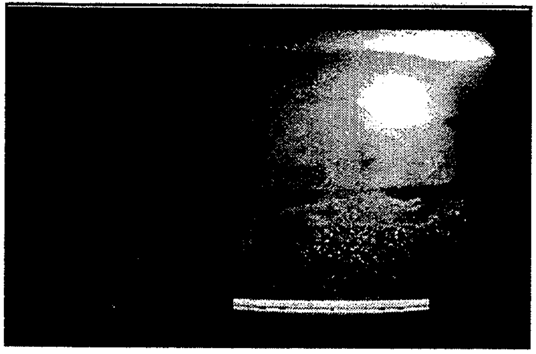
2-32

A common remedial action is to encase the H-pile with concrete from the underside of the deck to a few feet below mean low water.



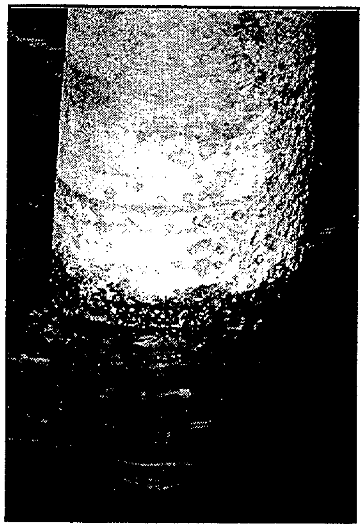
2-33

In many cases, this is only temporarily successful because the loss of metal is shifted to just below the concrete encasement. This repair may, in fact, make the situation worse, as the cathodic areas become smaller. Rapid and severe corrosion of H-piles has been noted below the concrete encasement.



2-34

This shows the type of deterioration that occurs just below the concrete encasement.



2-35

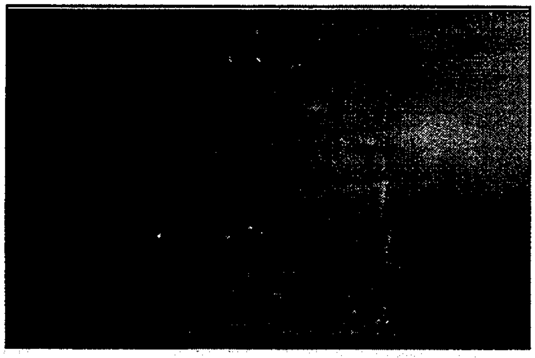
Bacterial corrosion is sometimes found below the waterline in fresh waters. This corrosion forms brownish orange nodules, which can be removed with a hand scraper. The metal under the nodule is usually shiny and pitting is normally found.

These nodules are formed by anaerobic sulphate producing bacteria and are generally worse near the surface.

2-36

Heavy marine growth, found in seawater, can sometimes inhibit corrosion, but it can also hide severe distress or loss of section. During an inspection, areas of heavy growth should be spot-cleaned to check for loss of section.

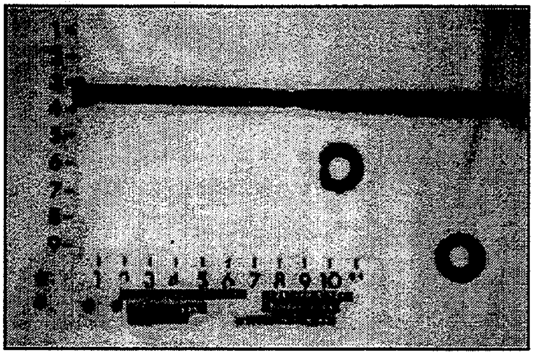
Connections, such as bolts, welds, and interlocks on sheet piling, are potential areas of corrosion. While bridge substructures are generally constructed without connections below water, there are some instances where underwater connections may be encountered, such as at splices in piles and at bracing connections, and on wales of sheet pile bulkheads. Connections are also often found in the splash zone for bracing members.



2-37

Connections such as H-pile splices should be examined at the welds. The dissimilarities between weld metal and the base metal can be corrosion producers. If backup bars for the weld have not been removed, these are highly suspect since their material composition may differ greatly from the base material. The configuration of the weld, if it has not been ground smooth, can also cause a local corrosion cell to develop. In coated structures, the area at welds should be closely examined since coatings are usually thinnest and tend to break at irregularities such as welds.

Connections are potential sites of corrosion because their composition may be dissimilar from the structure's main material, causing the formation of corrosion cells at these discontinuities.



2-38

Bolts and rivets should be cleaned and examined for corrosion and fit. Nuts should be examined for tight fit. Even the bolts used to connect timber bracing can corrode. Dissimilarities between materials of nuts and bolts can cause significant losses to either the nut or the bolt. This is a stainless steel bolt with a mild steel nut.

TIMBER DETERIORATION

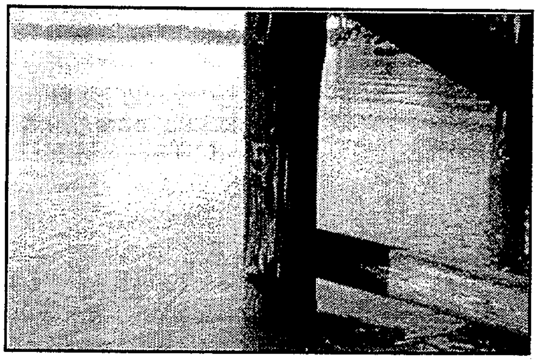
- PHYSICAL FORCES - ABRASION
- FREEZE - THAW
- DECAY
- FUNGI ATTACK
- MARINE BORERS
    - TEREDO
    - LIMNORIA
- CADDISFLY
- BACTERIAL DEGRADATION

2-39

V. TIMBER

Timber pile bents are common in smaller and shorter span bridges. On larger bridges, many protection devices are constructed of timber, and many piers and abutments are supported on timber piles.

Deterioration in timber members results from a variety of sources, including the decaying action of bacteria, fungus, marine infestations, abrasion, and collisions.



2-40

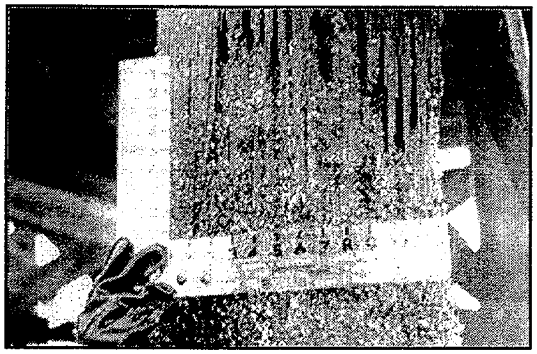
A. ABRASION

The abrasive action of waterborne materials, such as ice and sand, can damage timber members. Damaged areas appear worn and smooth. Abrasive damage typically occurs at the waterline and mudline. There are indications that the bacterial action in acidic waters may soften the surface of timber piles so that they are vulnerable to abrasion. A gradual and general reduction in diameter can occur along the entire length of the pile between the waterline and mudline. Detection of this general reduction in diameter may only be possible by measuring pile diameter.

2-41

B. FREEZE-THAW

The freeze-thaw action of surface ice can also break down the surface of timber piles.

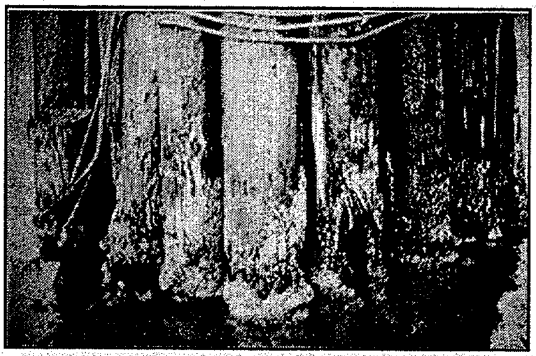


2-42

C. DECAY

Fungi thrive on the organic matter in wood cells. Ideal conditions for their growth include sufficient moisture, oxygen, and warmth. Near the waterline of timber elements, these conditions are at least present intermittently. These micro-organisms can easily penetrate untreated timber or older timber where the preservative has become ineffective. In early stages, decaying members appear slightly discolored.

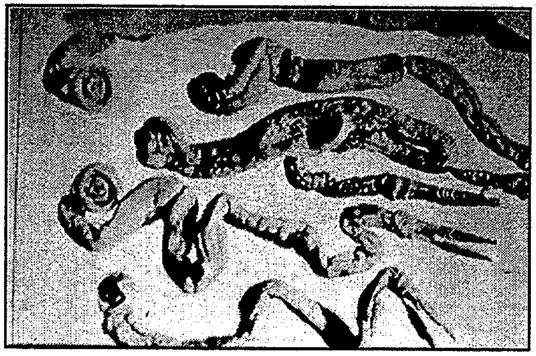
In advance stages of rot, the wood becomes spongy, stringy, crumbly, and splintered. Members with internal decay may appear slightly splintered and produce a hollow sound when struck with a hammer or metal bar. Vegetation growing from a pile is usually an indicator that decay is occurring on the interior of the pile.



2-43

D. BORERS

Two types of marine borers are most common to the saltwater environment: molluscan borers and crustacean borers. Because of their destructive capabilities, the teredo and the bankia, which have similar characteristics, are the most important molluscan borers, and the limnoria is the most important crustacean borer. Both infest wood that is untreated or whose preservative has become ineffective. Additionally, any holes drilled during construction or other defects invite the infestation of these creatures.



2-44

The teredo, or bankia, enters the timber at an early stage of life and remains there for the rest of its life. While the organism bores to the inner core of the timber it leaves its tail in the opening to obtain nourishment from the water.

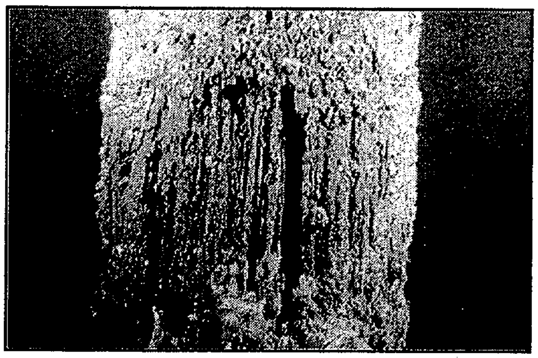
It is possible for some species to grow up to six feet in length. The hole made by the teredo varies from 1/4 to 1/2 inch in diameter, with some species of bankia growing to 3/4 inch in diameter and four feet in length.

DUAL TREATMENTS

- **CREOSOTE PROTECTS AGAINST TEREDO**
- **ARSENATE PROTECTS AGAINST LIMNORIA**

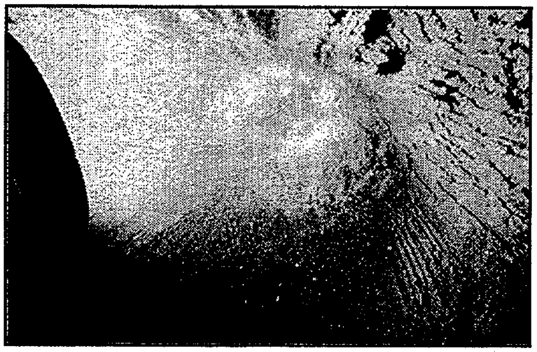
2-45

Damage from marine borers can occur anywhere between the mudline and the waterline. Creosote preservatives have proven effective against teredo attack and arsenate preservatives have been effective against limnoria. A combination of both of these preservatives can be used to protect against both borers.



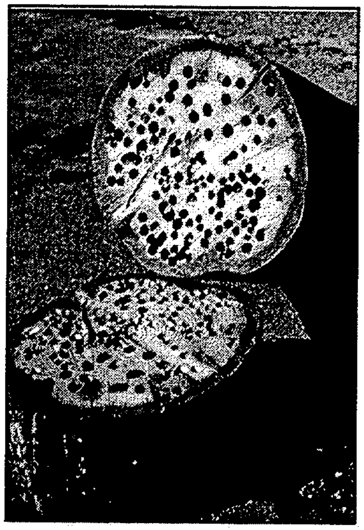
2-46

Timber pile with some surface damage looks like small void, but inside...



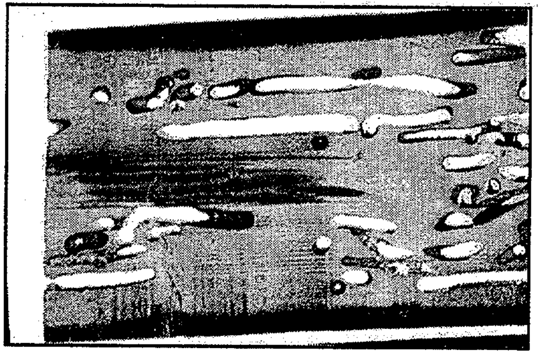
2-47

Picture of inside of pile taken below water showing interior of pile completely eaten out by teredo.



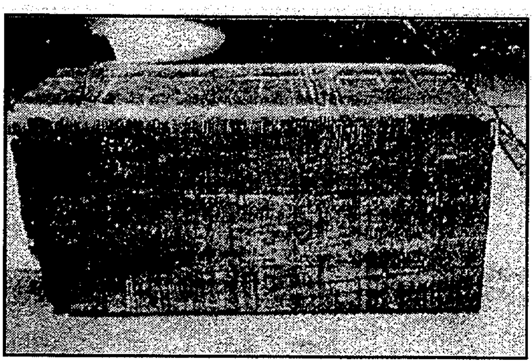
2-48

Early stages of teredo infestation. Note holes - 3/8 inch diameter +/-: smooth bore. Note surface appears good in treated areas.



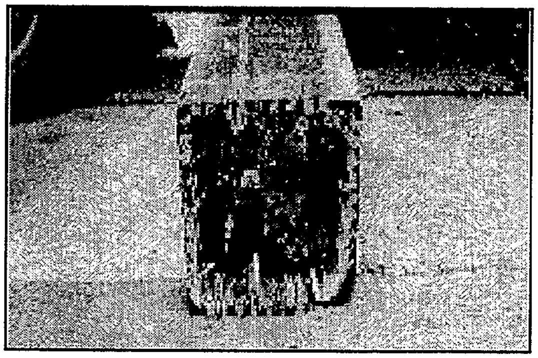
2-49

Teredos can be 2 feet long as shown in this section through an infested timber.



2-50

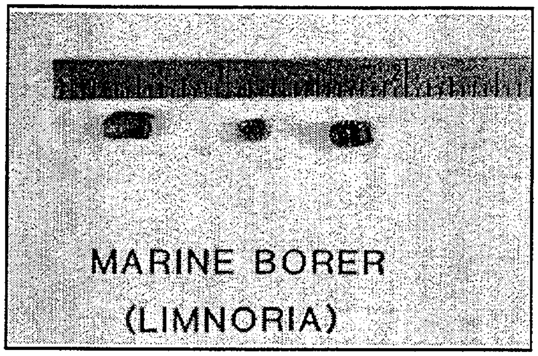
Even treated, dressed timbers that look good can be infested. Note the incisor marks from the treatment process that was used to protect the wood.



2-51

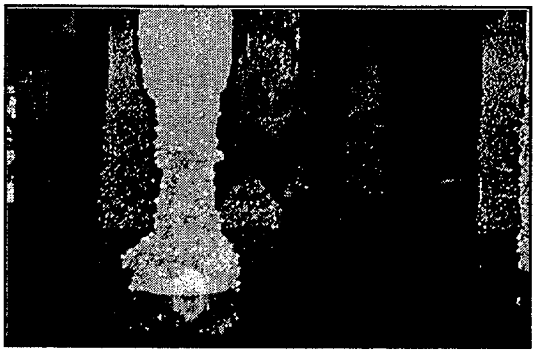
But look inside the member. It has been attacked by teredos. Note the limited penetration of the preservative. Some woods do not allow preservative to spread easily.

Since the damage caused by these shipworms is hidden within the timber, it is often difficult to detect. A close visual inspection for the entrance hole is one method of detection. Suspect areas may require destructive testing to confirm the teredo's presence.



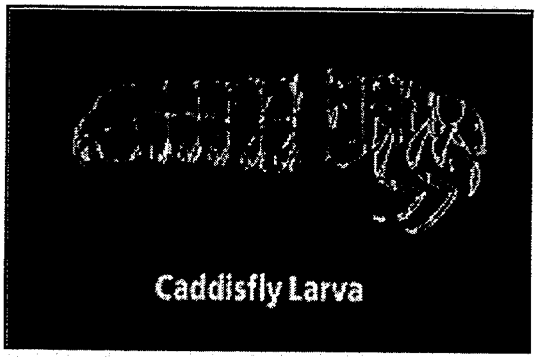
2-52

Unlike the teredo, the limnoria (also called the wood louse or gribble) is a surface boring crustacean. The limnoria, which is about 1/8 inch long, bores only a short way into the wood surface and, as water action breaks down the thin layer of wood protecting it, the crustacean bores deeper.



2-53

Eventually, it produces the hour glass shape commonly found in wood piles in the splash zone.


Caddisfly Larva

2-54

E. INSECTS

Caddisfly. The caddisfly, an insect which is generally found in freshwater, but can tolerate brackish water, can also damage timber piles.

The caddisflies are an order of insects closely related to moths and butterflies. In water, during the larva and pupa stages of their life cycle, they can dig small holes into the timber for protection. The homes consist of a silken retreat portion, which shelter the larva that is fixed to the substrate after the larva chews out a small depression to reduce its profile. In addition, an anterior net of some type which strains food from the flowing water is attached to the shelter. At the end of the larval stage, all species construct some sort of shelter for the ensuing pupa. At this time the shelter is enlarged, deepened and strengthened. After completion of the pupal period, the pupa cuts its way out of the shelter, swims to the surface, crawls out of the water and onto solid substrate. The pupa's skin splits and the adult emerges and files away, thus beginning the cycle again.

The next generation of larvae may inhabit the same hole and perhaps several larvae live in the same retreat, enlarging the hole until retreats intersect, and create large irregular depressions. While most species have a single life cycle annually, research has documented as many as two or three generations per year. The high density of caddisflies on a timber pile can create so many pits that pieces of timber have been characterized as having the appearance of a person scarred by smallpox. After being attacked for numerous years, the number of pits within a given area may not be distinguishable.

There have not been many occasions of caddisfly damage found. In fact, only Pocomoke Bridge Collapse in Maryland is attributed on caddisflies. Some people dispute that the caddisfly is a wood-destroying organism and believe that decay and biodeterioration was misdiagnosed.

F. BACTERIAL DEGRADATION

BACTERIAL DEGRADATION

- **STRENGTH REDUCTION**
- **LITTLE INFORMATION**

2-55

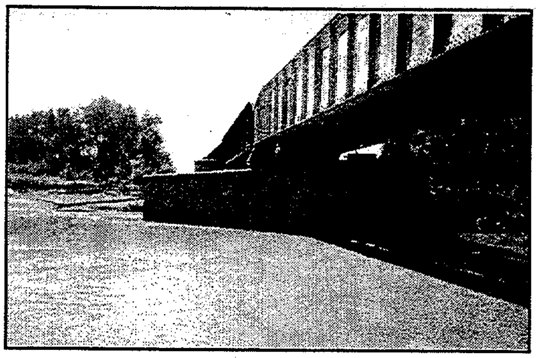
Over the last approximately twenty years, several instances have been reported in which continuously submerged timber structures have undergone considerable strength reductions over long periods of time. This degradation is the result of bacteria which can live in totally submerged piling.

Bacterial attack is a slow process promoted by wet conditions. The attack may be classified as tunneling, in which the bacteria penetrate the wood cell walls and thus produce channels within the walls; erosion, in which the layers of the wood cells are attacked; and cavitation, in which the bacteria form cavities within the cell walls. All three can significantly reduce the strength and other properties of the timber. While little quantitative data is available on these effects, degradation appears to be greatest near the outer area of the pile and decreases toward the center.

2-56

Zebra mussels are becoming a problem in U.S. They do not appear to damage material, but cover everything.

They are now spread throughout the Great Lakes, in major midwestern rivers and along the east coast.



2-57

Scour and undermining can cause problems at any structure.

About half of the pier of this railroad bridge was undermined, and the pier moved downstream 3 feet and settled about 3 feet. In the background, debris, which blocked a large part of the channel and increased flow velocity causing scour is visible.

SUMMARY OF MECHANISMS OF DETERIORATION

- **ADVERSE WATERLINE ENVIRONMENT**
- **MATERIAL DETERIORATION**
- **EXTERNAL FORCES**

2-58

VI. SUMMARY

The waterline environment provide conditions that can intensify or accelerate deterioration. It can serve as a host and sustainer of destructive animals and chemicals, and can exert large forces due to swift currents or freezing. It can also transport ships, ice and debris that can damage structures due to external forces.

In the next session, we will be evaluating the effects of this damage on structures.

SESSION 3

CONDITION SURVEYS

SESSION 3: CONDITION SURVEYS

TOPICS: **NATIONAL BRIDGE INSPECTION STANDARDS, (NBIS) REQUIREMENTS FOR UNDERWATER INSPECTIONS, TYPES OF INSPECTIONS, DIVER CAPABILITIES AND LIMITATIONS**

LESSON PLAN:

DURATION	60 minutes
GOAL	To review NBIS requirements and types of inspections, and to provide overview of capabilities and limitations of divers.
OBJECTIVE	The participant should understand the requirements for underwater inspections, be able to describe general inspection requirements, and have an understanding of considerations involved in underwater inspection.
REFERENCES	National Bridge Inspection Standards (NBIS) FHWA Technical Advisory No. TA5140.20, Revisions to the NBIS, September, 1988 Underwater Inspection of Bridges, FHWA-DP-80-1 November, 1989
OUTLINE	I. Types of Condition Surveys A. Reasons for Underwater Inspection B. NBIS Underwater Requirements II. Inspector-Divers III. Diving Equipment IV. Dive Safety V. Levels of Inspection VI. Conducting Diving Inspection VII. Condition Reports for Repair VIII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 3
CONDITION SURVEYS

3-1

I. TYPES OF CONDITION SURVEYS

The purpose of this section is to describe how underwater inspections are conducted and summarize deficiencies commonly found during underwater inspections. We also want to talk about what information needs to be collected during the inspection so repairs can be designed.

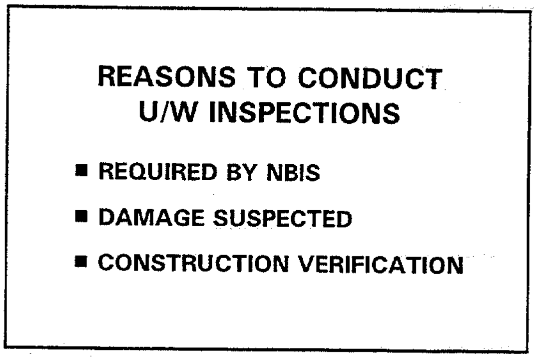
Structural problems topside that could lead to bridge failure are quite often observed by passing motorists, maintenance workers etc. Structural problems underwater that could lead to bridge failure are almost never observed by these groups.

Approximately 86% of all bridges listed on the NBIS are over water. It has been estimated that over half of all bridge failures are due to underwater causes. Underwater inspections are needed for safety.

Underwater inspections have often been neglected in the past, prior to the 1988 revision to the NBIS, because they were thought to be too difficult to conduct or too expensive.

Underwater Inspections can also reduce repair and maintenance costs.

Since the early 1970's, there has been a requirement for underwater inspection in the AASHTO (then AASHO) Manual for Maintenance Inspection of Bridges.



REASONS TO CONDUCT U/W INSPECTIONS

- **REQUIRED BY NBIS**
- **DAMAGE SUSPECTED**
- **CONSTRUCTION VERIFICATION**

3-2

There are several reasons we perform underwater inspections. The 1988 Revisions to the NBIS requires routine underwater inspections; the bridge may have visible or suspected damage; or we want to verify construction configuration.

We will look at each of these in more detail.

3-3

In 1985, the collapse of the Chickasawbogue Creek Bridge near Mobile, Alabama brought the potential for underwater problems to the attention of the bridge community. This bridge had steel H-pile bents with about 15 feet of steel pile exposed. It was located in brackish water and the tops of the piles were encased in concrete to below low water.

There was no loss of life, but after the collapse the steel piling (10BP42's) which had been installed in 1958 were found to have common losses of 50 to 75 percent similar to the condition shown in the slide. (This slide is not of the Chickasawbogue Bridge)

This collapse led the FHWA to issue a Memorandum to all Regions in June 1985 clearly indicating a requirement for underwater bridge inspection.

Special report

Thruway disaster

Bridge down...

3-4

In 1987, the collapse of the New York State Thruway Bridge over Schoharie Creek, in which 10 persons died, brought the problem dramatically to the public's attention.

The National Transportation Safety Board (NTSB) found the probable cause of failure to be the failure to maintain proper riprap protection of the footings allowing a failure through erosion of the soil beneath the spread footings. It also stated that inspections had not documented the streambed or riprap condition or underwater elements of the substructure, and recommended regular underwater inspections.

A further outcome of the Schoharie Creek collapse was an expanded research program in the areas of scour mechanism and prevention.

**NBIS
UNDERWATER INSPECTION
REQUIREMENTS**

- **IDENTIFY BRIDGE REQUIRING U/W INSPECTIONS**
- **DETERMINE INSPECTION PROCEDURE**
- **DETERMINE FREQUENCY OF INSPECTION**

3-5

In 1988, the NBIS was revised to require the states to:

- Identify bridges requiring underwater inspections.
- Determine the inspection procedures to be followed, and
- Determine the frequency of underwater inspection required for specific bridges.

**NATIONAL BRIDGE
INSPECTION STANDARDS (NBIS)**

"MAINTAIN A MASTER LIST OF THOSE BRIDGES WITH UNDERWATER MEMBERS WHICH CANNOT BE VISUALLY EVALUATED DURING PERIODS OF LOW FLOW OR EXAMINED..."

3-6

The states should have a written rationale for making those determinations.

The states are also required by the NBIS to establish a master list of bridges requiring underwater inspection.

The purpose of the master list is to promote inspection program management of non-routine inspections through planning, scheduling and monitoring.

TECHNICAL ADVISORY

"REVISIONS TO NBIS"

TA 5140.21

3-7

At the time of these revisions to the NBIS, FHWA issued a Technical Advisory, TA 5140.21, Revisions to the National Bridge Inspection Standards (NBIS) to provide guidelines for implementing the changes to the NBIS.

Typically, T.A.'s provide the FHWA's guidance or recommendations in a problem area. They are not rule making (as the NBIS is), and they do not have the force of law, but they do show what the FHWA would like to see as they review programs.

Probably, and important from a liability point of view, they establish a standard of care against which an agency or individual could be judged.

"UNDERWATER MEMBERS MUST BE INSPECTED TO THE EXTENT NECESSARY TO DETERMINE STRUCTURAL SAFETY WITH CERTAINTY. IN ADDITION TO STRUCTURE ELEMENTS, UNDERWATER INSPECTION MUST INCLUDE THE STREAM BED."

3-8

The technical advisory did not specify what types of inspections must be made, but required that states develop procedures as necessary.

Certainty is the key word.

TYPES OF UNDERWATER INSPECTIONS

- **WADABLE WATER - VISUAL AND TACTILE FROM ABOVE WATER SURFACE**
- **DEEP WATER - DIVING OR OTHER TECHNIQUES**

3-9

In shallow water, the above-water bridge inspector may be able to conduct the underwater inspection by wading. Some states have established water depths of two to three feet as the maximum depth for wading. In fast moving streams with slippery or unstable bottoms or in very turbid water, even that may be too deep.

The above-water inspector should determine when he cannot achieve the required "certainty" and should have the authority to require an underwater inspection.

OTHER TECHNIQUES

- ROV
- CORING
- IMAGING SYSTEMS
- FUTURE TECHNOLOGY

3-10

In deeper waters a diving inspection will be required, but diving is not the only way to accomplish the inspections. In some situations, diving is not practical and other means might be used if they can provide "certainty". The regulations are written to permit use of alternate and future technologies.

Other techniques which have been used include remotely operated vehicle (ROV's), which can provide a means of visually examining a structure. Their use for structure inspection is generally limited to low current areas with reasonably good visibility.

At the Peace Bridge, near Niagara Falls, the currents are very high and preclude diving unless expensive dive shields are used. At this location, vertical cores have been taken through the pier into the foundation to help verify pier condition and determine whether undermining was present.

Specially constructed imaging systems such as the "Scour Vision" system can also be used to at least obtain partial information about a substructure's condition. Sonar or other techniques may, in certain circumstances, yield useful data.

As technology continues to advance, new systems for underwater investigation will no doubt appear which may be of help to the bridge engineering community.

LEVELS OF INSPECTION

- LEVEL - VISUAL; MINIMAL CLEANING
- LEVEL II - LIMITED CLEANING & MEASUREMENT
- LEVEL III - HIGH DETAILED; NDT

3-11

In describing underwater inspections, "Levels of Inspection" have been developed in the offshore industry, and through their adoption by the U.S. Navy, have gained widespread acceptance. These levels of inspection do not refer to an overall type of inspection, but rather to parts that could be contained in any inspections.

A Level I inspection is more than a "swim-by". It includes a visual, or tactile, inspection of all parts of the underwater components. It is the most basic level of effort. It should determine the presence of major, obvious damage, and note any missing elements.

A Level II inspection includes cleaning at designated locations, generally bands or areas at the mudline, waterline and midheight. Level II inspections are in addition to Level I inspections.

A Level III inspection could include coring, non-destructive testing, hardness testing, obtaining of samples for testing, or measurement of remaining thickness.

In addition, for routine inspections, scour should be monitored by taking soundings around the piers and across the stream. These soundings should also be taken as part of each biennial above water bridge inspection.

These are the minimum requirements for a routine underwater inspection. For many bridges, it may be determined ahead of time that additional inspection work should be included as part of normal procedure.

If the scope indicated here for the routine inspection is not conclusive, i.e., if it does not result in "certainty" as to the structural safety, then additional Level II efforts and Level III efforts should be expended to achieve certainty.

LEVEL OF INSPECTION GUIDELINES

- **ROUTINE U/W INSPECTION**
  - + **LEVEL I - 100%**
  - + **LEVEL II - 10%**
  - + **SCOUR**
- **IN-DEPTH U/W INSPECTION**
  - + **IF ROUTINE INSPECTION IS NOT CONCLUSIVE**

3-12

These are the FHWA guidelines for routine inspections.

All underwater components should be given a Level I inspection; i.e., an arms length, wading or diving visual inspection. If the visibility is poor, that Level I inspection may have to be conducted by feeling each underwater component.

In addition to the Level I inspection, 10 percent of the submerged components should be given a Level II inspection. For piles, that means cleaning three bands around 10 percent of the piles.

For piers, the "10%" description does not work well, so generally, clean three 1 foot by 1 foot areas at the upstream and downstream noses, and on each side of the pier. That is a total of 12 cleaned areas on each pier.

U/W INSPECTION FREQUENCY

5 YEARS MAXIMUM FOR SOUND CONDITION AND NO CHANNEL INSTABILITY OR DELETERIOUS ENVIRONMENT

3-13

The maximum interval allowed by the NBIS between underwater inspections is five years, but that five year interval is only allowed for underwater units in sound condition, with no channel instability or deleterious substances in the water.

Bridges should also be inspected underwater after major flood events, and scour countermeasures should be inspected after the first high runoff event after construction or repair.

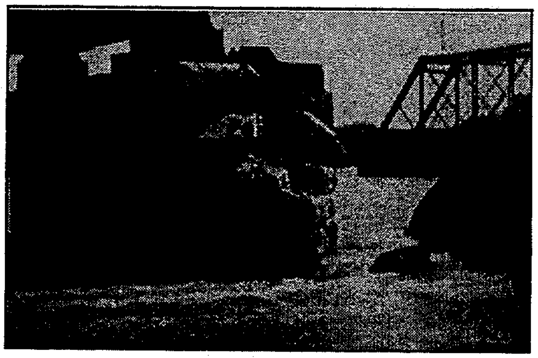
The states must determine the appropriate interval between underwater inspections. In many cases, that is less than five years. Some states perform their underwater inspections at intervals of not more than four years so that there is one underwater inspection with every other biennial inspection. One state defines separate underwater inspection intervals for each substructure unit.

DAMAGE INSPECTIONS

- VESSEL IMPACTS
- NOTICEABLE SETTLEMENTS
- EFFECTS OF RIVER CONTROL DEVICES

3-14

Structures which have known or suspected damage need inspection to determine its extent and severity.

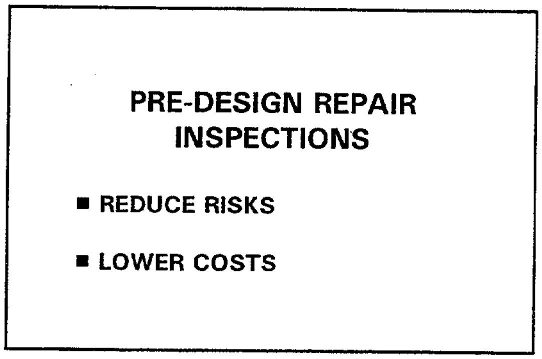


3-15

For example, a pier struck by a ship or barge should be inspected soon after the impact to determine the condition of the structure. A timely inspection will provide valuable information when it comes time to determine who is liable for any repairs in addition to determining if the structure is safe to use.

A bridge which has settled may need an underwater inspection to determine the cause of the problem and define the extent of damage. This is something which might be done in addition to monitoring the settlement and scour around the pier.

A dam, jetty or other river control device which alters river flow at an existing bridge may cause a problem. The device may cause currents which promote scour at the bridge. An inspection and sounding investigation should be performed to determine what, if any, effect the control structure has on the bridge.



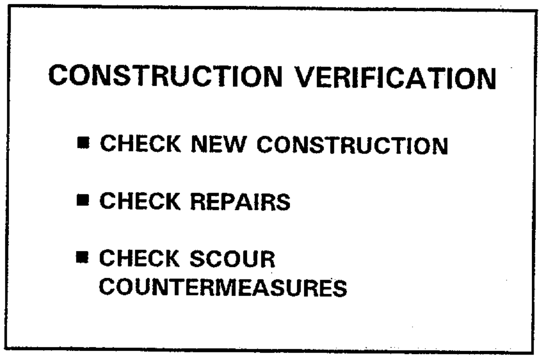
PRE-DESIGN REPAIR INSPECTIONS

- REDUCE RISKS
- LOWER COSTS

3-16

Engineers cannot specify appropriate, economical repairs without knowing the extent of damage below water.

If the exact extent of damage is not known, this poses a risk to the contractors bidding. This risk will result in greater cost to the owners. Designers sometimes try to pass the risk on to the contractor because they do not know the underwater conditions, but this usually results in higher bids.



CONSTRUCTION VERIFICATION

- CHECK NEW CONSTRUCTION
- CHECK REPAIRS
- CHECK SCOUR COUNTERMEASURES

3-17

The construction of new structures or repairs to existing facilities should be monitored. Inspector-divers should check construction below water to see if it is being done according to the plans and specifications. The only way to be certain construction is being done properly is by inspection.

3-18

This steel sheet pile wall, for example, had been built and failed twice. Nobody had inspected it underwater at the time of construction. If they had, they would have seen that the sheets were hitting the large rocks shown in the foreground, not getting any penetration, and in some cases splitting the interlocks.

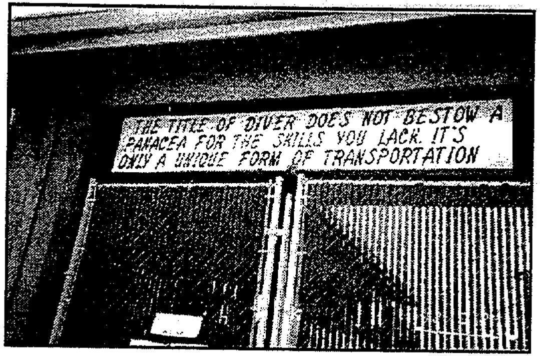
During repair operations it is important to check the contractor's preparatory work, such as cleaning structures before installing jackets.

3-19

It is not normally necessary to have a diving inspection crew on site at all times during construction. Inspectors can perform underwater checks at key points during the construction. The time when diving checks are needed can be coordinated by the on-site resident engineer.

During the inspections it is important to check the channel bottom for construction debris. Remember it is easier to have a contractor clean up before leaving than to have him come back and clean up. Also, the bridge owner could be held responsible by the EPA, Coast Guard or other agencies who regulate waterways.

II. INSPECTOR-DIVERS

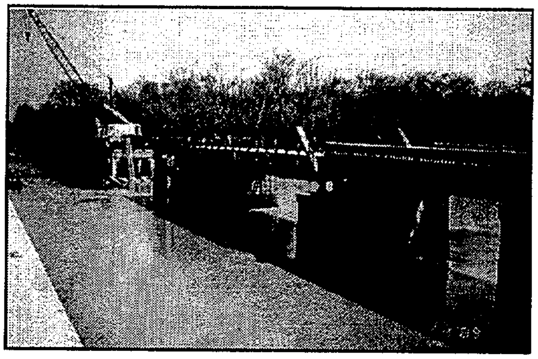


3-20

This plaque hangs over the door of a diving school in Washington State. It says "The title of diver is not a panacea for the skills you lack, it is only a unique form of transportation". It points out the importance of technical training as well as diving training.

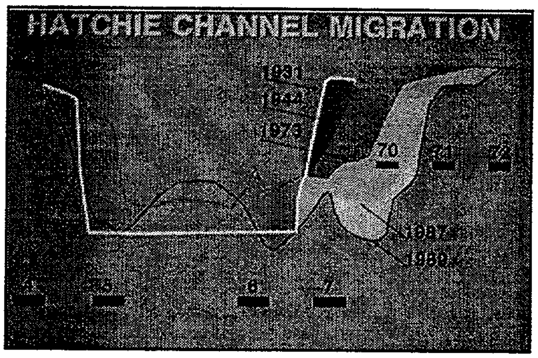
3-21

This is the US 51 Bridge over the Hatchie River, about fifty miles north of Memphis. This bridge is instructive for two reasons. First, an underwater inspection was not conducted, and although the collapse was due to scour and channel movement, an underwater inspection might have detected the problems. Secondly, following the collapse, reports by the search and rescue divers, who had the best of intentions, were not quite correct because they did not have structure inspection training and experience.



3-22

The Hatchie River Bridge was built in 1931 to carry two-way traffic. In 1974, another bridge was built to carry southbound traffic. The river was realigned at that time to pass through the truss span shown. The foundations of the bridge span in the river were designed and built to extend deeper than the approach spans.



3-23

Over time, however, the channel shifted to the north as shown in the slide, and the piles of the approach spans did not extend deep enough for this shift.

3-24

On April 1, 1989, one of the approach piers was scoured to the point that it is estimated only five feet of the piles were still in the ground. The pier failed and the collapse occurred. A total of two spans and three of the two-column piers collapsed. Eight people died.

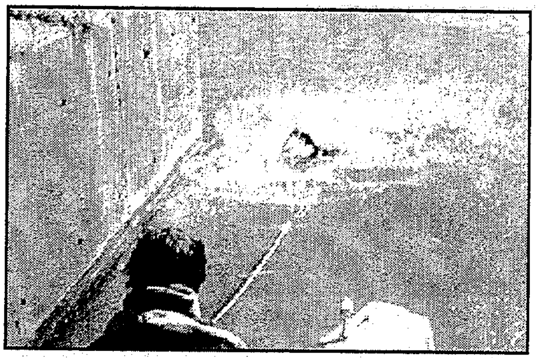
This was a bridge that had been carefully inspected above water, but no underwater inspection had been performed. The above water inspection records even gave some indications that the foundation piles were exposed.

IN ORDER TO CONDUCT A THOROUGH UNDERWATER INSPECTION, AN INSPECTOR NEEDS TO BE A COMPETENT DIVER.

3-25

On the other hand, in order for an inspector to conduct an effective and thorough underwater inspection, he needs to be comfortable and confident when diving. Diving conditions at bridges are often hazardous.

An inspector must be trained both as an diver and a bridge inspector. Training and experience in only one of these areas will not suffice.



3-26

This inspector is working in very strong current. Even an experienced diver would have trouble conducting a quality inspection in these conditions. If the inspector, because of lack of diving skills, is more concerned with survival than inspection, he cannot do a good job.

3-27

The underwater inspector must posses strong skills as both a diver and an inspector.

This diver has a lot of enthusiasm, but he needs training.

DIVER - INSPECTOR QUALIFICATIONS

- DEFINED BY STATE PROGRAM
- BASED ON TRAINING AND EXPERIENCE
- DEPENDS ON BRIDGE COMPLEXITY

3-28

Let's look at the FHWA Guidelines for Inspector-Diver Qualifications as given in TA 5140.21.

Training of diver-inspectors is critical to an underwater inspection program.

Persons trained in diving only are numerous:

- Dive training varies greatly from few hours to months.
- Dive shops and YMCA
  Professional Association of Diving Instructors (PADI)
  National Association of Underwater Instructors (NAUI)
- Commercial Dive Schools
  No standard curriculum
  Graduates are generally hired as tenders and advance to divers over a year or more.
- Military

Neither recreational dive training or commercial dive training is recommended, advocated or prohibited by FHWA. States must establish their own criteria for training.

DIVER-INSPECTOR QUALIFICATIONS

- TEAM LEADER FOR COMPLEX BRIDGES
- TRAINED INSPECTOR FOR NORMAL BRIDGES
- "DIVER" FOR LIMITED CASES WITH ON-SITE TEAM LEADER

3-29

The level of training necessary for the inspector depends on the type of bridge. The states must determine requirements, but the Technical Advisory gives these guidelines.

Some bridges are so complex they require actual diving to be conducted by a fully qualified team leader. Some may require a Professional Engineer Diver. A complex bridge is one in which the structural load path or response of the structure to loads is not clear, or one in which the construction type is unusual.

USING DIVERS NOT FULLY QUALIFIED AS INSPECTORS

- LIMIT TO SPECIFIC SITUATIONS
- ON-SITE TEAM LEADER REQUIRED
- TWO-WAY COMMUNICATION REQUIRED
- REQUIRED DOCUMENTATION

3-30

Remember the on-site team leader is responsible for the inspection adequacy.

The team leader must ensure that the information obtained from a diver who is not fully qualified is correct. This will require closer supervision, and detailed questioning.

FHWA RECOMMENDED INSPECTOR TRAINING

COMPREHENSIVE BRIDGE INSPECTION TRAINING COURSE BASED ON BRIDGE INSPECTION TRAINING MANUAL (BITM90)

3-31

Divers performing underwater inspections preferably should possess the same certifications as an above water inspector.

NBIS REQUIREMENTS FOR INSPECTION TEAM LEADER

- REGISTRATION AS A PROFESSIONAL ENGINEER
- ELIGIBLE FOR PROFESSIONAL ENGINEERING REGISTRATION
- COMPLETION OF A COMPREHENSIVE BITM90 COURSE + 5 YEARS EXPERIENCE
- NICET CERTIFICATION LEVEL III

3-32

The National Bridge Inspection Standards gives four options for certification as a Bridge Inspection Team Leader. The NBIS requires a certified Team Leader be on-site for all inspections and a team leader may be necessary to perform diving inspections of complex bridges.

DIVING QUALIFICATIONS

- TRAINING
- EXPERIENCE
- THINKING

3-33

The last one, "Thinking" may be the most important. Divers need to slow down and think about what they see. What effect do these conditions have on the bridge? Do I know enough? Do I need to do more?

DIVING SYSTEMS

- SURFACE SUPPLIED AIR
- SCUBA

3-34

III. DIVING EQUIPMENT

There are two modes of diving which are commonly used to perform underwater inspections. These are surface supplied air and scuba. There are other types of diving which use breathing gases other than plain air, but these are beyond the scope of this presentation and we will talk only about diving using air.

This section is concerned with diving for condition surveys. Later sessions will discuss diving for underwater construction.

There are significant differences. Diving techniques that are appropriate for inspection situations might not be appropriate for underwater construction.

Their appropriateness for any particular situation depends on a number of factors, including:

- Depth
- Time
- Task
- Experience and capability of the diver
- Environment

Each diving system has unique operational advantages and poses special hazards.

SURFACE SUPPLIED AIR DIVING

- AIR SOURCE IS ABOVE WATER
- SUPPLIED TO DIVER BY HOSE
- INCLUDES COMMUNICATION

3-35

In surface supplied air diving, air is supplied to the diver from the surface. An umbilical, consisting of an air hose, communication wire, strain relief line and pneumofathometer hose connect the diver to the surface.

The pneumofathometer allows the divers depth to be monitored. The operation of this device is simple. Air is forced through the hose until the air pressure equalizes with the water pressure at the divers end (when bubbles come out of the hose at the divers end this is accomplished). The pressure gauge on the console on the surface is marked in feet of sea water from which the diver's depth can be read.

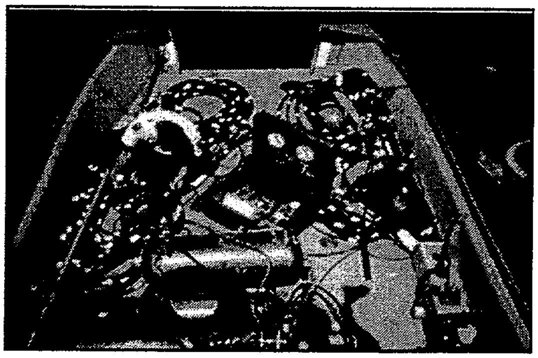
The diver wears a helmet or full face mask equipped with an air regulator, microphone and earphones. The helmet or mask allows the diver to talk with people topside.

3-36

This shows the old style hard hat diving equipment. It weighs 100 to 200 pounds and requires a large support operation.

3-37

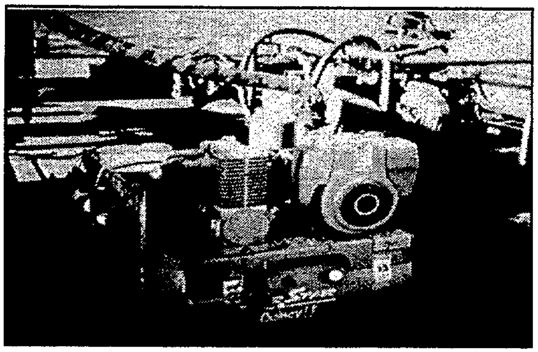
It has generally been replaced by lighter weight equipment as shown here.



3-38

On the surface, the umbilical is connected to a console. The console consists of an air regulator which can be adjusted to increase pressure as the depth of the dive increases.

A communication box, consisting of a speaker and amplifier, lets the diver and tender talk to each other.



3-39

One way air is supplied to the diver is by a low pressure, high volume compressor. Volume tanks are built into this rig in order to ensure a steady supply of air. Air can also be supplied from high pressure air tanks. Each of these tanks holds 220 cubic feet of air. The tanks are interconnected with a manifold and the air pressure supplied to the console can be adjusted with a regulator.

SURFACE SUPPLIED AIR GENERAL CHARACTERISTICS

- UNLIMITED AIR
- VOICE COMMUNICATION
- MAXIMUM CURRENT = 2.5± KNOTS
- LIMITED MOBILITY
- MAXIMUM DEPTH = 220 FEET
- SUPPORT SYSTEM

3-40

Surface supplied air equipment generally is applicable for deeper dives of longer durations in more hostile environments. This greater capability comes at a cost of less mobility and requires a larger support operation. Surface supplied air is well suited for underwater construction.

3-41

Most of us are familiar with scuba equipment already. We have seen documentaries on the ocean where people use scuba. Some of you also may be divers.

Scuba is the acronym for self-contained underwater breathing apparatus.

SCUBA - GENERAL CHARACTERISTICS

- LIGHTWEIGHT (70± LBS)
- PORTABLE
- MINIMUM SUPPORT
- EXCELLENT MOBILITY
- MAXIMUM DEPTH 130 FEET
- LIMITED AIR SUPPLY
- MAXIMUM CURRENT 1 KNOT (WITHOUT TETHER)
- LIMITED COMMUNICATION

3-42

Scuba is especially suited for dives of short duration at many locations, such as is common in bridge inspection work.

REGULATING AGENCIES

- OSHA
- COAST GUARD
- ARMY CORPS OF ENGINEERS
- INDIVIDUAL STATE REGULATIONS

3-43

IV. DIVE SAFETY

There are a number of agencies that regulate commercial dive operations. Which regulations need to be followed depends on where you are diving and who you are diving for. In most cases when doing Department of Transportation bridge inspections, either OSHA or State regulations will govern. We will, therefore, briefly talk about the OSHA diving regulations.

OSHA COMMERCIAL DIVING STANDARDS

ESTABLISHES:

- PERSONNEL REQUIREMENTS
- OPERATING PROCEDURES
- EQUIPMENT REQUIREMENTS
- RECORDKEEPING REQUIREMENTS

3-44

This OSHA subpart is a set of rules established to regulate commercial diving. OSHA establishes maintenance requirements; limits for the various modes of diving; numbers of personnel; minimum equipment, and a number of other requirements.

INSURANCE REQUIREMENTS

- WORKERS' COMPENSATION
- LONGSHOREMEN'S
- JONES ACT MARITIME
- PROFESSIONAL LIABILITY
- GENERAL LIABILITY/ PROPERTY DAMAGE

3-45

Diving work is unusual and has some special insurance requirements that differ from work above water.

Workers compensation is basically a no-fault insurance that covers employees. If the coverage is not in place, an injured employee could sue under other basis; it is very expensive - $35/$100 +/- salary.

Longshoremen's insurance is similar to W.C., but covers work over navigable water: The benefits are usually greater, so an endorsement to W.C. policy or a separate policy is necessary.

There could be a dispute about which applies, so it is important to know which is applicable.

Jones Act, or maritime, insurance covers crews of boats. It is debatable whether it is needed for small boats.

Professional liability (errors and omissions) is an insurance provided only by consulting firms.

LEVELS OF INSPECTION

- **LEVEL I - VISUAL, TACTICAL INSPECTION**
- **LEVEL II - DETAILED INSPECTION WITH PARTIAL CLEANING**
- **LEVEL III - HIGHLY DETAILED INSPECTION, NDT OR PARTIALLY DESTRUCTIVE TESTING**

3-46

V. LEVELS OF INSPECTION

We talked briefly before about levels of inspection, but now let's look at the inspection in greater detail.

In order to standardize the terminology of underwater inspection, FHWA has adopted and defined three types, or levels, of inspection.

A Level I inspection includes a visual examination or tactile examination (by feel) when visibility is limited. The purpose of this inspection is to detect major damage or deterioration.

The purpose of a Level II inspection is to clean the structure sufficiently to identify damage which may be hidden by marine growth, silt or mud.

A Level III inspection is a detailed inspection of a critical structural element. The purpose of this type of inspection is to detect hidden or interior damage, or loss in cross-sectional area.

LEVEL OF INSPECTION GUIDELINES

- ROUTINE U/W INSPECTION
  - + LEVEL I - 100%
  - + LEVEL II - 10%
  - + SCOUR
- IN DEPTH U/W INSPECTION
  - + IF ROUTINE INSPECTION IS NOT CONCLUSIVE

3-47

This is a summary of the FHWA guidelines showing the amount of each type of inspection that is needed. Remember these are minimums. It may be necessary to do more to obtain "certainty" as to safety of the structure.

LEVEL I INSPECTION

- WHOLE STRUCTURE
- VISUAL INSPECTION
- PROBE AND SOUND SUSPECT AREAS
- VERIFY CONSTRUCTION VERSUS DESIGN DRAWINGS
- SOUNDINGS

3-48

As previously noted, a Level I inspection is an overall arms length visual examination of the structure. Where visibility is poor, the inspection will be accomplished by tactile means. Some limited probing and sounding of areas where deterioration is usually expected will be made using ice picks, hammers, scrapers, or other means. The inspection should verify that the substructure was built in accordance with the design drawings, or in what ways it differs. Soundings are also to be run as part of this inspection.

LEVEL II INSPECTION

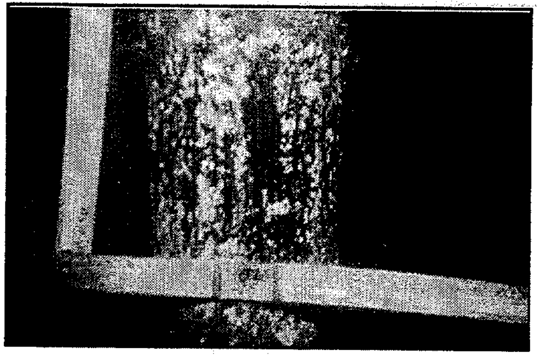
- SELECTIVE CLEANING
- MEASURE MEMBERS
- MORE EXTENSIVE PROBING AND SOUNDING

3-49

The Level II inspection includes all of those items performed for the Level I inspection. In addition, 10 percent (or more) of the submerged elements are cleaned in selected areas and subject to close visual examination along with further probing and sounding. Measurements should be made of sampling member's sizes as well as of any areas of deterioration which are found.

3-50

For small bridges, often diving equipment is not necessary. A wet suit or dry suit may be adequate so the inspector does not have to fear falling into the water while conducting a wading inspection.



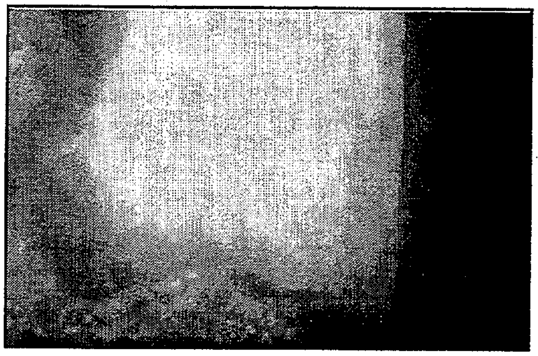
3-51

This is a pile which has received a Level II inspection. This timber pile has been cleaned using a hand scraper. In general, a Level II inspection consists of cleaning a band one foot high 3/4 around the perimeter of a pile at three elevations: mudline, near waterline, and midheight.

Note that, in this case, the cleaning has indicated the pile diameter might be reduced.

3-52

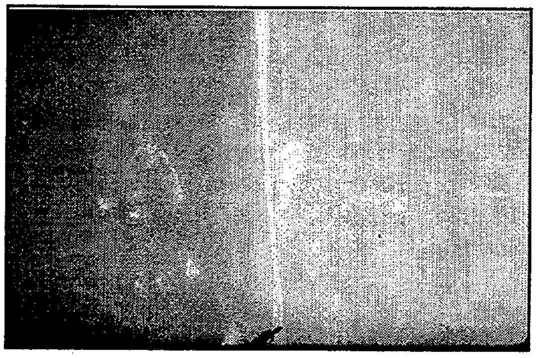
Any appropriate hand tool can be used to do a Level II cleaning. Lanyards have been attached to the hammer and crowbar to prevent the tools from being dropped and lost.



3-53

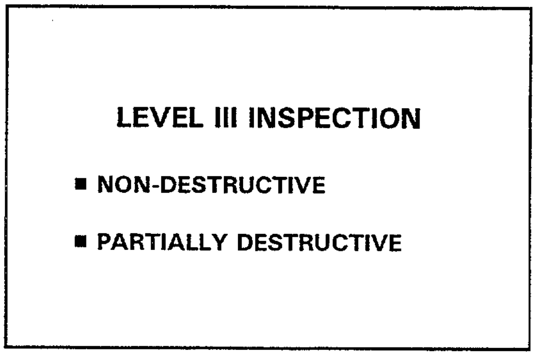
The cleaning of steel piles is essential to determine the remaining thickness of the steel as shown in this and the next slide.

This a view of the flange of an H-pile. It has been partially cleaned of marine growth. Note the pitting and striations of the steel.



3-54

This is a view of the edge of the flange. Notice its knife edge. This deterioration would not have been found without cleaning.

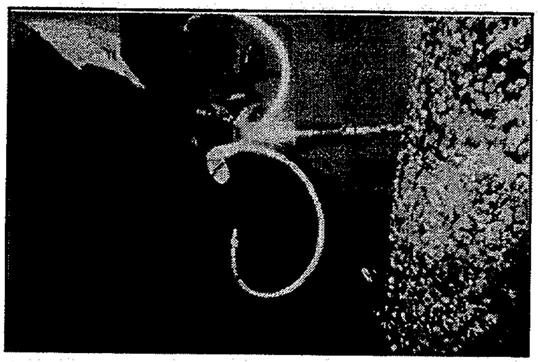


LEVEL III INSPECTION

- NON-DESTRUCTIVE
- PARTIALLY DESTRUCTIVE

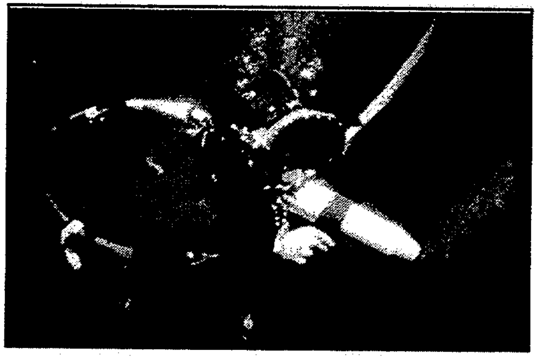
3-55

A Level III inspection incudes partially destructive or non-destructive testing. These are tests used above water and adapted as necessary for underwater use. We will be talking more about this in the next session, but here are two examples.



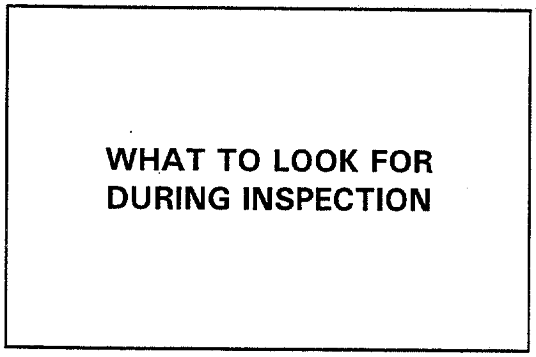
3-56

Here a bore hole is being drilled in a timber pile. The pile interior is probed to check for internal deterioration. Since internal damage of timber is common, corings or borings are normally taken on timber structures.



3-57

Thickness readings of steel members are commonly taken on sheet piling and H-piling. Here, a self-contained underwater ultrasonic thickness gauge with a digital readout is being used to measure remaining thickness.

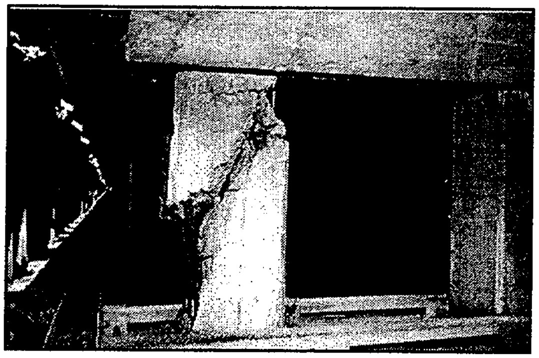


WHAT TO LOOK FOR
DURING INSPECTION

3-58

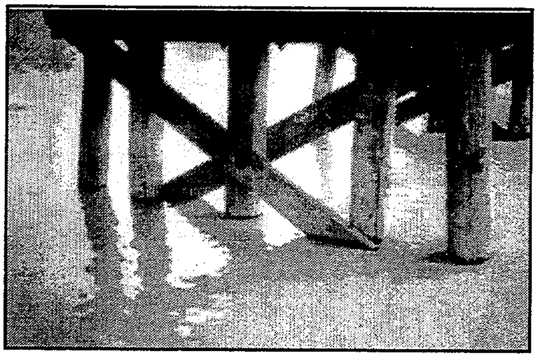
VI. CONDUCTING DIVING INSPECTIONS

There are a number of different substructure types. It is important, therefore, to know what the substructure is supposed to look like before conducting an inspection. As-built plans, design drawings and the most recent underwater inspection report should be reviewed prior to inspection. In addition to saving time and money, this will, in part, ensure a complete and thorough inspection.



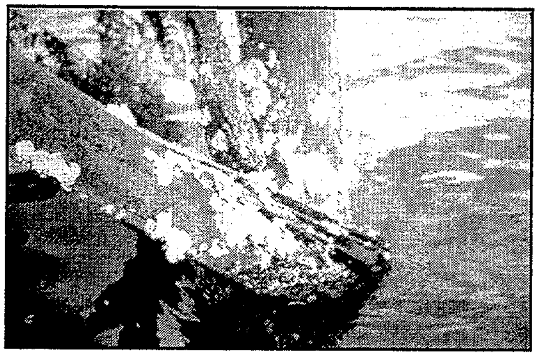
3-59

On pile bents, each pile should be visually inspected from the pile cap to the mudline. An examination of the pile cap should also be made.



3-60

Cross bracing, found on steel and timber bents, should be examined. The condition of the brace as well as the connection to the bent should be checked.



3-61

This is the end of a timber brace which has been damaged by teredo.

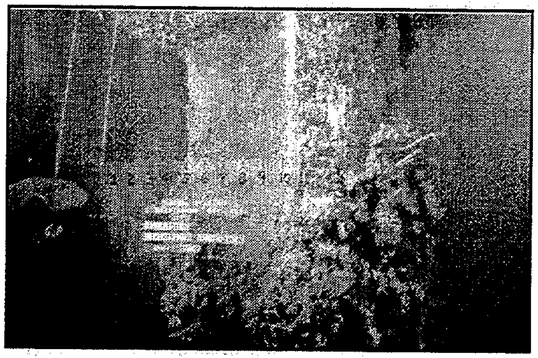
UNDERWATER INSPECTION PROCEDURES

- VISUAL - TACTILE INSPECTION OF ALL SURFACES
- PROBE AND SOUND SURFACES
- MOST DISTRESS AT ENDS, CORNERS, AND WATERLINE
- LOOK FOR FOOTINGS AND PILES
- START AT DOWNSTREAM END
- REPORT IN CONSISTENT FORMAT (LOCATION, HGT X WIDTH X PENETRATION)

3-62

Here are some of the key things to remember when conducting an underwater inspection.

Note that the term "penetration" is used to denote the extent of deterioration extending into the member. This is suggested in lieu of the more commonly used "depth" of a defect so that there is no confusion with the "depth" of water.



3-63

This slide shows the importance of cleaning. Note that the true condition is hidden by marine growth.

INSPECTION PLANNING

- SITE
  - DEPTH
  - ALTITUDE
  - CURRENTS OR TIDES
  - TEMPERATURE
  - ACCESS
- STRUCTURE
  - CONFIGURATION
  - MATERIALS
  - MARINE GROWTH

3-64

In planning for a diving inspection, these are some of the things to keep in mind.

SPECIAL REQUIREMENTS

- RECOMPRESSION DIVES
- HIGH ALTITUDE
- PENETRATION OF CULVERTS
- POLLUTION
- HIGH CURRENTS

3-65

They can lead to some special requirements.

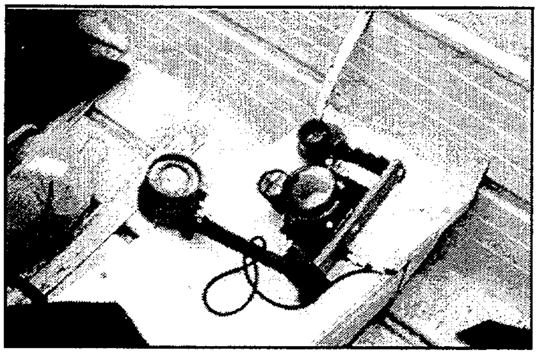
Satisfying these requirements generally requires larger dive crews and additional equipment.

DOCUMENTATION

- SKETCHES
- STILL PHOTOGRAPHY
- VIDEO TAPE

3-66

Documentation of the inspection is extremely important. Detailed notes and sketches are often enough. These should be prepared to cover the entire structure underwater. A comment should be made on all components, even if they are in good condition, so that later, one can be sure that a member was not missed. Where plans are not available, sketches are especially important. Key dimensions should be included, and measurements of significant structural components, such as timber pile diameter, should be noted. There may also be times when photographs or video are required.

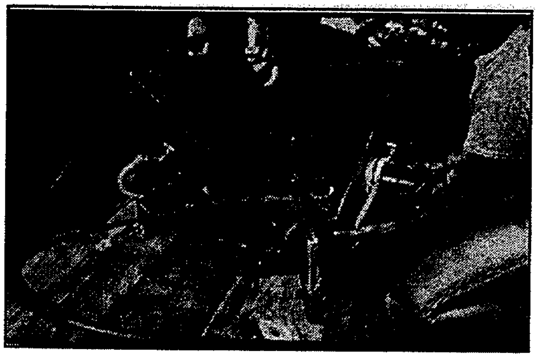


3-67

Underwater 35mm photographs can be provided easily with currently available underwater cameras, strobes, and lenses. This a 35mm underwater camera is equipped with a strobe and a close-up lens.

3-68

Underwater video, using self-contained camcorders or cameras with recorders and monitors on the surface, can be readily obtained. Here is a diver holding such a unit. The intensity of the light can be controlled from the surface to obtain the best picture. The umbilical cord to the surface can be seen at the right of the slide.



3-69

Good video and photographs are obtainable even in poor visibility using a "clear water" box. This is a plexiglass box which is filled with clean water. It can be pressed against the underwater object and displace the dirty water. The picture or video can then be taken through the clear water.

**CONDITION REPORTS
FOR REPAIR**

3-70

VII CONDITION REPORTS FOR REPAIR

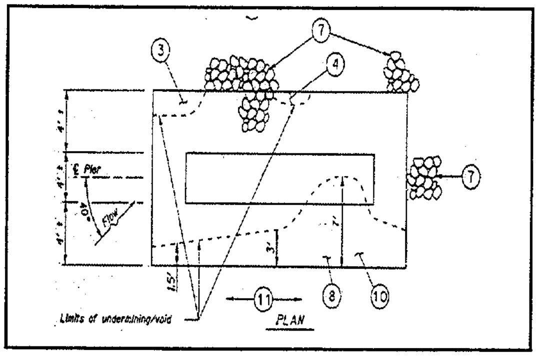
Condition reports made in anticipation of making repairs should be made in enough detail that the existing conditions can be evaluated and repair plans can be developed.

INSPECTION NOTES

- **EXTENT OF DAMAGE**
- **LOCATION OF DAMAGE**
- **REPAIR RECOMMENDATION**

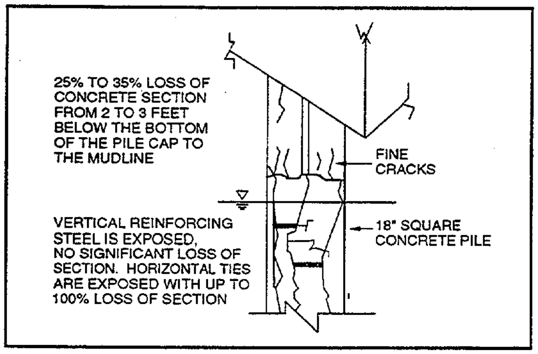
3-71

The inspection notes in the report should show the location and extent of damage in enough detail that repairs can be designed without another inspection. The inspection should also provide a general recommendation for the method of repair. The inspector's recommendation will also give another indication of the true condition of the element.



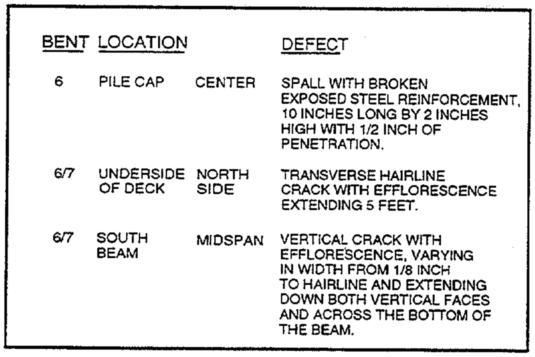
3-72

This is a plan of a pier on a spread footing showing various areas of undermining. Additional sketches show other defects in the pier. These sketches are necessary to accurately depict the conditions.



3-73

Typical sketches of deterioration such as this will aid in understanding the condition of the structure.

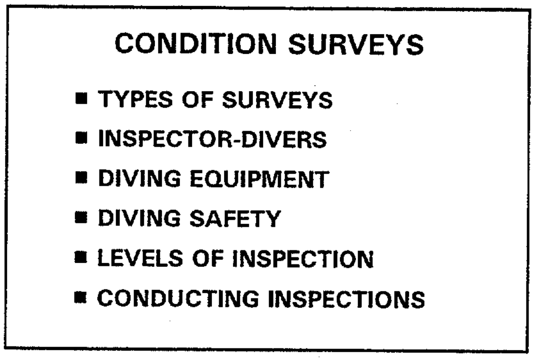


BENT	LOCATION		DEFECT
6	PILE CAP	CENTER	SPALL WITH BROKEN EXPOSED STEEL REINFORCEMENT, 10 INCHES LONG BY 2 INCHES HIGH WITH 1/2 INCH OF PENETRATION.
6/7	UNDERSIDE OF DECK	NORTH SIDE	TRANSVERSE HAIRLINE CRACK WITH EFFLORESCENCE EXTENDING 5 FEET.
6/7	SOUTH BEAM	MIDSPAN	VERTICAL CRACK WITH EFFLORESCENCE, VARYING IN WIDTH FROM 1/8 INCH TO HAIRLINE AND EXTENDING DOWN BOTH VERTICAL FACES AND ACROSS THE BOTTOM OF THE BEAM.

3-74

A detailed list of defects is essential for preparing detailed repair plans.

Finally, the most important part of the inspection is the engineering evaluation. In that evaluation, the inspector must be certain that the structural safety of the bridge is assured or additional investigations must be recommended.



CONDITION SURVEYS

- TYPES OF SURVEYS
- INSPECTOR-DIVERS
- DIVING EQUIPMENT
- DIVING SAFETY
- LEVELS OF INSPECTION
- CONDUCTING INSPECTIONS

3-75

VIII. SUMMARY

- Condition surveys are necessary for safety; to reduce maintenance and repair costs; and to comply with NBIS.
- Inspector-divers need training in bridge inspection and diving; they need practical experience; and they need to think.
- Both scuba and surface supplied diving equipment can be used. Each has advantages and disadvantages. Select the appropriate equipment for the structure and site.
- OSHA provides a good overview of safety requirements.
- A Level I inspection is visual; a Level II includes cleaning; a Level III includes non-destructive or partially destructive testing.
- Inspection equipment is constantly changing and almost anything that can be done above water can be done underwater at additional expense.

SESSION 4

SPECIALIZED TESTING EQUIPMENT

SESSION 4: SPECIALIZED TESTING EQUIPMENT

TOPICS: CHOOSING EQUIPMENT FOR LEVEL III INSPECTIONS AND NDT INTERPRETATION

LESSON PLAN:

DURATION	90 minutes
GOAL	Present types of special equipment available, its use and limitations. Indicated reliability of data obtained.
OBJECTIVE	Ability to select equipment and interpret results of testing.
OUTLINE	I. Introduction II. Timber Testing A. Boring B. Coring C. Ultrasonic Testing III. Steel Testing A. Thickness Testing B. Transducers C. Weld Testing IV. Cathodic Protection V. Concrete Testing A. Ultrasonic Testing B. Rebound Hammer C. R-Meter D. Concrete Coring E. Ground Penetrating Radar VI. Demonstration A. Boring and Probing B. V-Meter C. Steel Thickness VII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 4
SPECIALIZED TESTING EQUIPMENT

4-1

I. INTRODUCTION

Level III inspections involve partially destructive and non-destructive testing (NDT) of selected components. This work requires specialized testing equipment.

Generally, The equipment and techniques were developed for above water use and adapted for use below water.

We have already talked about some of these methods in previous sessions. This session describes adapting the equipment, if required, for below water use; the type of data the equipment provides; and how the data is obtained and presented.

PERSONNEL QUALIFICATIONS

4-2

As with all testing equipment, the divers and support staff must be trained and experienced in its use. This training may include:

- American Society for Non-Destructive Testing (ASNT) certification.
- On-the-job training.

Generally, the underwater tests are very specific and probably do not require the breadth of training or practical experience required for ASNT Levels of certification.

TESTING PLAN AND OBJECTIVES

4-3

A carefully thought out plan for Level III testing should be made prior to beginning the work, especially in view of the costs for underwater work. The purpose of the test, the type and frequency of testing, and expected methods of data reduction should be considered.

Data should be interpreted by experienced engineers who are aware of test limitations and expected data variability.

II. TIMBER TESTING

Common methods of timber NDT include boring, extracting small wood core samples, and ultrasonic examination.

TIMBER TESTING

- BORING
- CORING
- ULTRASONIC TESTING

4-4

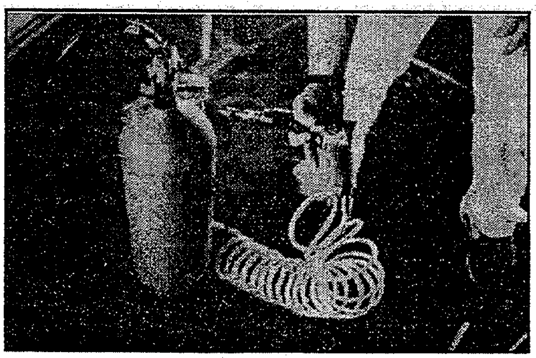
A. BORING

Boring is the simplest non-destructive (actually partially destructive) testing technique for timber. A hole is simply drilled into the timber, and the resulting hole is examined by probing with a hooked wire probe. The method gives a qualitative evaluation of soft areas and voids. Changes in drilling resistance may also help indicate soft areas.

BORING

4-5

Holes can be drilled by hand with a brace and auger bit, but a small air drill is faster and still fairly cheap. The drill can be operated from a scuba cylinder, or large air source.



4-6

CORING

4-7

B. CORING

Timber cores are easy to take and can give good information on the condition of a pile.

An increment borer, in addition to being used for structural inspections, is an instrument used in the logging industry to check growth rates of trees and wood soundness. The instrument consists of a hollow shaft bit, handle and extractor. The bits are available in 5mm(.2") and 12mm (.5") diameters. For bridge inspections it is used to investigate for interior damage due to decay, marine borer attack or other internal defects (termites, etc.). No modifications to the equipment are necessary for underwater use. Use of the larger core size may be advantageous.

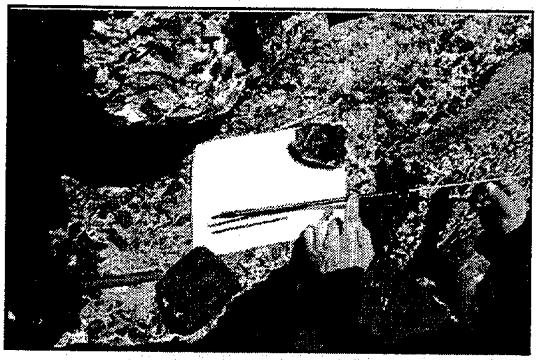
The borer should be wiped down with a WD-40 type lubricant, to keep it from rusting after each use. Also, the tool will need to be sharpened periodically.

Core holes should be plugged with a treated dowel.

Core samples can be visually checked for creosote penetration and decay, and species; and laboratory tests and exams can also be performed to determine preservative retention. Microscopic examinations can be made to determine if baterialogical attack has occurred.

4-8

This slide shows a diver using the increment borer below water.



4-9

Increment borers can be obtained from forestry supply companies such as:

Forestry Suppliers, Inc.
P.O. Box 8397
Jackson, Mississippi 39284
(601) 354-3565

The cost is about $150.

As the samples are taken, they are put into a holder and labeled (pile number & elevation). A log of the samples is maintained. The condition of the core is noted (creosote penetration, creosote odor (strong/none), color, soundness).

Timber cores provide good information on the condition of a pile interior. However, it is important to remember that information obtained is specific to the location where the core was taken along the pile length. Core samples alone may not allow a complete evaluation of a pile to be made.

Assistance with species identification of wood samples can be obtained at no cost from:

Forest Products Laboratory
P.O. Box 5130
Madison, Wisconsin 53705
(608) 231-9200

**ULTRASONIC TESTING
(PULSE VELOCITY)**

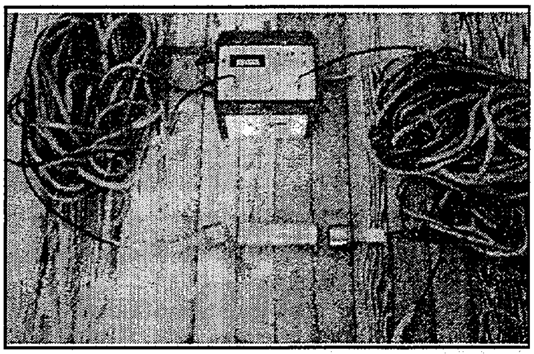
4-10

C. ULTRASONIC TESTING

Ultrasonic inspection of materials has been used for many years and has become a well developed technique in steel, and more recently in concrete and timber.

Following collapse of a timber pile supported bridge in Maryland, an ultrasonic method for the non-destructive evaluation of submerged timber piling was developed by the Federal Highway Administration and University of Maryland. The method is based on the principle that ultrasonic waves (sound waves) travel faster in undamaged wood than in damaged and decayed wood, and uses waves passing transversely through the timber.

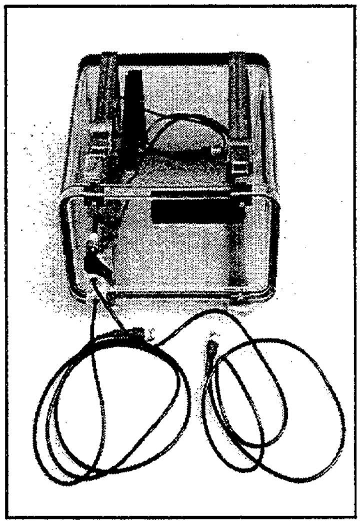
This method of testing is described in detail in FHWA Publication FHWA-IP-89-013 "Inspection of Bridge Timber Piling".



4-11

The equipment used for performing the field testing is a commercially available device called a V-meter. This equipment is available from at least two manufacturers. The device consists of two transducers attached to the electronics of the system by co-axial cables.

Normally the instrument remains above water while the diver takes the transducer below water to make readings. For cable lengths over approximately 100 feet, signal boosters can be put into the cables so the return signal can be read more easily.



4-12

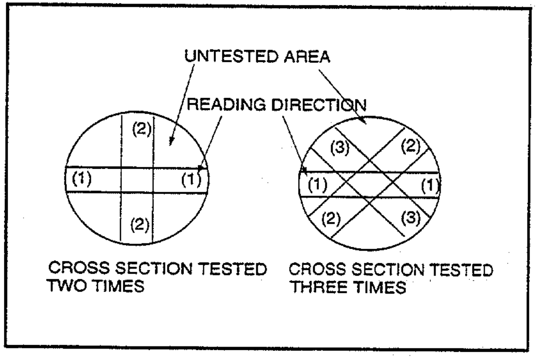
In order to prepare the device for use below water, the transducers and electrical connections at the transducers have to be waterproofed. This can be done by constructing housings for the transducers or using a RTV silicone sealer. Special underwater transducers are also available, but expensive.

The electronics can, however, be placed in a waterproof housing and completely submerged as shown in this slide.

4-13

Prior to starting actual testing, a sampling pattern should be determined. The pile must be well cleaned at the test locations and in some cases a couplant will aid in obtaining good signal transfer. Silicone couplant and white water pump grease have both worked well.

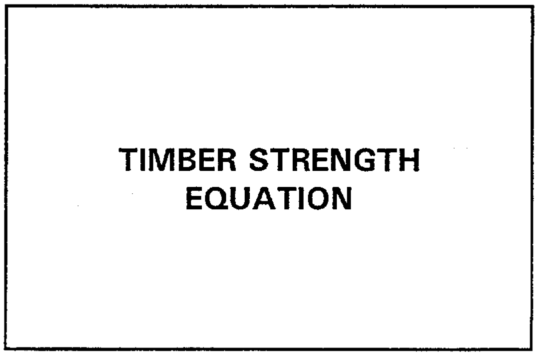
This slide shows the diver placing the transducers on a pile. The transducers are placed directly opposite each other (180° apart) on each side of the cleaned pile. The time it takes the sound wave to travel through the diameter of the pile is obtained from the V-meter's digital readout at the surface, and the data recorded. The diameter (or circumference) of the pile at that location is measured by the diver, and recorded with the pulse travel time data.



4-14

At each pile elevation selected for testing, at least two readings, 180° apart, should be made. Additional readings provide improved "coverage" of the pile section by the ultrasonic signal and improve the probability of detecting defective pile areas. Generally, data is gathered at least at three pile elevations, the mudline, mid-height, and above water level. If defects are found, measurements are made at more locations in order to determine the extent of the damage.

From the information collected (time and distance) the velocity of the sound wave can be calculated. This information can be used to determine the compressive strength of the piling using equations provided in the FHWA publication.



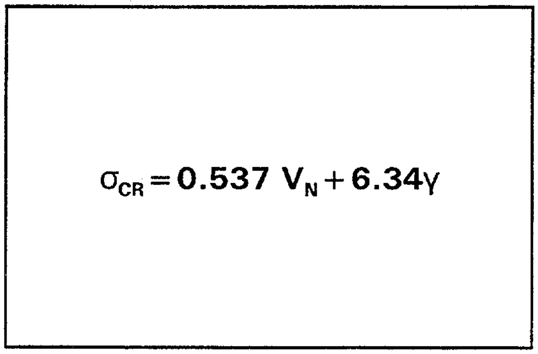
TIMBER STRENGTH EQUATION

4-15

Equations in the FHWA publication have been developed for strength determination of the following types of timber:

- Dry, new treated sections
- Moist, old treated sections (for underwater section)
- Dry, old treated sections
- Dry, very decayed treated sections

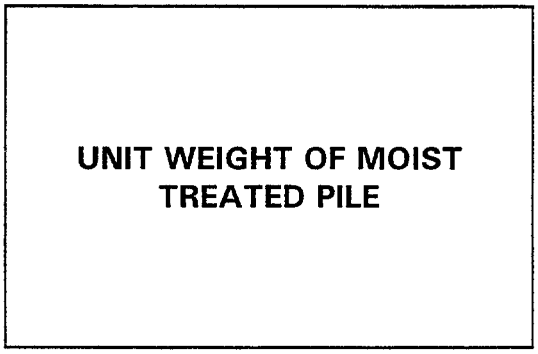
These equations were empirically derived from test data on piles which were ultrasonically tested and then subjected to laboratory strength tests.



$$\sigma_{CR} = 0.537\ V_N + 6.34\gamma$$

4-16

This is the equation used for determination of southern yellow pine compressive strength. In order to use this equation the value of velocity and unit weight must be known. We discussed how the velocity is obtained (diameter of section/time from V-meter). The unit weight, however, can be obtained in several ways. The best and most accurate way, of course, would be to cut out the section of piling where you took the readings, though this is seldom practical. A convenient way is to take core samples using an increment borer. The samples can be checked for unit weight. Another option is the use of timber unit weight tables.



UNIT WEIGHT OF MOIST TREATED PILE

4-17

An approximate unit weight can be determined from an equation in the FHWA manual. For moist treated piles the equation is:

$$Vn = 7845 - 67\gamma$$

This should be used when it is not possible to get a sample. It is, however, strongly recommended that samples be taken in order to confirm the results of the equation.

The advantage of ultrasonic timber testing is that it is fast and easy to implement and it will quickly provide much information on the condition of the structure.

There are limitations to this method. The equations developed in the FHWA manual were based on tests conducted predominantly on southern yellow pine. It is important, therefore, to know the species of wood you are examining. (This can be done by simple laboratory examination of a core sample.)

It has been our experience with Douglas Fir, that the results are similar and consistent, but the method generally underestimates the compressive strength determined by destructive testing by about 10 percent. This testing has not been extensive enough, however, to accept that value for all cases.

One technique for assessing pile condition where the specie is unknown or little strength correlation data is available is to locate a section of sound timber through sounding and follow-up core extraction, and use readings through this area as a benchmark.

For major projects, or critical structures, consideration should be given to taking a portion of pile as a sample and conducting laboratory compression tests to correlate the pulse velocity readings. Often a broken pile or old test pile can be located from which to take the sample section.

Though increment cores and pulse velocity can be used independently, their use in combination provides additional and complementary data. This increases the confidence in the overall structure assessment.

A method of examining timber by use of longitudinally transmitted sound waves is also available. This method has been used on transmission poles and other structures successfully. It has not been used below water to the best of our knowledge, though it could probably be modified for such use.

STEEL TESTING

- **STEEL THICKNESS MEASUREMENTS**
- **WELD TESTING**

4-18

III. STEEL TESTING

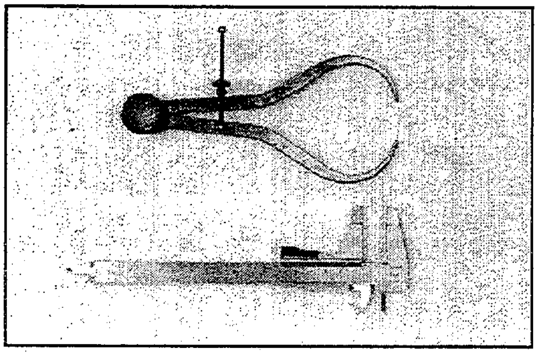
Level III testing of steel includes obtaining member or element material thickness using ultrasonics, and testing of welds using one of several methods.

THICKNESS TESTING

4-19

A. THICKNESS TESTING

Steel thickness measurements indicate if the capacity of a structural element has been reduced. There are several methods of obtaining steel thickness measurements.



4-20

The easiest way is using calipers. These are fine for measuring pile flanges and other members where both sides of the steel can be accessed. They don't work for sheet piling, pile webs, pipe pile walls, and similar locations.

4-21

Another method is to use an ultrasonic gage. The gage is a device that measures steel thickness using sound. The unit consists of a transducer and a set of electronics. A sound pulse is transmitted into the steel by the transducer. It travels through the steel until it comes to the other surface where it is reflected back to the transducer. The device measures the travel time for the pulse from the transducer to the back face of the steel and back to the transducer. The device converts that elapsed travel time to a thickness. The equipment in this slide is a self-contained unit.

The electronics and transducer are packaged in a watertight case. A digital display of the steel thickness is read by the diver.

4-22

This is an above- water ultrasonic thickness gage which has a waterproofed transducer. The transducer cable has been lengthened to 100 feet.

The length of cable does effect the output of the unit. A longer cable means more signal loss and more electronic noise. It is important to check and calibrate the unit for accuracy before use.

In general, a 100 foot length is a maximum cable length that will produce acceptable data. Signal boosters may be placed in the lines to improve performance.

4-23

Ultrasonic gauges are also available which were specifically designed and built for underwater use. Here a diver is using one to measure the remaining thickness of a steel sheet pile.

IMPROVING RELIABILITY OF THICKNESS DATA

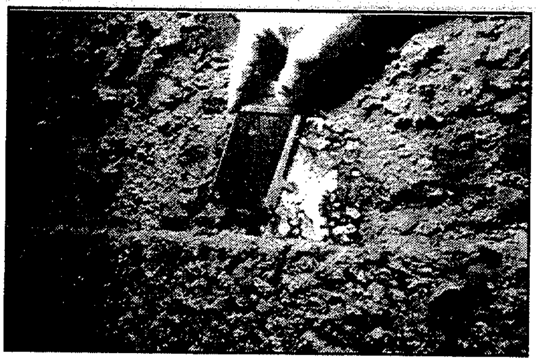
- CLEAN SUBSTRATE
- CALIBRATE
- TRANSDUCER TYPE
- MULTIPLE READINGS

4-24

B. TRANSDUCERS

Because underwater surfaces are usually pitted from corrosion, obtaining reliable thickness readings can be difficult. The rough surface produces multiple signal reflections that cannot always be discriminated from the actual thickness readings. Reliability is improved by the following:

- The surface should be well cleaned. Scraping may not be sufficient and spot grinding may be needed. Initial scraping often exposes a dull grey layer that looks like a sound substrate, but is actually an underlayer of corrosive product.
- Gauges should be checked against calibration blocks before use. Gauge blocks can simply be pieces of steel plate of known thickness within .01".
- Use of a gauge with split transducers (one sends; one receives) gives better results than a single transducer unit.
- Take multiple readings, three readings are often taken, over an area about 2 inches in diameter. Compare results. The average reading may be used or the smallest of the values based on judgement and experience.



4-25

A pit gage is an easy to use tool which measures the depth of pits in steel. No modification is required to use this instrument below water. The gage should be cleaned and lubricated after every use.

WELD TESTING

4-26

C. WELD TESTING

Underwater NDT of welds is practiced widely in the offshore petroleum industry, though its need for bridge structures is not extensive. It is possible, however, that as advances in underwater welding continue its use may become more common.

The techniques used underwater are modifications of standard topside procedures and should be performed by qualified NDT weld inspectors.

METHODS

- **MAGNETIC PARTICLE**
- **ULTRASONICS**

4-27

Common methods of inspection include:

- Magnetic (Mag) particle
- Ultrasonics

For all inspections, a very high degree of local structure cleaning is needed. Also, these tests are virtually impossible to perform in very low visibility water.

MAGNETIC PARTICLE

4-28

Magnetic particle inspection is performed as above water. The iron particles themselves are carried in a gel which displaces the water at the test area and allows the particles to move within it. A waterproofed yoke is used to provide the magnetic field to cause the particles to align. A visual observation is made of the particle alignment and is usually photographed for record. This technique helps locate and size surface defects.

4-29

This shows a magnetic particle inspection taking place.

ULTRASONICS

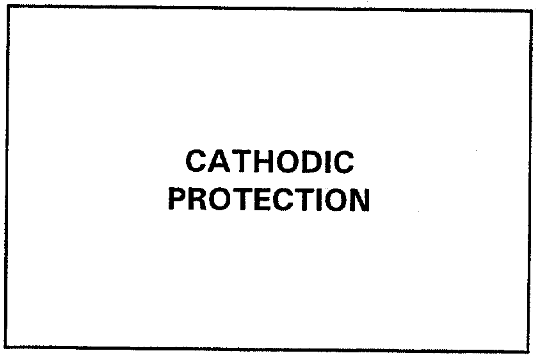
4-30

Ultrasonic inspection can be conducted with the instrument on the surface and the transducers alone taken underwater, or using a fully waterproofed unit. Because of the transducer patterns which must be run, good communication is critical when the unit itself is kept and read topside.

When the inspector takes the instrument with him, he can make adjustments in his scanning patterns based on the observed signal output. Good visibility is needed.

4-31

This shows a self-contained ultrasonic unit being used to inspect a weld underwater. The unit sends a sound wave into the steel at the weld at a specific angle. The display in the unit will show discontinuities in the metal as spikes on the screen.



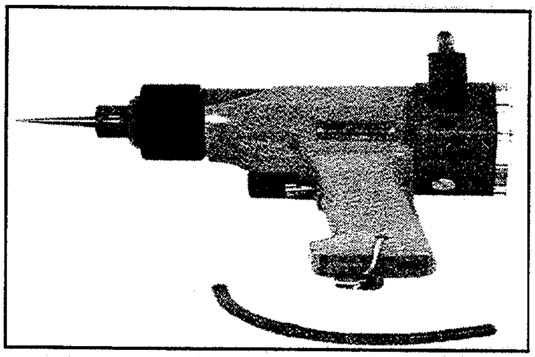
CATHODIC
PROTECTION

4-32

IV. CATHODIC PROTECTION

The effectiveness of a cathodic protection system also needs to be checked periodically. Some tasks can be done as part of an underwater inspection. The presence of anodes and the amount of material remaining should be noted. Also, the locations of anodes should be noted.

Broken or detached wiring of protection systems should be noted.



4-33

Half-cell readings can also be taken to determine if a cathodic system is working. This is especially important in structures where an active cathodic system is used. An active cathodic protection system requires an electric current to drive the protection system. The current is supplied by a rectifier. An active system may appear to be operational (anodes in place, steel in good condition, connections o.k.) visually but if the rectifier is not operating or a wire is broken, the system won't work. Therefore, in active systems it is important to visually check the system and also use a half-cell to check the various areas around the structure to determine if the system is working. Shown here is a submersible self-contained half-cell and voltmeter.

NATIONAL ASSOCIATIONS OF CORROSION ENGINEERS (NACE)

- **STANDARDS**
- **CERTIFIED CORROSION ENGINEERS**

4-34

A cathodic survey can be done separately from a diving inspection and in most cases is. As part of a diving inspection, it is recommended that tasks performed by inspectors inexperienced in cathodic surveys be limited to visual inspection of the anodes and wiring. For more complex corrosion studies and measurements, the work should be performed in accordance with NACE standards and be performed by a NACE certified corrosion engineer.

CONCRETE TESTING

- **ULTRASONICS**
- **REBOUND HAMMERS**
- **PACHOMETER (R-METER)**
- **CORES**
- **RADAR**

4-35

V. CONCRETE TESTING

Most surface methods of non-destructive and partially destructive concrete testing can be adopted for underwater use. Special cases and power systems are used. Limitations on test methods are consistent with use above water, and may include additional restrictions. Available test techniques include:

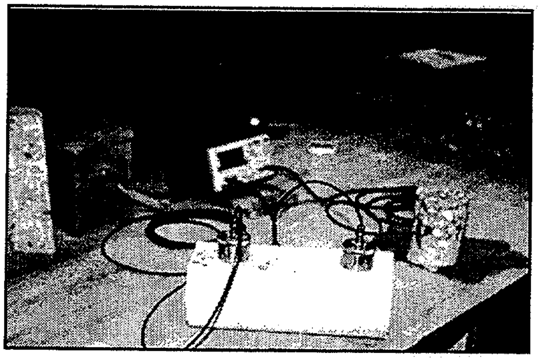
- Ultrasonics
- Rebound Hammer
- Pachometer
- Cores
- Radar

ULTRASONIC TESTING

4-36

A. ULTRASONIC TESTING

The same V-meter used for timber testing (54 kHz) can also be used to assess the uniformity and relative quality of concrete. In dry concrete, the depth of surface cracks can also be estimated. This is difficult below water because water will conduct sound across the crack.



4-37

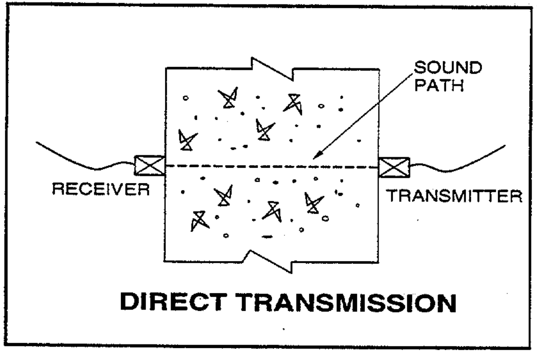
Ultrasonic pulse velocity testing is based on the fact that the travel speed of the sound wave increases as material modulus of elasticity increases. Since concrete strength and modulus of elasticity are related, the method also allows assessment of concrete strength.

General guidelines relating pulse velocity to compressive strength have been published. However, the ranges are large and are influenced by many factors.

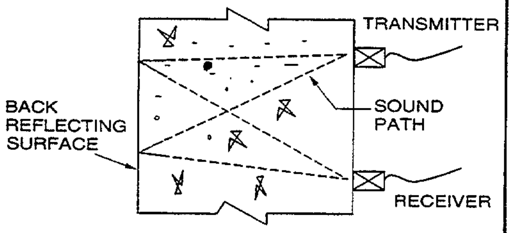
A job-specific empirical relationship of velocity versus strength may be established by the determination of pulse velocity and compressive strength on a number of concrete samples (cylinders or cores). This relationship may serve as a basis for the estimation of strength by further pulse-velocity tests with a much higher confidence level on similar concrete.

ASTM standard C 597 details procedures for use of pulse velocity equipment for testing concrete and indicates some of its limitations.

For best results, the transducers should be placed opposite one another which is referred to as direct transmission. In direct transmission the stress wave passes through the concrete in a straight line shortest path providing information on the interior material.



4-38



INDIRECT TRANSMISSION

4-39

Indirect readings should only be made when access to only one side of the member is available. These readings may only provide information as to the quality of the concrete on the surface of the member.

INFLUENCE FACTORS

- **AGGREGATE**
- **AGE**
- **REINFORCING**

4-40

Factors that influence pulse velocity measurements include:

- Aggregate type affects reading due to density. Lightweight aggregate gives lower pulse velocities.
- Age effects readings by virtue of strength gain with age. This is usually negligible for in-service structures.
- Reinforcing can provide alternate travel paths for the ultrasonic pulse in a more dense, steel, material. The effect of reinforcing on velocity readings is dependent on its quantity and orientation. Correction factors are available which allow these effects to be taken into account in data evaluation.

REBOUND HAMMER

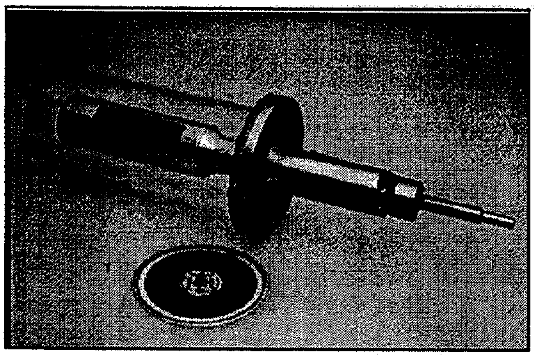
4-41

B. REBOUND HAMMER

The rebound hammer, often called a "Schmidt" hammer, can be used to determine the relative near-surface concrete quality of members. This method is covered in ASTM C80. The unit consists of a spring loaded plunger, a hammer and a metal casing. The rebound hammer is placed perpendicular to the concrete surface and the unit is pressed against the member. The spring loaded mass is released and impacts a shoulder on the plunger. The concrete absorbs some energy while the remaining energy causes the hammer to rebound, providing a reading from 1 to 100 on the rebound hammer scale.

4-42

This shows a rebound hammer in use testing a column above water.



4-43

The rebound hammer is made for use above water, and the unit has to be waterproofed through construction of a housing for underwater use. A modified rebound scale must also be used.

LIMITATIONS

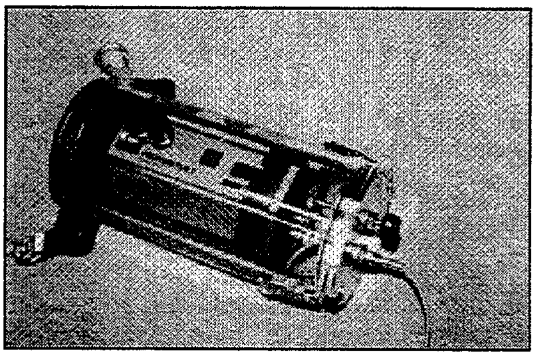
4-44

The rebound hammer readings can be used along with charts supplied with the equipment to obtain an estimate of concrete strength. However, due to the low mass of the plunger, even this is representative of only a small surface volume of the structure's concrete. The area to be tested should be cleaned and at least three readings taken over a local area and averaged. Correction factors are applied to the readings depending on whether the concrete surface is vertical, overhead, or downhand.

The rebound hammer is a convenient way to obtain a general assessment of near surface concrete quality. It does not give a reliable indication of compressive strength.

R-METER
OR
PACHOMETER

4-45



4-46

C. R-METER

The R-Meter or Pachometer, is a device which uses magnetics to locate reinforcing steel (rebar). Widely used above water, these meters can be waterproofed for below water use.

The meter is capable of either identifying the depth of cover if the rebar size is known, or identify rebar size if the depth of cover is known. For condition surveys it is most often used to verify reinforcing cover.

One limitation of the instrument is that it cannot locate rebar more than 7 inches from the surface of the concrete. In addition, it may not be effective at all in heavily reinforced sections.

The results from the test can be verified by drilling to expose a portion of the steel and confirming cover and bar size.

The R-meter may be used prior to concrete coring operations to reduce the probability of coring through reinforcing steel.

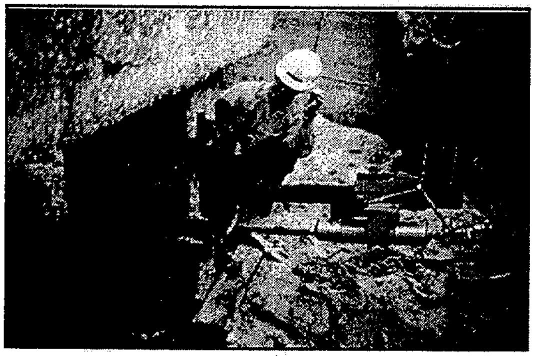
An R-meter is shown here in a waterproof enclosure available from the instrument manufacturer.

CONCRETE CORING

4-47

D. CONCRETE CORING

Concrete cores can be taken below water using drilling equipment with coring bits.



4-48

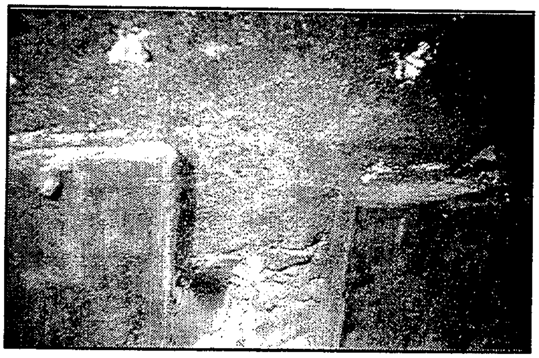
This shows a core rig for underwater core sampling being used on a column just above water level. Except for use of a hydraulic powered drill, this is a standard core rig.

The machinery is heavy. As with any construction type equipment or procedure, working below water normally takes longer than performing the same task above water. Additional maintenance of the equipment is also necessary especially when it becomes exposed to salt water.

An option to coring underwater is to take a sample in the tidal zone where the equipment can be used in the dry at low tide.

Drilled core samples obtained underwater are tested in accordance with ASTM C42. Tests for compressive strength should be run with the samples kept wet, so that the core is representative of the concrete as it is in service.

Along with visual core examination, visual examination of the core hole can yield useful information.



4-49

Underwater core holes as shown in this slide should be hand packed with mortar to fill the resulting voids.

Guidance in interpreting core test data is available in American Concrete Institute (ACI) literature. One aspect of particular note for bridge substructures relates to column strength. In order to take core samples above water, piles and columns are often cored near their tops. Tests show, however, that such concrete can be expected to show lower compressive strength and higher water-cement ratios than is characteristic of the overall member.

Core test results provide an excellent means for developing correlation data with pulse velocity readings. The use of a few core samples can be coupled with numerous pulse velocity tests to provide an effective condition assessment of the concrete in a structure.

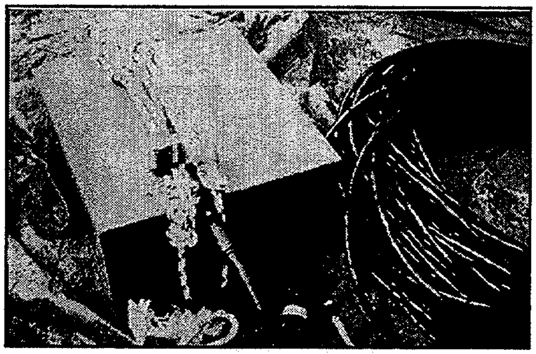
GROUND PENETRATING RADAR

4-50

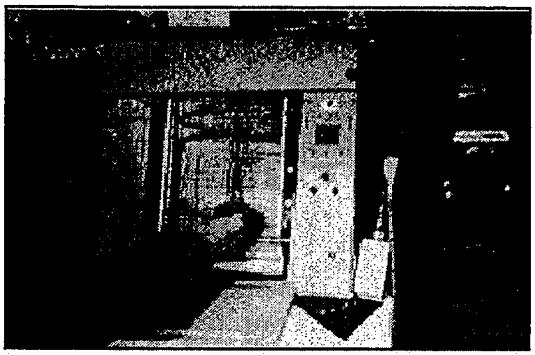
E. GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) can be used to identify voids or areas of reinforcing steel in concrete. Used above water for several years, it has more recently been used below water in limited cases. The device sends out an electromagnetic signal from an antennae. The antennae also acts as a receiver. When the signal strikes a boundary between different materials or areas with different electrical properties, a portion of the pulse is reflected back to the antennae. Knowing the velocity of the signal in concrete, the depth to the interface can be determined. This equipment can be used to determine the depth of reinforcing steel and locate voids within concrete.

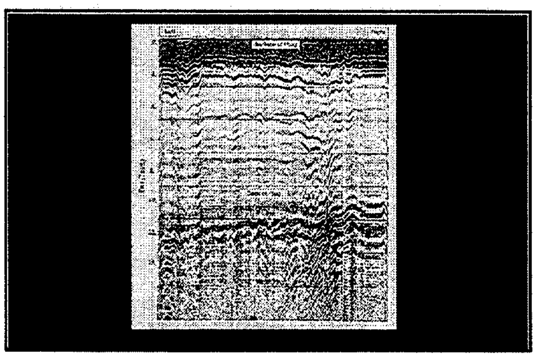
Because this equipment uses an electromagnetic signal, it penetrates less when the electrical conductivity is high.


4-51

The equipment consists of an antennae, cable and transmitter/receiver. The information is recorded on a thermal printer. In order to use the equipment below water, the antennae is placed in a waterproofed housing. The antennae can then be carried by a diver and passed over the member being investigated.


4-52

This shows the thermal printer with the test output being reviewed.


4-53

This record was obtained from a concrete plug in a water tunnel. The purpose of this particular application was to identify the thickness of the concrete, and in conjunction with pulse velocity testing establish the overall concrete condition.

SUMMARY
LEVEL III TESTING

- **DEVELOP WORK PLAN**
- **TIMBER TESTING**
- **STEEL TESTING**
- **CATHODIC TESTING**
- **CONCRETE TESTING**

4-54

VII. SUMMARY

Develop a work plan
Timber Testing
    Boring
    Coring
    Ultrasonic Testing
Steel Testing
    Thickness Testing
    Transducers
    Weld Testing
Cathodic Testing
Concrete Testing
    Ultrasonic Testing
    Rebound Hammer
    R-meter
    Concrete Coring
    Ground Penetrating Radar

Almost any method used above water can be adapted for underwater use, although it may cost more and take ingenuity to accomplish.

SESSION 5

EFFECTS OF MEASURED DETERIORATION UPON STRUCTURES

SESSION 5: EFFECTS OF MEASURED DETERIORATION UPON STRUCTURES

TOPICS: INITIAL EVALUATION, DETAILED ANALYSIS, DETERIORATION RATES

LESSON PLAN:

DURATION	60 minutes
GOAL	Understanding of the effects of deterioration and damage on structure.
OBJECTIVE	Participant should be able to recognize damage which is significant to structural capacity
OUTLINE	I. Initial Inspection II. Initial Evaluation III. Detailed Analysis IV. Steel Section Loss V. Timber Deterioration and Damage VI. Concrete Deterioration and Damage VII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 5
EFFECTS OF MEASURED DETERIORATION

5-0

The effect of measured deterioration is dependant upon not only its severity but also its location within the structure. Good inspection data is needed to make subsequent engineering analysis.

INITIAL INSPECTION

- **DETERIORATION**
- **VESSEL DAMAGE**
- **UNDERMINING**
- **LATERAL STABILITY**

5-1

I. INITIAL INSPECTION

- Initial items to be observed on-site.
- Some can be observed above water, others require underwater inspection or soundings.
- Some conditions may only be visible under load.

INITIAL INSPECTION

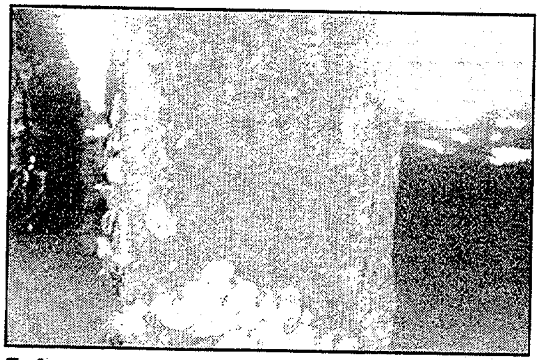
- **SEVERITY**
- **LOCATION**

5-2

- All structures have some deterioration or damage.
- Most foundations are massive and minor defects are not significant.
- But defects in key locations are important.

5-3

For example, the piles of this timber bent are generally in good condition, but lateral bracing is poor.



5-4

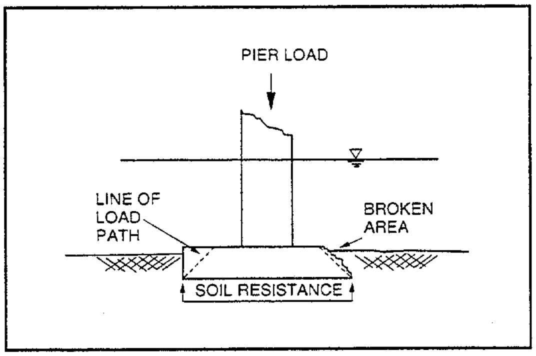
Cracks on corners of this prestressed concrete pile have not substantially reduced the load carrying capacity of the pile at this time.

They do, however, provide a starting point for more severe deterioration, and may indicate reinforcing corrosion.

5-5

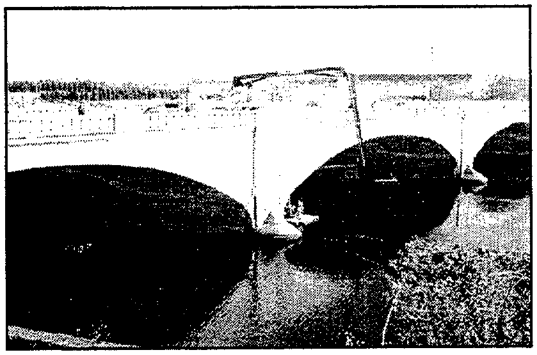
The loss of concrete cover in this case is serious. It reduces the effectiveness of the spiral and, therefore, the capacity of the pile.

Thus, it is important to have an understanding of how various components behave under load in order to evaluate the significance of the conditions found.



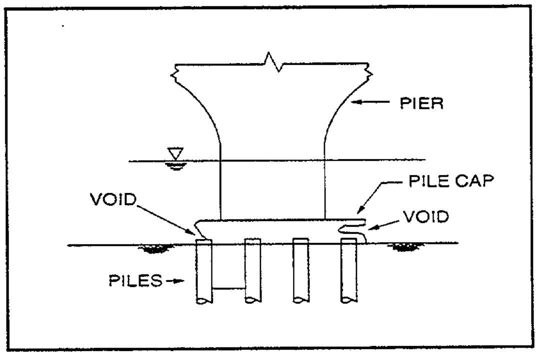
5-6

The location of the defect can also determine its structural effect. Here is a spread footing with a part broken off, but the load path is not through the damaged area and there is no loss of structural capacity.



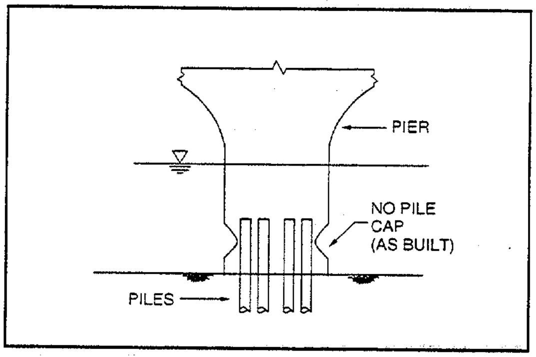
5-7

Here is an actual bridge to demonstrate this concept. It is an earth-filled concrete arch bridge supported on timber piles.



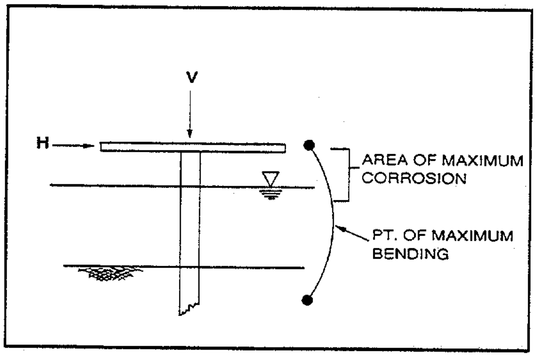
5-8

This sketch shows the configuration of the pier pile cap shown on the original drawings, and a diver's inspection notes are superimposed on it showing some significant losses. In effect, the outside rows of piles are not contributing to the capacity of this pier.



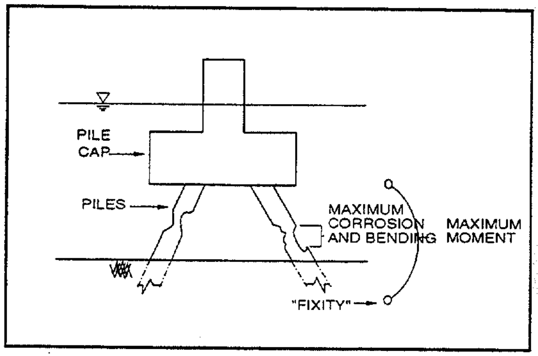
5-9

The original design drawings, however, do not reflect the actual constructed configuration of the pier. This sketch does. The piles were actually all within the area of the pier shaft.



5-10

The location of the deterioration in a steel structure determines the importance of the condition. Here, for example, is a steel H-pile which has suffered corrosion and section loss in the splash and tidal area near the top of the pile. Because of the structural system used here, however, the area of maximum moment occurs much below that maximum section loss.



5-11

Here is a different structural system where the maximum deterioration and point of maximum moment occur at the same location.

So, it is important to understand the structural action of the bridge.

INITIAL ON-SITE EVALUATION

CONDITIONS POSSIBLY INDICATING LOSS OF CAPACITY

- **LOSS OF SECTION**
- **SETTLEMENT**
- **EXPOSURE OF BURIED COMPONENTS**

5-12

II. INITIAL ON-SITE EVALUATION

The preceding slides show, in general, the types of conditions the inspector must find in the field and evaluate immediately. While it is necessary to make a detailed analysis to determine the remaining load carrying capacity, there may be some judgments that you can, and should, make immediately at the site.

Initial on-site evaluation may disclose conditions serious enough to immediately restrict bridge usage.

VERTICAL CAPACITY OF PILE

$f_a = P/A$

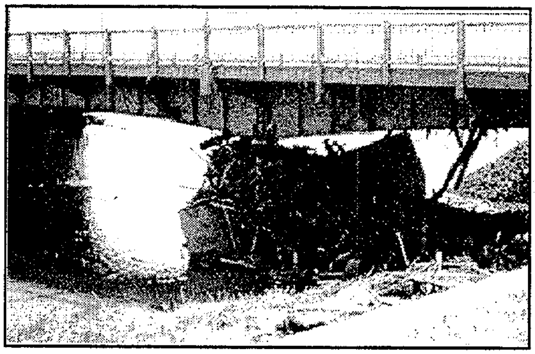
if $f_a = 0.55\ Fy$, F.S. $= 1.82$

if $A_{actual} = 0.55\ A_{original}$, F.S. $= 1$

5-13

Loss of section can be an indication of significant reduced structure capacity. In the design of steel structural members it was quite common to use a factor of safety of about 1.82; i.e., 0.55 fy to establish the allowable working stress. If the area of a member is reduced by 40 to 50 percent, the factor of safety could be approaching unity.

It must be remembered, though, that cross sectional area may not be the controlling feature of the design.



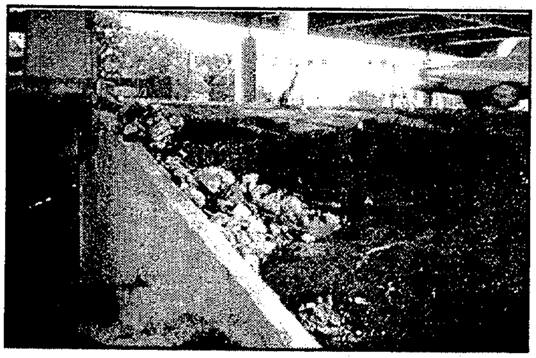
5-14

Settlement can indicate local or general failure has already occurred. Settlement of an interior support, as shown here (or an exterior support), of a continuous girder span can induce large, and undesigned for, stress in the superstructure.

5-15

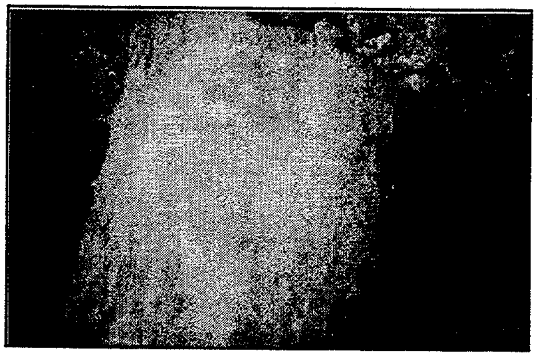
Exposed piles under footings or scour around pile bents can reduce the lateral support and can increase the unbraced length of the piles, and that condition may not have been accounted for in the design.

It is often hard to determine the importance of pile exposure without detailed analysis.



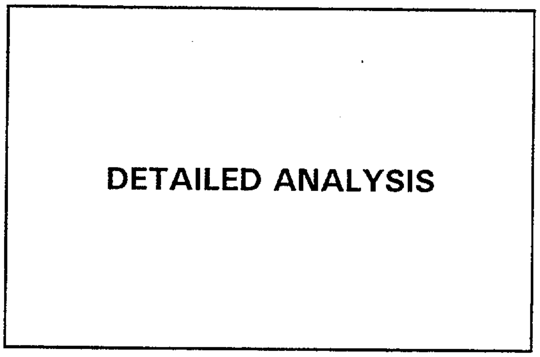
5-16

Undermining can reduce the total load bearing capacity of the footings. In this case, loss of material from behind the wall may have reduced the capacity of the adjacent column foundation.



5-16A

Scour can expose substantial lengths of piles in some cases. This photo shows the pile cap and pile connection where over 12 feet of timber pile had become exposed. Emergency measures (such as posting) may be required while the effects of the pile exposure are evaluated. The condition of the pile and pile cap connection should also be evaluated for any effects of loss of concrete around the pile, a reduction in pile diameter, or pile rot.

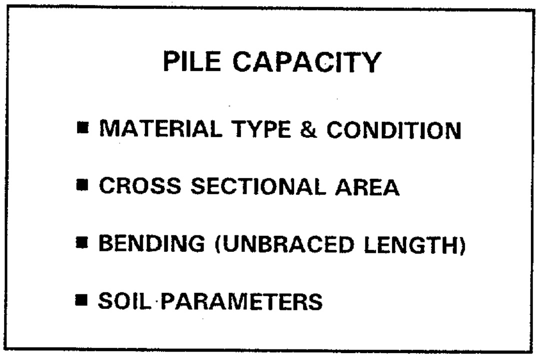


DETAILED ANALYSIS

5-17

III. DETAILED ANALYSIS

After the initial inspection, conditions between obviously good condition and obviously very poor condition must be analyzed to evaluate the effect of distress on the structure. The effect of distress may not be readily apparent.



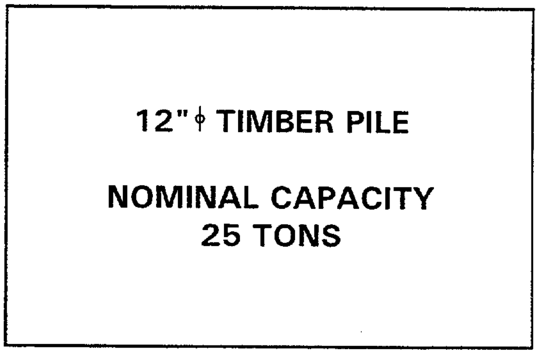
PILE CAPACITY

- MATERIAL TYPE & CONDITION
- CROSS SECTIONAL AREA
- BENDING (UNBRACED LENGTH)
- SOIL PARAMETERS

5-18

For example, pile capacity depends on:

- Material Type and Condition
- Cross Sectional Area
- Bending (Unbraced Length)
- Soil Parameters



12" ϕ TIMBER PILE

NOMINAL CAPACITY
25 TONS

5-19

Consider 12-inch diameter timber piles supporting a pier. Often that pile has a nominal design capacity of 25 tons.

12"ϕ TIMBER PILE

**STRUCTURAL CAPACITY
OF BRACED TIMBER
68 TONS**

5-20

The actual structural capacity of the round timber, assuming it is axially loaded, adequately braced and supported by soil of adequate strength, could be 50 to 100 tons

$$\begin{aligned} P &= A\,fa \\ &= (3.1416)\,(6")^2 \times (1200\text{ psi}) \\ &= 135{,}719\# \\ &= 68\text{ Ton} \end{aligned}$$

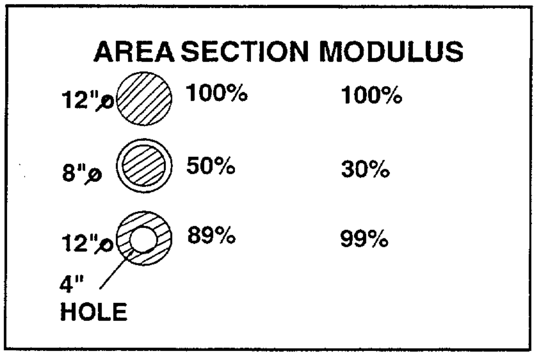
The use of an allowable stress of 1200 psi shown above is a common value for timber in good condition. However, deterioration of the timber due to decay and bacteria may result in a lower value of stress being used for calculating remaining member capacity.

**BACTERIAL
DEGRADATION**

5-21

Bacteria have recently been shown to be important colonizers of untreated wood in very wet environments, causing increased permeability and softening. The process is very slow, but can be serious where untreated wood is submerged for long periods such that damage to the wood microstructure can occur. This type of damage can reduce pile capacity by actually changing material parameters such as strength and density without a loss of cross sectional area. Because it also reduces the modulus, it can have a compound effect on long piles.

Material strength losses of over 30 percent have been reported in research conducted by the Forest Products Research Lab in Research Note FPL-0229.



AREA SECTION MODULUS

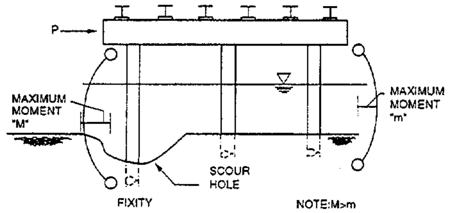
	AREA	SECTION MODULUS
12"⌀	100%	100%
8"⌀	50%	30%
12"⌀, 4" HOLE	89%	99%

5-22

Loss of section will also reduce a member's capacity and can be due to deterioration from:

- Limnoria
- Teredo
- Abrasion

Look at the effect of various losses on strength. Note that the hole in the center has less effect than losses on the outside.



5-23

As previously noted, the unbraced length of a pile and the location of maximum bending stress must be considered in analyzing pile capacity.

The point of minimum cross sectional area may not correspond to the point of maximum stress.

TYPICAL 12" PILE

COLUMN	l/d	Fc
SHORT	<11	1600 PSI
INTERMED	22	1050 PSI
LONG	44	280 PSI

5-24

Scour may significantly increase the unbraced length of piles and change what had been designed as a pile, laterally braced along its full length, to an unbraced long pile.

This table shows the effect of unbraced length on the allowable axial compression in timber piles.

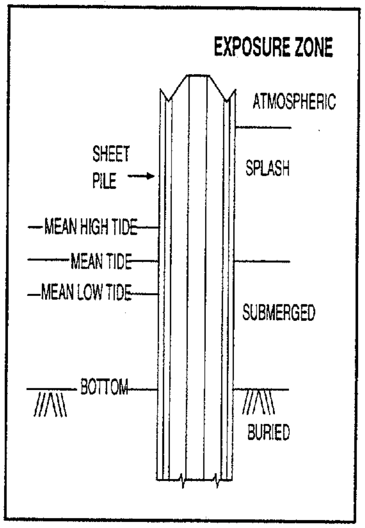
GEOTECHNICAL CONSIDERATIONS

- END BEARING
- FRICTION

5-25

Geotechnical considerations often determine pile capacity. The size of the pile required for soil conditions may be much larger than required for structural considerations. Even if pile diameter is reduced by abrasion or damage, the overall capacity of the pile may not be reduced.

All these factors must be considered in evaluating the effect of losses.



5-26

IV. STEEL SECTION LOSS

Corrosion of steel is largely dependent on the environment in which it is located. This shows the exposure zones, or conditions, in a marine environment. The range of tidal changes and expected area subjected to splash can vary widely.

TYPES OF CORROSION

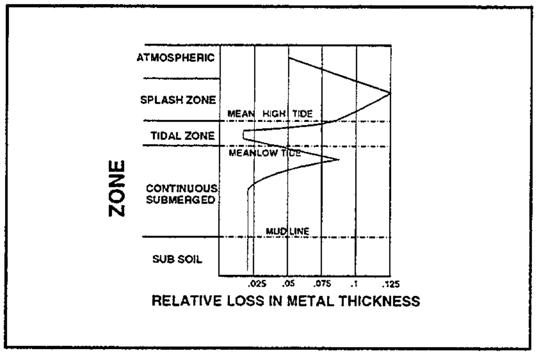
- UNIFORM
- PITTING

5-27

There are two general types of corrosion in the marine environment:

- Uniform - general overall roughening of the metal surface resulting in its gradual thinning.
- Pitting - localized form of attack; may be more serious than uniform corrosion since it may form at sites where stresses are higher.

Pitting corrosion rates can be five to ten times the uniform rate.



5-28

Corrosion rates vary considerably by zone. In general, the maximum reduction occurs in the splash zone, immediately above mean high water and a significant loss usually occurs a short way below mean low water:

- Least affected zone is usually below mudline.
- Higher losses at water-mudline interface.
- Low loss area in tidal zone about halfway between mean high water and mean low water.
- Steel sheet piling exposed to water on one side: average corrosion rate 1 - 4.5 mils per year
- Water on both sides: total corrosion rate doubled.

FACTORS AFFECTING MARINE CORROSION RATES

- **EROSION**

5-29

- Erosion - Steel in marine environments corrodes initially at a high rate until protective film forms. Tidal action, wave forces and abrasive bottom material can destroy the protective film.

FACTORS AFFECTING MARINE CORROSION RATES

- EROSION
- WATER TEMPERATURE

5-30

- Water Temperature - Complex variable; warmer water accelerates chemical reactions such as corrosion, but this is usually offset by an increase in the marine fouling rate and a decrease in oxygen solubility.

FACTORS AFFECTING MARINE CORROSION RATES

- EROSION
- WATER TEMPERATURE
- OXYGEN CONCENTRATION

5-31

- Mechanisms that increase oxygen at the base of steel surfaces will increase corrosion rate. These include: wave action, water velocity and turbulence.

FACTORS AFFECTING MARINE CORROSION RATES

- EROSION
- WATER TEMPERATURE
- OXYGEN CONCENTRATION
- PH VALUE

5-32

- ph of seawater is almost constant ranging from 7.2 to 8.2.
- ph < 7 is acidic
- ph > 7 is alkaline
- If ph > 9.5, iron becomes passive and forms protective films which retard diffusion of oxygen.
- If ph < 4, alkaline protective films are dissolved and acid acts directly on the metal.

FACTORS AFFECTING MARINE CORROSION RATES

- EROSION
- WATER TEMPERATURE
- OXYGEN CONCENTRATION
- PH VALUE
- SALINITY

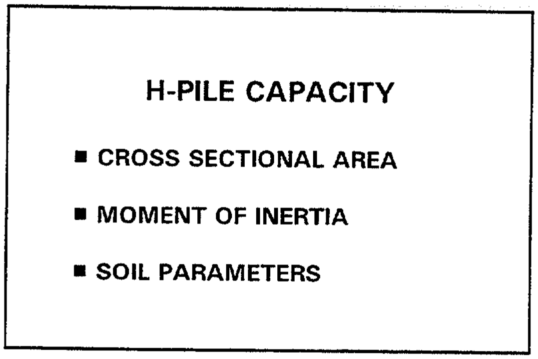
5-33

FACTORS AFFECTING MARINE CORROSION RATES

- EROSION
- WATER TEMPERATURE
- OXYGEN CONCENTRATION
- PH VALUE
- SALINITY
- MARINE ORGANISMS

5-34

- Even in harbors, where ph may vary somewhat, these extremes are very unusual, and corrosion rate is almost constant.
- Open sea: 3.5% salt content.
- Harbors and rivers diluted.
- Chloride ion is able to penetrate protective films formed by corrosion products, to cause localized corrosion.
- Corrosion rate increases with increasing salinity until it reaches a peak of about one percent sodium chloride and then decreases with increasing salinity. Thus, freshwater and seawater are not as aggressive as brackish waters.
- Organisms, such as barnacles, grasses and worms, generally accelerate the corrosion rate in localized areas because of differential environmental conditions caused by their biologic processes.
- Dense, continuous marine growth can sometimes stifle general corrosion by impeding the diffusion of oxygen to the metal surface.
- Fouling organisms can penetrate soft protective coatings and expose bare metal surfaces.
- Anaerobic bacteria thrive in oxygen-free environments and are capable of converting sulfates to sulfides which aggressively attack steel.



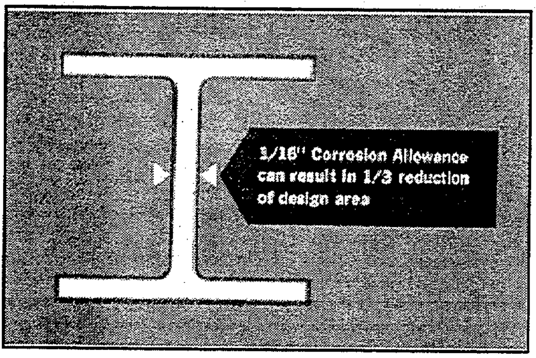
H-PILE CAPACITY

- CROSS SECTIONAL AREA
- MOMENT OF INERTIA
- SOIL PARAMETERS

5-35

After looking at all the environmental factors which can reduce the load carrying capacity of piles, we have to look at the effect these losses can have on pile capacity. For steel H-piles, as for any other piles, capacity is a function of:

- Remaining cross section areas (what is its capacity to carry axial loads?).
- Moment of Inertia (what is its lateral or bending capacity? - Often a function of its buckling capacity as determined by its unbraced length)
- Soil Parameters (determined by point bearing capacity and friction; although H-piles generally derive all their capacity from soil near the point).



1/16" Corrosion Allowance can result in 1/3 reduction of design area

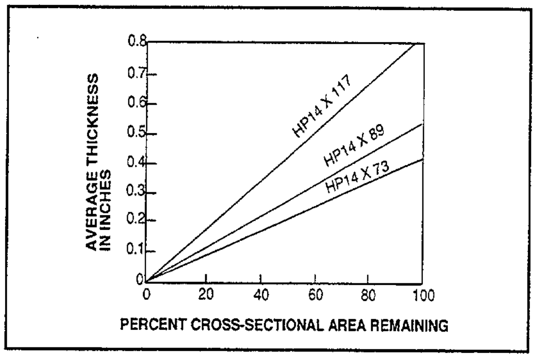
5-36

This shows the effect that corrosion losses can have on the remaining areas of a pile. Metal measurements are necessary to determine the remaining section.

For H-piles, the initial survey should determine the thickness at four locations on each flange, and the measurements should be taken at representative elevations along the accessible length of the pile.

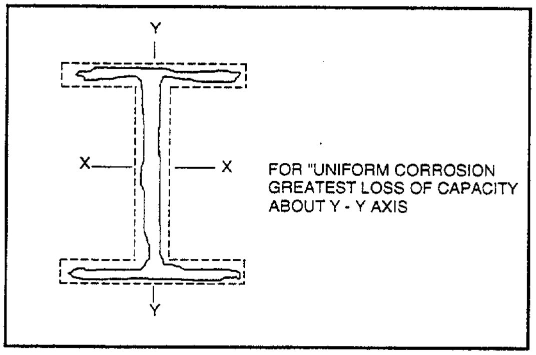
For pipe piles, four thickness measurements should be taken at each elevation.

After the pile thickness data has been obtained, the estimated remaining cross-sectional area of the pile can be calculated or estimated.



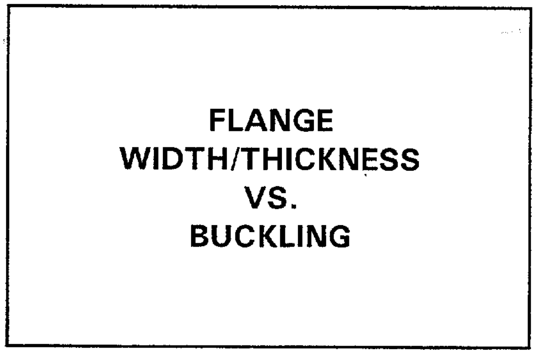
5-37

This figure can be used to estimate the remaining cross-sectional area of H-piles. (Full size figures corresponding to Slides 5-37, 5-39, 5-40 and 5-41 can be found on Pages 5-24 and 5-25)



5-38

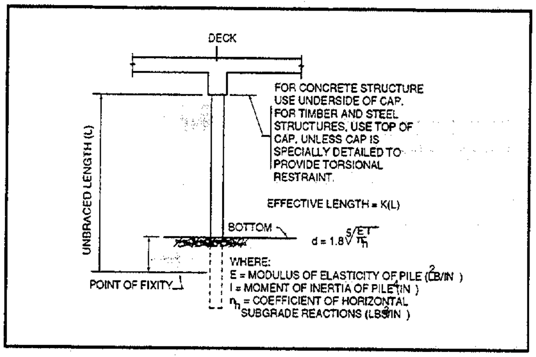
The moment of inertia and the effective length of the piles can be the controlling parameters for the evaluation. These determine the critical buckling load, or the Euler load. Due to corrosion, the moment of inertia will also be reduced, and the location of the neutral X-X axis may shift if the corrosion is more pronounced on one flange than on another. The loss of moment of inertia about the X-X axis is generally proportional to the loss of cross sectional area, but the proportional effect about the Y-Y axis is generally greater.



**FLANGE
WIDTH/THICKNESS
VS.
BUCKLING**

5-38A

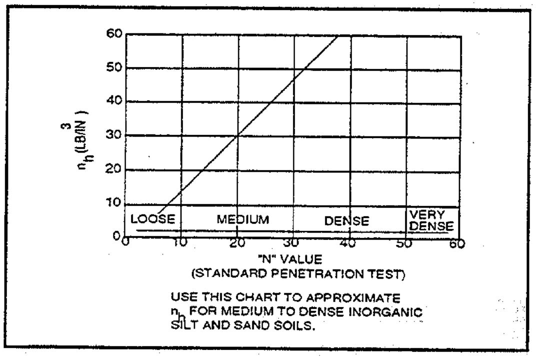
Corrosion which thins down the flange can increase its width to thickness ratio. These values define "compact" and "noncompact" sections, and as the ratio increases allowable compression stresses are reduced to preclude local flange buckling. For uneven corrosion, the flange thickness measured midway out should be used to compute this ratio.



5-39

The effective length of a pile driven into the soil is a function of the pile properties and the soil parameters. The procedure shown here is a procedure used by the Navy to estimate the effective length, knowing the pile properties, and blow counts for granular soils and unconfined compressive strength for clays. This procedure is shown in the figure at the end of this session.

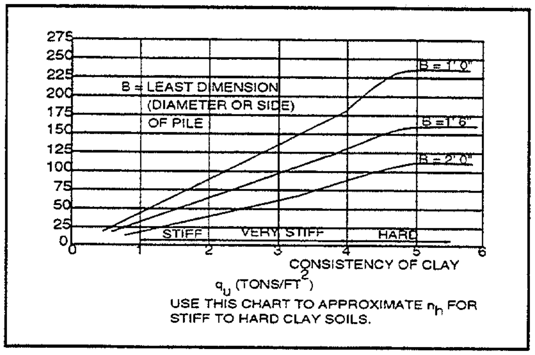
Other methods of evaluating the pile effective length using soil structure interaction programs are available. However, this method is suitable for fairly easy hand calculation and unless extensive soils data is available, may yield as reliable data as more theoretical methods.



USE THIS CHART TO APPROXIMATE n_h FOR MEDIUM TO DENSE INORGANIC SILT AND SAND SOILS.

5-40

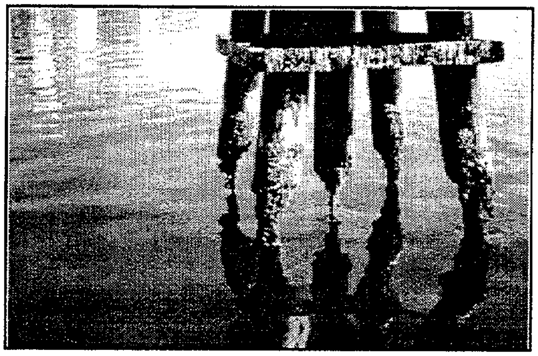
This shows the graph for granular soils.



USE THIS CHART TO APPROXIMATE n_h FOR STIFF TO HARD CLAY SOILS.

5-41

This is the graph for cohesive soils.



5-42

V. TIMBER

We have talked before about the various types of timber deterioration. Timber structures (exposed above the mudline) generally have design lives of 10 to 40 years. The interaction between the environment, protection of the timber (in the form of preservatives and wraps) and external forces such as vessels and abrasion can extend or shorten the life.

Salt water is generally worse than fresh water because of marine borers.

STRENGTH LOSS FACTORS

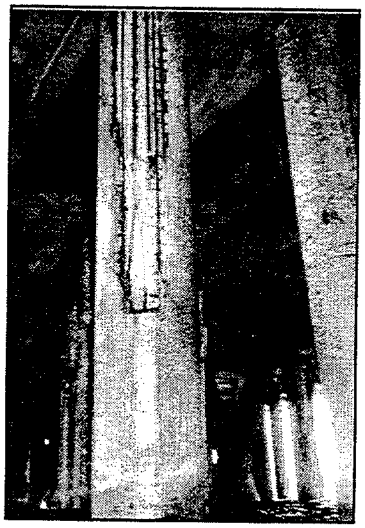
- **SALT VERSUS FRESH WATER**
- **POLLUTION**
- **WATERLINE ELEVATION**
- **ABRASION**

5-43

Polluted waters inhibit marine borer growth, but severe pollution can affect the timber. As we clean up harbors and rivers, marine borer attack can be a problem where it never was a problem before.

The most severe losses normally occur near the waterline - both above and below. Many timber structures are very flexible so loads are redistributed when one member is weakened.

AASHTO requires foundation design to consider deterioration of piles due to decay, insects or marine borer. Evaluation must also consider losses due to abrasion.



5-44

VI. CONCRETE

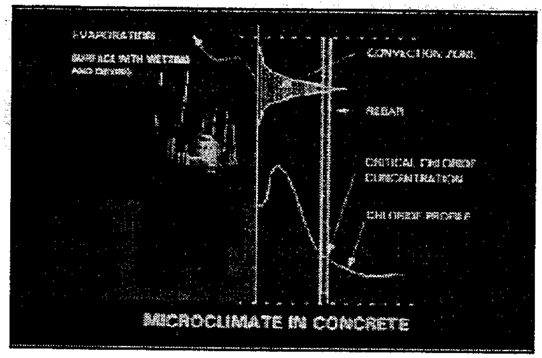
Evaluating the effect of deterioration on concrete must consider the condition of both concrete and reinforcing steel, and the location of the distress as previously described.

Concrete's load carrying capacity can be reduced through loss of section caused by spalling, scaling and external forces.

Separation of larger concrete members into smaller members, due to splitting and loss of restraints from ties, can change a short massive member into more than one thin member. This could be the result of deterioration or external damage.

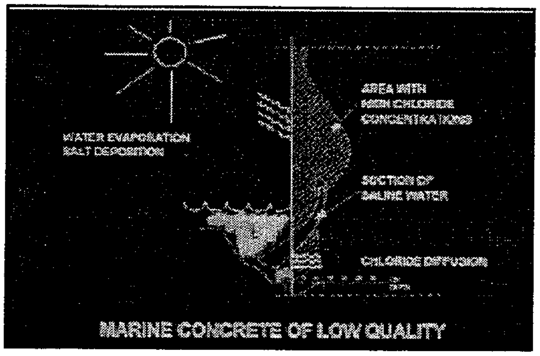
Reactive aggregates and sulphate attack can also turn a solid concrete member into a soft material that can be picked away.

Reinforcing steel deterioration, usually in the form of corrosion, can: 1) reduce the cross sectional area of the member, 2) result in loss of lateral restraint of the vertical bars through loss of ties, 3) expand and break off corners and surfaces. This is a concrete pile with mild steel exposed. Losses outside of the main steel cage probably will not affect load capacity. If the prestressing strand is damaged, however, loss prestress could occur.



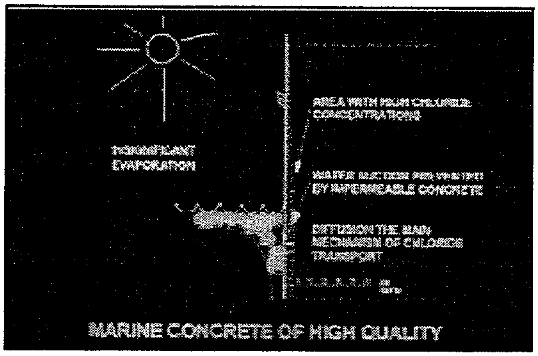
5-44A

In a sea water environment, the highest concentration of chlorides occurs above the water level. This is due to the evaporation of sea water that intermittently wets the surface, leaving a buildup of salts, as well as the evaporation of water which is absorbed and rises due to the concrete's porosity.



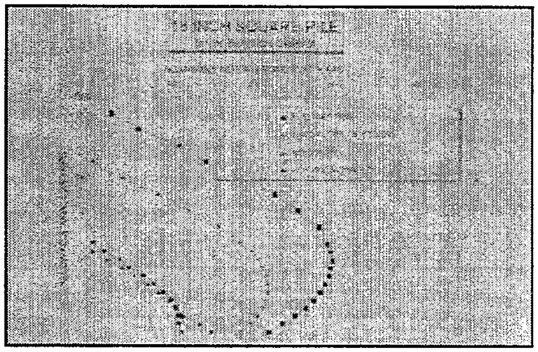
5-44B

In low quality concrete, with high porosity, the chlorides can diffuse more rapidly into the member when chloride concentrations of approximately 1.5 pounds per cubic yard are reached, corrosion of black bar reinforcing is initiated.



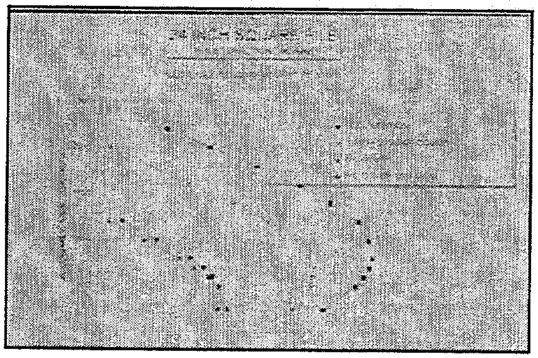
5-44C

In high quality, low porosity concrete, the chloride diffusion is slower. In theory, it could take many years before sufficient chloride would buildup at the level of the reinforcing to start corrosion.



5-44D

The axial compression capacity of a pile is based upon its full concrete cross sectional area. As shown in this interaction diagram for an 18 inch square prestressed pile, as the "cover" concrete is lost through abrasion, scaling, spalling, etc., the capacity decreases significantly. For example, losing 1 inch of concrete all around reduces the axial capacity by approximately 20 percent.



5-44E

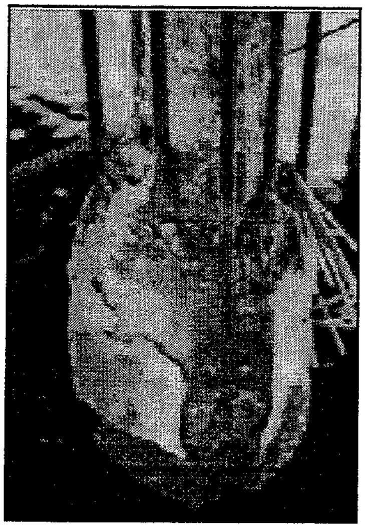
This interaction diagram shows similar effects on a 24 inch square prestressed pile.

5-45

In this repair project the original scope of work was to remove the deteriorated pile jackets, repair the expected spalled pile corners, and place new jackets. However, as can be seen here, more concrete than simply "spalled corners" was easily removed. Note the corner cracks above the jackets.

5-46

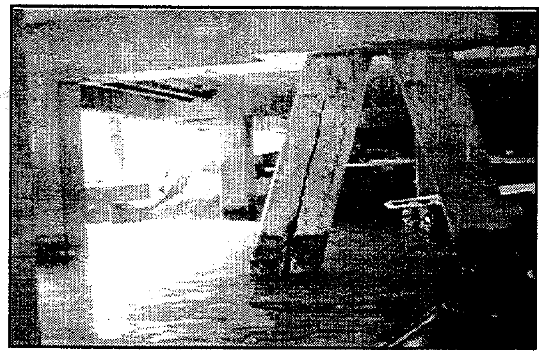
This shows the extent of removal. The vertical bars were not corroded badly, but the ties fell apart. Only one pile per bent was worked on at a time and no traffic was allowed in the lane overhead.



5-47

Note the severely deteriorated concrete. Such discoveries should result in a thorough study to determine the cause of deterioration and develop appropriate revised repair methods. Repair projects should always be ready for the unexpected.

In this case, the piles were rebuilt by forming with stay-in-place forms pumped with concrete. These techniques will be discussed in Session 9.



5-48

This vertically split pile is one of several in this structure. In effect, we now have two smaller piles sharing the load. In such cases, temporary repairs may be made while the cause of the deterioration is investigated. It is important to discover whether this problem can be expected in the other piles over the future.

RATES OF DETERIORATION

- MAINTENANCE HISTORY
- PROJECTED RATE

5-49

Finally, we need to evaluate the rate at which deterioration is occurring and project future rates based upon the historical maintenance history and the severity of damage. Not all distress needs to be repaired immediately, but we need to estimate what will happen if repairs are delayed. Maintenance history will be useful for some types of continuing deterioration. Some types of damage, however, may accelerate future distress.

SUMMARY

- **INITIAL INSPECTION**
- **INITIAL EVALUATION**
- **DETAILED ANALYSIS**
- **STEEL SECTION LOSS**
- **TIMBER DETERIORATION AND DAMAGE**
- **CONCRETE DETERIORATION AND DAMAGE**

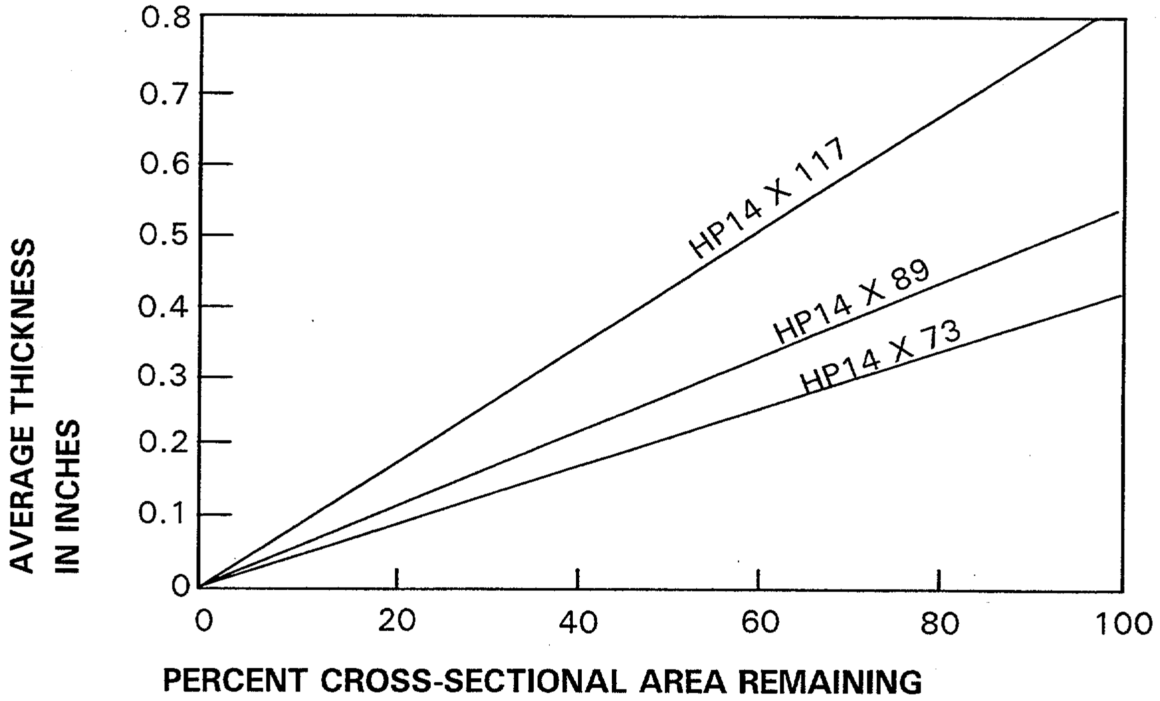
5-50

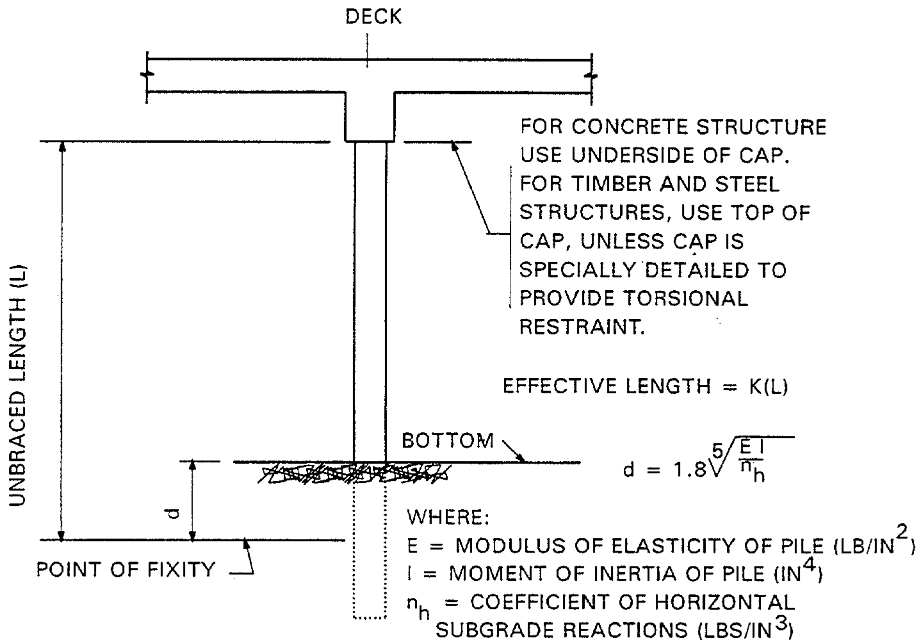
VII. SUMMARY

The initial inspection can indicate if significant losses have occurred. An understanding of the severity and location of damage and deterioration can permit a rapid rough evaluation of the significance of conditions.

A detailed analysis may be necessary to evaluate conditions more accurately. Losses which visually appear severe may not actually significantly reduce the structure capacity.

For steel, concrete and timber, we need to know how their strength is affected by deterioration.





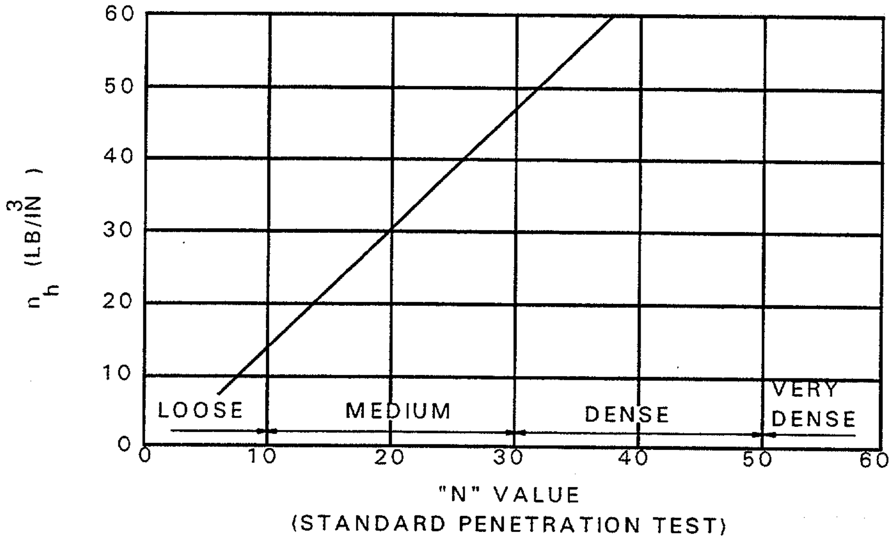
FOR CONCRETE STRUCTURE USE UNDERSIDE OF CAP. FOR TIMBER AND STEEL STRUCTURES, USE TOP OF CAP, UNLESS CAP IS SPECIALLY DETAILED TO PROVIDE TORSIONAL RESTRAINT.

EFFECTIVE LENGTH = K(L)

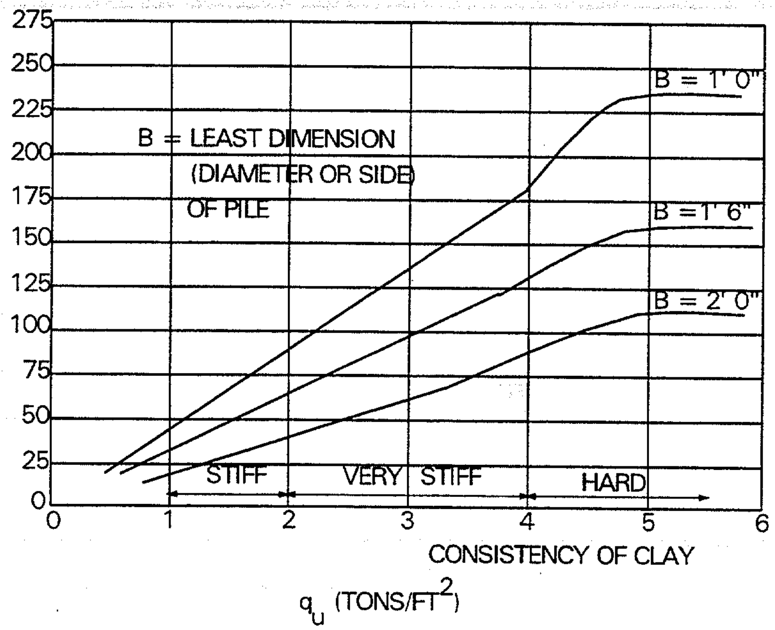
$$d = 1.8\sqrt[5]{\frac{EI}{n_h}}$$

WHERE:
E = MODULUS OF ELASTICITY OF PILE (LB/IN^2)
I = MOMENT OF INERTIA OF PILE (IN^4)
n_h = COEFFICIENT OF HORIZONTAL SUBGRADE REACTIONS (LBS/IN^3)

DETERMINATION OF UNBRACED PILE LENGTH



USE THIS CHART TO APPROXIMATE n_h FOR MEDIUM TO DENSE INORGANIC SILT AND SAND SOILS.



USE THIS CHART TO APPROXIMATE n_h FOR STIFF TO HARD CLAY SOILS.

DETERMINATION OF UNBRACED PILE LENGTH

SESSION 6

UNDERWATER REPAIRS

SESSION 6: UNDERWATER REPAIRS

TOPICS: **CHOOSING "WET" VERSUS "DRY" METHODS**
ENVIRONMENTAL CONSIDERATIONS
DRY REPAIRS

LESSON PLAN:

DURATION	45 minutes
GOAL	Present alternate means of repairs for wet structures and their constraints.
OBJECTIVE	Develop ability to determine when to use underwater repair methods.

OUTLINE

I. Introduction
II. Wet versus Dry Repairs
    A. Environment
    B. Contractors
III. Repairs in the Dry
    A. Cofferdams
    B. Dikes
    C. Portable Dams
    D. Plugs
IV. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 6
UNDERWATER REPAIRS

6-1

I. INTRODUCTION

Previous presentations have presented types of deterioration that may be expected at or below the waterline in bridge structures, as well as techniques for determining the extent and criticality of deterioration.

WET?
OR
DRY?

6-2

II. "WET" VERSUS "DRY" REPAIRS

Repairs to elements in water can generally be performed either by divers working underwater or by drying out the work area and using traditional and familiar repair techniques.

6-3

There are few repairs that cannot satisfactorily be completed underwater. However, underwater repairs will generally take longer and will be more expensive than comparable work done on land. Still, underwater repairs are often more cost effective than constructing temporary works and dewatering the repairs site.

Here, epoxy crack injection is being performed.

A. ENVIRONMENT

ENVIRONMENT

- **CURRENTS**
- **DEPTH**
- **TEMPERATURE**
- **POLLUTION**
- **REGULATIONS**

6-4

Just as environmental conditions shown here may make underwater inspection difficult, so too may they hinder repairs using divers. Additional environmental constraints may be imposed by regulatory agencies. These aspects must be carefully considered in the design of repairs.

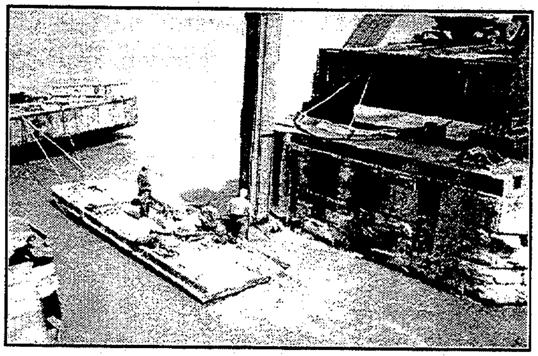
CURRENTS

6-5

One of the greatest problems working in water is currents. This affects both divers and topside operations. Divers must be tethered in currents greater than 1 knot. It is very difficult to work in more than 2 knots and handle tools, forms, materials, etc.

It is also difficult to handle boats and barges around construction in high currents. Bridge sites with consistently high currents will probably require cofferdams or similar measures. However, sheet piling is hard to position and drive at currents greater than 4 fps.

High currents are not only found in rivers, but may also be due to tidal effects.



6-6

Use of a diving shield as shown here is one special technique for working in high currents. Costs rise rapidly in such areas.

DEPTH

6-7

Most bridges are located in waters less than 30 feet deep, and only a very few in waters exceeding 100 feet. Thus, depth alone seldom precludes performing a repair by diving. However, unlike an inspection, the diver engaged in repairs may be at the maximum water depth for his complete work time. For a bridge in, say, 60 feet of water this would mean either short work periods or the need for time spent in decompression (non-productive time).

TEMPERATURE

6-8

Diving can be conducted in all weather conditions. Obviously, conducting diving in moderate weather conditions is preferable.

6-9

For extended work in cold water, special hot water suits are available. Increased support equipment is needed and the work is inefficient. Such techniques may be needed in emergencies but should otherwise be discouraged.

Diver fatigue is a concern also in warm, polluted water where dry suits and helmets are required.

Problems of currents, cold, and sometimes water depth can often be mitigated by when work is scheduled.

POLLUTION

- **DIVER**
- **CONSTRUCTION ACTIVITY**

6-10

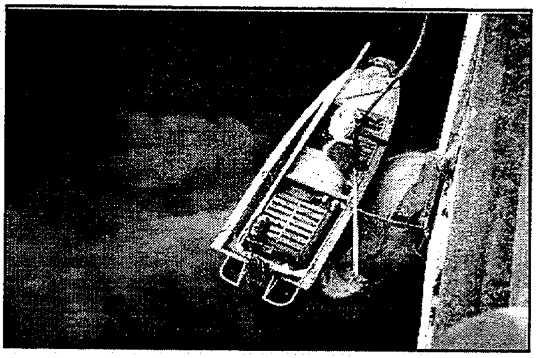
Pollution concerns fall into two categories:

- The effect of the water on the diver.
- The effect of the construction activity on the river.

As in other construction work, materials removed from polluted water, such as silt or concrete debris, may require disposal as hazardous waste.

6-11

Divers can work in polluted water using dry suits with neck seals and helmets and a positive air flow. Suspect waters should be sampled so that appropriate precautions can be taken.

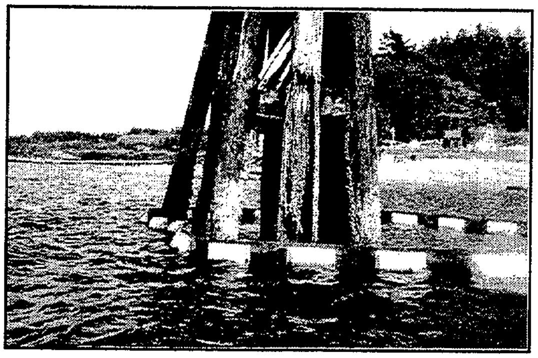


6-12

It is equally important that the repair activities not cause pollution. Possible sources include:

- Fuel spills
- Lubricating and hydraulic oil spills
- Construction debris
- Form oils
- Cement mortars
- Construction chemicals

This slide shows mortar being discharged into a river.



6-13

Here we see an isolated spill control containment ring around a pile bent.

REGULATIONS

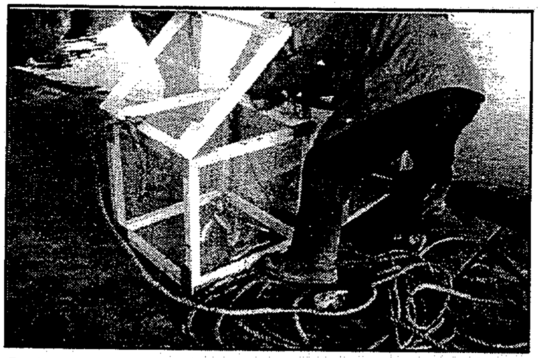
6-14

Government regulations, primarily pollution related, may have significant effects on how work is performed.

6-15

Checks with fish and wildlife staff should be made in project planning. Construction activities may be controlled by fish habitats and spawning, presence of endangered species, effect of repair materials on aquatic life, etc.

Schedules and construction windows may need modification to protect nature. Special or ongoing tests, such as water quality sampling shown here, may be needed to assure no damage is done.



6-16

This slide shows a fish "survival" test being run during construction. The fish were placed in the basket and suspended just downstream of the work area. If the fish did not die, the temporary pollution was acceptable.

ENVIRONMENTAL RESTRAINTS

- WORK WINDOW
- MORTAR TESTS
- CHEMICAL DATA
- SHEETING REMOVAL

6-17

Some examples of environmental restraints are the following:

- A 6 week work window to allow fish migrations.
- Tests on mortar leakage through fabric forms.
- Submission of complete chemical data on concrete materials.
- Removal of sheeting so there is no effect on fish.

Use of a dewatered cofferdam can separate the construction materials and activities from the water and may be required for this reason. However, pile driving disturbs the bottom and may be unacceptable.

QUALIFIED CONTRACTORS

6-18

B. CONTRACTORS

In choosing wet versus dry repair techniques, the availability of qualified contractors must be considered. Because it is somewhat specialized, diving contractors may not be readily available, especially away from the coasts.

Sufficient contractors are needed to allow meaningful competition. Many diving contractors are small and work only locally.

PREQUALIFICATION

- EQUIPMENT
- STAFF

6-19

Because underwater repairs are specialized and also more difficult to inspect than repairs in dry conditions, contractor prequalification is recommended. Two major factors in evaluation are available equipment and experience of the contractor's supervisors and divers.

Where experienced underwater contractors are not available, construction of cofferdams or other means of working in a dry condition may be preferred construction methods.

OH NO!

NEVER AGAIN

6-20

Agency experience is another consideration in designing for a wet repair. Where unsatisfactory results have occurred in the past, regardless of the particular technique, there is natural reluctance to place oneself in a similar situation. It is important that the contracting agency be confident of its ability to properly design and administer the work, and of the contractor's ability to satisfactorily complete the work.

**CAUSE
OR
EFFECT**

6-21

It is important in all repair designs to fix the problem and not the symptoms. For instance, repairing a volume change crack is of no use if we only cause the crack to reform elsewhere. This seems obvious but still is often overlooked.

Where the cause of problems cannot be determined based on underwater inspection and testing, access to the structure in a dry condition may be desired to more fully evaluate the causes of the deterioration. In these cases, it is most effective to use the same cofferdam for subsequent repair.

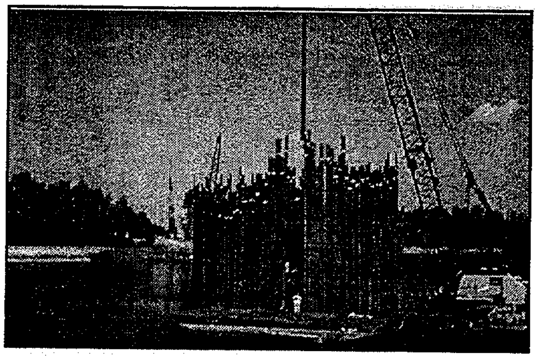
REPAIRS IN THE DRY

- COFFERDAMS
- DIKES
- PORTABLE DAMS

6-22

III. REPAIRS IN THE DRY

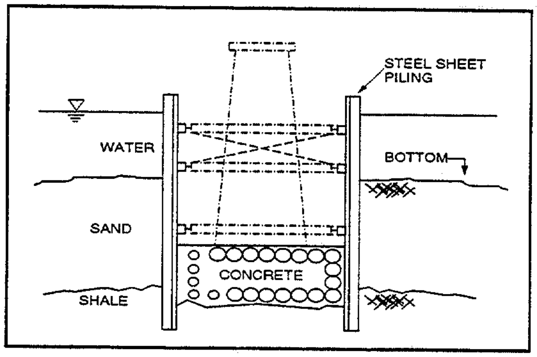
Three main techniques are available to allow repair work to be carried out in dry conditions: cofferdams, dikes, portable dams. These could also be used in combination.



6-23

A. COFFERDAMS

Cofferdams have a long history and are widely used in marine construction. They typically consist of driven interlocking sheeting and often contain interior bracing systems.



6-24

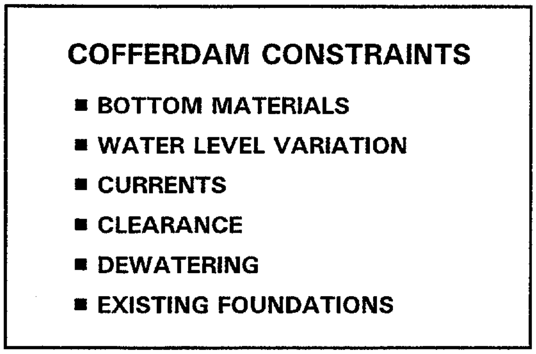
A typical cofferdam, noting:

- Sheet piling
- Interior bracing
- Bottom penetration
- Seal
- Existing foundation

The cofferdam is subject to water pressures and soil pressures and may also experience current, ice, debris, and vessel loads. If the cofferdam is to be dewatered, the seal must be designed to resist hydrostatic uplift. Detailed cofferdam design may be provided by the department or left to the contractor.

6-25

In this cofferdam, note the bracing both across the walers and to the pier shaft.



COFFERDAM CONSTRAINTS

- BOTTOM MATERIALS
- WATER LEVEL VARIATION
- CURRENTS
- CLEARANCE
- DEWATERING
- EXISTING FOUNDATIONS

6-26

Prior to selecting a cofferdam for use in repair, potential construction problems should be evaluated. Among these are:

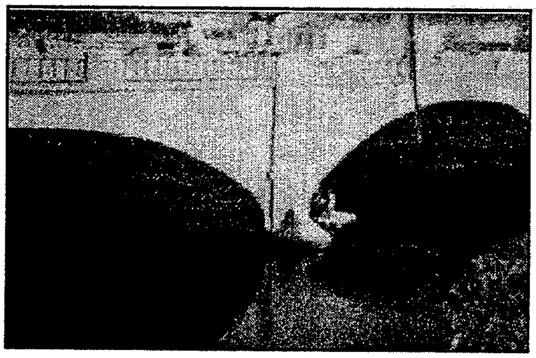
- Bottom materials - Hard to drive in rocky soil.
- River elevation variation - Large variation may mean large freeboard requirements.

6-27

- Currents - Difficult to set sheets in over about 4 fps. Here a temporary diversion wall, shown at the right of the slide, of sheets was set to direct currents around the pier in order to drive the main cofferdam.

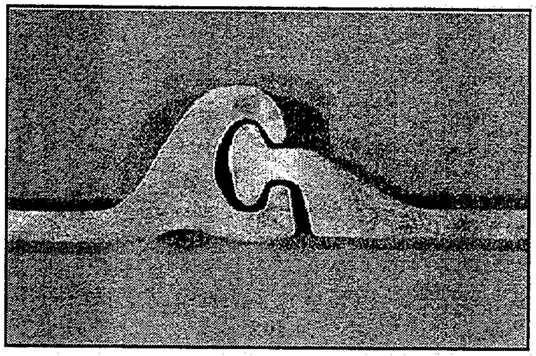
6-28

- Overhead clearance - Must have room for pile, leads, hammer. For rail bridges, ties can be shifted and piles set from above.



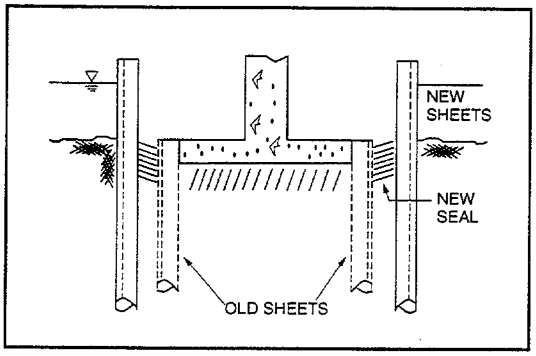
6-29

Arch structures and low decks often provide insufficient overhead clearance for pile driving.



6-30

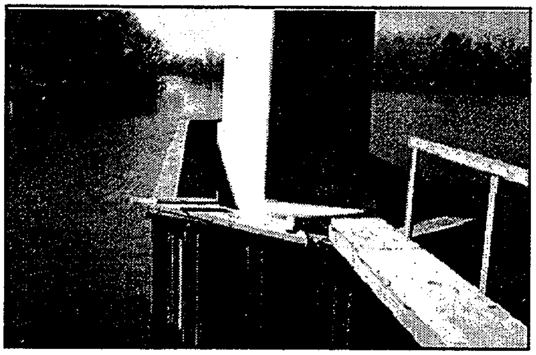
- Dewatering may be costly in labor.
- Estimate leakage through the exposed sheet pile walls at .025 gal/min/s.f. of wall/ft. of head for hot rolled sheets. This will increase for cold rolled sheets. Shown here are hot rolled interlocks.



6-31

- Existing construction may require an excessively wide cofferdam to clear old seals and sheeting.

Note here, difficulty to place seal between old and new sheets.



6-32

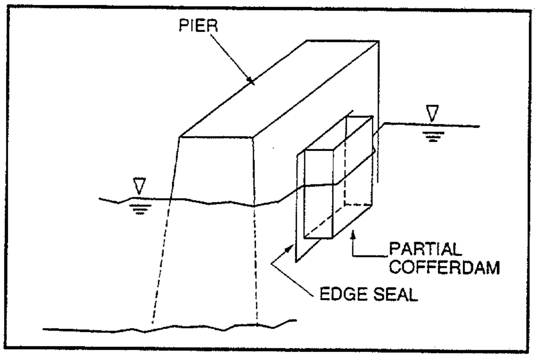
Cofferdams are either dewatered (most common) or used as forms for tremie concrete. Once dewatered, work may take place in dry conditions using dry land techniques. Tremie work will be addressed in Session 8.

Cofferdams can sometimes be left in place. This eliminates pulling costs and can add scour protection. Sheets can be cut off underwater if required.

PARTIAL COFFERDAMS

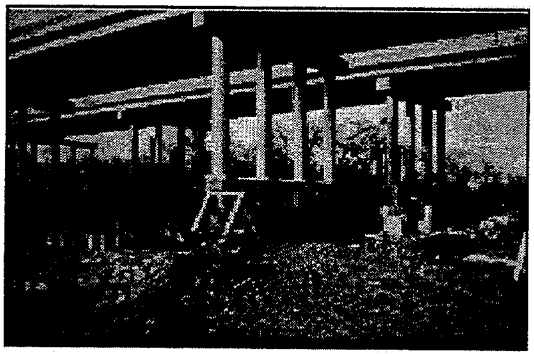
6-33

Sometimes only a portion of a structure requires repair. A partial cofferdam can be constructed in this case, often allowing reuse. Repairs to larger areas could be made by repeatedly "stepping" the cofferdam along a wall for instance. The method of sealing the cofferdam against the structure must be carefully considered, and an extremely rough surface may preclude use of this approach.



6-34

This shows a schematic drawing of a partial cofferdam. This technique is frequently used in dam rehabilitation.



6-35

B. DIKES

Construction of dikes or islands may also allow repairs in dry conditions. Dikes are constructed by placing cohesive materials to isolate the area to be repaired. For very small structures sand bags may even be used.

The diked area is pumped dry and repairs made.

Well point dewatering can also be used if soil conditions are satisfactory.

An island can be constructed around the pier and an excavation made to access repair areas.

Both of these techniques work best in shallow water and must be reviewed for adverse environmental effects. Upon completion of repairs, the materials placed in the river must be removed. In some cases this material, or any over excavated material, may have to be disposed of as hazardous waste.

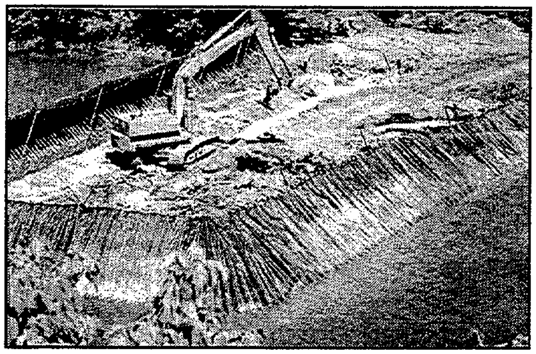
Temporary islands may be combined with cofferdams allowing easier cofferdam construction.

PORTABLE DAMS

6-36

C. PORTABLE DAMS

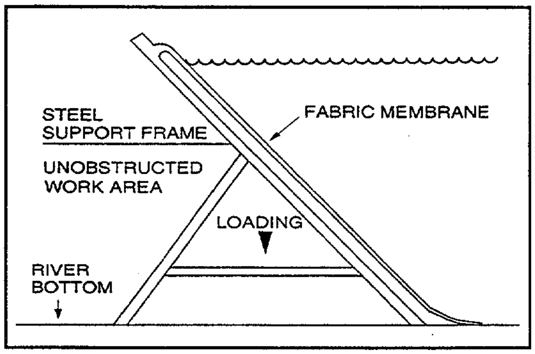
Several types of portable dams are available that can be used to produce a dry work area. Usually their use is limited to shallow water.



6-37

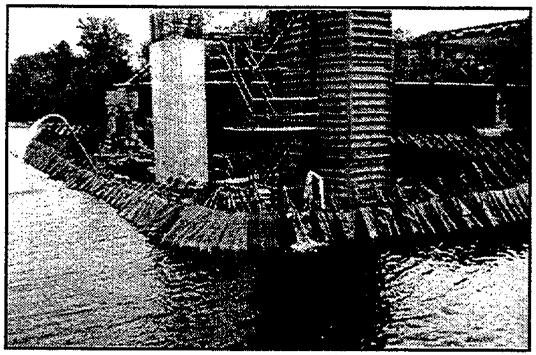
Porta Dams are a patented system of portable barriers used in a manner similar to a cofferdam.

Use of portable dams is another method of creating a dry work area through dewatering which can work well is shallower water.



6-38

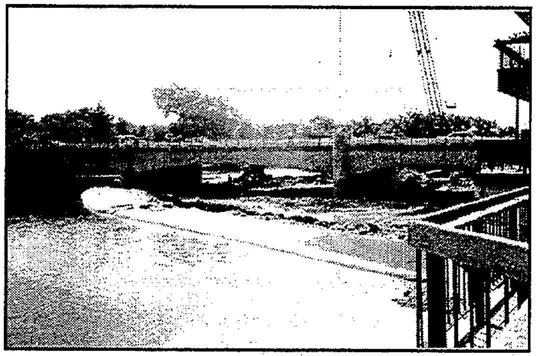
Porta Dams are light frames covered with an impermeable membrane which is placed to the water side. The downward water pressure on the sloping side holds the Porta Dam in place.



6-39

They are used in shallow water and are easily transported from site to site.

They can also be use to dam off the intake end of a culvert or short span bridge utilizing a pipe to bypass part or all of the normal flow.



6-40

Another type of portable dam is shown here. This is basically a large rubber tube that is water filled to give it volume and mass.

PLUGS

6-41

D. PLUGS

Expandable plugs are available to seal pipes and allow repair work to be performed in dry conditions. Many sizes and shapes are available and custom shapes can be fabricated. The plugs are filled with air or water and affect a seal through friction with the conduit wall. Considerations in using plugs include:

- Can not be used for repair at the inlet.
- Silt and debris must be cleaned in the plug area to affect a proper seal.
- Bypass of flows may be required.

6-42

This photo shows a plug being laid out to place in a large tunnel opening.

SUMMARY

- WET VERSUS DRY REPAIR
- ENVIRONMENTAL CONDITIONS
- TECHNIQUES FOR DRY WORK
- AGENCY EXPERIENCE

6-43

IV. SUMMARY

This session has presented considerations in deciding whether to conduct repairs underwater, or by other methods. Each project will have its own particular problems and constraints.

Part of the decision will be based on agency knowledge and experience. It is the intent of this course to extend the knowledge base related to underwater repair capabilities to aid in such choices.

SESSION 7: EQUIPMENT FOR UNDERWATER REPAIR

TOPICS: DIVING EQUIPMENT, SUPPORT EQUIPMENT, UNDERWATER TOOLS, UNDERWATER WELDING

LESSON PLAN:

DURATION	45 minutes
GOAL	To learn types and capabilities of equipment and tools available for underwater repair projects.
OBJECTIVE	Familiarity with available equipment.

OUTLINE

I. Introduction
II. Diving Equipment
    A. Scuba
    B. Surface Suppy Air
III. Topside Equipment
IV. Underwater Tools
    A. Hand Tools
    B. Power Tools
    C. Cleaning Tools
V. Underwater Excavation
VI. Welding and Cutting
VII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 7
EQUIPMENT FOR UNDERWATER REPAIRS

7-1

I. INTRODUCTION

There is an extensive array of equipment available to the underwater worker. Not only does it include diving equipment, but also a full range of hand and power tools. Topside equipment supports the diver in his work.

DIVING SYSTEMS

- **SCUBA**
- **SURFACE SUPPLIED AIR**

7-2

II. DIVING EQUIPMENT

There are a variety of diving systems available to contractors that perform bridge substructure repairs. Each system has unique operational characteristics which may make one system more desirable for a certain type of work. These decisions should be made by the Contractor.

SCUBA

- **LIGHT WEIGHT**
- **MOBILE**
- **LIMITED AIR SUPPLY**

7-3

A. SCUBA

Underwater inspection techniques typically require a diver to be highly mobile and normally involve short duration dives using lightweight testing equipment and measuring devices.

Scuba equipment used for commercial work is similar to that used for sport diving, though OSHA places requirements on specific equipment and limitations on its usage.

SURFACE SUPPLY AIR

- **UNLIMITED AIR SUPPLY**
- **CONTINUOUS COMMUNICATION**
- **PROTECTION**

7-4

B. SURFACE SUPPLY AIR

While scuba equipment is sufficient for inspection purposes, only surface supplied (hard hat) diving systems can provide adequate protection and meet the operation requirements of most underwater construction.

Underwater construction requires a diver to handle underwater power tools, construction materials, excavation equipment, and perform welding and other operations under hazardous conditions for long durations.

Some characteristics of surface supplied diving equipment that make it well suited for underwater construction include the following:

1. Surface supplied systems provide a continuous air supply which allows a diver to remain below water for long durations.
2. Surface supplied systems typically are constructed with a hard helmet shell, modest protection from the many obstructions and obstacles associated with underwater construction.
3. Surface supplied systems normally have hardwire communication systems for improved safety and control.
4. Surface supplied diving systems are typically heavier than scuba systems, providing a diver with leverage; an important factor in performing underwater work.
5. Various attachments such as cameras, lights and welding shields can be affixed to the diving helmet to improve a diver's ability to perform work.

7-5

DIVER SUPPORT

- AIR COMPRESSOR(S)
- AIR BANKS
- AIR CONSOLES
- COMMUNICATIONS
- RECOMPRESSION CHAMBER

7-6

Specialized diving surface support equipment is often required to perform the actual construction dive. Typical equipment includes:

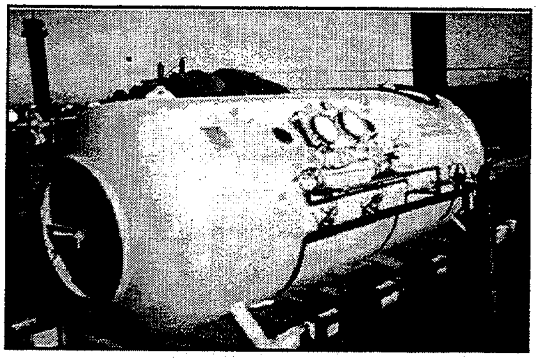
- Air Compressors
- Air Banks
- Air Consoles
- Communications
- Recompression Chamber

7-7

The topside support equipment such as compressors, diver control consoles, communication boxes, etc. must be protected from damage due to crane lifts or materials storage. Here equipment is shown on a construction float.

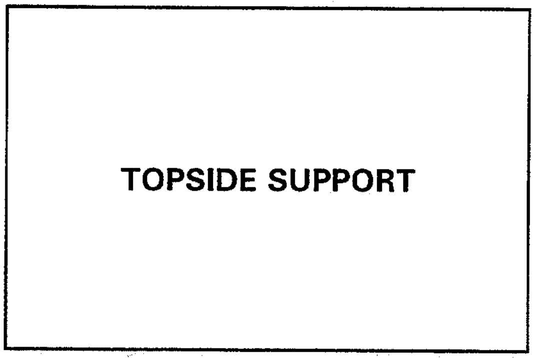
7-8

This shows a typical dive console. The console routes and controls the diver's air supply and allows monitoring the diver's depth by use of a pneumatic pressure line (pneumo line) worn by the diver. It may also house the communication system.



7-9

Recompression chambers are required for long or deep dives, as provided by OSHA and dive tables. The chamber is used to repressurize a diver either to eliminate or reduce in-water decompression, or to treat pressure related accidents. Use of a chamber requires various support air supplies and a trained operator.



TOPSIDE SUPPORT

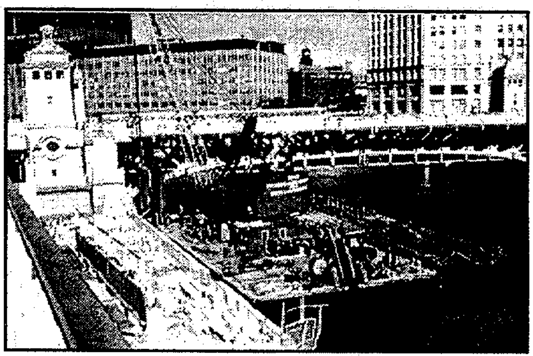
7-10

III. TOPSIDE SUPPORT

A variety of surface support equipment is often required to assist divers in performing underwater construction. Common types of construction equipment include:

- Cranes
- Backholes
- Pile Drivers
- Pumps, Generators
- Welding Rigs

Generally, the diver will give directions to surface support equipment operators via a communications cable normally used with surface supplied diving equipment.



7-11

Usually boats and barges are used for equipment support and materials storage.

7-12

Barges may be either large river or ocean going types or may be assembled from sections that are easily trucked to a specific location. Sectional barges, or floats, allow work in rivers and lakes not normally navigated by commercial equipment.

UNDERWATER TOOLS

- **HAND TOOLS:** FOR SMALL JOBS SIMPLE TASKS
- **POWER TOOLS:** LARGE JOBS HAND TOOLS NOT SUFFICIENT

7-13

IV. UNDERWATER TOOLS

Divers use hand and power tools to perform their work underwater. Hand tools are most often used to complete relatively small or simple tasks. Power tools are generally used on large jobs or when hand tools will not suffice.

In using any tool, the diver must be able to maintain position, bracing him/herself against the tool reaction.

HAND TOOLS

- SAWS
- WRENCHES
- CALIPERS
- CROW BARS
- HAMMERS
- SCRAPERS
- HAND DRILLS

7-14

A. HAND TOOLS

Almost any hand tool used above water can be used by a diver below water. Additional maintenance is normally required to prevent corrosion after exposure to a marine environment. Some typical hand tools used underwater include:

- Saws
- Wrenches
- Calipers
- Crow bars
- Hammers
- Scrapers
- Hand Drills

7-15

Here divers are assembling a pipe connection with hand wrenches.

POWER TOOLS

- **PNEUMATIC**
- **HYDRAULIC**

7-16

B. POWER TOOLS

There are two types of power tools suitable for use underwater; pneumatic and hydraulic.

Inexpensive pneumatic tools designed for above water use are readily available at most hardware or automotive supply stores. The surface models can be used below water for short duration jobs. Because the tools were not originally designed to be used below water, extensive maintenance is usually required after each use, which consists of a fresh water wash followed by an oil flush. It is recommended that the tool be stored completely submerged in oil after use below water.

At least one company has modified a pneumatic chainsaw to operate underwater. The modification consists of a special vent to redirect the discharge air away from the work area. Extensive maintenance, however, is still required. The effectiveness of pneumatic tools is dependent on water depth and the air pressure supplied by the compressor. One disadvantage in their use is the stream of exhaust air which can hinder the diver's vision.

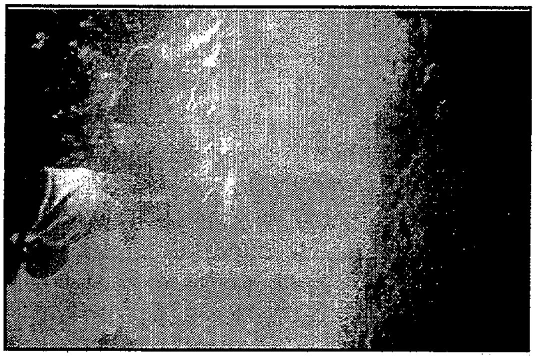
PNEUMATIC TOOLS

- DRILLS
- IMPACT WRENCHES
- CHAIN SAWS
- GRINDERS
- CUT-OFF SAWS
- CHIPPERS

7-17

Some pneumatic tools commonly used by divers include:

- Drills
- Impact Wrenches
- Chain Saws
- Grinders
- Cut-Off Saws
- Chippers



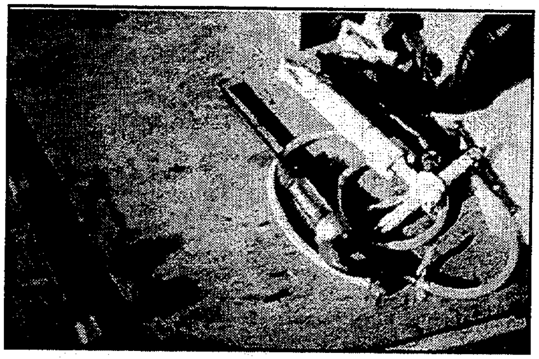
7-18

This shows a pneumatic needle gun for cleaning. The needles are impacted against the surface by the air. The tool is good for moderate cleaning of small areas.

Note the exhaust air stream.

7-19

Pneumatic drills can be used to set anchors in concrete, as shown here. Drilling holes in timber and steel are other uses.



7-20

This shows a pneumatic chipping gun. Above it on the deck is a low pressure water cleaner made by the contractor.

HYDRAULIC TOOLS

- DRILLS
- IMPACT WRENCHES
- CHAIN SAWS
- CHIPPERS
- CABLE CUTTERS
- ROTARY SCALERS

7-21

Hydraulic power tools designed specifically for underwater use can be ordered through most equipment supply stores and diving equipment suppliers. The only difference between surface hydraulics and underwater hydraulics is that corrosive resistant paint and steel is used on the underwater versions. A typical hydraulic setup includes the power pack, hose and a tool.

A variety of hydraulic tools are available which include:

- Drills
- Impact Wrenches
- Chain Saws
- Chippers
- Cable Cutters
- Rotary Scalers
- Grinders
- Pipe Cutters
- Concrete Saws
- Pumps
- Jacks

HYDRAULIC TOOLS

- GRINDERS
- PIPE CUTTERS
- CONCRETE SAWS
- PUMPS
- JACKS

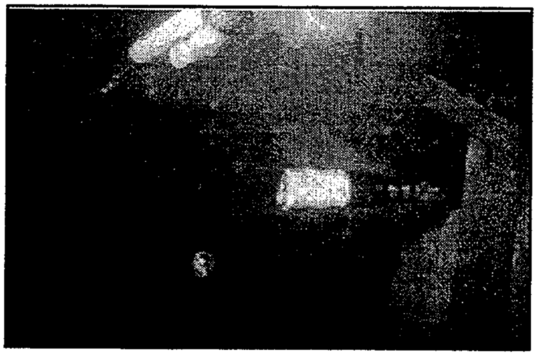
7-22

While underwater hydraulic tools perform well and are relatively low maintenance, they can cost several times more than their pneumatic counterparts. If limited use of power tools is anticipated, it is often more economical to use inexpensive pneumatic tools, discarding them when they no longer operate.

Most hydraulic tools use standard hydraulic fluid, however, biodegradable hydraulic oil is available when tools are used in environmentally sensitive areas.

Recently, an underwater tool system which uses water as the hydraulic medium has come on the market.

The following slides show some underwater hydraulic tools typically used for construction.



7-23

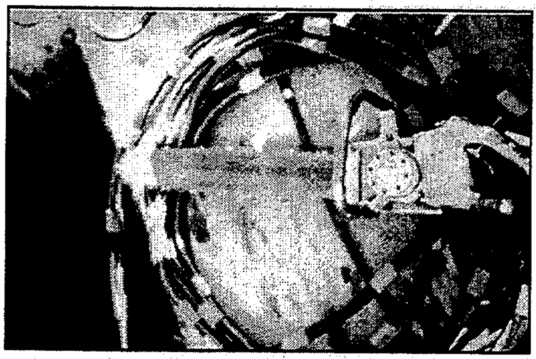
A hydraulic powered drill. Note that no bubbles are produced to obscure vision.

7-24

A hydraulic heavy duty impact wrench is shown here.

7-25

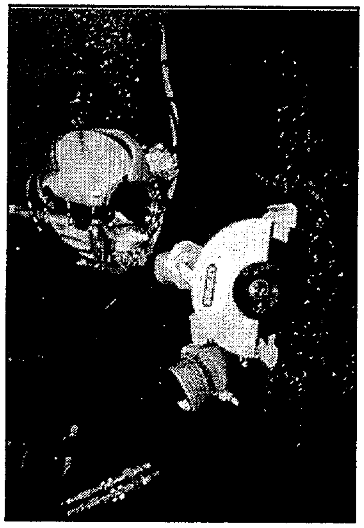
The hammer drill shown here can drill holes up to 2 inches in diameter and 30 inches deep.



7-26

Chain saws are used to cut timber piles and perform other rough wood cutting functions.

Note the tool has both a supply and return line for the hydraulic fluid.



7-27

Cut-off saws are used to make more precise timber cuts than can be made with a chain saw. Typical uses would be trimming the formwork used to make repairs to a bridge pier. Cut-off saws capable of cutting concrete and steel are available as well.

CLEANING

- HAND
- POWER

7-28

C. CLEANING

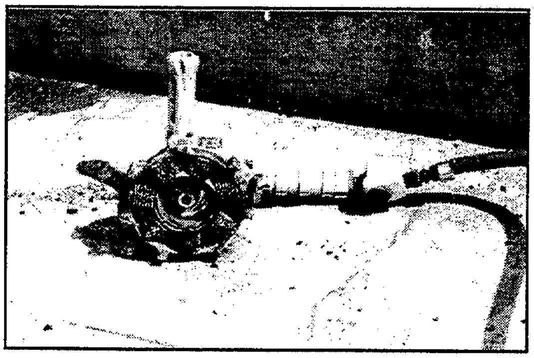
Divers usually clean small areas on bridge piers of marine growth and sediment to perform a complete assessment of the substrate condition. More extensive cleaning is normally required if underwater repairs are to be performed. A surface that is free of marine growth and sediment is essential to insure a good bond is made between the repair material and the new structural component.

7-29

Cleaning submerged portions of bridges can usually be accomplished with hand tools, such as scrapers and wire brushes, when areas are small and marine growth and sediment are easily removed. For larger areas and heavy marine growth, specially designed power tools are available to clean areas quickly. In this slide a diver is using a scraper to clean portions of a concrete pile for inspection.

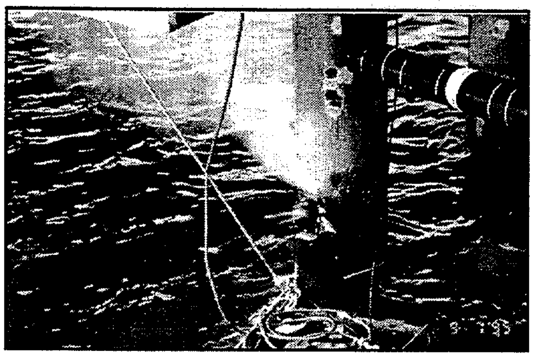
7-30

This photograph shows a device which can be attached to the shaft of a pneumatic or hydraulic grinder or sander. It has, according to the manufacturer, the capacity to remove 6 inches of barnacle-type growth at a rate of 3 to 6 square feet per minute, more than adequate for most bridge structures. Marine contractors are generally required to perform a great deal of cleaning, and typically construct devices that allow them to mount several tools to work in tandem for more rapid cleaning.



7-31

This shows the cutting head of a similar tool.



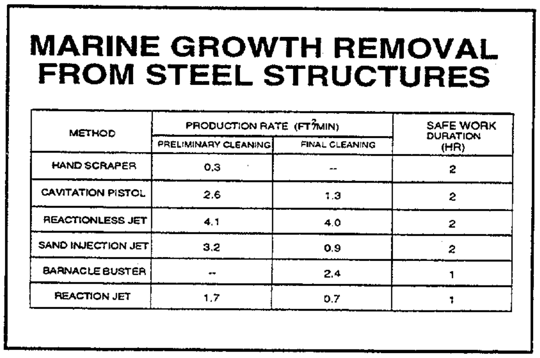
7-32

Water pressure systems are available to clean submerged components. Cleaning is accomplished by directing a high pressure water jet at the area to be cleaned, blasting away marine growth and debris. The water pressure required to effectively clean a pile can range from 5,000 to 10,000 psi.

7-33

Underwater pressure systems are essentially the same as above water systems, except that a second water jet flows from the rear of the unit to counter the reaction of the cleaning jet. It is essential that the proper pressure is used so that the water jet does not damage the structural material during cleaning. This is important on timber and concrete structures. Various types of nozzles are available depending upon the surface type and extent of area to be cleaned.

Abrasive blasting systems are also available and are particularly effective in cleaning corroded reinforcing.



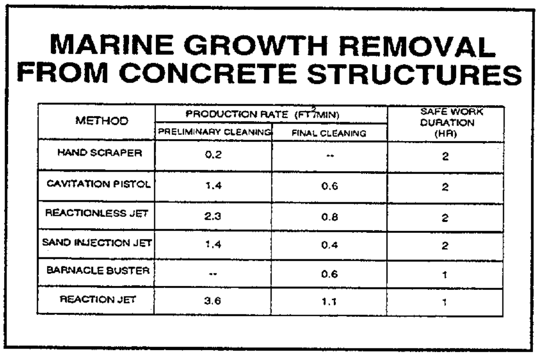
MARINE GROWTH REMOVAL FROM STEEL STRUCTURES

METHOD	PRODUCTION RATE (FT^2/MIN)		SAFE WORK DURATION (HR)
	PRELIMINARY CLEANING	FINAL CLEANING	
HAND SCRAPER	0.3	--	2
CAVITATION PISTOL	2.6	1.3	2
REACTIONLESS JET	4.1	4.0	2
SAND INJECTION JET	3.2	0.9	2
BARNACLE BUSTER	--	2.4	1
REACTION JET	1.7	0.7	1

7-34

This chart shows typical cleaning rates that may be achieved by various types of equipment on steel structures.

(Full size copy of Tables 7-34 and 7-35 can be found on Page 7-25)



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
CAVITATION PISTOL	1.4	0.6	2
REACTIONLESS JET	2.3	0.8	2
SAND INJECTION JET	1.4	0.4	2
BARNACLE BUSTER	--	0.6	1
REACTION JET	3.6	1.1	1

7-35

This chart shows typical cleaning rates that may be achieved by various types of equipment on concrete structures.

UNDERWATER EXCAVATION

7-36

V. UNDERWATER EXCAVATION

Underwater excavation is often required when performing substructure repairs. Excavation can be accomplished by a variety of means. Heavy construction equipment is most often used when large amounts of material must be removed and adequate access is available.

COMMON HEAVY EXCAVATION EQUIPMENT

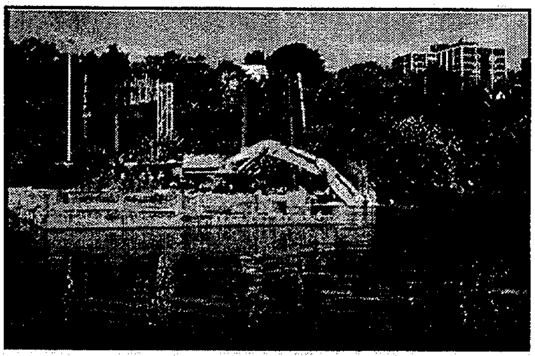
- **BACKHOE**
- **CRANES**
  - **CLAMSHELL**
  - **DRAGLINE**

7-37

Common types of heavy equipment include:

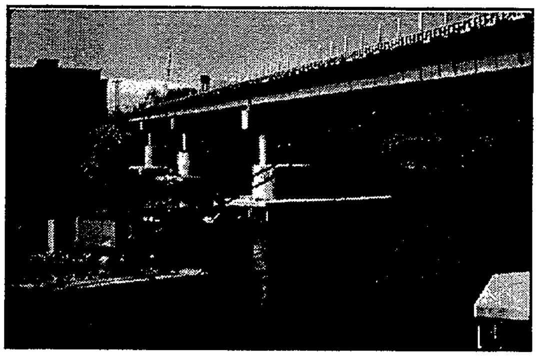
- Backhoes
- Cranes
  - Clamshell
  - Dragline

Because of the inability to see the work underwater, tolerances on work must be large.



7-38

Here a backhoe is being used off a barge. The operator monitors depth by placing marks on the excavator arm. In some cases, underwater cameras are mounted on the buckets or arms to allow visual control underwater.



7-39

This slide shows a crane using a dragline to excavate a construction site.

UNDERWATER EXCAVATION TECHNIQUES

- AIRLIFTS
- JETTING
- DREDGING
- CONTROLLED BLASTING

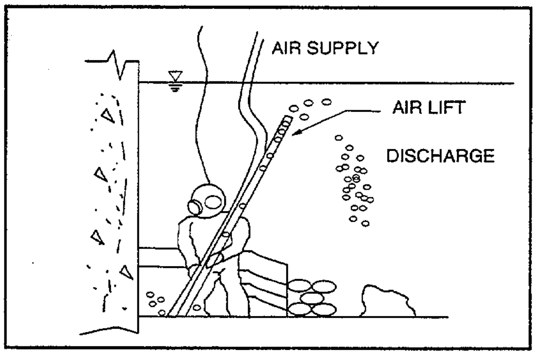
7-40

There are situations where an excavation site is impossible to access with heavy construction equipment, or when it is more economical to use underwater excavation techniques.

The four basic techniques for underwater excavation include:

- Airlifts
- Jetting
- Dredging
- Controlled Blasting

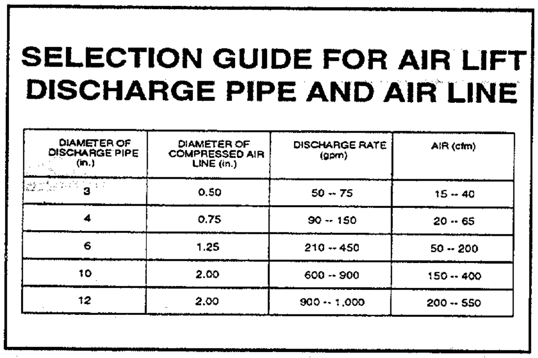
Diver held equipment generally allows excavation to be better controlled than with topside equipment.



7-41

Airlifts

An airlift operates by introducing compressed air near the submerged inlet of a pipe, with the outlet located higher in the water or above the surface of the water. The air and water mix rapidly, decreasing the density of the water inside the pipe, and causing the air and water mixture to rise and create a suction at the inlet. An airlift can be used to move mud, sand, silt, clay and cobbles. The effective depth range of an airlift is 25 to 75 feet. The discharge can be deposited back into the waterway or collected into a barge and moved off site.

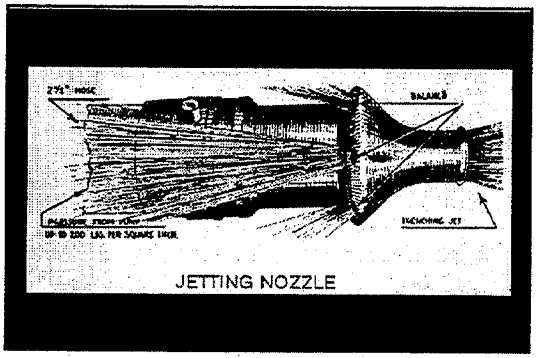


SELECTION GUIDE FOR AIR LIFT DISCHARGE PIPE AND AIR LINE

DIAMETER OF DISCHARGE PIPE (in.)	DIAMETER OF COMPRESSED AIR 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 -- 550

7-42

This slide shows the mechanical requirements for different size pipes used to construct an airlift, per U.S. Navy guidelines.

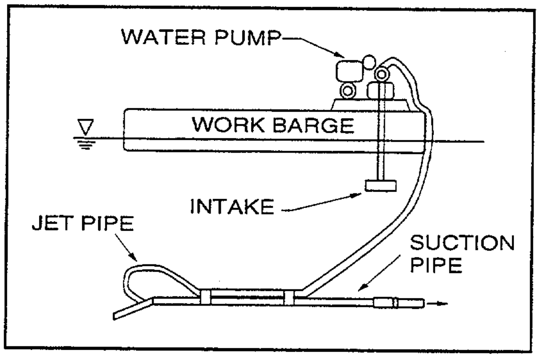


JETTING NOZZLE

7-43

Jetting

Jetting is a technique that is useful for moving bottom materials to bury cables and pipelines, and for installing structural piles and instrument tubes. The basic principal involves supplying pressurized water from a pump on the surface to a jetting nozzle controlled by a diver. The pressurized water pushes the bottom material away from the nozzle, creating a trench or a hole. Jetting can be done to a limited extent with an ordinary hose, a medium pressure water supply and no special attachments. However, if the discharge water pressure is high, specially designed jetting nozzles are available, such as the nozzle shown in this slide. These are designed to help to offset the force created by the trenching jet which tends to push a diver away from the work area. The jetting technique has no depth limitations, and is effective with bottom materials consisting of mud, sand, silt and clay. Environmental concerns may restrict its use.



7-44

Dredging

Underwater dredging is a useful technique for moving large quantities of soft bottom material in shallow water. A typical underwater dredge arrangement is shown in this slide. Unlike an airlift which uses air to create a suction, a dredge uses a water jet inside the pipe to create suction at the dredge intake. The height of the vertical lift attained is dependent on the size of the pipe and the output of the pump. The material excavated is normally deposited away from the work-site in the water channel.

SUCTION DREDGES

SUCTION PIPE BORE	PRESSURE INLET BORE	RECOMMENDED MIN. PUMP OUTPUT
2.0 (in)	1.0 (in)	55 (gpm)
3.0 (in)	1.0 (in)	100 (gpm)
4 .0 (in)	1.5 (in)	125 (gpm)
6.0 (in)	1.5 (in)	300 (gpm)
8.0 (in)	3.0 (in)	500 (gpm)

7-45

This slide shows the mechanical requirements and characteristics for different size pipes used to construct an underwater dredge, per U.S. Navy guidelines.

UNDERWATER BLASTING

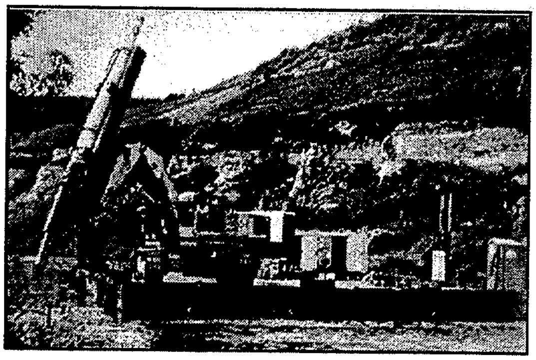
- **SPECIALIZED TRAINING**
- **SPECIALTY OF CERTAIN CONTRACTORS**

7-46

Controlled Blasting

Controlled blasting is used for excavation when other methods are impractical or impossible (such as when the bottom material is bedrock). Explosives may also be used to remove obstacles or old bridge piers. Underwater blasting requires specialized training, and should only be used when other alternatives will not work.

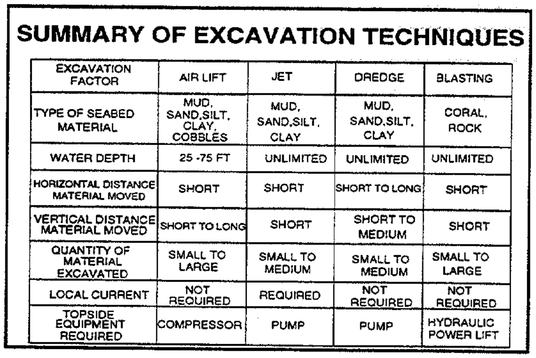
Pressure waves set up by underwater demolition may be hazardous to marine life or nearby structures.



7-47

Special insurance and regulatory requirements should be carefully evaluated prior to any blasting operations.

Rock excavation can also be accomplished by hydraulic tools, such as this large hydraulic hammer mounted on a track and barge.

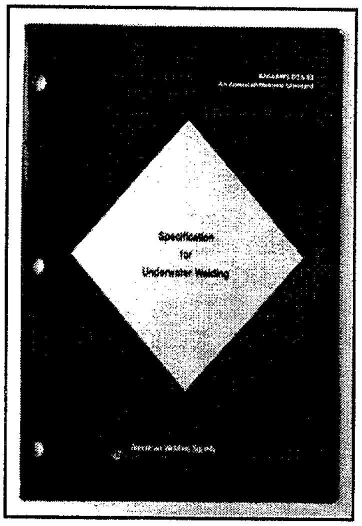


SUMMARY OF EXCAVATION TECHNIQUES

EXCAVATION FACTOR	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	25 -75 FT	UNLIMITED	UNLIMITED	UNLIMITED
HORIZONTAL DISTANCE MATERIAL MOVED	SHORT	SHORT	SHORT TO LONG	SHORT
VERTICAL DISTANCE MATERIAL MOVED	SHORT TO LONG	SHORT	SHORT TO MEDIUM	SHORT
QUANTITY OF MATERIAL EXCAVATED	SMALL TO LARGE	SMALL TO MEDIUM	SMALL TO MEDIUM	SMALL TO LARGE
LOCAL CURRENT	NOT REQUIRED	REQUIRED	NOT REQUIRED	NOT REQUIRED
TOPSIDE EQUIPMENT REQUIRED	COMPRESSOR	PUMP	PUMP	HYDRAULIC POWER LIFT

7-48

This table summarizes several of the underwater excavation methods and their applicability. (A full size chart of Table 7-48 can be found on Page 7-26)

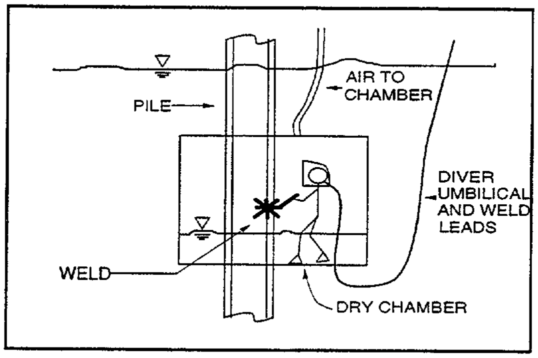


Specification
for
Underwater Welding

7-49

VI. UNDERWATER WELDING AND CUTTING

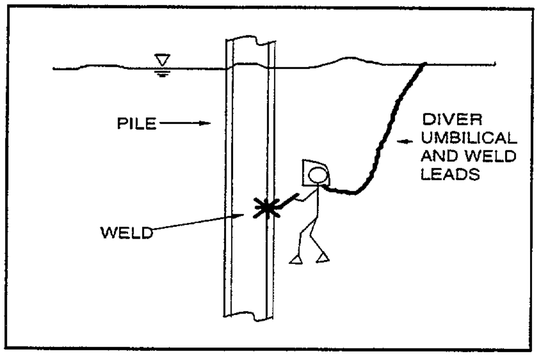
Underwater welding and cutting is an economical alternative when it is impractical or impossible to remove the object to be repaired. The American Welding Society published the first Specification for Underwater Welding (ANSI/AWS D3.6-83) in 1983, and updated it to reflect changes in technology in 1989 and again in 1993. The development of the specification was driven by the economic benefit of performing underwater welds on ships and in the offshore industries.



7-50

Underwater welding can be performed in an evacuated "dry" chamber. Use of the chamber increases confidence in the weld quality but is often difficult to accomplish due to chamber sealing.

The welder uses diving equipment to gain access and to work in the chamber, though the work area is purged of water by air pressure.



7-51

As an alternative, "wet stick" welding can be used. In this case the electrode and weld surface are both submerged in the water.

UNDERWATER WELDING IS AFFECTED BY

- **RAPID QUENCHING OF THE WELD**
- **FORMING OF BUBBLES**
- **HYDROGEN IN THE BUBBLES**

7-52

Underwater, "wet stick", welding is effected by:

- Rapid quenching of the weld.
- Forming of bubbles.
- Hydrogen in the bubbles.

The heat generated by the welding process causes water at the weld to break down into its components of hydrogen and oxygen, with this hydrogen in bubbles at the weld.

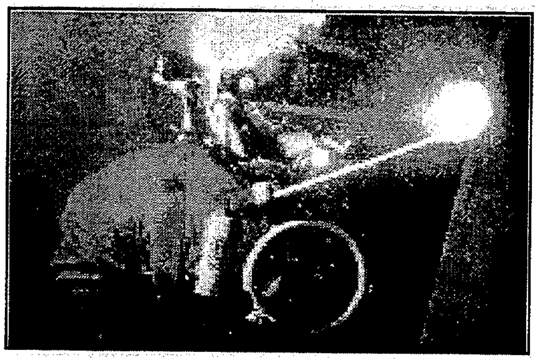
CHARACTERISTICS OF WELDING EQUIPMENT AND ELECTRODE

- **HIGH DEPOSITION RATE**
- **ACCEPT HIGHER AMPERAGES**
- **ALL POSITION CAPABILITIES**
- **MEDIUM PENETRATION**

7-53

The AWS D3.6-93 specification sets guidelines for universal wet welding. To perform a quality underwater weld, the equipment and electrodes must have the following capabilities:

- High deposition rate.
- Ability to accept higher amperages.
- All position capabilities.
- Medium penetration.



7-54

Special underwater electrodes and holders (stinger) are available which allow quality underwater welds to be performed economically and quickly. In this slide, a diver is using an underwater welding rod and stinger to perform a weld on a pier support pile. Cost savings are typically around 50% on most underwater welding jobs when compared to the cost of removing the object from the water or the consequences of not performing the repair.

WELD TYPES

- **STRUCTURAL**
- **FITNESS FOR PURPOSE**
- **NON-STRUCTURAL**
- **CUSTOMER CODE**

7-55

The AWS specification provides for four weld classes.

A. Structural
B. Fitness for Purpose
C. Non-Structural
D. Customer Code

The design engineer must determine the requirements for his particular case and call out welding criteria accordingly. This puts much more of the actual weld design up to the engineer than is common for other structures.

CERTIFICATION OF UNDERWATER WELD

- **CURRENTLY NO CERTIFICATION FOR PERSONNEL**
- **PROCEDURES ARE CERTIFIED**

7-56

Unlike above water welding, there is currently no certification required for the individual diver/welder, however, many contractors have developed their own certification procedures. Current procedures require the designer to specify a class A, B, C, or O type weld in the design documents, based on the definitions provided in ANSI/AWS D3.6-93. Mr. Roger Holdsworth, the committee chairman of the Underwater Welding Committee, American Welding Society (AWS), has indicated that a certification for diver/welders by the AWS is anticipated, probably by 1997. (Once the AWS diver/welder certification is approved, divers must go to one of several approved training sites to receive certification that he/she is capable of performing standard welds as defined in AWS D3.6)

PRE-QUALIFY

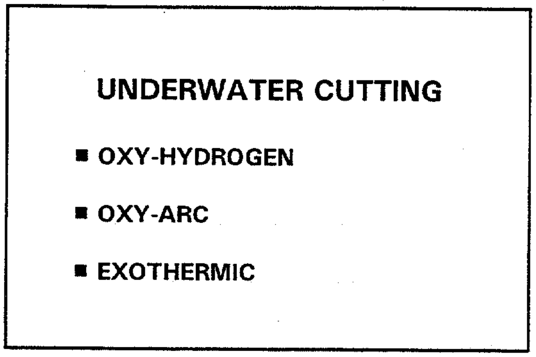
- **PROCEDURE**
- **DEPTH**

7-57

To pre-qualify a weld and procedure, the contractor should submit a procedure for performing and meeting the specified weld type to the designer or owner for approval. Once the designer (or owner) has approved the procedure, the contractor should submit a method he/she will use to qualify divers on the approved procedure. Once the qualification method is approved by the engineer (or owner), the contractor qualifies all divers on the procedure.

The weld qualification is very specific and must be done at each working depth.

Weld inspection requirements should be tailored to the weld type. Class A, structural welds, are normally subject to mag particle and/or ultrasonic tests. Classes B, C, and O are less commonly tested.

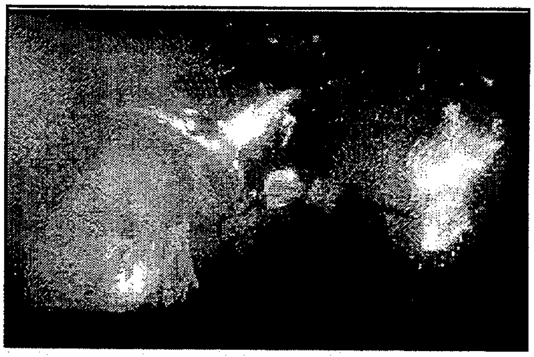


UNDERWATER CUTTING

- OXY-HYDROGEN
- OXY-ARC
- EXOTHERMIC

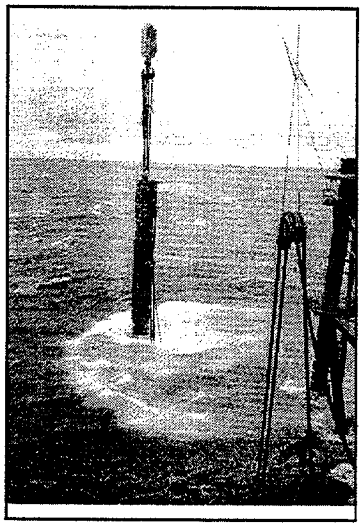
7-58

Underwater cutting has been performed by commercial divers since early in this century. The early systems were variations of the standard open flame process, and were grossly inefficient. While several methods of cutting are currently available, most modern cutting equipment uses either an oxygen arc or exothermic process. The exothermic process is the most widely used method and recommended by the US Navy. Once the exothermic rod is ignited, the extreme heat generated allows the diver to cut through concrete, rock, wood and marine growth as well as steel.



7-59

In this slide a diver is using an exothermic cutting rig to remove a section of steel pipe.



7-60

Many marine and diving contractors develop specialized pieces of equipment to help them work more efficiently. The variety of customized tools is limited only by the imagination. This photo shows a hydraulic pile hammer which can operate underwater.

UNDERWATER EQUIPMENT

- DIVE SYSTEMS
- HAND TOOLS
- POWER TOOLS
- HEAVY EQUIPMENT
- WELDING AND BURNING

7-61

VII. SUMMARY

A variety of tools and equipment are available for use in underwater construction. While many are the same as used in dry work, others are specially made. The designer will seldom specify the tools, or diving equipment to be used, but should be aware of the range of possibilities. Newer techniques such as underwater welding should be carefully considered for cost effectiveness.

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
CAVITATION PISTOL	1.4	0.6	2
REACTIONLESS JET	2.3	0.8	2
SAND INJECTION JET	1.4	0.4	2
BARNACLE BUSTER	--	0.6	1
REACTION JET	3.6	1.1	1

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
CAVITATION PISTOL	2.6	1.3	2
REACTIONLESS JET	4.1	4.0	2
SAND INJECTION JET	3.2	0.9	2
BARNACLE BUSTER	--	2.4	1
REACTION JET	1.7	0.7	1

SUMMARY OF EXCAVATION TECHNIQUES

EXCAVATION FACTOR	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	25 -75 FT	UNLIMITED	UNLIMITED	UNLIMITED
HORIZONTAL DISTANCE MATERIAL MOVED	SHORT	SHORT	SHORT TO LONG	SHORT
VERTICAL DISTANCE MATERIAL MOVED	SHORT TO LONG	SHORT	SHORT TO MEDIUM	SHORT
QUANTITY OF MATERIAL EXCAVATED	SMALL TO LARGE	SMALL TO MEDIUM	SMALL TO MEDIUM	SMALL TO LARGE
LOCAL CURRENT	NOT REQUIRED	REQUIRED	NOT REQUIRED	NOT REQUIRED
TOPSIDE EQUIPMENT REQUIRED	COMPRESSOR	PUMP	PUMP	HYDRAULIC POWER LIFT

SESSION 8

MATERIAL CONSIDERATIONS

SESSION 8: MATERIAL CONSIDERATIONS

TOPICS: STEEL, CONCRETE, MASONRY, PLASTICS AND TIMBER

LESSON PLAN:

DURATION	1 hour and 15 minutes
GOAL	Develop understanding of requirements for marine construction materials related to durability and appropriateness for repair usage.
OBJECTIVE	Be able to select materials suited to specific repair needs.

OUTLINE

- I. Introduction
- II. Steel
- III. Concrete
    - A. Durability and Workability
    - B. Materials
    - C. Admixtures
    - D. Reinforcing
- IV. Masonry
    - A. Stone
    - B. Mortar
- V. Structural Plastics
    - A. Materials
    - B. Properties
    - C. Usage
- VI. Timber
    - A. Characteristics
    - B. Preservatives
- VII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair and Bridge Components

SESSION 8
MATERIAL CONSIDERATIONS

8-1

I. INTRODUCTION

A variety of materials are available for use in repairs to underwater elements. Proper selection is important for economical and durable repairs.

Because repairs are often needed due to past poor material performance, proper selection is important to extend structure life.

While this class is presented as it applies to repairs, similar concerns for material durability should govern design of new facilities, hopefully eliminating the need for future repairs.

MATERIALS

- **STEEL**
- **CONCRETE**
- **MASONRY**
- **TIMBER**
- **POLYMERS**

8-2

Materials to be considered in this Session include:

- Steel
- Concrete
- Masonry
- Timber
- Polymers

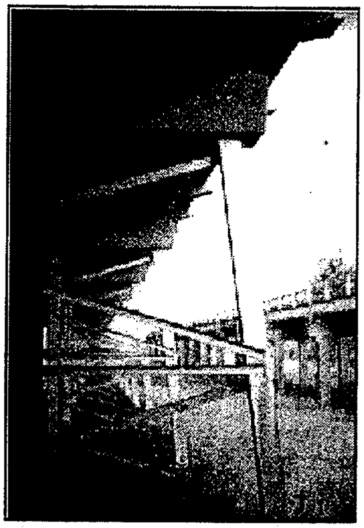
Piers are usually constructed of concrete or masonry while piles may be steel, concrete, or timber. Polymers are not often used in new construction but are rapidly developing. Concrete is the most often used repair material for marine structures.

STEEL

8-3

II. STEEL

Steel and its properties are well known to bridge engineers. In substructures, it is usually found as bearing piles and steel sheet piling. Sometimes steel bracing may also be found in or under water.



8-4

For substructure rehabilitation, steel piles may be driven to increase pile bent or footing capacity or to replace damaged and deteriorated piles.

Sheet piles may be used to repair damaged cells, repair or reconstruct walls, or as temporary works.

CORROSION PREVENTION

- **ENCASEMENT**
- **COATING**
- **CATHODIC PROTECTION**
- **SACRIFICIAL THICKNESS**

8-5

Due to corrosion problems, steel is often a poor material choice unless corrosion protection is provided. Protection can be provided by:

- Encasement (usually in concrete)
- Coating (including galvanizing and metalized aluminum and epoxy)
- Cathodic Protection, both active and passive
- Sacrificial Thickness

Cathodic protection will be addressed in Session 11.

COATING DESCRIPTION	PERIOD OF PROTECTION
COAL TAR EPOXY (15 TO 20 MILS THICKNESS)	10 - 20 YEARS
GALVANIZING (7 TO 9 MILS THICKNESS	10 - 15 YEARS
METALIZED ALUMINUM	15 - 20 YEARS
CONCRETE ENCASEMENT	25 YEARS

8-6

This slide shows the periods of protection for steel in marine environments to be expected from various coating systems, as given in the Navy's Manual "General Criteria for Waterfront Construction".

Coal tar epoxy has been used on marine piling for many years with generally good performance. Recently, at least two transportation departments have called for fusion bonded epoxy coating of shell piles.

Galvanizing is subject to abrasive losses and thick coatings require care in controlling silicon content of the steel.

8-7

Where connections are required, steel can be bolted underwater and with care welded.

Here welding is being performed on an offshore platform.

CONCRETE

8-8

III. CONCRETE

Concrete is the most common repair material for substructure repairs, whether or not the substrate is concrete. Proper material selection and specification is critical to long lasting repairs.

CONCRETE CONSISTS OF

- COARSE AGGREGATE
- FINE AGGREGATE
- CEMENT (PORTLAND)
- WATER
- ADMIXTURES

8-9

Concrete Consists of:

- Coarse aggregate
- Fine aggregate
- Cement (Portland)
- Water
- Admixtures

Each of these constituents plays a critical role in overall performance. Both their individual characteristics and combined properties must be carefully selected.

It should be noted that many times the need for repair is due to an inappropriate original concrete mix.

DURABILITY

WORKABILITY

8-10

A. DURABILITY AND WORKABILITY

For repair work, durability and workability are usually more important than strength. These properties may be enhanced with proper admixtures. Special mix designs are required for marine repairs which account for harsh exposure and difficult placement conditions.

DURABILITY PROBLEMS

- **FREEZE-THAW**
- **MOISTURE ABSORPTION/ PERMEABILITY**
- **SULFATE ATTACK**
- **ABRASION**
- **REACTIVE AGGREGATES**

8-11

Concrete that has low durability is more likely to experience the problems shown here.

- Freeze-thaw causes major problems in northern climates and results from moisture expansion in the concrete.
- Moisture Absorption/Permeability, if high, increases the rate of freeze-thaw attack as well as chemical attack from aggressive waters.
- Sulfate Attack can occur due to naturally occurring sulfates of sodium, potassium, calcium and magnesium which are often found in both sea and fresh water. Reaction products expand, causing concrete deterioration.
- Abrasion can be caused by ice, debris, sediments, etc. Aggregate type and mix effect concrete resistance to abrasion.
- Reactive Aggregates cause concrete deterioration through expansion. Moisture is needed for the reaction and is more available in porous mixes.

Deterioration from these factors is discussed in Session 2.

LOW PERMEABILITY

- ■ LOW WATER/CEMENT
- ■ POZZOLANS
- ■ CURING
- ■ CONSOLIDATION

8-12

Probably the single most important factor in durability is low permeability. Low permeability is achieved with:

- Low Water/Cement Ratio - This reduces the void spaces caused by loss of free water.
- Use of Pozzolans - Any of several pozzolans can be used to reduce permeability.
- Proper Curing - Reduces surface and shrinkage cracking.
- Good Consolidation - Eliminates voids and joints.

WORKABILITY PROBLEMS

- ■ PUMPABILITY
- ■ FLOWABILITY
- ■ AGGREGATE SIZE
- ■ WASHOUT OF FINES
- ■ SET TIME

8-13

Poor workability of the concrete mix creates placement problems that adversely effect durability. Required workability is dependent on the repair technique and construction requirements. Department standards developed for new construction may not adequately address special mixes used for underwater repairs. Areas of concern include:

- Pumpability - Repairs often use small diameter and long pump lines for easier handling. Mix design must accommodate these.
- Flowability - Repair concrete often must flow around reinforcing and fill narrow areas requiring high slumps at the point of placement.
- Aggregate Size - Small aggregates are often needed.
- Washout of Fines - In underwater placement the concrete fines, including cement paste, are lost if special precautions are not taken.

- Set Time - Placement of repair concrete is often tedious and slow. Concrete must remain workable for longer periods of time than for typical structural placements in piers, beams, walls, or decks.

SEAWATER MIX GUIDELINES

- MAXIMUM WATER/CEMENT RATIO = 0.40
- MINIMUM CEMENT CONTENT = 600 PCY
- TYPE II OR V CEMENT
- ADMIXTURES

8-14

B. MATERIALS

Proper selection of mix designs will provide durable, long lasting repairs.

Guidelines for Mix Design (Sea Water):

- Maximum Water/Cement Ratio = 0.40 -Decreases permeability.
- Minimum Cement Content 600 pcy - Produces dense, low permeability concrete.
- Type II or V Cement (low tricalcium aluminate) - Provides added resistance to sulfates found in sea water.
- Admixtures - A variety can be used to aid workability and durability.

FRESHWATER MIX GUIDELINES

- MAXIMUM WATER/CEMENT RATIO = 0.40
- MINIMUM CEMENT CONTENT = 600 PCY
- TYPE I CEMENT
- ADMIXTURES

8-15

Guideline for Mix Design (Freshwater):

- Maximum Water/Cement Ratio = 0.40
- Minimum Cement Content 600 pcy
- Type I Cement - Use Type II if sulfate waters are expected.
- Admixtures - Similar usage to sea water.

Note both mixes are quite similar.

AGGREGATES

- **HIGH QUALITY, CLEAN**
- **WELL GRADED**
- **MAXIMUM SIZE**

8-16

Aggregates should be durable and ease placement:

- High Quality, Clean - Hard, low absorption, non-reactive materials are preferable.
- Well Graded - Proper grading improves workability and mix density. This also lowers shrinkage.
- Maximum Size - For small pump lines and repair areas coarse aggregates of 3/8 or 1/2 inch are commonly used. Sometimes coarse aggregate should be omitted.

ADMIXTURES

- **WATER REDUCING**
- **AIR ENTRAINING**
- **POZZOLANS**
  FLY ASH, SILICA FUME
- **RETARDERS**
- **ANTI-WASHOUT**

8-17

C. ADMIXTURES

Numerous admixtures are available to help concrete mixes satisfy particular requirements. Some of these include:

- Water Reducing
- Air Entraining
- Pozzolans
  Flyash, Silica Fume
- Retarders
- Anti-Washout

Various water reducing agents are available conforming to ASTM. Their effects on set and bleeding should be checked. Water reducing admixtures are almost always used to get needed low water cement ratios. High range reducers are well suited to repair work.

Air entraining should be used in freeze-thaw exposure. It may not be desirable to use in other places as it can increase permeability. Nine percent air, as a percent of the mortar fraction, is needed for proper freeze thaw protection. Also, the size and spacing of the air bubbles is important. Thus for repairs with small aggregate, and consequently a larger proportion of mortar, the percent of air in the mix will be higher than for typical mixes in bridge specifications.

Use of up to 30%, by weight of cement, of pozzolan aids in reducing permeability and susceptibility to sulfate attack. Strength gain is slowed and moist curing is needed. Silica fume is extremely effective, though expensive.

Repairs often have small quantities of material, long placing times, and are located long distances from concrete plants. Retarders provide added working time for these conditions as well as unplanned occurrences.

Anti-washout admixtures aid in retaining the fines in underwater placement. Other means of reducing wash-out include high cement content, use of silica fume or fly ash, and low slumps.

The compatibility of the various admixtures used together should be verified by trial mixes. All admixtures should conform to applicable ASTM requirements.

ANTI-WASHOUT
ADMIXTURES
(AWA)

8-18

Anti-Washout Admixtures are concrete additives developed over the past 15 years, primarily in Europe and Japan. They increase water retention and thixotropy of concrete by binding up free water. Several chemical formulations are marketed.

Generally, these admixtures are used in conjunction with high range water reducers, rich mixes and fly ash or silica fume to obtain maximum benefits.

ADVANTAGES

- FREE FALL IN WATER
- REDUCES TREMIE
- THIN PLACEMENTS

8-19

Advantages of AWA include:

- Allows free fall through water since fines are not washed out of the mix.
- Reduces need to use tremie equipment since the deposited concrete can be in contact with the water.
- Thin placements are easier since no tremie embedment is needed.

DISADVANTAGES

- COST
- STICKY
- SENSITIVE TO MIX CHANGES
- LIMITED EXPERIENCE
- AIR ENTRAINMENT

8-20

Disadvantages of AWA include:

- Cost may double material price. This may be only a small part of total cost of placement though.
- The concrete mix is sticky for handling and clean up.
- Sensitive to change in water/cement ratio or admixture brand and dosage.
- Material is new in U.S. with limited usage history.
- Incompatibility with air entraining admixtures may occur causing air percent and bubble spacing problems.

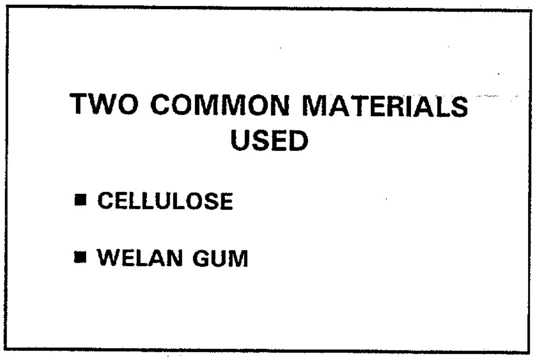
ADMIXTURE COMPATIBILITY

- TRIAL MIX
- TRIAL PLACEMENT

8-21

Compatibility of admixtures can be a problem. This is always the case but is accentuated with use of pozzolans, HRWR, AWA, etc. in the same mix.

Trial mixes should be tested for properties, and for larger projects trial placements are recommended.



TWO COMMON MATERIALS USED

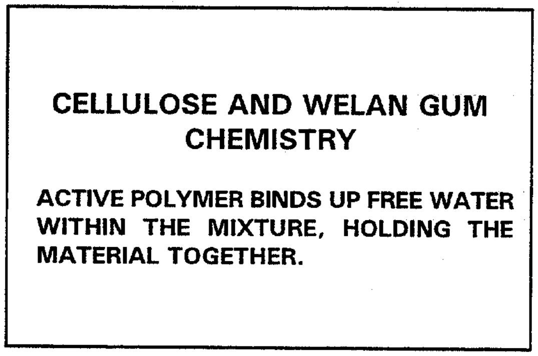
- CELLULOSE
- WELAN GUM

8-22

Because of the potential benefits of anti-washout admixtures, let's look at them in more detail. The following ten slides were provided by Master Builders as part of one of their technical presentations. The most common base materials are:

- Cellulose
- Welan Gum

Both are effective anti-washout and thixotropic agents.

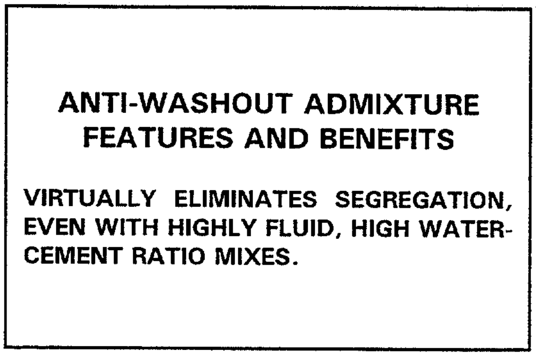


CELLULOSE AND WELAN GUM CHEMISTRY

ACTIVE POLYMER BINDS UP FREE WATER WITHIN THE MIXTURE, HOLDING THE MATERIAL TOGETHER.

8-23

The AWA binds the free water in the mix, thus holding the material together.

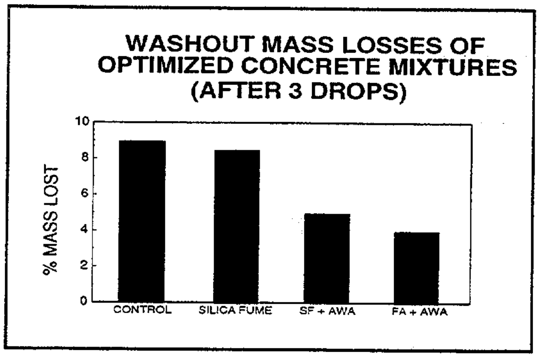


ANTI-WASHOUT ADMIXTURE FEATURES AND BENEFITS

VIRTUALLY ELIMINATES SEGREGATION, EVEN WITH HIGHLY FLUID, HIGH WATER-CEMENT RATIO MIXES.

8-24

AWA as part of an overall mix design can largely eliminate segregation of the mix while maintaining a workable material.

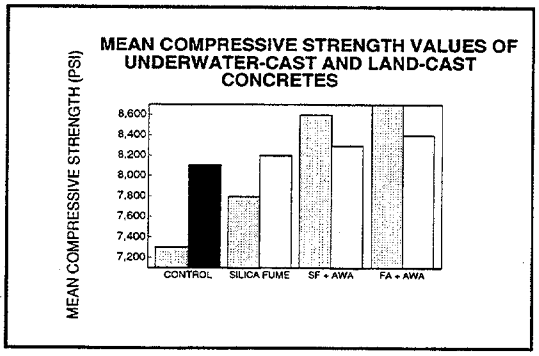

WASHOUT MASS LOSSES OF OPTIMIZED CONCRETE MIXTURES (AFTER 3 DROPS)

8-25

This slide of test results indicates the effect of the AWA. The test was run using the Corp of Engineers test CRD C61, which was developed to test mix washout loss.

The washout test apparatus consists of a clear acrylic tube about 7 feet tall filled with water. A metal basket with perforated holes is filled with concrete, a lid is placed on top of the basket and it is then allowed to freefall through the water. The basket is actually raised, and dropped three different times in the water. The weight loss is measured before and after the test is complete, to determine the overall percentage of washout or material that is lost.

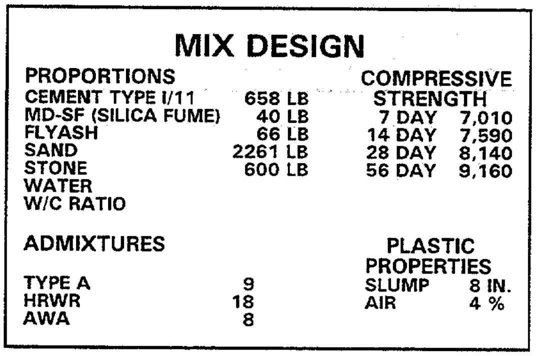
As shown in the graph, the control mix has 800 pounds of cement per cy and experienced the higher washout. The mix with silica fume did a little better. The last two mixes with AWA and silica fume or fly ash performed much better than the other two.


MEAN COMPRESSIVE STRENGTH VALUES OF UNDERWATER-CAST AND LAND-CAST CONCRETES

8-26

The benefit on strength of concrete cast underwater compared to concretes cast above water is shown here.

Note that the AWA with silica fume or fly ash strength results were even higher when placed underwater than when placed above water. The reason for this is not clear, but may be due to improved curing.



MIX DESIGN

PROPORTIONS	
CEMENT TYPE I/11	658 LB
MD-SF (SILICA FUME)	40 LB
FLYASH	66 LB
SAND	2261 LB
STONE	600 LB
WATER	
W/C RATIO	

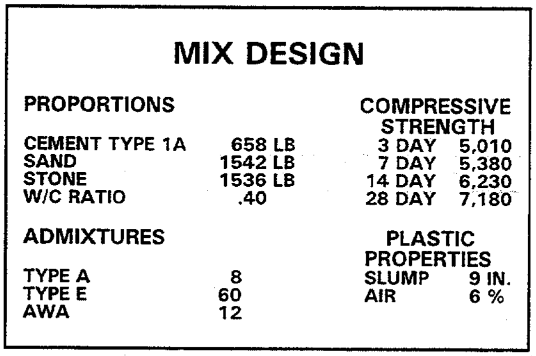
COMPRESSIVE STRENGTH	
7 DAY	7,010
14 DAY	7,590
28 DAY	8,140
56 DAY	9,160

ADMIXTURES	
TYPE A	9
HRWR	18
AWA	8

PLASTIC PROPERTIES	
SLUMP	8 IN.
AIR	4 %

8-27

This shows a typical mix design using a variety of admixtures including silica fume and fly ash at about 10 percent of the cement, as well as AWA. This mix yields over 8000 psi compressive strength at 28 days from an 8 inch slump.



MIX DESIGN

PROPORTIONS	
CEMENT TYPE 1A	658 LB
SAND	1542 LB
STONE	1536 LB
W/C RATIO	.40

COMPRESSIVE STRENGTH	
3 DAY	5,010
7 DAY	5,380
14 DAY	6,230
28 DAY	7,180

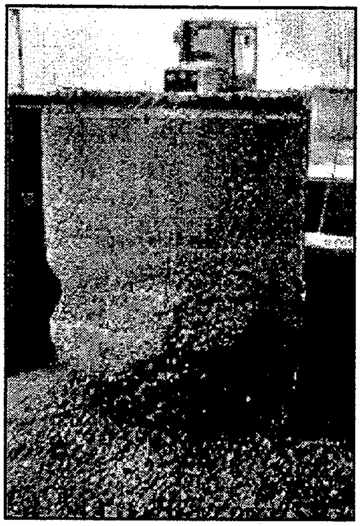
ADMIXTURES	
TYPE A	8
TYPE E	60
AWA	12

PLASTIC PROPERTIES	
SLUMP	9 IN.
AIR	6 %

8-28

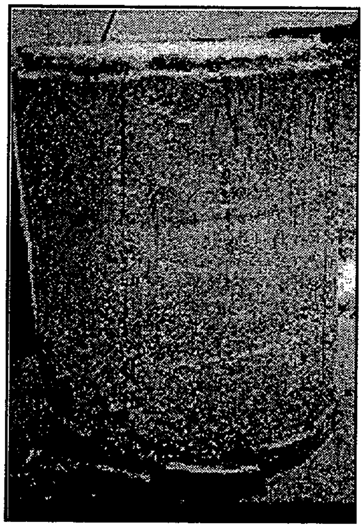
Here, a typical mix design with less admixtures but still including AWA is shown.

Note the lower (but still very high) strength, along with 9 inch slump and 6 percent air entrainment.



8-29

This is a barrel test showing non AWA concrete behavior. Concrete was dumped into a water filled barrel and the barrel removed after the concrete hardened. Note the absence of cement paste and fines in the lower area.



8-30

This is the same test using AWA. Note minimal concrete segregation compared to the previous test result. The admixture dosage in this test was 16 to 18 ounces of admixture per 100 pounds of cement.

8-31

Underwater deposition of concrete from pump line. Note lack of washout indicated by lack of water clouding.

At the end of this session, we will conduct a demonstration of anti-washout admixture behavior.

REINFORCING STEEL

- **MILD STEEL**
- **PRESTRESS**
  - **STRAND**
  - **BAR**

8-32

D. REINFORCING

Most concrete substructures will have some type of steel reinforcing. In piers, pedestals, footings, pile caps, walls, etc. it is mild steel bars. In driven piles it may be prestressing steel wires or strands.

Similar materials are used in repairs.

CORROSION PROTECTION

- COVER
- DENSE CONCRETE
- EPOXY COATING

8-33

Reinforcing must be protected from corrosion. Dense concrete and adequate cover are required. A minimum of 3 inches of cover is recommended for marine work.

Differences currently exist about the effectiveness of epoxy coated bars particularly in marine exposure. Their use should be considered within now acknowledged limits on handling and quality control. Added specification controls on bar surface preparation prior to coating, fabrication prior to coating, added quality assurance testing and more stringent requirements on field placing are probably warranted for marine construction.

CORROSION PROTECTION

- GALVANIZING
- CORROSION INHIBITORS

8-34

Galvanizing has been used for over 40 years to protect reinforcing, including for marine structures. ASTM Specification A767 covers hot dipped galvanized reinforcing. Use of Class I coating thickness (of approximately 5 mils) is recommended, with fabrication done before galvanizing.

Bond of galvanized bars is similar to plain bar, but may take longer concrete age to fully develop.

Corrosion inhibitors are agents added to concrete that produce chemical reactions at or around the reinforcing to lower its corrosion potential. Since these are relatively new materials that vary from supplier to supplier, their use in marine repairs should be considered based on relevant test data. Resistance to long term leaching should be evaluated as well as other effects on the concrete.

EXOTIC REINFORCING

- STAINLESS STEEL
- POLYMERS
- COMPOSITE

8-35

Other reinforcing materials that could be considered in special applications include stainless steel and various polymer and composite bars, strands and fibers.

Stainless steel bars have been used in navy facilities (due to their non magnetic properties). While stainless bars may cost 8 to 10 times more than plain bars, the overall cost of the in place concrete may be only a few percent higher.

Typical yield stress for stainless bars is 35 to 40 ksi, though cold working can increase this.

Many types of polymer reinforcing bars and strands are being used in experimental and trial applications. Their properties vary widely. The modulus of elasticity of these materials may be much less than steel, such that design stresses are controlled by deflection or crack width rather than reinforcing strength.

CABLES

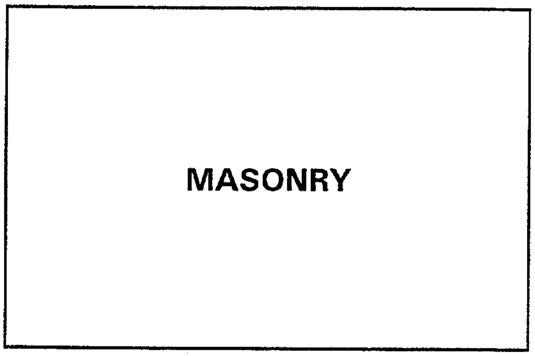
	F_U (Ksi)	E (Msi)
CARBON	235-295	22
E-GLASS	190-220	7.7

8-36

The Navy is presently building a pier at Port Hueneme using fiberglass reinforced concrete, including prestressed piles and pile caps. Representative properties of the reinforcing for this project are shown here.

Representative value for E-glass reinforcing bar are:

F_u = 110 Ksi (#4)
E = 7 Msi



MASONRY

8-37

IV. MASONRY

Masonry, primarily stone, has been used in bridge foundations for many years, predating concrete. Generally is it very durable.

Brick masonry is also found in some older bridges.

8-38

Mortar joints in masonry are usually the "weak link". Note also the freeze thaw damage to this stonework.

8-39

A. STONE

Where stone is to be replaced, it is critical to specify good quality material, which is increasingly hard to obtain. This stone has split along bedding planes.

The types of stone used vary with geographic location and may include limestone, granite, and others.

STONE QUALITY

- POROSITY
- BEDDING PLANES
- CRACKS
- COMPRESSIVE STRENGTH

8-40

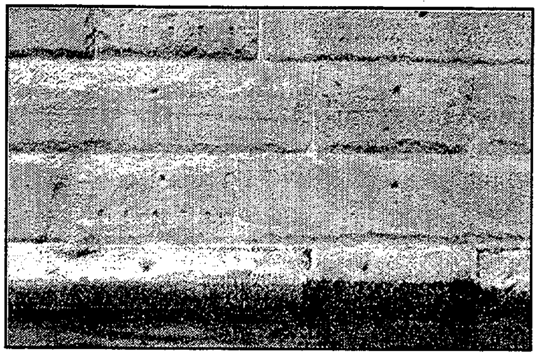
Replacement stone should match the existing in type. This may be a strict requirement for a historic bridge. Specifications for stone should include limits on maximum porosity and on bedding planes or cracks. Minimum allowable ompressive strength is usually stated, though actual stresses are typically small due to foundation mass.

QUARRY METHODS

- BLASTING
- SPLITTING
- AGING

8-41

Years ago, building stone was quarried by drilling and splitting. Now blasting is often used, at least for initial breakage. Blasting, unlike splitting, produces cracks, often hard to see, which can reduce durability. Stone should be aged before use to allow stress relaxation and moisture equilibrium. The aging process makes cracks more readily detected as well.


8-42

This slide shows drill holes in the stone face resulting from the quarrying operation.

MORTARS

- **CEMENTITIOUS**
  - **SAND**
  - **CEMENT**
  - **LIME**
- **POLYMERS**

8-43

B. MORTAR

Mortars for masonry joints typically are made of:

- Sand
- Cement
- Lime

Some newer mortars may be polymers with fine aggregate.

Older mortars were softer than current practice. This reduced volume change cracking. Sometimes new mortars should match existing compositions to maintain structure flexibility. Hard mortar containing large amounts of cement can increase the likelihood of cracks and edge spalls.

STRUCTURAL PLASTICS

8-44

V. STRUCTURAL PLASTICS

Over the past 20 years a variety of polymer products have been introduced for civil and structural engineering applications. This trend is continuing and accelerating. As a group, these products are often referred to as plastics, though this is often not technically correct. In this group are non-metallic compounds, synthetically produced (usually from organic compounds by polymerization) which can be molded into various forms and partially or fully hardened.

FIBER

- **REINFORCED PLASTICS (FRP)**
- **NON-REINFORCED**

8-45

A. MATERIALS

Plastic materials for structural applications are usually composites consisting of a polymer resin matrix reinforced with fibers. Non-reinforced plastics are also made and used for applications such as pile wraps.

The fibers carry the load while the resin binds the fibers together, allows uniform load distribution among fibers, and protects the fibers.

FRP

- **RESINS**
  - **EPOXY**
  - **POLYESTER**
  - **OTHERS**
- **FIBERS**
  - **GLASS**
  - **CARBON**
  - **ARIMID**

8-46

Resins for fiber reinforced plastics are often epoxy, vinylester or polyester, though other types are also used. Fillers and other additives may also be included.

Reinforcing fibers include:

- Glass - E-glass is often used and is inexpensive. It is not attacked by alkali in cement.
- Carbon - Carbon fibers are manufactured from coal tar, petroleum, and other sources. Fibers formulated for high elastic modulus are usually used.
- Aramid - Aromatic polyamide fibers (Kevlar) are used for many applications.

MANUFACTURE

- **PULTRUSION**
- **LAYUP**
- **FILAMENT WINDING**

8-47

FRP products are manufactured by:

- Pultrusion - Pulling fibers and resin continuously through dies. Often used for shapes and rods.
- Layup - Placing resins and fibers (usually in sheets) in molds. Often used for pipe fittings, and special shapes.
- Filament Winding - Winding fiber filamats around a resin covered mandrel. Generally used for pipe.

Specialized shapes can be manufactured.

MECHANICAL PROPERTIES

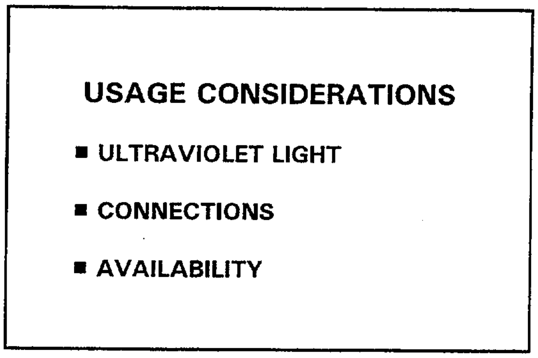
- **NON-ISOTROPIC**
- **HIGH STRENGTH: WEIGHT RATIO**
- **TIME DEPENDANT**
- **MODULES OF ELASTICITY**
- **CREEP**
- **NON-CORROSIVE**
- **TEMPERATURE DEPENDANT**

8-48

B. PROPERTIES

Mechanical Properties of plastics differ in several ways from the more familiar steel or concrete materials.

- FRP members generally have different mechanical properties in each direction (non-isotropic) due to the fiber orientation links to manufacturing process.
- High strength to weight rations due to high fiber tensile strengths.
- Failure strength and other properties are time dependant. Allowable sustained load is much smaller than short term tensile strength.
- Though fiber E many range from 11 x 10^6 to 35 x 10^6, low E of resins reduces overall value. This results in the potential for large deflections.
- FRP materials are subject to larger creep deformation than steel or concrete.
- Materials are not subject to corrosion which is their main advantage in marine environment.
- Mechanical properties are much more temperature dependent than for traditional materials. Properties may reduce at relatively low temperatures (less than 180° F).



USAGE CONSIDERATIONS

- ULTRAVIOLET LIGHT
- CONNECTIONS
- AVAILABILITY

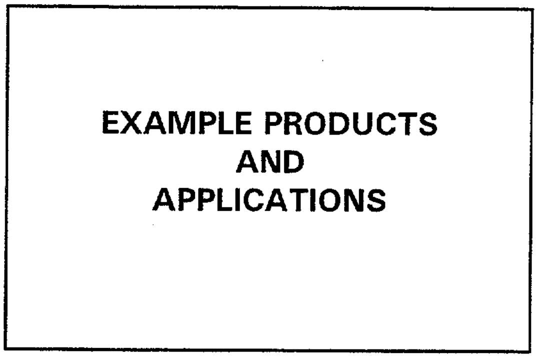
8-49

C. USAGE

Most resins are adversely effected by the ultraviolet portion of sunlight. Pigments may be incorporated in the resin to limit light penetration or surfaces can be painted.

FRP members may be connected by bolting, welding or adhesive bonding. For bolted connections, stainless or FRP bolts are often used.

Product availability is generally limited to only a few suppliers for a given product.

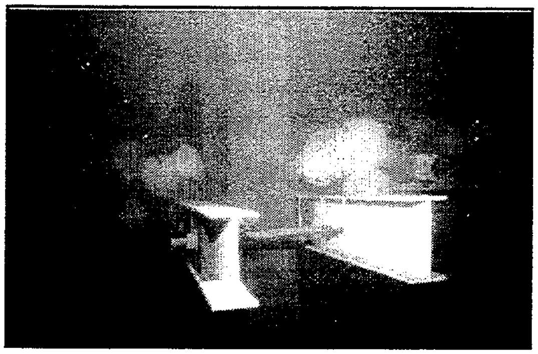


**EXAMPLE PRODUCTS
AND
APPLICATIONS**

8-50

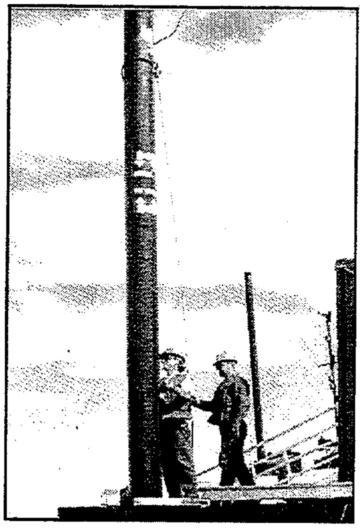
Figerglass jackets are widely used for pile repair as well as various plastic pile wraps. Examples of these are shown in Session 10.

Many other applications are possible, and more products continue to appear in the construction market place.



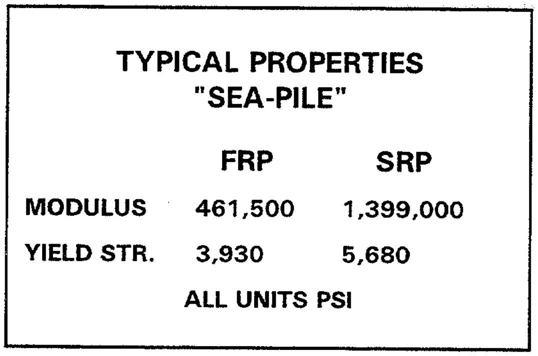
8-51

This shows a pair of fiberglass wide flanges used to support a cable tray underwater. Various member sizes are available and are widely used in corrosive areas.



8-52

This is a plastic pile, reinforced with FRP reinforcing bars. It is made of recycled plastic. These are primarily used for fender piles. The same company also makes square plastic "timber".



TYPICAL PROPERTIES "SEA-PILE"

	FRP	SRP
MODULUS	461,500	1,399,000
YIELD STR.	3,930	5,680

ALL UNITS PSI

8-53

Typical pile properties for fiber and steel reinforced piles shown above are given in this table.

8-54

Another type of plastic pile available is sheet piling. Here the sheets are being driven using a 2000 pound drop hammer. They can also be driven with vibratory hammers of jetted.

TYPICAL PROPERTIES
"KEPT" PRODUCTS

COMP STR.	5,200
TENSILE STR.	3,500
MODULUS	530,000

ALL UNITS PSI

8-55

This slide shows mechanical properties of plastic members which are similar to common lumber such as 2x4. They are marketed for decking and light framing.

8-56

Here plastic "timbers" are seen above pressure treated wood members to compare their behavior in an underwater support system.

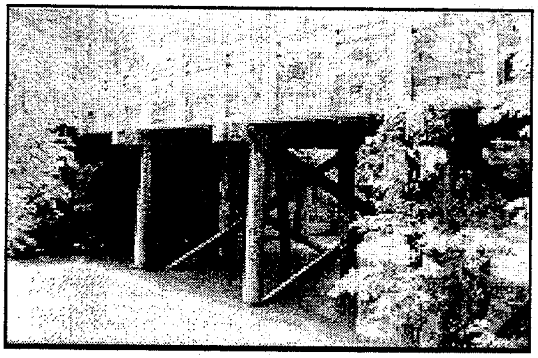
TIMBER

8-57

VI. TIMBER

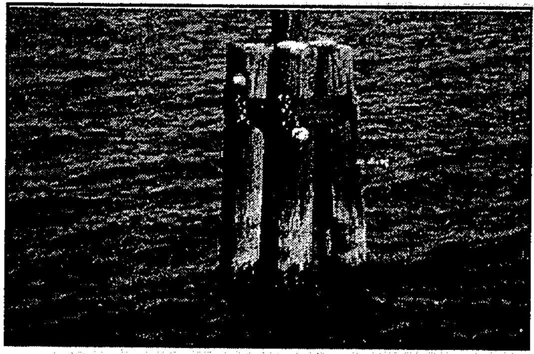
A. CHARACTERISTICS

Timber is a natural cellular material. The strength-to-weight ratio along its longitudinal axis is higher than perpendicular to its longitudinal axis.



8-58

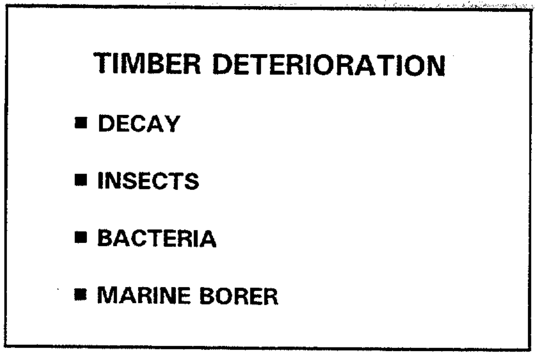
Timber is commonly used to construct smaller bridges. This is a timber pile supported bridge. The pile bents are stiffened using timber cross-bracing.



8-59

Protection systems, such as this dolphin, are often constructed of timber. Some advantages of using timber as a construction material are:

- Light weight, easy to handle.
- Good strengthto weight ratio.
- Has good energy absorbing properties.



TIMBER DETERIORATION

- **DECAY**
- **INSECTS**
- **BACTERIA**
- **MARINE BORER**

8-60

There are several types of deterioration that wood has to be protected against in order to be useful, especially in a marine environment. These were presented in Session 2 and include:

- Decay (Commonly found in area above but near the waterline)
- Insects (Normally above water)
- Bacteria (Below water)
- Marine Borer (Salt water)

Natural resistance to deterioration varies between wood species, however, it is important when using wood as a construction material to properly protect the material against deterioration.

There are basically two ways to protect timber: Either by using chemical preservatives or by encapsulating members in barriers to separate them from the environment.

GENERAL CLASSES OF NATURAL WOOD

- SAPWOOD
- HEARTWOOD

8-61

The natural wood found in raw timber can be divided into two general classes; sapwood and heartwood. The sapwood is located on the outside of the tree, and is usually 1 to 4 inches thick depending on the species. Heatwood is located within the outer sapwood shell.

Heartwood is generally resistant to decay, while the sapwood is typically softer and very susceptible to decay causing organisms. Most marine timbers are primarily cut from heartwood, and are pressure treated with a preservative.

WOOD PRESERVATIVES

- OIL-TYPE
- WATERBORNE

8-62

B. WOOD PRESERVATIVES

Timber preservative treatments can be placed into two categories: Oil-type preservatives and waterborne preservatives or salts. A wood preservative must have the ability to penetrate the wood and persist in sufficient quantities for long periods. Treatments can increase timber life by as much as 5 times or more. For most marine applications it is necessary that timber members be commercially treated under pressure.

American Wood-Preserver's Association (AWPA) Standard C3 covers preservative treatment of piling, while AWPA C18 is the Standard for Pressure Treated Material in Marine Construction.

OIL-TYPE PRESERVATIVES

- CREOSOTE
- PENTACHLOROPHENOL
- COPPER NAPHTHENATE

8-63

Oil-type Preservatives

In a marine environment, creosote is frequently used to protect marine piling. Creosote was first patented in 1831. It is a complex mixture of polynuclear aromatic hydrocarbons normally produced as a byproduct in coal production or the processing of oil shale. Creosote is available in its undiluted form (coal-tar creosote) or as a blend in solvents. In recent years, environmental concerns have diminished its use, and it is prohibited by some states.

Pentachlorophenol (penta) was first patented in 1935. Although effective at preventing most decay causing organisms, it is not effective against marine borers and, therefore, not recommended for saltwater use.

Copper Naphthenate is the third oil-type preservative. It was originally developed in the 1940's, and is considered environmentally safe by the EPA. It has not been extensively used in the past due to the high production cost compared to other oil-type preservatives. Its use may increase due to more restrictive environmental considerations for other oil-type preservatives.

WATERBORNE PRESERVATIVES

- CCA
- ACA
- ACC
- ACZA
- CZA

8-64

Waterborne Preservatives

Waterborne Preservatives include formulations of organic arsenical compounds in a water solution. The first waterborne preservatives were developed in the late 1800's; however, most were susceptible to leaching from the wood and performed poorly in service. It was not until the 1930's, when chromium was added to serve as a binding agent in the wood, that waterborne preservatives became an effective treatment.

Waterborne preservatives include:

- CCA (Cromated Copper Arsenate) usually used to treat southern panderosa and red pine.

AWPA TREATMENT STANDARDS FOR ROUND SOUTHERN PINE PILING

	CREOSOTE(pcf)	CCA(pcf)
FOUNDATION	12.0	0.8
LAND AND FRESH WATER	12.0	0.8
MARINE	20.0	2.5
DUAL TREATMENT	20.0	1.0

8-65

- ACA (Ammoniacal Copper Arsenate) often used for Douglas-fir and other hard to penetrate species.
- ACC (Acid Copper Chromate) good for difficult to treat species.
- ACZA (Ammoniacal Copper Zinc Arsenate)
- CZC (Chromated Zinc Chloride)

This table is from the American Wood Preservers Association (AWPA) book of standards. While the intent of this table is to show minimum preservative retentions, it also shows which preservatives are not recommended for a given usage.

In salt water, creosote is commonly used to protect timber. This preservative works well against all hazards with the exception of limnoria tripunctata. This species of marine borer is capable of attacking wood in warmer climates protected with creosote.

Limnoria can be found in most warm salt waters in North America. In the regions where limnoria tripunctata thrive, a dual treatment of a waterborne preservative and creosote is the most effective in preventing borer attack.

In fresh water, creosote is the most commonly used preservative. It is effective in controlling bacterial attack and biological decay.

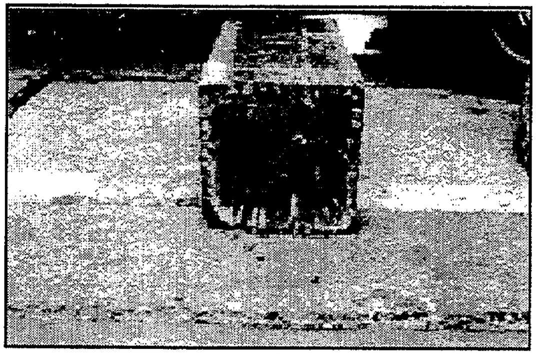
Preservatives are applied to timber members under pressure. The members are placed into a large tank and impregnated with preservative.

DEPTH OF TREATMENT

TYPICALLY 1 TO 2 INCHES

8-66

After treatment, the outer 1 to 2 inches of a member are typically protected with preservative. The preservative serves as a barrier protecting the interior of the member from external hazards. If the surface treatment is breached, a path is provided for attack by borers, decay, etc.



8-67

This shows the inside of a timber. Note the preservative conditions, with very little preservative in some locations.

AWPA M4

2% COPPER NAPHTHENATE

\+

COAL TAR ROOFING CEMENT

8-68

It is important to protect cut ends of bracing, drilled holes, areas damaged by handling, etc. in the field. Field application involves brushing, dipping, spraying or soaking members in an approved preservative. AWPA Standard M4 covers the recommended procedures for field treatment. This should include treating the cut area with 2 percent copper naphthenate solution and then coating with coal tar roofing cement. In most states, a state applicator's license is required for the purchase and application of most wood preservatives. Field treatments do not protect timber as well as those areas treated using the pressure processes. Field cuts and modifications, therefore, should be kept at a minimum.

PRESERVATIVE TREATMENTS ARE PREVENTIVE, NOT REMEDIAL

8-69

Preservative treatments are considered a preventative measure, not remedial. If internal decay is present, typical surface treatments will not penetrate deep enough to eradicate the decay. Additionally, surface treatments are relatively ineffective on submerged timber members.

8-70

This shows the use of wraps and concrete jackets to protect partially deteriorated members. These will be discussed in Session 10.

Timber piles also can be wrapped in a plastic barrier to separate the material from the surrounding environment as part of new construction, i.e., a pile can be wrapped before driving.

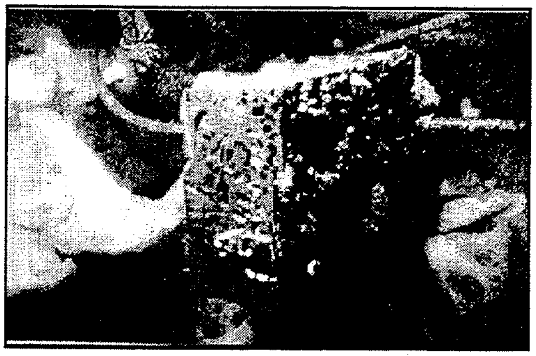
EXOTIC WOODS

- EKI
- BUNGAZI

8-71

Certain exotic hardwoods claim to be resistant to marine borer attack. These woods come from rain forests in South America and Africa. Two of the common names are Eki and Bungazi wood.

AASHTO specifications contain no mention of the strength or other information about these woods. In addition, to the best of our knowledge, there has been little testing done on these woods to support the claim of being resistant to marine borer attack.



8-72

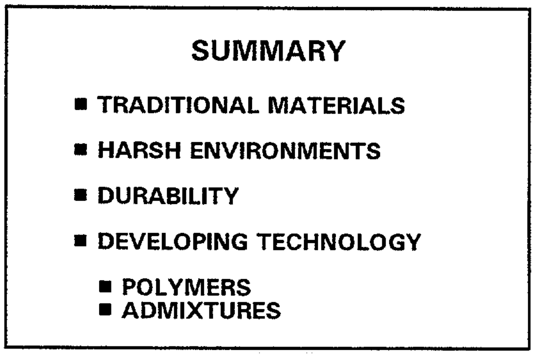
This is a photo of a piece of one of these hardwoods which was used as cross-bracing for a timber pier. As you can see there are holes from teredo attack in the end of the bracing. This piece of wood was in service for 4 years before the photo was taken. In this situation the wood was susceptible to attack.

Fabrication

Structural timber members can be easily manufactured at commercial sawmills. It is best to have all components cut and treated with preservative commercially to insure adequate protection of the wood.

It should be emphasized that when commercially treated timber is cut or drilled, the protective barrier has been compromised, and surface treatments must be applied to deter decay and infestations. Surface treatments are much less effective than commercial treatment, and field modifications should be minimized whenever possible.

So-called exotic woods are quite dense requiring use of carbide tools and are usually shop fabricated. This makes field rework more difficult.



SUMMARY

- **TRADITIONAL MATERIALS**
- **HARSH ENVIRONMENTS**
- **DURABILITY**
- **DEVELOPING TECHNOLOGY**
  - **POLYMERS**
  - **ADMIXTURES**

8-73

VII. SUMMARY

We have looked at a variety of materials that are used for construction and repair of bridge substructures. Each has particular characteristics which must be considered in its use. Material properties must be evaluated and a material selected with the severe marine environment and particular repair method as foremost considerations. New materials are continuously being developed and should be evaluated for their potential in providing long lasting and durable, cost-effective repairs.

SESSION 9

PIER REPAIRS

SESSION 9: PIER REPAIRS

TOPICS: **HAND AND FORMED REPAIRS, CONSTRUCTION METHODS UNDERMINING AND INJECTION**

LESSON PLAN:

DURATION	90 minutes
GOAL	Learn the repair techniques applicable to piers.
OBJECTIVE	To be able to select appropriate repair schemes.

OUTLINE

- I. Introduction
- II. Pier Replacement
- III. Hand Patching
- IV. Formed Repairs
  - A. Rigid Forms
  - B. Flexible Forms
- V. Concrete Placement
  - A. Reinforcing and Anchorage
  - B. Placement Methods
- VI. Masonry
  - A. Stone Replacement
  - B. Concrete Fill
  - C. Mortar Joints
  - D. Encasement
- VII. Epoxy Injection
  - A. Materials
  - B. Installation
- VIII. Undermining
  - A. Formed Concrete
  - B. Grout Bags
  - C. Grouted Stone
  - D. Footing Extensions
- IX. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 9
PIER REPAIRS

9-1

I INTRODUCTION

Many bridges are supported on piers of stone or concrete. Piers may be founded on shallow foundations or pile supported. They may experience material deterioration and undermining which require repairs to be made.

REPAIR OPTIONS

9-2

Repair options are available and depend on the specific problem and the designer and agencies past experiences. Similar techniques as those used in repairs may be considered for use in constructing extensions to existing piers. We will include the shaft, footing, seal, etc. in this presentation as part of the pier. Repairs range from simple techniques (hand patch) to complex underpinning designs.

All repair projects should start with an engineering study of the problem and possible solutions prior to selecting the final repair technique.

PIER REPLACEMENT

9-3

II PIER REPLACEMENT

In some cases the extent of deterioration, concerns for repair effectiveness, or high cost of repair may indicate that the pier should be replaced. Some examples include:

- Extreme deterioration
- Inherent material or design problem - Reactive aggregates may be susceptible to further deterioration even with repair or the pier could be inadequate for seismic loads.
- Bridge reconfiguration

HAND PATCHING

- SIMPLE
- INEXPENSIVE
- VARIOUS APPLICATIONS

9-4

MATERIALS

- PC MORTAR
- HYDRAULIC MORTARS
- NEAT EPOXY, ETC.
- POLYMER MORTARS

9-5

III. HAND PATCHING

Hand patching is the simplest and least costly repair method. It is primarily used for shallow, localized areas of deterioration.

Various materials can be applied and minimal support equipment is needed.

As with above water repairs, local patching, particularly in cases of reinforcing corrosion, can set up local corrosion cells due to differing chloride concentrations and permeability.

Materials that are available and commonly used for hand patching include:

- PC Mortar - Portland cement mortar, possibly with pea gravel.
- Hydraulic Mortars - Prepackaged mortars, may have fibers or other additives.
- Neat Epoxy, etc. - Many suppliers make epoxy mortars formulated to be used and cure underwater. These may have fine aggregate added.
- Polymer Mortars - Similar to epoxies, but of differing chemical make up. Epoxy is much more common underwater.

The bond of hydraulic cement mortars placed on wet substrates is typically reduced below that expected above water by a smaller factor than are epoxies, and might exhibit nearly a full "dry" bond strength. Though the coefficient of thermal expansion of the epoxies and other polymers is higher than that of concrete, concrete patching materials generally perform satisfactorily even with a coefficient of thermal expansion up to three to four times that of concrete. Epoxies do create a vapor barrier and this can cause debonding of patches. This is primarily a problem for large areas above, or extending above, the waterline.

APPLICATION

- CLEAN AREA
- MIX MATERIAL
- HAND APPLY

9-6

Application of these materials generally involves the following steps::

- Clean repair areas, usually with hand tools. Local chipping may be done to make keyed edges.
- Mix material topside in small quantities. Care must be taken not to exceed pot life, especially with many of the epoxies.
- Apply with hand using mit, trowel, etc.

Bonding agents are not recommended since they effect vapor transmission and permeability.

9-7

This shows a patch being hand applied underwater. Gloves provide protection from chemicals as well as the water.

FORMED REPAIRS

- RIGID
- FLEXIBLE

9-8

IV. FORMED REPAIRS

Used for larger repairs, there are many possibilities. Two main forming systems can be classified as rigid and flexible.

- Rigid forms have marked internal or external stiffeners and are needed only until the repair material has cured.
- Flexible forms assume the shape of the element to which they are attached.
- Forms, particularly rigid forms, may add strength or protection if specially designed.

RIGID FORMS

- TYPES
- INSTALLATION
- ADVANTAGES
- DISADVANTAGES

9-9

A. RIGID FORMS

Rigid forms are familiar due to their extensive use in above water construction. Many combinations of materials and usage are possible.

Form selection and design is usually left to the contractor who will consider not only the types available but also ease of installation and advantages and disadvantage based on specific project requirements.

FORM DESIGN

9-10

Because hydrostatic pressure acts on one face, form pressures are reduced underwater, allowing use of lighter forms and fewer anchors or ties.

TYPES

- PATENT
- CUSTOM

9-11

Manufactured or patented form systems such as Symons, Efco, etc. are used underwater. Installation is similar to above water usage. Since they are modular systems they are readily configured to different pier sizes.

Especially where repetitive usage is possible, custom forms may be made to facilitate ease of placement.

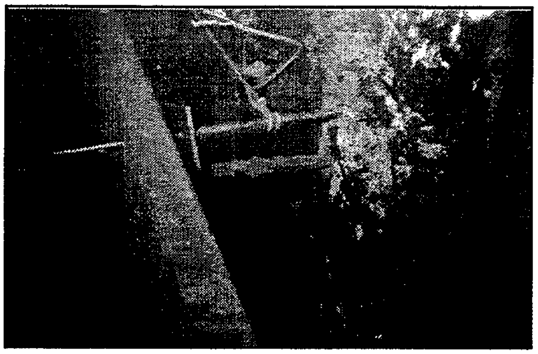
Custom forms may be used as stay-in-place forms also.

MATERIALS

- WOOD
- FIBERGLASS
- STEEL
- CONCRETE

9-12

A variety of materials may be used for forms. Many manufactured and custom forms are wood or wood/metal. Where curved surfaces are involved, custom fiberglass forms may be used, and they are often used for piles and shafts. Steel and concrete forms are often used for stay-in-place forms. Polymer concrete can be used to produce thin forms. Forms may require special cleaning of oils, etc. before use so as not to cause pollution.



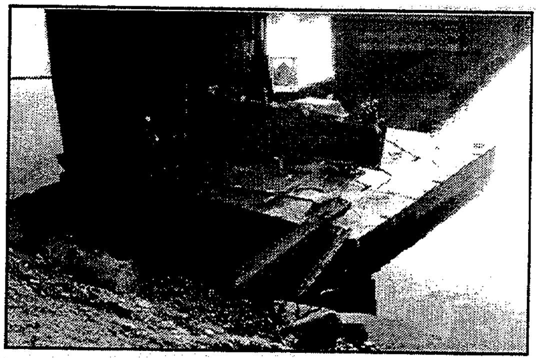
9-13

Here a wood/metal form is set along a pier, looking much like a wall form above water.

9-14

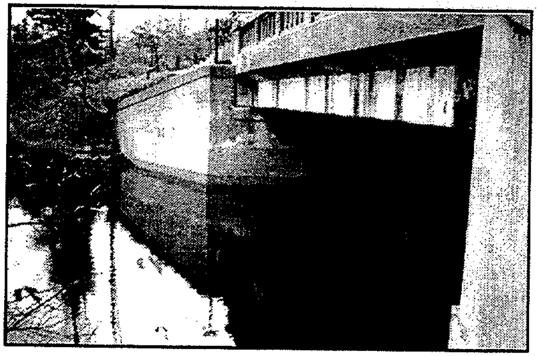
As previously noted, fiberglass is most often found in column forms as shown here.

They may be stay-in-place or removable. When left-in-place they can provide resistance to chemical attack.



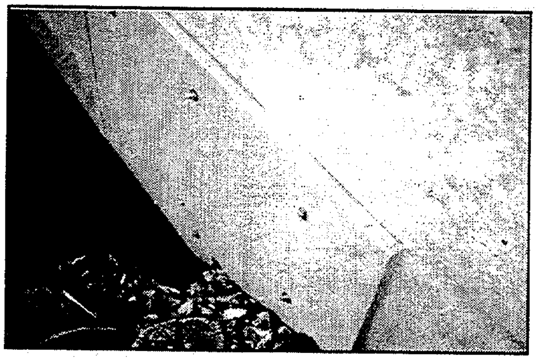
9-15

Steel is used for manufactured forms and custom forms. This is an example of a custom steel form trimmed to fit a scour hole. It will be left in place.



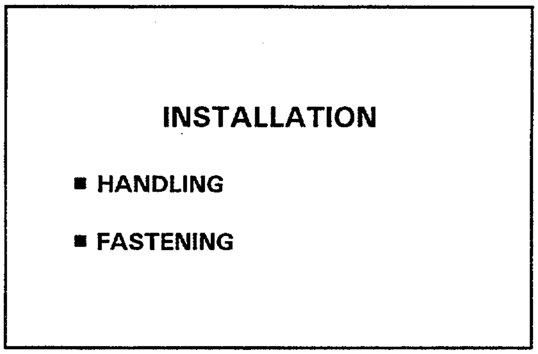
9-16

This is a precast polymer concrete panel used along the base of the wingwall and abutment which can be left in place to add weathering protection. It may be desirable to use studs or keys on the back of the panel to keep it from debonding.



9-17

This shows a close-up view of the precast form panel and its attachment.



INSTALLATION

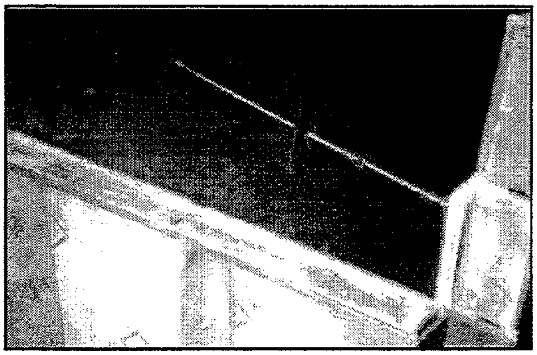
- **HANDLING**
- **FASTENING**

9-18

Forms are often hand set and secured. For large areas, efficiency is gained by prefabrication and setting panels by crane.

Forms are subject to current and wave forces, particularly during installation. This may limit form size.

Wood forms are readily handled despite a tendency to float. Floating tendency can be advantageous if "dropped" in deep water.



9-19

Forms can be attached to piers with expansion anchors or grouted anchors, as shown here, coupled to the form tie rods.

Design considerations for anchors are discussed later in this session.

Bottom edges at the river bottom are often staked or sand bagged. Along with providing side resistance, bags help seal leakage at uneven bottoms.

Column forms can be fastened with manufactured column clamps or banded.

Unique fastening systems may be developed by contractors for specific projects. One example is the use of tension cables to secure sectional forms at an elliptical pier.

Forms are often left in place underwater due to high labor costs for removal. This may lead to a contractor using old worn out forms; a condition to address in project specifications.

ADVANTAGES

- **FAMILIARITY**
- **REUSE**
- **CLEAN LINES**

9-20

Rigid forms are familiar to most engineers which is an advantage in their use. Their design is covered in texts and recommended practice publications, such as ACI 347. Other advantages to their use include:

- Contractors are experienced in their use.
- Forms can be reused.
- Forms leave clean lines and good appearance to work. This is mainly important where repairs extend above water.

DISADVANTAGES

- **CUMBERSOME**
- **IRREGULAR SURFACES**

9-21

Possible disadvantages include being cumbersome to handle by divers, and difficulty in fitting irregular surfaces resulting from extensive deterioration or uneven bottoms.

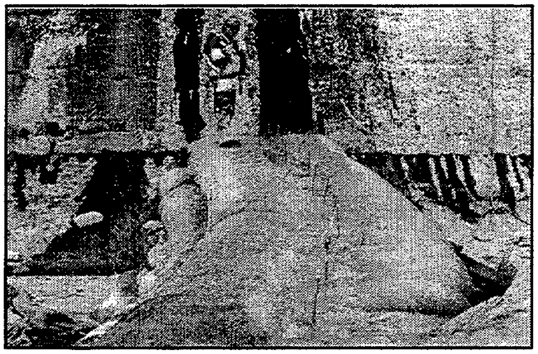
FLEXIBLE FORMS

9-22

B. FLEXIBLE FORMS

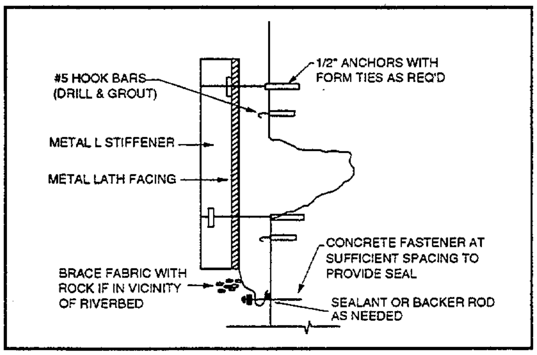
Flexible forms do not have inherent stiffness. Examples include fabric pile jackets, fabric bags, and plastic membranes. (Flexible forms for pile repairs are covered in Section 10)

Flexible forms are left in place.



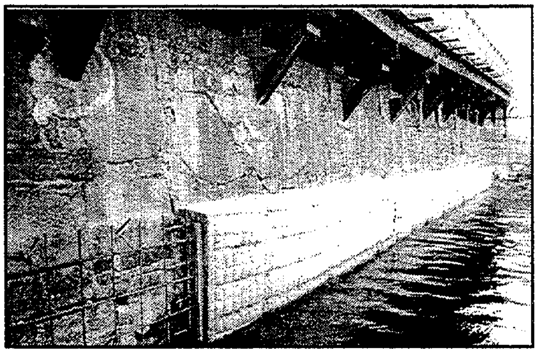
9-23

This shows large tubular fabric forms above water.



9-24

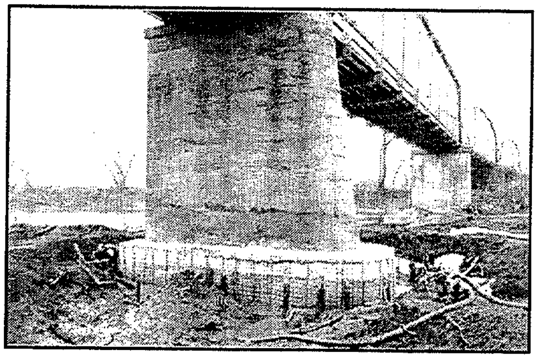
For flat surfaces, flexible forms are supported by timber or steel walers or frames in order to aid in resisting lateral loads due to concrete placement. This shows a repair design where light metal angles are used to stiffen a fabric for a wall repair.



9-25

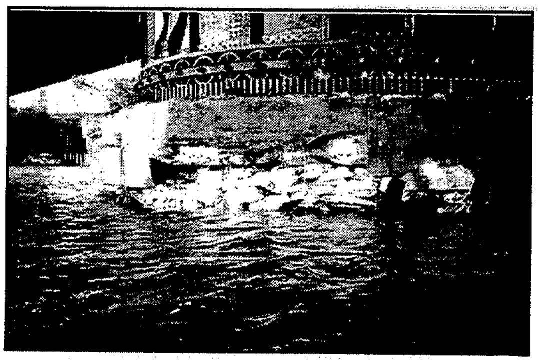
Another method of adding stiffness is to weave reinforcing bars or to drive small pipe and fasten fabric to it.

Possibilities for use are dictated by imagination.



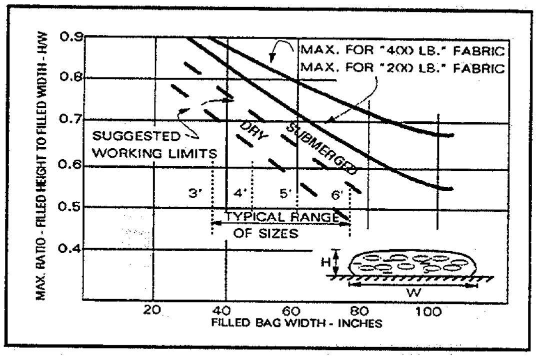
9-26

This shows another example of a "quilted" form system on an Ohio bridge rehabilitation.



9-27

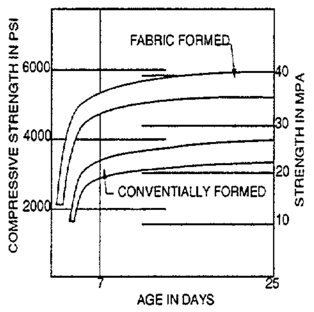
Fabric bags can be grout filled and packed into voids. Here a temporary repair to a pivot pier was made. Dry concrete mix is often bagged for below water use, on the assumption that it will hydrate as a result of submergence. Complete curing of anything but small bags is probably suspect. Bags are also pumped full of mortar or concrete in place. Their use for scour protection will be described in a later session.



9-28

When used for large forms, tables are available to show the shape when grout filled. Long tubes or bags will flatten due to the weight of the concrete.

Materials used for fabric forms include burlap, membrane plastic, and synthetic fiber fabric. Some have an open mesh, while others are tight. Typical fabric strengths range from 200 to 400 pounds per linear inch. Form design is normally by the manufacturer.



9-29

Loss of mix water through the fabric can increase concrete strength, at least near the surface of the concrete. This chart shows this effect.

ADVANTAGES

- COST
- HANDLING
- PREFAB
- FORMABILITY

9-30

Advantages of flexible forms include:

- Flexible forms of fabric or plastic are low cost materials.
- They are lightweight for shipping and handling. Thus the need for topside cranes is reduced.
- Forms are usually prefabricated and sewn, then field fitted and fastened with zippers, ties, or clips.
- They are easily formed and fitted to irregular surfaces.

DISADVANTAGES

- IRREGULAR SURFACE
- ULTRAVIOLET DETERIORATION
- MAINTAINING COVER
- ALKALINITY
- STRENGTH
- STRETCH

9-31

Disadvantages include:

- Repair surfaces are generally irregular and in currents they tend to billow and can be very hard to place.
- Some materials are degraded by ultraviolet light. They partially decompose and may look ragged.
- Because they are flexible, it can be hard to hold the form away from the substrate and maintain repair thickness and reinforcing cover. This is especially a problem for horizontal members and batter piles. Repair thickness/uniformity is hard to control.

- Depending on fabric mesh size, cement particles may escape into the waterway and increase water alkalinity. This is especially a problem in areas with fish populations.
- Fabric may tear. Concrete placement must not overstress the fabric or connections such as zippers.
- Fabrics may stretch up to about 10 percent. This adds weight and effects costs. It may cause payment disputes due to volume computations.

V. CONCRETE PLACEMENT

A. REINFORCING AND ANCHORAGE

**REINFORCING
AND
ANCHORAGE**

9-32

Prior to setting forms, any work on existing or new reinforcing or anchorage steel must be completed.

REINFORCING STEEL

- **CLEAN**
- **REHAB**
- **NEW**

9-33

Normally, reinforcing should be cleaned of corrosion prior to repairs. Reinforcing may require splicing new steel or adding steel to unreinforced areas.

CLEANING

- **WATER BLAST**
- **ABRASIVE BLAST**
- **WIRE BRUSH**
- **CHEMICAL**

9-34

Several types of cleaning techniques may be used for reinforcing steel below and above water. Reinforcing may be cleaned by water or abrasive blasting for large projects or by wire brushing for smaller areas. Poultices of jelled phosphoric acid followed by wire brushing have been used to clean steel, but environmental concerns may make this unacceptable.

REHABILITATION

- **DETERMINE LOSS**
- **ADD BARS**

9-35

Where steel section loss takes place, the extent of loss must be measured, and new steel may need to be added. Replacement/supplemental steel is often used if over 25 percent of the original reinforcing section has been lost. (What is Agency Practice?)

Add new bars by lap splice. Minimize splice length of added steel by using (several) smaller bars, thus reducing extra concrete removal to allow for the splice. Mechanical couplers can be used, but may be problematic with older or deteriorated steel.

MINIMUM REINFORCING

- **.125 SQ. IN. PER FOOT**
- **.3 PERCENT**
- **#4 @ 18**

9-36

For unreinforced concrete, use of a minimal steel area in bars and hooked anchors to tie the repair to the substrate is recommended. The amount of steel to be used is up to the design engineer, with the following sometimes used.

- For walls, at least 1/8 square inch per foot in each direction, spaced at three times the wall thicknesses or 18 inches (maximum). This is an AASHTO provision.
- A steel area of .3 percent of the concrete area in each direction, for wall type repairs.

- Drilled and grouted hooked bars, number 4 bars at 18 inch centers, each way.

ANCHORAGE

- EXPANSION ANCHORS
- GROUTED ANCHORS
  - CEMENT
  - RESIN

9-37

Anchorage to concrete may be short term or permanent and is needed for dowel bars, form attachment, fendering, etc.

Expansion anchors are set in drilled holes and secured by mechanical means (friction or sometimes undercut), while other anchors are secured in drilled holes by grout (adhesion).

Grout typically is either portland cement based or a resin.

EXPANSION ANCHORS

- CONCRETE QUALITY
- HOLE SIZE
- SWEDGE TYPE
- SLEEVE TYPE

9-38

Anchors for above water can be used below water. If corrosion is a concern, stainless steel anchors are available.

Concerns in anchorage capacity include:

- Concrete Quality - This is particularly a concern in deteriorated areas.
- Hole Size - Hole tolerances are important for anchor strength.

Both are apt to be of poorer quality below water than above.

Expansion anchors of both the sleeve type and driven in swedge anchors are available.

9-39

This shows an expansion anchor fastening a steel plate form.

GROUTED ANCHORS

- CEMENT
- RESIN

9-40

Grouted anchors can be placed in grout filled holes or grout can be pumped in after anchor placement.

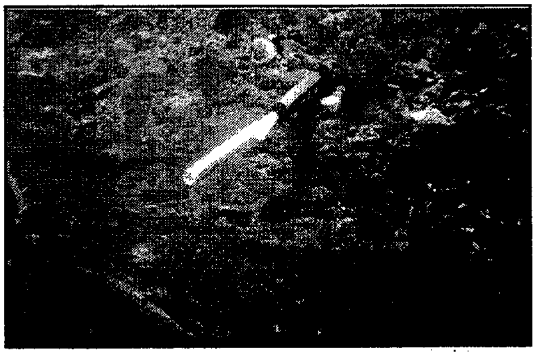
Cement grout is typically neat portland cement and water, perhaps with an expansive admixture. Resin anchors may be epoxy or polyester.

Corps of Engineers tests have shown that cement grouts are preferred for below water usage. Tests showed pull out strengths for cement grouts placed below water were comparable to placement above water, while epoxy grout strengths were about 10 percent and polyester were about 35 percent lower when placed in wet conditions. (REF: Corps of Engineers TECHNICAL REPORT REMR-CS-23)

For both cement and resin anchors, pull out is improved if the holes are well cleaned before grouting. This is especially important for drilled (as opposed to cored) holes.

For resin anchors, cure rates will be slowed in colder waters, and Corps tests indicate substantially higher creep rates for polyester anchors than for cement or epoxy.

Grouted anchors are not effected by hole size tolerances as are expansion anchors.



9-41

Hollow stem anchors, as shown here, are available and work well. They allow the grout to be pumped through the anchor so that it pushes out around the anchor from behind. A special fitting is used to couple the pump line and anchor.

RESIN

- CAPSULE
- PUMP

9-42

Resin anchors include capsule systems and pumped systems. Polyester or epoxy are usually used.

Corps' research shows that capsule anchor systems where the cartridge is inserted in the hole and the anchor is then inserted and rotated to mix the resin, do not perform well underwater. This is at least partly attributable to the mixing of water into the resin as the anchor is rotated.

Anchors should be placed into resin filled holes or have resin pumped into place after anchor insertion.

9-43

Where anchor strength is critical, testing can be performed with a torque wrench or center hole jack. Here a torque wrench is being used.

PLACEMENT METHODS

- IN DRY
- TREMIE
- PUMP
- PREPLACED AGGREGATE

9-44

B. PLACEMENT METHODS

Once forms are placed, concrete placement can begin. Several placement techniques are commonly used as listed here. The choice is dependant on the location and extent of repair and may effect form requirements.

Concrete can be placed by direct dumping using special closed bottom dump hoppers or chuted. Free falls should be limited to around 3 feet.

Concrete can also be chuted into place but this is not recommended.

Anti-washout admixtures should be used with these methods. Results of past work are mixed.

CONCRETE PLACEMENT IN DRY

9-45

Concrete for bridge repairs can usually be supplied from trucks on a closed lane on the bridge deck. Otherwise trucks can be barged to the site, or small batch plants set up on barges at the site.

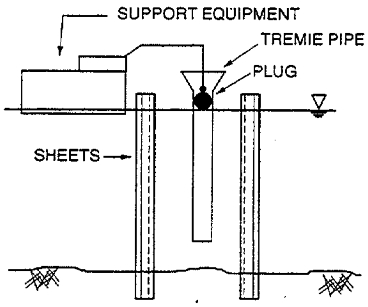
Where cofferdams are built and dewatered or tight forms extend above the water surface, the area can be pumped dry and concrete placed as for above water work. Chutes, conveyors, pumping or buckets can be used to deliver the concrete to the forms.

TREMIE

9-46

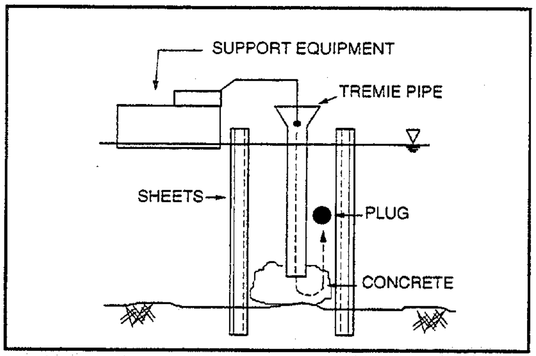
Tremie is the "traditional" placement method for underwater work, and has been in use for many decades.

The following slides illustrate the tremie method.



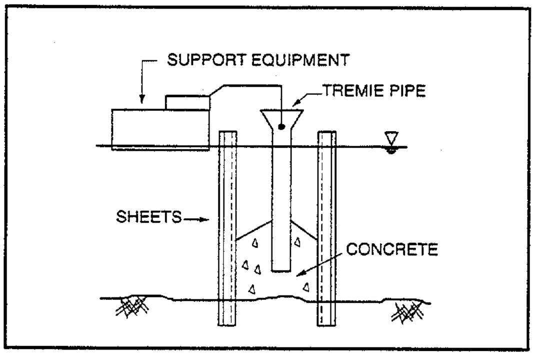
9-47

In this figure, we see a barge, a sheeted area ready for concrete, and a tremie pipe extending down into the waterfilled space between the sheeting. Heavy equipment is required to handle the tremie pipe. The tremie process is quite simple; its proper execution requires great care, Tremie pipes typically range from 8 to 12 inches in diameter.



9-48

The tremie pipe may be open ended at its base, or it may have one of several patented valve arrangements. With the more common open end, a plug or ball is placed ahead of the concrete to push out the water and provide an initial concrete flow with minimal water dilution. The concrete weight pushes the plug out the tremie and placement begins. Embedment of the tremie in the concrete is usually maintained at 3 to 5 feet. If the tremie seal into the concrete mass is lost, it is very hard to reestablish the tremie, and cold joints are usually developed.



9-49

As concrete is deposited the tremie rises, pipe is kept buried in deposited concrete.

A sufficient supply of concrete must be available for uninterrupted placement. For large areas multiple tremie pipes can be used. As general guidance, one tremie pipe is used for each 300 horizontal square feet of placement. Concrete slopes ranging from 1 vertical to 6 horizontal, to flat may be expected. For jointed tremie pipes, joints should be tight so water is not sucked in by venturi action of the falling concrete.

Calculations of expected concrete quantities and actual quantities should be kept as a check against a form blow out or line plug.

TREMIE MIX

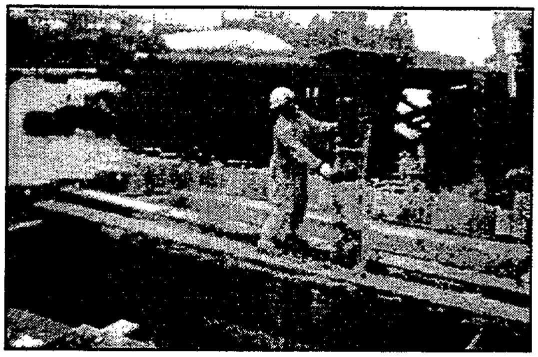
9-50

Concrete for tremie placement should have high workability while being cohesive enough to limit segregation and washout. A typical mix is as follows:

- Slump, 8 to 10 inches
- Cement content, 600 pounds per cubic yard.
- Aggregate, 3/4 inch maximum size if reinforcing is present with up to 1 1/2 inch used in plain placements.
- Fine aggregates make up 45-55 percent of total aggregate volume.
- Water/cement ration, 0.45

- Pozzolans, water reducing and retarding admixtures are usually used. Anti-washout admixtures are also beneficial.

High range water reduces should only be used if they have adequate working life, or in small placements. For large placements, the heat generation of a rich mix should be evaluated. For placements in reinforced areas, a clear spacing between bars of at least four times the maximum aggregate size is recommended, with a 2 inch clear spacing as a minimum.



9-51

Small tremie pipes are often used for grout placement. The same principles apply to grout proportioning and tremie usage as with a concrete mix.

Tremie is best suited for large pours or deep pours with minimal tremie movement. Two limitations to its use are:

- Water flow across placement must be stopped.
- Placement width is limited by concrete "mound" depth and slump angle.

This picture shows the top of the tremie pipe in place to receive concrete.

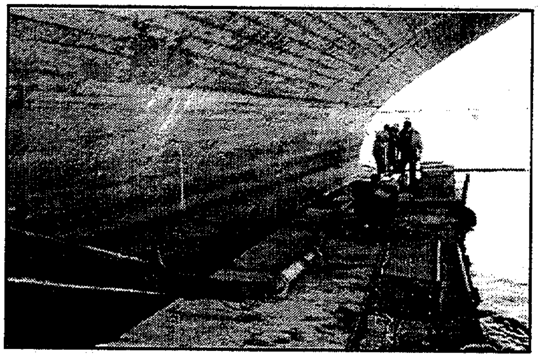
PUMPING

9-52

Pumping can be used similar to above water practice. Placement techniques for tremie are generally applicable to underwater pumped placement as well.

Several differences in the technique include:

- The pump line can be manipulated for depositing concrete under footings or into oddly configured forms.
- The pump line may tend to be jerked out of the placement by pump pulsations.
- A vent line may be required at the high point of the pump line to prevent a vacuum developing.



9-53

- A diver controls discharge of the mix.
- Pumping equipment is usually smaller then tremie.
- A diver controlled valve can be used to allow withdrawal of the pump line from a placement and start of a new placement.
- Hoses should be small for diver control.

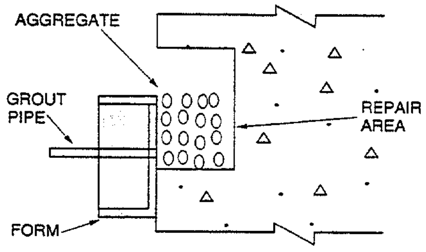
This shows a pump line leading to underwater pier repair. Note that a long pump line is used requiring very good workability of the concrete, and a long set time.

PREPLACED AGGREGATE
ACI 304

9-54

Preplaced aggregate concrete (PPA) is produced by placing coarse aggregate in a form and later pumping a cement-sand grout to fill the voids between the course aggregate particles. Usage is covered in ACI 304. Preplaced aggregate concrete has been used for large placements underwater, and is also well suited for repairs.

PPA has a long history of use for repairs. It exhibits low shrinkage and good bond to existing substrates. Durability is very good and air entrainment is possible. Grout is not significantly diluted by the amount of water in the aggregate voids.



9-55

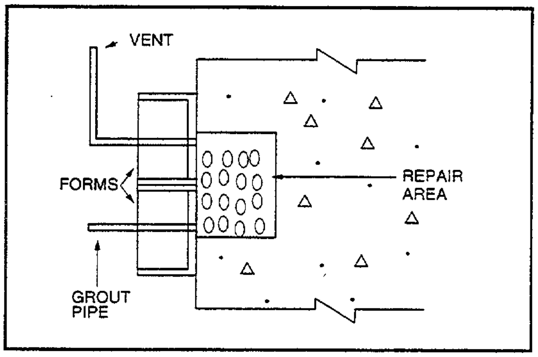
The following two figures figure show a schematic of PPA placement.

In this figure the first portion of forms and grout pipes are in place with aggregate in the repair.

PPA is placed as follows:

- Prepare surface.
- Set forms (partial height of the repair) and grout pipes within the repair area and fill remaining area with aggregate through hand holes. Forms must fit tightly to prevent grout leakage.
- Place coarse aggregate.
- Complete forms, in sections if needed.
- Pump grout working from the bottom up.

Grout is pumped through pipe nipples on forms or through pipes previously embedded in the aggregate mass.



9-56

In this figure, the forms are completed, the repair area filled with coarse aggregate, and the grout and vent pipe installed. Grout will then be pumped into the aggregate resulting in concrete. Pipes are usually 1 1/2 inch schedule 40 or PVC pipe. Grout is pumped until it flows from the vent lines. Usually a small amount of grout is wasted in overflow.

Coarse aggregate should have a low void ratio and is usually uniformly graded from the smallest to largest size. Grouts may be a prepackaged products or site mixed. Grout fluidifiers are usually used, and sometimes an expansive agent. Grout consistency is measured by a flow cone (ASTM C939 test method) with flows of 20 to 22 second usually used for underwater repairs.

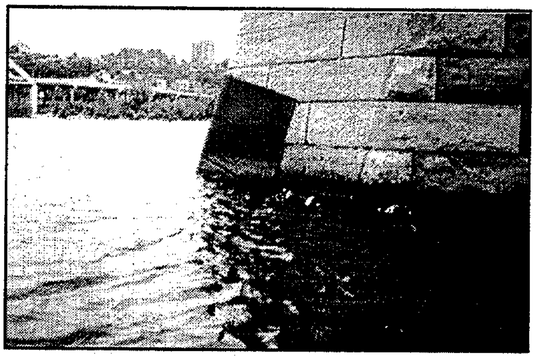
In highly polluted water, heavy silt load areas, or areas of rapid marine life growth, aggregate may become contaminated if work is not promptly carried out, sometimes within 48 hours.

MASONRY

9-57

VI. MASONRY

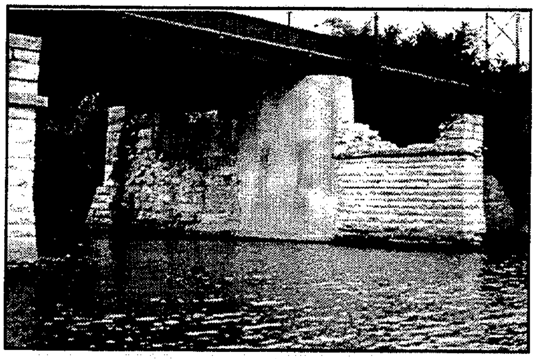
Many bridge piers are masonry, most often of stone. This is especially common on older structures.



9-58

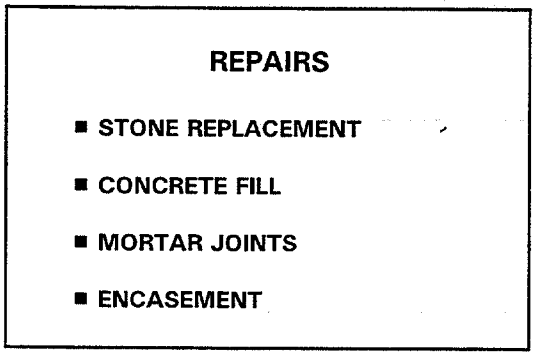
Both the stone and the mortar joints deteriorate.

In many cases, repairs are intended to prevent further deterioration. It is rare for major structural repairs to be needed to the pier itself. Here, a repair has included adding steel plates on the pier nose to reduce further ice induced abrasion.



9-59

This slide shows a heavily deteriorated pier with a variety of materials. Note the original stone facing with cyclopean masonry fill. Both brick and concrete repairs have been made.



REPAIRS

- STONE REPLACEMENT
- CONCRETE FILL
- MORTAR JOINTS
- ENCASEMENT

9-60

Common repair techniques include:

- Stone replacement
- Concrete fill of stone voids
- Mortar joint tuckpointing
- Encasement of the pier with concrete

STONE REPLACEMENT

- FOR APPEARANCE

9-61

A. STONE REPLACEMENT

Stone replacement is used where structure appearance must be maintained (i.e., historic bridges).

New stone should match the type and size of existing stone.

Because many quarries are no longer producing building stone, and accessible high quality stone has often been previously depleted, good quality stone may be hard to find.

Replacement stone is normally set on spacers and mortar pumped around it to fully fill the joints on all faces.

CONCRETE FILL

9-62

B. CONCRETE FILL

Deteriorated/missing stones may have the resulting void filled with concrete. This is less expensive than stone replacement but unattractive.

The old stone is removed, area formed, and concrete placed. Venting of the formed area is required to fully fill the void area. A form liner can be used to give an appearance more nearly matching the adjacent masonry.

MORTAR JOINTS

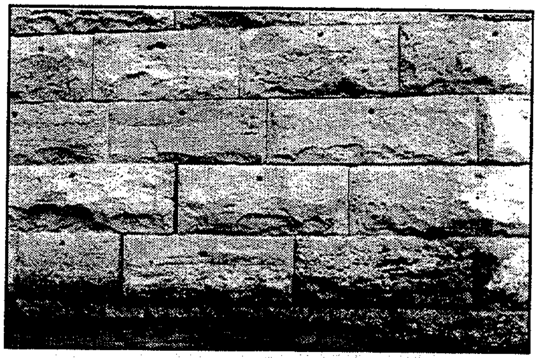
9-63

C. MORTAR JOINTS

Erosion of joints can be repaired by:

- Hand applied mortar
- Caulking
- Pressure grouting

For all repair methods the joints should be first cleaned of loose and deteriorated material, dirt, and marine growth.



9-64

Hand applied mortar joint repair is conducted in the same manner as above water tuckpointing. Hydraulic cements are often used for underwater work. They are placed with a pointing trowel or squeeze bag.

If joint strength is not jeopardized, caulk may be used to stop further deterioration.

Joints can also be pressure grouted with cement grout or epoxy after a seal is placed over the joints.

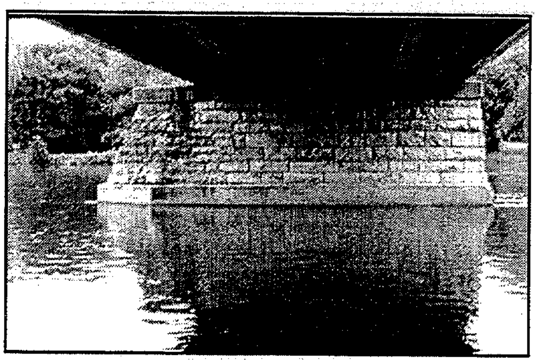
Note that the use of very hard materials as joint fillers can cause edge spalls and cracks when used to repair older, softer mortar joints.

ENCASEMENT

9-65

D. ENCASEMENT

Masonry piers are (partially or wholly) encased in concrete to restore deteriorated areas and add future protection. The encasement may extend to the base of the pier or to an elevation below water where no deterioration has, or is expected to, occur.



9-66

Concrete is formed and placed usually from above water. Mixes must have excellent durability. The encasement should be reinforced. Partial height encasements must be tied to the pier with dowels to aid in supporting the encasement vertical load.

EPOXY INJECTION

9-67

VII. EPOXY INJECTION

Epoxy injection is commonly used above water to repair cracks. The technique involves filling cracks with special epoxies under pressure and can restore structural strength, limit water penetration, etc., depending on resin choices.

The method and materials are also used underwater with good success.

Note: Resins include other polymers than true epoxy.

MATERIALS

9-68

A. MATERIALS

Resins used underwater are specially formulated to be water insensitive. Resins designated simply as moisture insensitive may not work in immersed conditions.

CAUTIONS

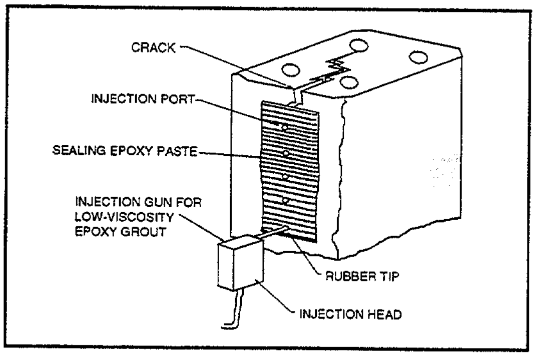
- CONTAMINATED CRACKS
- WATER TEMPERATURE
- LONG HOSES
- SLOW WORK

9-69

Several areas can present problems for injection repairs, and influence material selection..

- Contaminated cracks can be flushed with clean water or cleaning agents so that proper crack penetration and bond of the surfaces can be achieved.
- Water temperature will effect the cure rate of both the seal coat and injected resin. Colder water, particularly below 55°F may drastically slow or even prevent proper curing unless special formulations are used.

- Long hoses for resin transport are common in underwater work where the proportioning equipment and pump are kept topside. This contributes to resin temperature loss. Mixing heads should be at the injection point so mixed resin does not harden in the lines.
- Slow work is usual due to added constraints on the diver. This produces similar effects to long hoses.



9-70

B. INSTALLATION

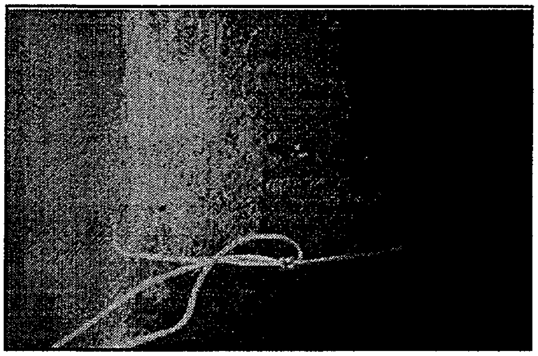
This drawing shows the injection process.

- A seal coat of epoxy is troweled over the cleaned crack surface.
- Injection ports are set in the seal coat over, or drilled into, the crack.
- The injection resin is pumped into the crack through the port, working from the bottom of the crack.
- As resin flows from the port above, the lower port is sealed and the injection point is moved up to the port above the process continues till the crack is full.
- Where appearance is important, the seal may be ground off.

We will now look at a series of slides showing the injection process on an actual crack. The purpose is both to seal the crack and to restore strength across it.

9-71

The first step is cleaning the crack for the seal coat. Here a needle gun is being used for cleaning.



9-72

Here is the cleaned surface with the crack visible. Cracks as small as .003 inches wide can be injected.

9-73

Holes are drilled for setting the injection ports. In some producer's systems, no port is used. Rather a gap in the seal coat is left and the injection nozzle has a fitting so it can be pressed to the crack and resin injected.

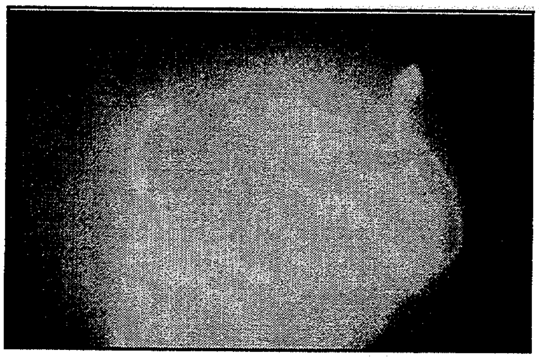
9-74

Diver hammering in port. The spacing of ports is largely based on the contractor's experience. Spacing between equal ports to the expected depth of the crack is a simple rule of thumb.

9-75

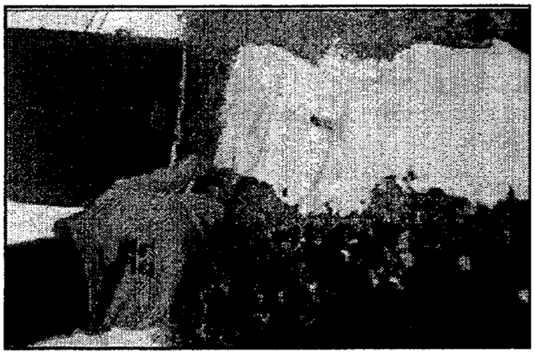
The seal coat is mixed topside and is a two component neat epoxy.

It can then be carried to the point of application in a bucket. Application to the crack surface can be by hand or trowel. The epoxy must have sufficient pot life that it does not harden prior to application.



9-76

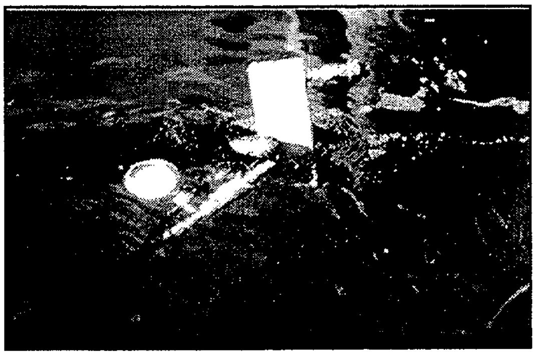
Note mix stays in the pail.



9-77

This shows the trowel application of the seal coat.

Where cracking is extensive, or spalled areas are injected, care must be taken that the injection pressure does not cause the cracked surface to fully fracture. The seal coat is not strong enough to do this and special banding may be required to resist these tensile forces.



9-78

A mixing head and injection nozzle can be seen here being taken underwater. The mixing head mixes the two epoxy components immediately prior to injection. This prevents problems with epoxy set-up in hoses. Note the pressure gauge for monitoring injection pressure. Lower pressures are preferred to aid in crack filling. Typical pressures are 20 to 40 psi. Changes in pressure during injection may indicate blown seals or undetected interior voids.

9-79

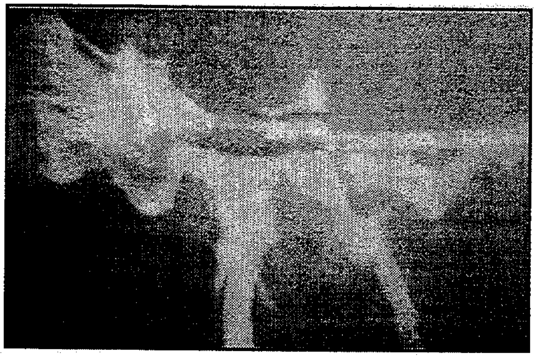
This shows the epoxy being pumped into the ports. The adjacent ports are monitored, and pumping continues till the port above starts to flow epoxy.

9-80

This shows a pier crack with a different style of port being set. The process is the same as previously described; only the equipment and parts are somewhat different. As the technique has grown in usage, a variety of proprietary "hardware" has been developed.

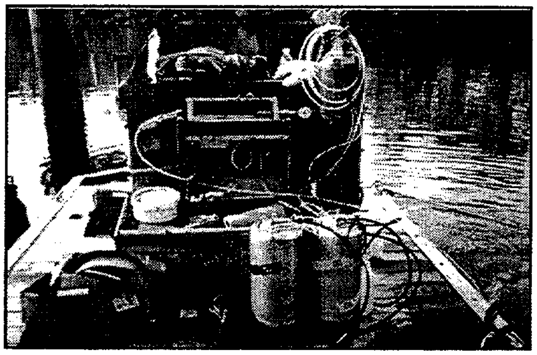
9-81

The ports and seal coat are shown here in place.



9-82

The injection hose is coupled to a port. Note this is a single hose system and not a mixing head. The mixing and pressure are monitored at the pump.



9-83

Mixing equipment for epoxy injection on a float. This system consists of epoxy component storage chambers, mixing and proportioning equipment, and a pump to supply the epoxy to the injection head.

UNDERMINING

9-84

VIII. UNDERMINING

Undermining of footings is a relatively common and potentially dangerous condition. Most often this is caused by local scour, but can be more extensive as a result of general scour.

Both pile supported and spread footings are effected.

LOAD CAPACITY

- VERTICAL
- HORIZONTAL

9-85

Undermined foundations may have both their vertical and horizontal load carrying capacity reduced. An engineering analysis should be made to evaluate the effects of the undermining and establish the parameters for repairs.

Where general scour has occurred, exposing more of the pier to lateral loads while perhaps also reducing soil restraint, horizontal stability may be a particular problem.

For pile supported foundations, concrete placement in voids created by undermining may add undesirable dead load to the piles. In some cases, piles have been wrapped with plastic as a bond breaker to prevent adhesion of fill concrete.

TYPICAL REPAIRS

- FORMED CONCRETE
- GROUT BAGS
- GROUTED STONE

9-86

Repairs of undermined foundations generally involve filling the undermined area, and providing protection, such as riprap, against future problems. Measures for protection will be addressed in Session 13.

Many repair schemes are used to fill the undermined area. The following are commonly used:

- Form and place concrete in the void
- Grout bags can be packed into the void or be used as forms
- Place and grout stone extending beneath the foundation

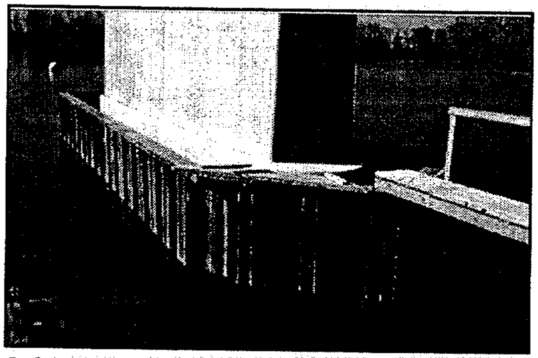
FORMED CONCRETE

9-87

Formed repair of the void areas is often used. Forms, of various types, are set around the undermined area and concrete placed into the void, usually by tremie or pump.

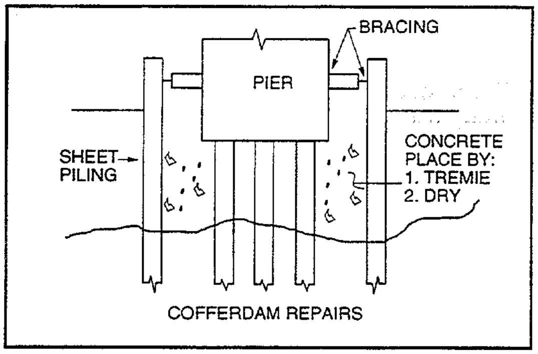
The area under the footing should be cleaned of debris and loose sediments prior to setting forms.

The forms can be set in shallow trenches to help reduce the chance of the fill concrete being lost under form edges at pockets of loose material.



9-88

Sheet pile can be used as forms and when left in place can also provide protection against further undermining, if driven sufficiently deep. The depth of driving can be determined through scour calculations using HEC-18 and HEC-20, and is further covered in Session 13.

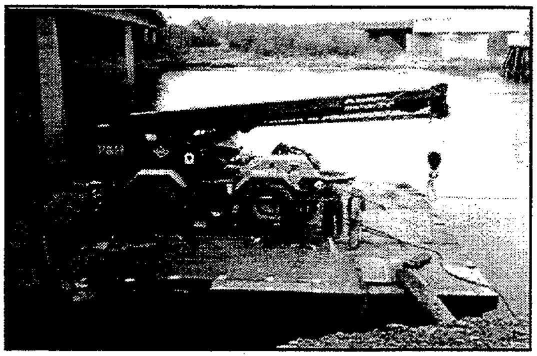


9-89

This drawing shows typical construction of sheeting for pier rehabilitation. Sheeting will add to the footing width and this will have an adverse effect on scour. At blunt nosed piers, this can be mitigated somewhat by using a pointed nose for the sheeting, thus reducing the pier nose coefficient.

If the repair is kept to the original pier width, flow is not adversely effected.

After sheeting is placed, concrete is deposited by tremie, or the area pumped out and concreted in the dry.



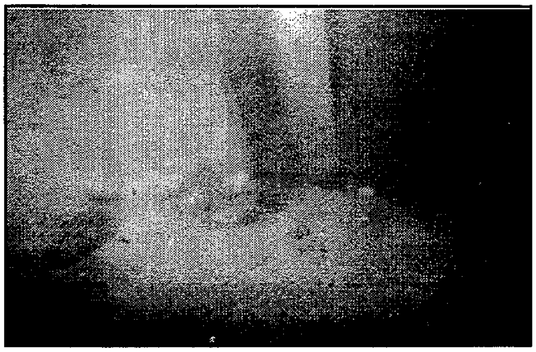
9-90

The void area can be formed tight to the existing structure with standard or custom rigid forms. Concrete is pumped into the void, or can also be placed by inclined tremie.

Pier width is not increased, but further protection of undermining can not be built into the repair.

Forms are usually left in place due to the cost of removal.

This slide shows a custom fit, stay-in-place steel form ready to be set.



9-91

Note the fit of the form to the river bottom. The weight of the steel allows it to bite into the bottom several inches, helping reduce any chance of a blow out during concrete placement.

Viewing ports and small vent lines should be placed so that complete filling of the void can be verified, and water is not trapped at high points under the footing.

GROUT BAGS

9-92

Grout bags can be used for forms and to do a variety of repair schemes. Fabric for forms and grout bags was discussed earlier. Some of the uses for grout bags include:

- Concrete filled bags can be taken down and placed in the void.
- Fabricated bags can be set into the void and pumped with grout
- Bags can be used as forms around the void which are then pumped with grout and after curing serve to contain concrete pumped into the void.

Bag size and shape are tailored to their specific end use.

9-93

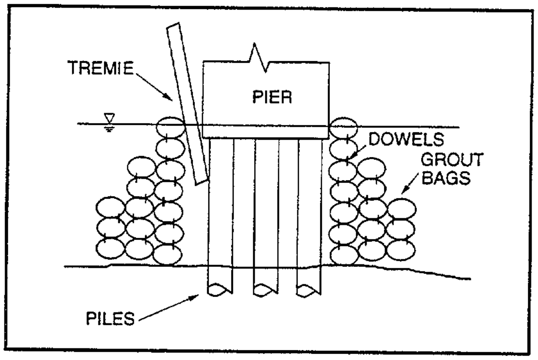
Simplest use is to pact the undermined area with bags full of concrete/grout.

Commercial bagged concrete mixes have also been used for small projects. The bags are sometimes placed with the dry mix with the expectation that moisture will move through the bag and eventually hydrate the concrete mixture. Since most bags now have moisture resistant liners, holes can be punched to aid in letting water reach the cement. Use of very low slump bagged concrete is preferable to assure curing.

9-94

Larger bags can be custom fabricated and sewn to fill the area. These are placed, and then pumped full of grout or concrete.

Accessible areas of bags are often pinned to each other with reinforcing bars as shown here. This can be done with bags of all shapes and sizes, and adds to overall strength.



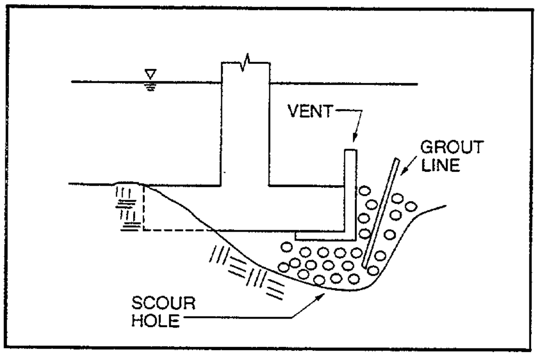
9-95

Bags can be used to partially fill void while acting as forms to contain pumped or tremied concrete fill as illustrated here. Though exaggerated in this schematic, pier width effects should be evaluated as noted for sheet pile forms. Where groups of bags will serve as forms it is important that they are well doweled together. Setting the lower layer partly into a trench adds lateral stability and perhaps some minor scour protection. During bag setting, grout pumping lines and vent pipes should be placed between bags for filling of the void area.

GROUTED STONE

9-96

Grouted stone is another technique used to fill scour areas around and under piers. Stone can be placed around/under a pier with grout pipes set and the void area under the pier and within the stone grouted.



9-97

This shows a schematic of a grouted stone placement. The stone is usually placed by dumping.
Grout is usually sand/cement with anti-washout and water reducers added.

Placement should be monitored by divers for leakage of grout.

STONE GRADATION

- D50 = 1' DIA.
- 1.26 D50 ≤ D100
- D100 ≤ 1.71 D50
- D15 = 0.5 D50

9-98

This shows a typical stone gradation which has been used. Stone unit weight of 165 pounds per cubic foot and a 10 percent tolerance on gradation were also specified.

Note: D50 designates the stone size for which 50 percent are smaller.

GROUT

- 1 PART CEMENT
- 2 PARTS SAND
- W/C = 0.7
- ADMIXTURES

9-99

The grout mix used for the stone shown above is given here. Admixtures include water reducers, a pumping aid, and anti-washout agent. Pump pressure was 5 psi over the water depth.

FOOTING EXTENSIONS

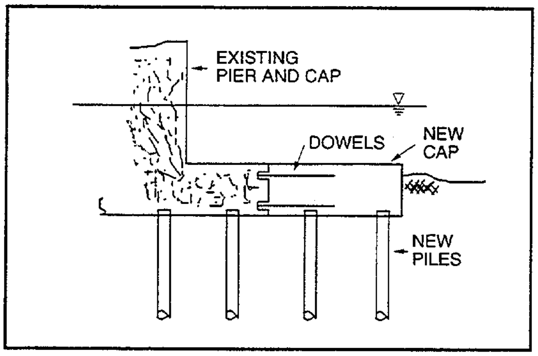
- SPREAD
- PILE

9-100

Footing extensions which may be required as a result of bridge widening or stability concerns due to scour assessments usually will be built in a cofferdam, but can be constructed underwater.

Extensions of spread (or shallow) foundations or pile foundations can be built using techniques similar to those for repair.

While there may be many reasons not to construct a footing extension underwater for any given project, and the scheme illustrated is not ment as a "recommend" solution, it is important to not simply dismiss underwater methods out-of-hand for such problems.



9-101

Spread footing or pile cap extensions can be constructed as above water. Since edges of the foundation are not seen, they can be formed with bags or fabric.

- Dowels and reinforcing are set as previously discussed.
- Concrete can be placed by pump, tremie, or bottom dump. Unless the footing or pile cap is quite thick, establishing a tremie seal is difficult.

Piles are usually driven from above water. They can be cut-off underwater by burning, or hydraulic pipe cutters if pipe piles.

Piles can also be driven underwater with hydraulic pile drivers. This is usually only done in very deep water where piles would be quite long if driven from above.

Cap construction proceeds as for footing extensions.

SUMMARY OF PIER REPAIR TECHNIQUES

- REPLACEMENT
- HAND PATCHES
- FORMED REPAIRS
- CRACK INJECTION
- MASONRY
- UNDERMINING

9-102

IX. SUMMARY

Various processes and techniques for repairs to bridge piers have been presented in this section. While extreme cases could necessitate partial or complete pier replacement, most problems can be repaired.

Common repair techniques include hand patches, formed repairs, and crack injection. These are carried out underwater in much the same manner as above water. Potential areas of difficulty such as anchorage, surface preparation, and mix design have been addressed. Repair techniques for concrete are also applicable to masonry, unless stone replacement is needed.

Undermining of piers involves filling of the void area using a variety of containment methods to keep the fill material in the void area.

SESSION 10

PILE REPAIRS

SESSION 10: PILE REPAIRS

TOPICS: PILE REPLACEMENT
PILE WRAPS
PILE JACKETS

LESSON PLAN:

DURATION	90 minutes
GOAL	To show types and design considerations for pile repairs.
OBJECTIVE	Ability to evaluate alternate repair systems and select appropriate techniques.

OUTLINE

I. Introduction
II. Replacement
    A. Total
    B. Partial
III. Pile Wraps
IV. Pile Jackets
    A. Concrete Filled
    B. Polymer Filled
V. Coatings
VI. Crack Injection
VII. Repairs to Wraps and Jackets.
VIII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 10
PILE REPAIRS

10-1

I. INTRODUCTION

Piles are widely used to support bridge structures. A variety of repair techniques are available. Choice of repair type is partly dependant on the extent and type of damage and deterioration and may be preventative and/or remedial. Repairs may be partial or full length.

PILE MATERIALS

- **STEEL**
- **TIMBER**
- **CONCRETE**

10-2

Piles are constructed of three basic types of materials:

- Steel H-piles or pipe piles
- Timber
- Concrete
    - Cast-in-Place, large diameter shafts
    - Precast with mild steel reinforcing
    - Prestressed, usually square or octagonal or hollow cylinder "Raymond" piles

Repair techniques partly depend upon the pile type

PILES CAN BE DAMAGED BY

- **VESSEL IMPACT**
- **OVERLOADING**
- **DEFECTIVE MATERIALS**
- **IMPROPER INSTALLATION**
- **WEATHERING**
- **CONSTRUCTION PRACTICES**

10-3

Piles can be damaged by:

- Vessel Impact
- Overloading
- Defective Materials
- Improper Installation
- Weathering
- Construction Practices

Information of types of damage and deterioration can be found in the "FHWA Underwater Bridge Inspection Manual", and also in our previous Session 2. In many cases, repairs may be required due to deterioration resulting from a combination of factors.

Pile damage during construction should be repaired as part of the "punch list" work, thus starting with a sound structure.

REPAIR OPTIONS

- FULL OR PARTIAL REPLACEMENT
- WRAPS
- JACKETS
- COATINGS
- CRACK INJECTION

10-4

Several options are available for pile repair.

If a pile is sufficiently damaged that the member can not be effectively repaired, it must be replaced or other design alternatives considered. Wraps, jackets, coatings and crack injection are techniques commonly used for pile repair. Repair decisions must be based on an engineering assessment of each structure.

REPLACEMENT

10-5

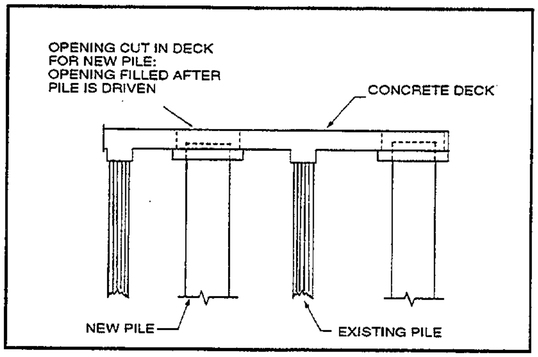
II. REPLACEMENT

A. TOTAL REPLACEMENT

It is sometimes preferred to completely replace a damaged pile. Replacement techniques are generally similar for steel, timber and concrete piles. The damaged pile is normally cut off well below the waterline, or may be pulled, so as not to create an obstacle. In some instances it is possible to leave the damaged pile in place and drive the new pile adjacent to the old pile.

10-6

This slide shows a new pile driven immediately adjacent to a damaged pile. The new pile is usually of the same size as the pile it "replaces". Normally the old and new pile are not considered to share any load.

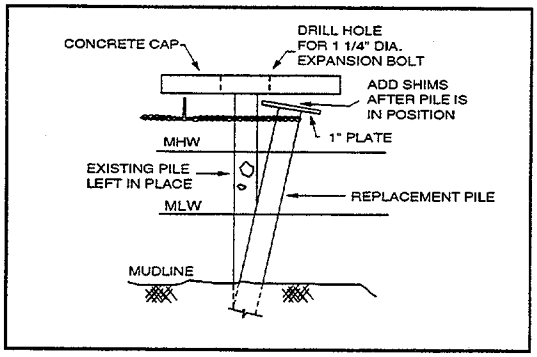


10-7

One method for replacing a pile is to cut a hole in the deck or cap adjacent to the damaged pile. A new pile is then driven using the hole for access. A new or modified cap is formed around the new pile(s) as required.

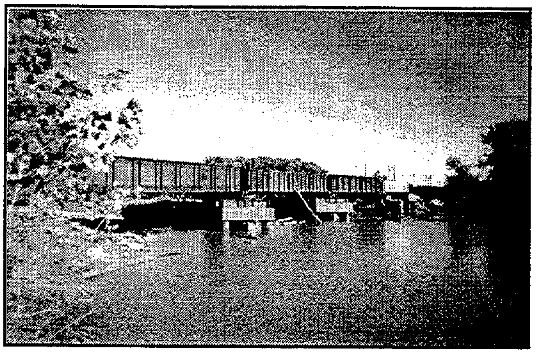
In order to reduce the size of hole, small diameter pin piles may be used. Where headroom is low, piles may be jacked into place rather than driven. Attention must be given to load transfer of the cap/pile junction.

This method can also be used simply to add piles to increase capacity, with existing piles at full strength. Load distribution between existing and added piles must be evaluated and an assessment of how much, if any, dead load is to be considered carried by the old piles.



10-8

This slide illustrates a technique for replacing perimeter piles without cutting a hole in the deck. The replacement pile is driven adjacent to the damaged pile at an angle, or vertically. Once driven to the proper tip elevation, the pile is pulled into position. While this technique introduces undesirable bending stresses into the pile, it may be successfully used if these stresses are included in design. It may also be used as a temporary or emergency measure.



10-9

If it is not desirable to form a new cap, a crunch bent can be used. The technique involves driving two piles on opposite sides of a damaged pile, and forming an intermediate cap to transfer loads from the new piles to the existing cap. This photo shows a crunch bent configuration.

Access will often determine whether replacement techniques are used, and if so what method is most effective.

PARTIAL REPLACEMENT
(SPLICING)

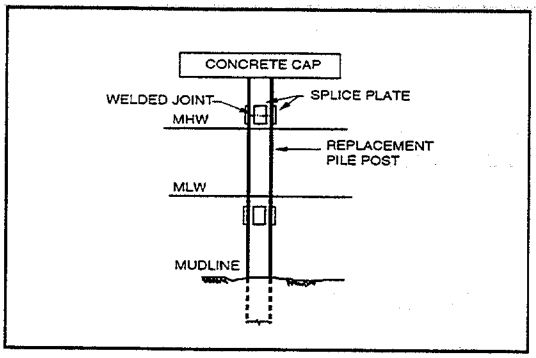
SUITABLE WHEN A SMALL PORTION OF THE PILE IS DAMAGED.

10-10

B. PARTIAL REPLACEMENT

Partial replacement, also known as splicing or stubbing, is the process of replacing the damaged portion of a pile with a new section. Piles with isolated deterioration in the splash zone are ideal candidates for partial replacement. While partial replacement can be used with steel and timber piles, it is very rarely used with concrete.

Partial replacement details must be carefully considered for their capability to carry pile axial loads as well as any shears or moments. In some cases partial replacement is followed by concrete encasement.

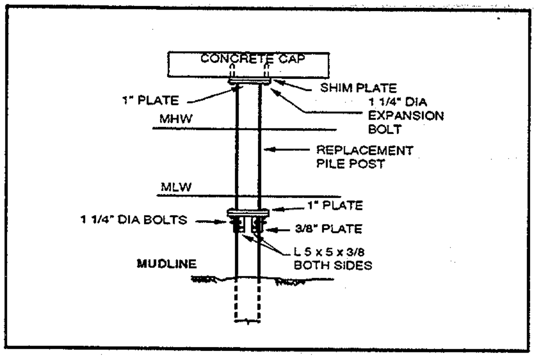


10-11

Steel Piles

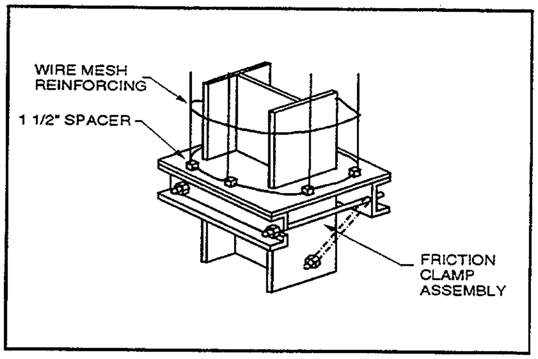
Partial replacement is an effective method to restore the load bearing capacity to damaged steel piles. The effectiveness of the repair is dependent on the quality of the connections. There are several common techniques used to splice a new section to an existing steel pile.

The preferred method of making a splice connection is welding. Steel plates are welded to the flanges and web.



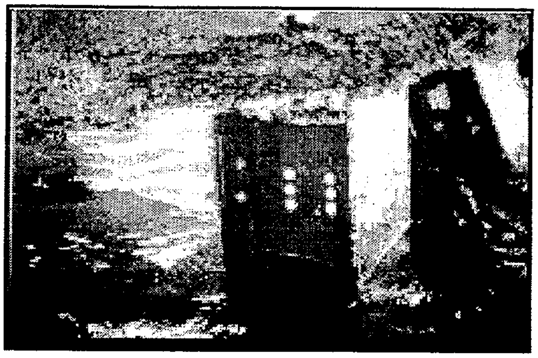
10-12

If welding can not effectively be performed, bolting the replacement section to the existing pile or deck is possible. Holes can be drilled underwater using the splice plate holes as a template. This slide shows techniques recommended by the US Navy. It should be emphasized that splice connections should always be designed by a structural engineer.



10-13

This shows an alternate bolted connection at the pile base. In some cases it may be possible to reduce difficult underwater work by making connections during periods of low water, either at low tides or seasonal low water fluctuations.



10-14

Piles may be strengthened by adding plates or members to add section. Again, welding or bolting can be used for connections. Here channel sections have been bolted to the inside of H-piles.

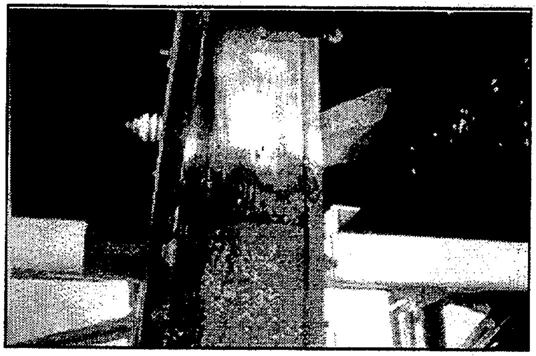
Steel used for repairs should be coated for corrosion protection and sacrificial thickness provided.

10-15

Timber Piles

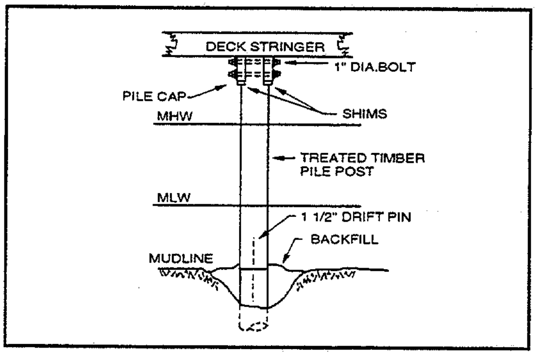
The partial replacement of timber piles is not a preferred method of repair. Partial replacement should be used only on small structures that are not subject to significant axial or lateral loading, and only as a temporary repair when other repair methods are not practical. Splicing can be used on large structures as long as the percentage of spliced piles remains low (i.e. less than 20%). Splicing is less favorable than other repair methods because of the larger number of variables that can affect the transfer of axial load, and the fact that timber splice connections have very little moment transfer capacity.

When treated timber piles are cut, the untreated timber core is exposed, making the pile susceptible to decay and marine borer attack. All untreated timber should be coated with a timber preservative as discussed in Session 8. Metal or polymer pile caps can be used on the top of the pile or top of a lower cut section as a means of protection.



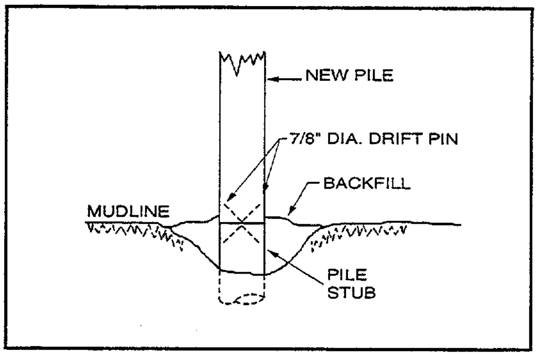
10-16

Once a partial replacement is made to a timber pile structure, a new lateral bracing system must be installed. If a pile wrap system was applied during repairs, the bracing system should be attached using friction connections to avoid damaging the wraps. If the new bracing system must be bolted to the repaired pile, an attempt should be made to drill only one hole in the pile, and to create a water tight seal when the fasteners are tightened.



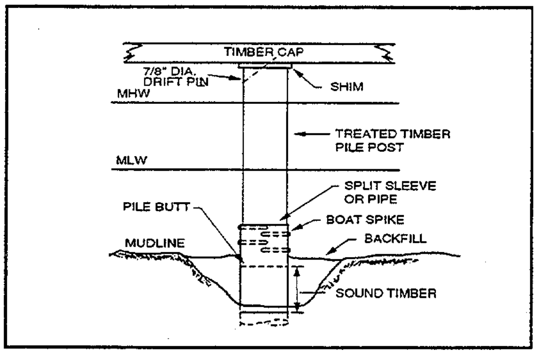
10-17

One of the easiest timber pile connection methods is with a steel dowel. To accommodate the new pile section, the damaged pile is cut at a point just below the mudline. An effort should be made to keep the cut as horizontal as possible, so as to minimize eccentric loading of the new pile post. Holes are drilled in the center of the top of the exposed stump and the bottom of the new pile post. The hole diameter in the post should be the same as the steel rod, while the hole diameter in the stump should be 1/2 inch larger than the steel rod. A snug fitting corrosion resistant steel rod (normally 1 1/2 inch in diameter) is then inserted into the new pile post to a depth of at least 12 inches. The pile post is lowered onto the exposed stump so that the steel rod slides into the hole drilled in the center of the stump. Prior to sliding the new pile post onto the stump, a generous amount of epoxy grout should be applied on the top of the stump to help distribute axial load and fill the annulus around the steel rod. The new pile post is then put into position and attached to the cap.



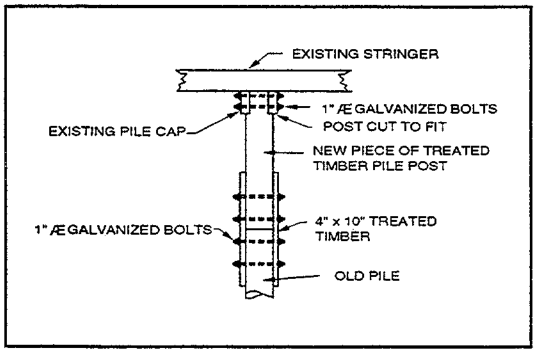
10-18

Another relatively simple connection utilizes driftpins as shown in this slide. Driftpins are large diameter metal rods with no threads, driven into predrilled undersized holes. As with the steel dowel connection, the existing pile should be cut off just below the mudline. Driftpin connections provide virtually no member load transfer capability, and are not considered a preferred method for making a splice connection.



10-19

A third method of making a splice connection on timber piles is using a pipe sleeve connection. The damaged pile is cut off just below the mudline in preparation to receive the new pile post. A pipe sleeve is prepared on the surface by burning several nail holes in the sleeve through that portion of the pipe which will be attached to the new post. The pipe sleeve is then placed over the pile stump at least 18 inches. The new post is inserted into the sleeve, and wood shims are driven between the pile post and the sleeve as required. Large nails, or boat spikes, are then driven through the pre-cut holes to secure the new pile post.



10-20

Fish plating is a method to form a splice when the pile post is shorter, and does not extend to the mudline. This slide shows the fish plate technique. As with the other splicing techniques, this method should be limited to use on smaller structures not subject to large axial or lateral loads.

PILE WRAPS

- **PROTECTIVE MEMBRANE**

10-21

III. PILE WRAPS

A pile wrap is a synthetic membrane designed to wrap around a damaged pile and create a water tight seal. Pile wraps are generally made of a flexible polymer material such as PVC.

They can be effectively used to arrest deterioration on steel, concrete or timber piles.

WRAPS CREATE

- **PROTECTIVE BARRIER**
- **ANAEROBIC CONDITION**

10-22

The pile wrap creates a protective barrier between the pile surface and the surrounding marine environment, and isolates the pile from it. Once the damaged pile is isolated, stopping the circulation of oxygen rich water and creating an anaerobic condition or a passivating layer within the wrap boundaries stops further deterioration and kills timber destroying organisms. On non-timber piles they provide simply a protective barrier. Pile wraps do not provide any structural strength and should be used only when the pile has sufficient structural capacity remaining. Good engineering judgement should be exercised when deciding whether to use a pile wrap or a structural repair technique.

Wraps used with preservative treatment in timber prolong treatment life, and can be used as a dual protective system for new timber piling. In these cases, the wrapping material must not be damaged by pile installation.

ADVANTAGES

- **COST**
- **LITTLE EQUIPMENT**
- **CHEMICAL RESISTANCE**

10-23

Pile wraps offer several advantages over other rehabilitation methods:

- Cost is less than pile replacement or installation of jackets.
- Little Equipment is required for their installation due to their lightweight and simplicity.
- Chemical Resistance is provided as a by product of their polymer composition.

Another advantage of pile wraps over various jackets is that wraps can be fairly easily removed to periodically inspect the pile condition.

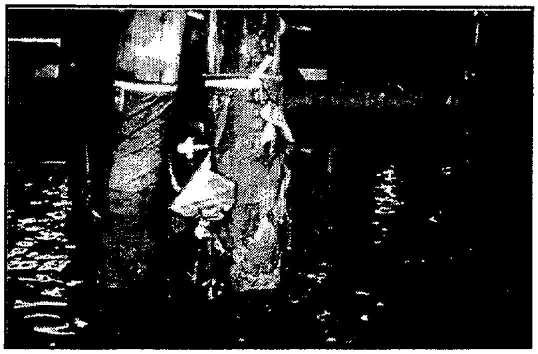
DISADVANTAGES

- **ULTRAVIOLET**
- **ABRASION**
- **PHYSICAL DAMAGE**

10-24

Disadvantages of wraps include:

- Ultraviolet light may deteriorate the wrap material. Carbon black is often added to the wrap material during manufacture to reduce ultraviolet attack. Test data should be reviewed for anticipated life expectancy.
- Abrasion can cut through plastic materials as a result of ice flows, river grit load, or debris.
- Physical Damage can occur from boats or floating debris.

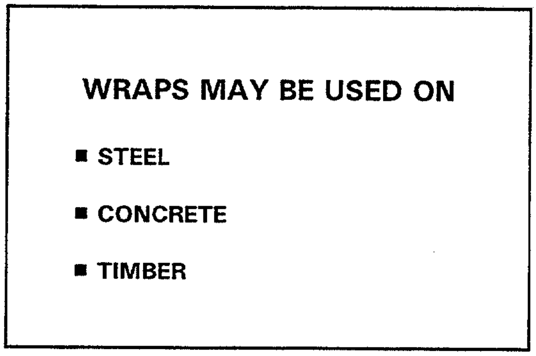


10-25

Here is an example of a damaged wrap on a timber pile. The susceptibility of a given pile wrap to abrasion or physical damage is dependant on the material thickness and toughness. Where such deterioration can be expected, the thicker wrap materials, and those with internal reinforcing are recommended.

Due to water movement, the pile wrap abrades itself on materials left on the pile surface also.

Timber piles are the predominant pile type protected with pile wraps. However they may be used on all types of piling.



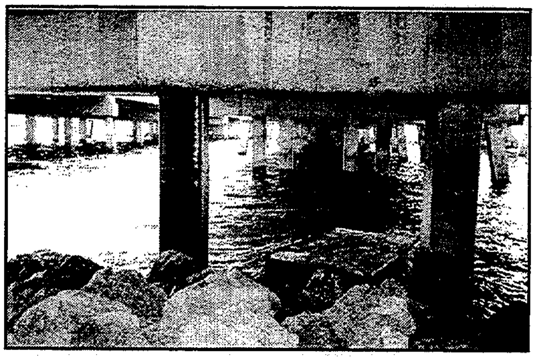
WRAPS MAY BE USED ON

- STEEL
- CONCRETE
- TIMBER

10-26

Steel Piles

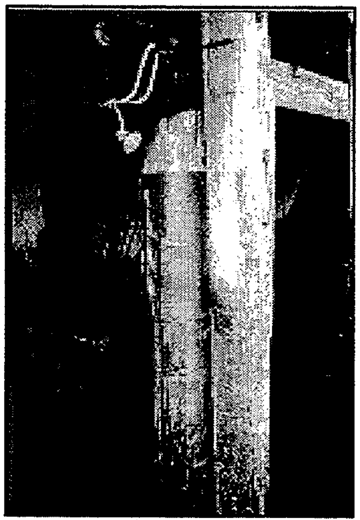
Pile wraps can effectively inhibit corrosion on steel H-piles and pipe shapes. The protective properties come from a combination of the anaerobic environment created on the interior of the wrap and corrosion retarding compounds that can be applied to the steel surface prior to wrapping or embedded in the wrap material. A water tight seal is facilitated on steel H-piles with a formed blocking system that fits between the flanges, allowing a tight fit of the wrap material.



10-27

Concrete Piles

Pile wraps inhibit further deterioration of concrete piles by creating an anaerobic environment inside the wrap system, and reducing chloride penetration into the concrete in the area covered by the wrap. They also create a barrier against chemically aggressive waters.



10-28

Timber Piles

As previously noted, pile wraps protect timber piles by creating a barrier which prevents marine organisms, such as marine borers in coastal areas, from getting to the pile. If the pile is already infested with borers, the wrap creates an anaerobic environment which kills the borers. Navy publications recommend installing wraps before 5% section loss has occurred and allows their use (with engineering judgement) at up to 15% section loss, without added strengthening.

Prior to the installation of a pile wrap, all marine growth and sediment should be removed to insure a good seal is achieved and eliminate any sharp objects which could damage the wrap.

INSTALLATION

- CLEAN SUBSTRATE
- GOOD FIT
- FASTENINGS
- JOINTS

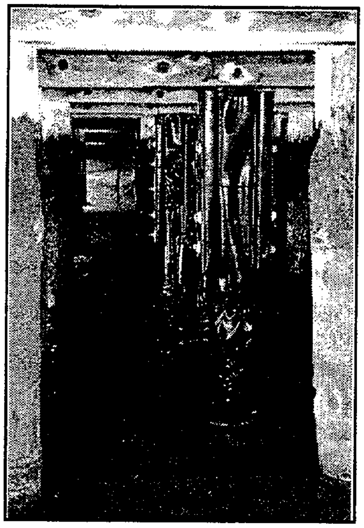
10-29

Installation of most wraps is fairly quick and requires minimal equipment. Care must be used to ensure tight seals and to assure no loose ends on the sides that can unravel.

Pile wraps for marine borer protection should extend from two feet into the mudline to two feet above high water. On steel or concrete piles, they are typically applied only over the area to be protected, such as the splash zone.

Aluminum nails should not be used to fasten wraps to Copper-chromium-arsenic or ammoniated-copper-arsenic treated piles as their salts corrode aluminum rapidly.

Joints of vertical wrap segments are overlapped and banded, or a proprietary seal is applied.



10-30

Normally bracing is removed, the wrap applied, and then the bracing replaced rather than try to wrap around it. The bracing itself should also be wrapped. This slide shows a connection detail.

EXAMPLE INSTALLATIONS

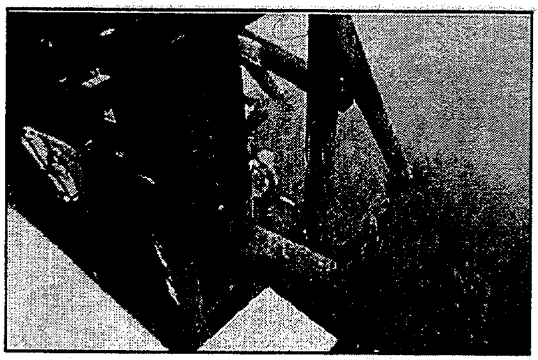
- "PILE-GARD"
- "T.C. ENVIROSHIELD"
- "CORROSION TECHNOLOGIES"
- "PILE-CAP"

10-31

The following product installations show a range of technology, all of which may be considered to function as pile wraps.

- Pile-Gard is a PVC wrap.
- T.C. Enviroshield.
- Corrosion Technologies is a protective tape system with jacket over.
- Pile-Cap is a rigid polymer encapsulation.

These are but a few of the many systems available. Each system has features which its manufacturer feels are advantages. Careful review of manufacturer fact sheets, independent tests if possible, and usage history is very important. Few standard tests are available for direct product comparisons.

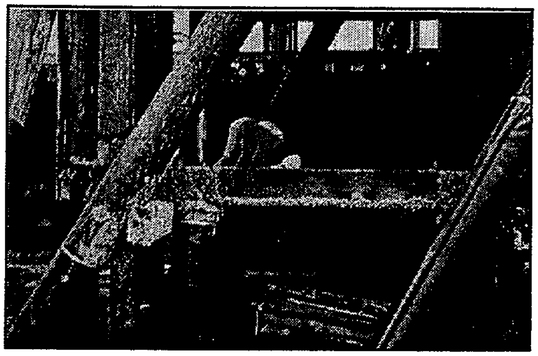


10-32

The "Pile-Gard" system is one of several wraps using PVC, nailed and/or banded. The first step is cleaning of piles. Here, cleaning timber piles is being done using a long handled scraper.

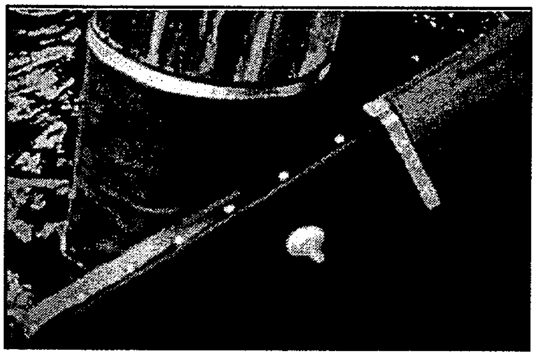
10-33

This slide shows the wrap laid out on work floats. Wraps are made of polyvinyl chloride in a standard thickness of 30 mils. Sixty mil wraps are also available to offer better abrasion and impact projection.



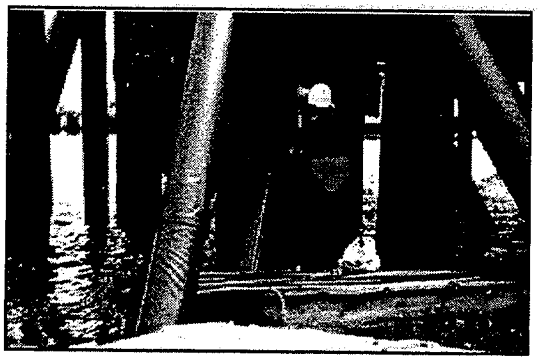
10-34

Installation. Note nails and fastening bands at top and side seam. Bands and fasteners should be non-corroding.



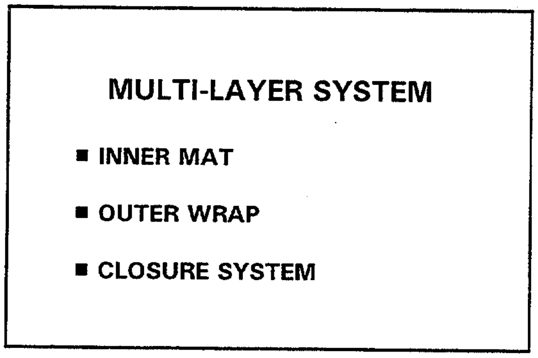
10-35

Detail of connection. In tidal zones a seal must be placed at the top and bottom of the wrap to eliminate "pumping" of water up along the pile sides under the jacket.



10-36

This is another installation photo. Note the horizontal joint in wrap sections and tight fit to piles.



MULTI-LAYER SYSTEM

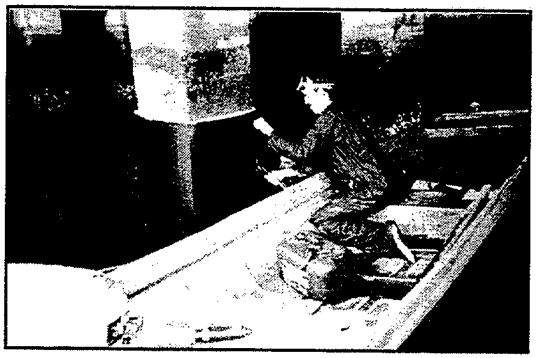
- INNER MAT
- OUTER WRAP
- CLOSURE SYSTEM

10-37

Some wraps are multi layered, incorporating a preservative/protectant saturated mat under a wrap. Usually a special closure is also provided.

The T.C. Enviroshield product is illustrative of this family of wraps.

The inner mats are generally saturated with petroleum derivative waxes which retard pile deterioration and help create a watertight seal.



10-38

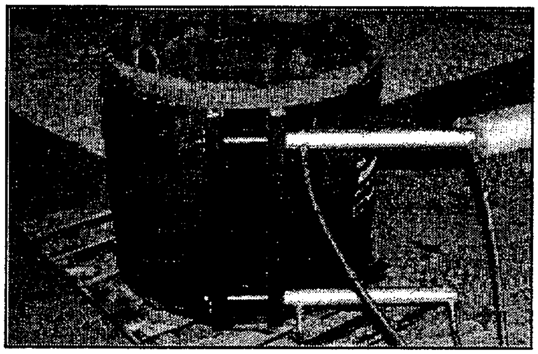
This shows the wrap being placed on a square concrete pile. The inner mat is visible at the top. In this particular system, the outer wrap is 30 mils thick and has a fiber reinforcing.

10-39

Here, the closure system is shown. A plastic clamp which is screwed up to tighten the wrap is used. The clamp grips fiberglass rods in the edge of the wrap.

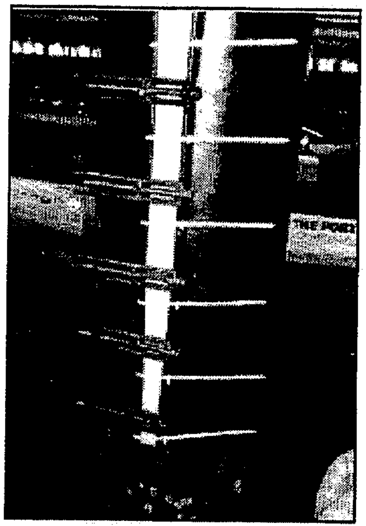
10-40

This shows a diver tightening the clamp using a "speeder" wrench. Note that this is on a timber pile.



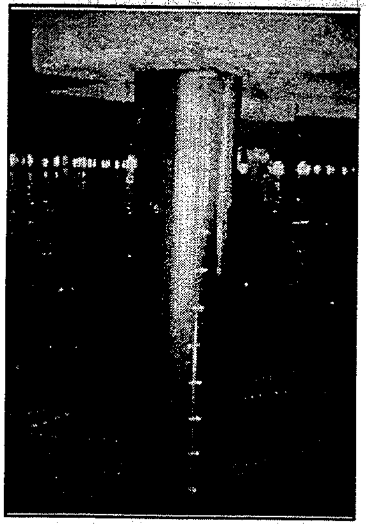
10-41

Many types of wrap closures are used, as shown here. This photo shows a typical section of the "Armowrap" system. Note inner protective layers and outer wrap. This method of sealing/clamping of wrap uses small jacks and clamp.



10-42

Another photo showing a clamping system and final ties.



10-43

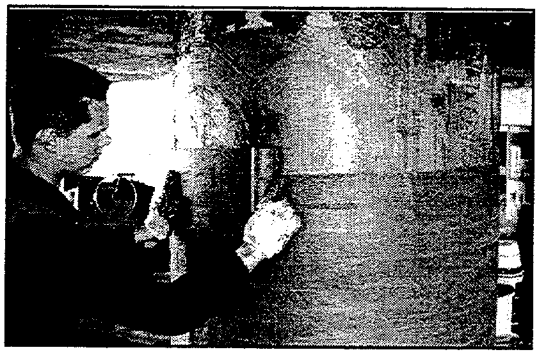
Finished pile wrap. Note tight fit and smooth surface.

10-44

Another style of wrap being applied to a steel H-pile. Wraps can be designed for any pile shape. Blocking to fill the flange areas is sometimes used for H-piles, or the wrap is sized to fit the series (i.e. HP 10, 12, 14) pile flanges, as shown here.

10-45

Multi-layer systems of wraps can also be applied one layer at a time. Here the layer of petroleum wax is being hand applied to a steel pipe pile. The particular system shown is by Corrosion Technologies.



10-46

A layer of protective tape is applied next. The tape is also impregnated to add protection and seal tightly. Tape must be applied tightly with sufficient overlap.

10-47

The outer wrap of PVC is then applied. In this particular system, heat is used to seal and shrink fit the wrap. This system then, can only be applied above water, which may be difficult. Similar systems that do not require heating are also available.

10-48

A view of a finished wrap with final added banding.

"PILE CAP"

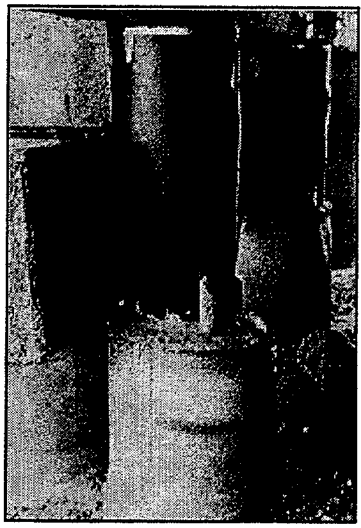
MORTAR WRAP

10-49

"Pile-Cap"

Pile-cap uses a form, into which a thin layer of polymer is pumped. After curing, the form is removed leaving a thin barrier "wrap" of cured polymer mortar.

The system can be used on differing pile cross sections and substrates.



10-50

Pile forms and wraps can be used in various combinations. Here a column with a concrete filled fabric form has a PVC wrap above.

PILE JACKETS

- PROTECTION
- STRENGTH

10-51

IV. PILE JACKETS

Pile jackets, or encasements, are used to make a structural repair to a damaged pile, as well as provide protection to the original pile. The ability of a pile jacket to restore or add structural strength to the pile differentiates it from a pile wrap.

Note: Some of the encapsulation systems to be discussed may add little strength but are usually still considered to be jackets.

COMPONENTS

- FORM
- REINFORCING
- GROUT

10-52

Conventional jacket systems have three basic components in common; form material, a reinforcing system and a cement or epoxy based concrete or grout. The procedure to install an encasement system is nearly the same whether the encased pile is timber, steel or concrete.

JACKETS ALTER

- PILE SIZE
- PILE WEIGHT
- SEISMIC RESPONSE

10-53

Depending on jacket type, the pile size after jacketing may increase several inches. This adds dead weight and increases lateral loads resulting from currents and wave actions. Such effects should be evaluated by the design engineer and may control the type of jacket system utilized.

A further concern, particularly for thick jackets, is their effect on bridge seismic response. These jackets locally stiffen the pile elements. This changes the lateral response of the pile bent and also alters the moment and shear distribution in the pile itself.

FORMING SYSTEMS

- FLEXIBLE
- RIGID

10-54

Forming Systems

Forms can generally be classified as flexible, usually fabric, or rigid such as metal or wood. Fiberglass forms are included here as rigid through they are often more semi-rigid. Note that similar systems are used for pier repair.

FLEXIBLE FORMS

10-55

Flexible Forms

The most common type of flexible forms are generally constructed of an industrial strength fabric. These forms are basically a tube, usually having a zipper up one side to allow installation. They have been used for many years.

Session 9 noted various aspects of fabric forms that are also applicable when they are used for pile repair.

ADVANTAGES

- COST
- HANDLING
- PREFAB
- FORMABILITY

10-56

These systems have advantages and disadvantages as summarized in the following two slides. The advantages and disadvantages are discussed further as we look at example installations.

DISADVANTAGES

- SURFACE
- ULTRAVIOLET DETERIORATION
- MAINTAINING COVER
- ALKALINITY
- STRENGTH

10-57

Here are some disadvantages of the system.

- Surfaces are somewhat irregular.
- Many jacket materials are adversely effected by sunlight.
- Very flexible jackets make it hard to control cover over reinforcing.
- Some jacket materials can be attacked by the alkalinity of the concrete or cement grout.
- Strength must be sufficient for grout head.

DESIGN CONSIDERATIONS

- FABRIC STRENGTH
- FASTENER STRENGTH
- TOP/BOTTOM CLOSURE
- INCLINED MEMBERS
- LEAKAGE

10-58

Design of fabric forms is usually provided by the fabric supplier for the contractor. Among design factors are:

- Fabric strength must be adequate for grout head.
- Seam fasteners must be strong, durable, and easy to close.

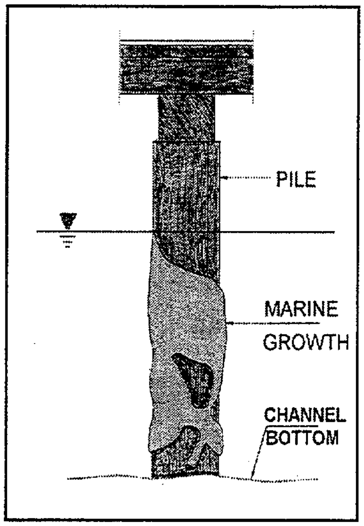
- Failures of materials or seams may not be quickly detected prior to grout placement.
- Top and bottom closures must be tight and easily installed.
- On inclined members it is hard to maintain final shape and clearances.
- At least one firm manufacturers an "ultra-thin" (about 1/16" thick) fiberglass form to compete with fabric which is said to hold its shape on inclined surfaces.
- Leakage of cement fines through the fabric may be an environmental concern. Materials are available which are of a fine enough mesh to prohibit loss of cement particles.

EXAMPLE INSTALLATIONS

10-59

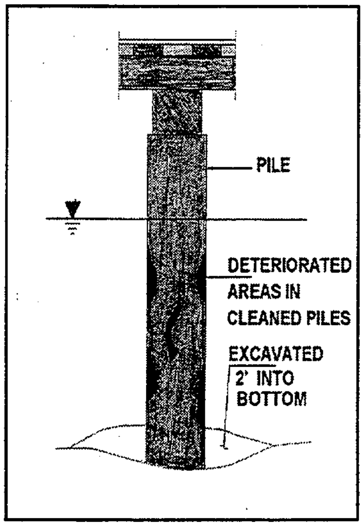
A typical installation is shown on the following schematic drawings. Then a series of slides showing an actual installation will be shown.

As we go through the schematic drawings, we will note aspects of jacket installation which are generally applicable to all systems.



10-60

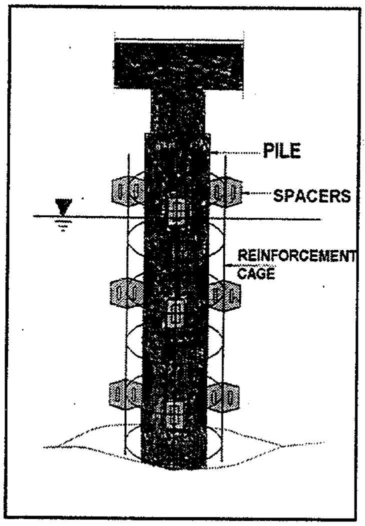
Here we see a deteriorated pile with marine growth. An engineering assessment has determined that this pile is to be jacketed to restore strength.



10-61

As the first step in repair, the pile has been cleaned. Normally all marine growth and deteriorated pile material is removed, either with power equipment or by hand. For jackets that are several inches thick and concrete filled, some designers will allow "tight" marine growth to remain (such as some mullosks and barnacles). The potential to destroy a badly deteriorated pile by heavy cleaning should be considered. A sequence of repair may have to be developed so that adequate support of the structure is maintained during repair operations.

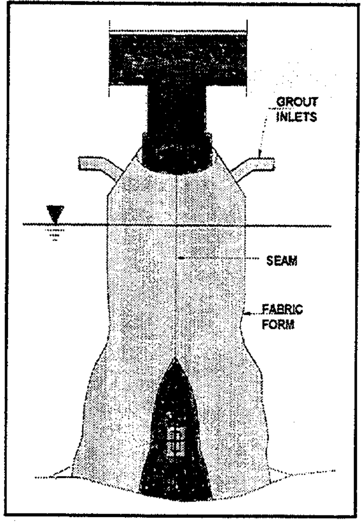
Where jacket installation is part of arresting active concrete pile corrosion, cleaning efforts must expose and clean all effected reinforcing steel. Note that this will not reduce the concrete chloride content near the bars, unless concrete is removed beyond the bars. Corrosion may continue in the old concrete beneath the jacket, and unless the jacket is heavily reinforced may induce jacket failure.



10-62

After cleaning is complete, the reinforcing cage is placed. Note spacers separate the pile from the reinforcing and also from the jacket. Spacers usually are plastic. The amount of reinforcing to be used is an engineering decision, but at least mesh should be provided with concrete or mortar jackets to give the jacket added integrity and resistance to cracking.

Where corrosion loss to reinforcing steel, or a structural section, is significant, or added strength is desired, heavy reinforcing cages can be placed.

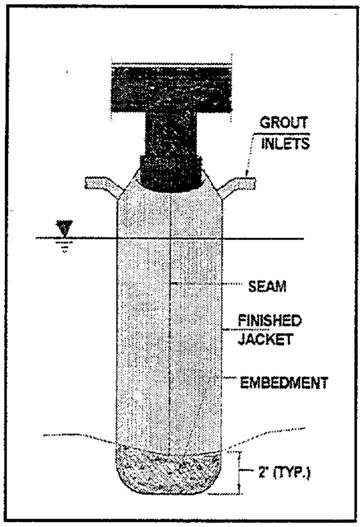


10-63

Next, the fabric form is placed and sealed at top and bottom. Sealing is often done using metal bands.

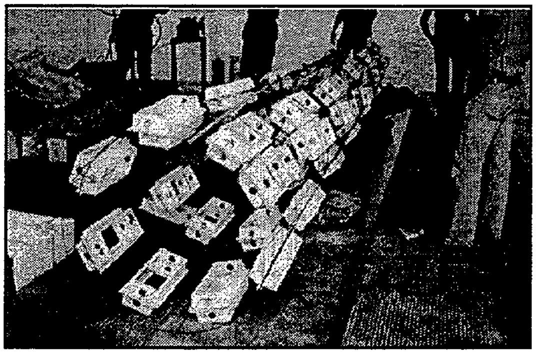
Grout or a small aggregate concrete mix is usually placed through a small tremie pipe inserted from the top. Concrete placement requires high slumps, 8 to 10 inches, and care must be taken to assure uniform filling around the pile so the form is not pulled out of shape. Stretching of the fabric, sometimes by as much as 10 percent, should be expected and accounted for in estimated grout quantities.

Grout may also be placed by pumping from the bottom of the form, and this is a preferable procedure.



10-64

Completed installation. Note jacket goes below the mudline. However, it is not tight to the underside of the pile cap. If direct load transfer is needed, the gap can be formed and dry packed or pumped under pressure using a local rigid form.



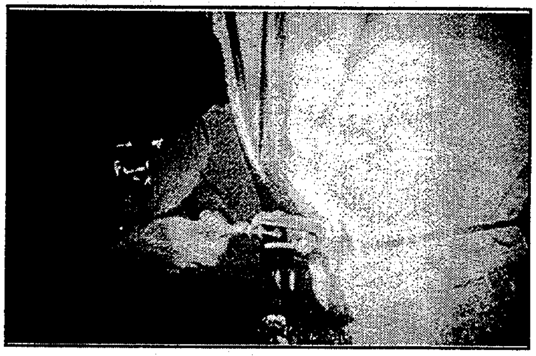
10-65

An actual installation is very similar.

Here, a mesh reinforcing cage is seen on the barge deck. A large number of white plastic spacers are attached to the cage. The cage will be opened and placed around the pile. Cages are usually suspended from above, particularly for heavy reinforcing.

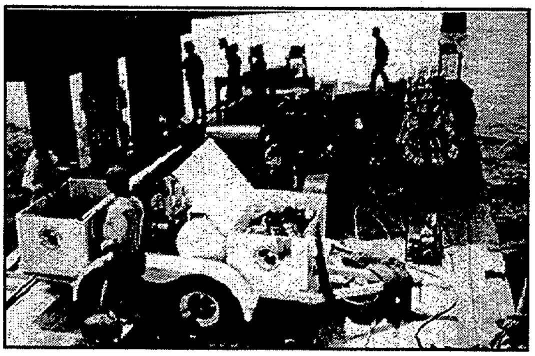
10-66

Here a worker is setting the fabric form at the top. Hanging the material from the top makes handling easier.



10-67

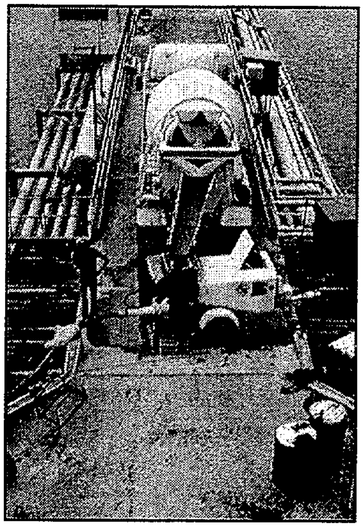
Banding is being used to seal the form at the bottom. Concrete or grout is placed from bottom to top. A diver should continuously check for uniform filling and consolidation during placement. Vibration is rarely used but probing of the fabric bag from outside can aid if consolidation becomes a problem. As previously noted, placement can be through bottom valves or tremie pipe.



10-68

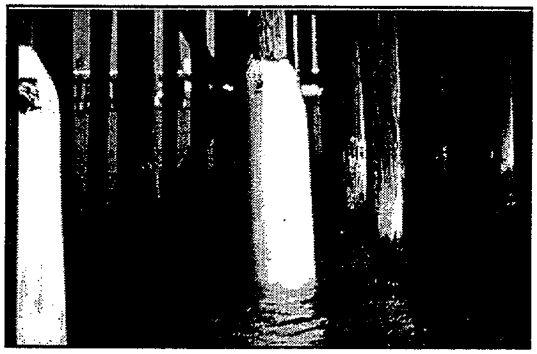
Topside support. Note the square concrete piles, but the final shape of the jacket will be circular.

Here we see the grout pump and other equipment. It is important that an ample grout supply is available to allow for uninterrupted placement at each pile.



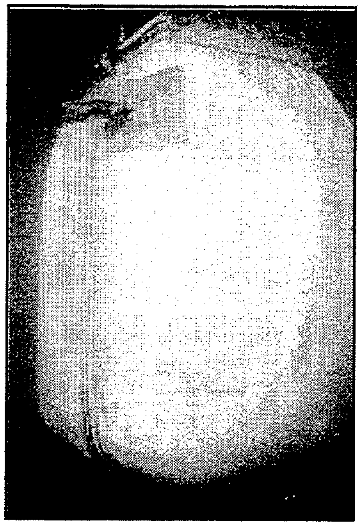
10-69

Grout supply can be by transit truck on barges, trucks an a bridge deck, or by barge mounted readimix plants.



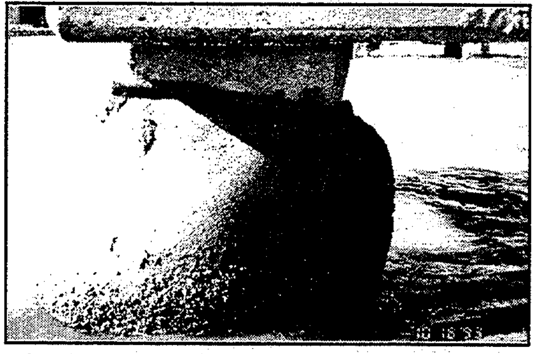
10-70

Here we see typical repaired piles. Note the sleeves near the tops of the piles used for grout placement.



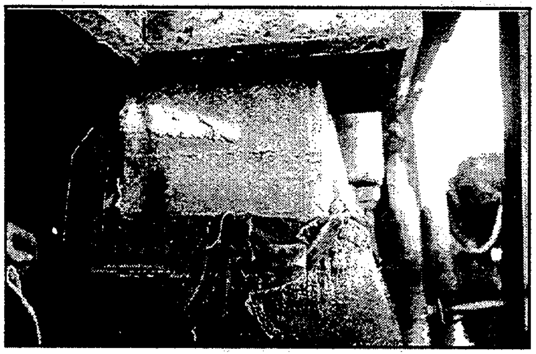
10-71

Underwater view of a fully submerged application. Note zipper side fastener.



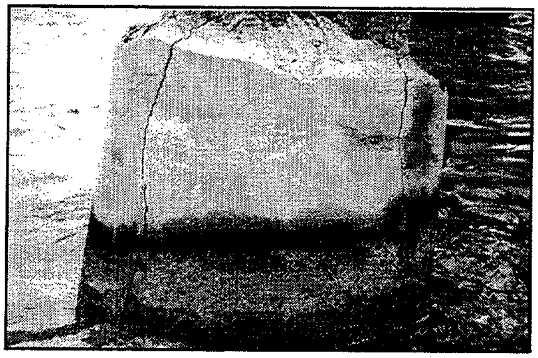
10-72

This slide shows an example of a fabric jacket on a batter pile. As noted previously, the displacement of the jacket to the lower side of the pile is evident. The protection afforded by the jacket is obviously lower in the thin areas.



10-73

This shows corner cracking, probably as a result of reinforcing corrosion, occurring at the top of the pile left unprotected by a jacket terminated below the pile cap. Eventual spalling of the pile, gradually extending into the jacket area, can be expected.



10-74

Drying and shrinking of the concrete in this jacket has caused wide vertical cracks to occur. Particularly in a cold climate, this could cause rapid jacket failure. The need to use low water content grouts is apparent.

RIGID FORMS

- REMOVABLE
- STAY-IN-PLACE

10-75

Rigid Forms

Rigid forms can be constructed from a variety of materials. Rigid form repairs are constructed using the same general techniques as those for flexible forms, except that constructing the form around the existing pile is often more difficult.

Rigid forms similar to those used for above water column construction can be used underwater. However, they are costly to set and the good visual appearance they were designed to help produce is not usually needed.

Rigid forms used underwater are usually of the stay-in-place type due to the high cost of removal and lack of appearance concerns.

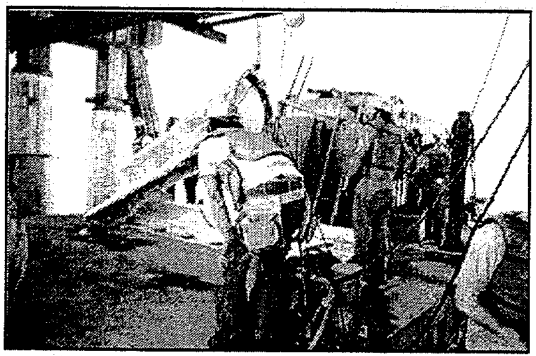
FORM DESIGN

- BY CONTRACTOR
- INTEGRAL SYSTEM
  - FORM
  - FILLER

10-76

Form design is typically left to the contractor. However, since many of these are part of proprietary jacketing systems, specification of a rigid form pile repair is often of a performance type.

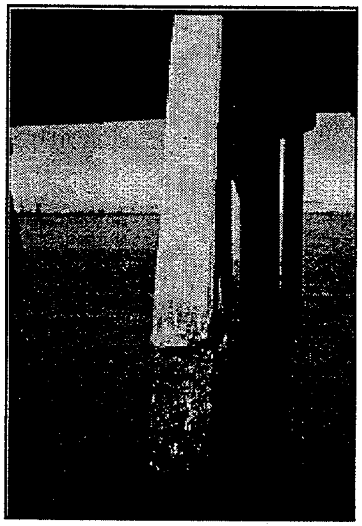
The proprietary rigid form systems are designed such that the interaction of the form and grout is critical and thus components should not be mixed.



10-77

Probably the most common rigid form is a circular fiberglass form, as shown here, filled with concrete or cement grout. The circular shape is efficient in producing a light, easily fastened form. Because the form is loaded in tension by the grout mix it can be quite thin. The form can be sized as needed to place reinforcing. The form does not act with the grout but merely contains it. As a result, bond between the form and grout and substrate are not critical (though desirable). The form shown is reusable, but stay-in-place forms are also available.

An epoxy cap is often used at the top of the jacket for appearance and to shed water. The cap is trowel applied.



10-78

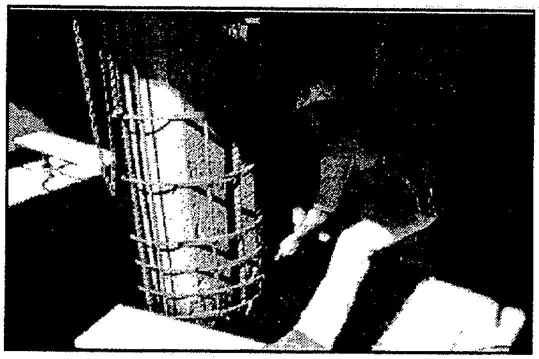
This slide shows a square concrete pile with section loss and corrosion. In order to restore this pile a rigid formed concrete jacket will be placed. Normally the jacket would extend to two feet or so above high water, but could be full height.

10-79

Here, for the first step of cleaning the pile, a water blaster is being used. Chipping hammers may be needed if concrete removal is required.

10-80

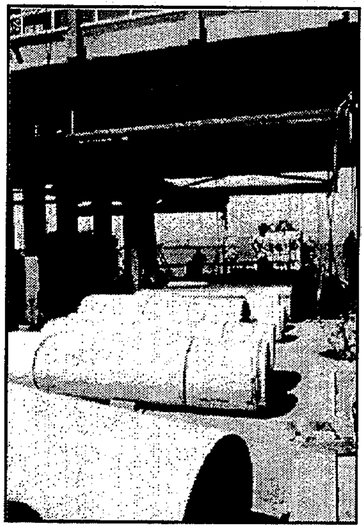
Steel reinforcing is being placed. Note that this is a standard reinforcing bar cage with verticals and ties. Where cages extend underwater, they can be assembled around the pile from a barge and lowered into place. Note the short lengths of pipe placed on the rebar cage, used as form spacers.



10-81

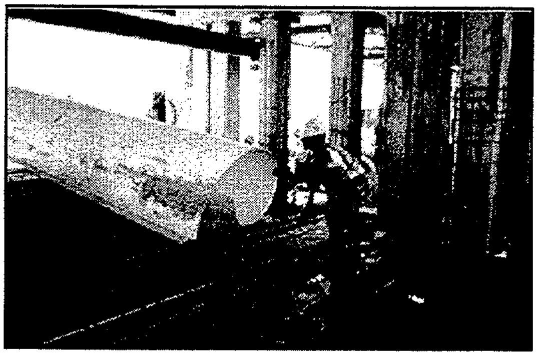
This shows a closer view of the reinforcing cages being lowered to divers below water, suspended from above.

Note the well cleaned concrete surface.



10-82

Fiberglass form segments are stored on barges in this project. They are supplied in standard length segments, with "specials" as required for fit up.

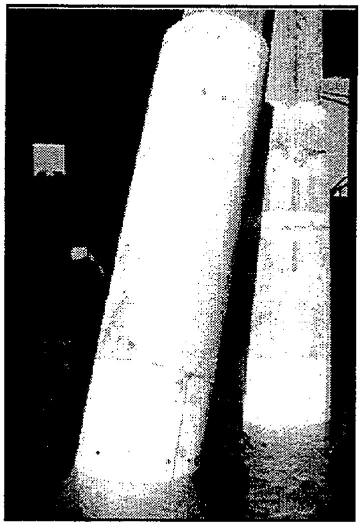


10-83

Form being moved. Note the form flexibility and lap type joint configuration.

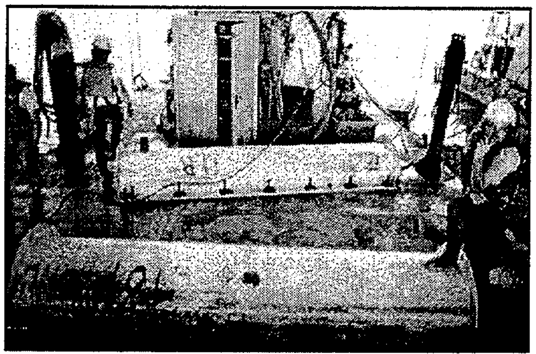
10-84

Forms being placed. Segments are "stacked" above water and lowered to any required depth. A "lip" type of joint is used for horizontal joints.



10-85

Finished installation. Note the form seam along batter pile, and the horizontal seam. Also, note the finish mounding of the concrete at the top of the repair to aid in shedding water.



10-86

This is a heavy duty, removable fiberglass form system. The form halves bolt together along the flange.

10-87

Note the flanged attachment arrangement for the form halves. The worker is installing a proprietary one way flap valve for grout placement. Valves are placed at the lowest form element, and could be added at vertical increments for especially high placements.

10-88

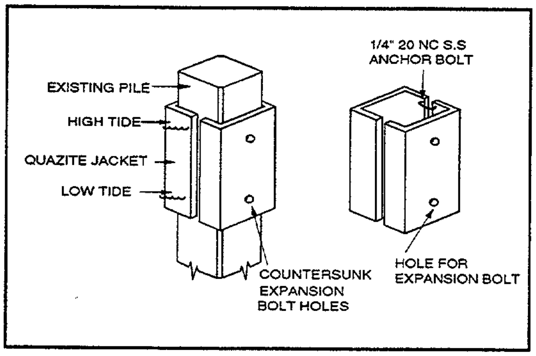
Forms in place. Note use in conjunction with stay-in-place forms.

10-89

Form removal with the completed repair beneath. The exposed concrete should be properly cured.

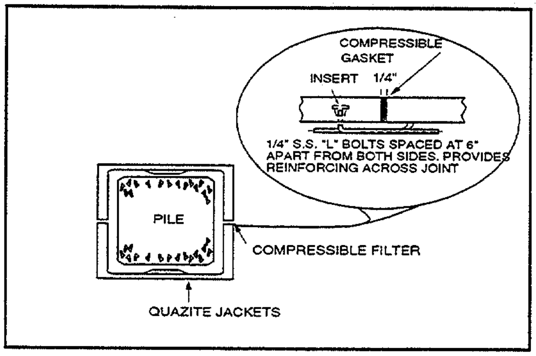
10-90

This is a group of stay-in-place rigid form segments composed of polymer concrete. The form is about 1 inch thick and is custom made to fit the pile size and shape. Polymer concrete gives abrasion and corrosion resistance.



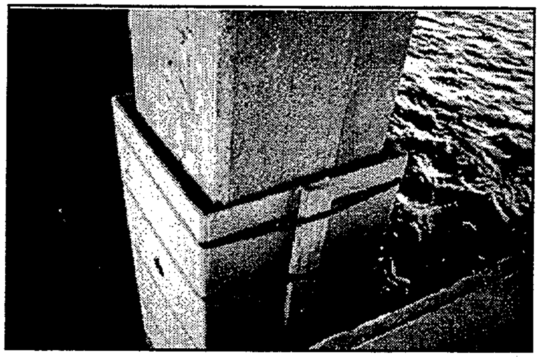
10-91

While vendor details would vary, this shows one method of form installation. The form is in two halves with expansion bolt holes for securing the forms. Form segments for this and many systems are 10 feet long.



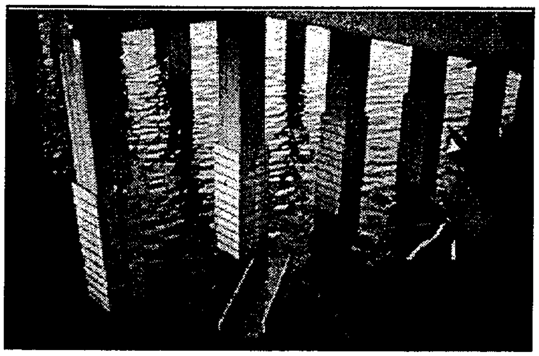
10-92

In reviewing form types, placing details, connections, and spacer arrangements should be examined. It is important that the form can be held securely in position with tight joints.



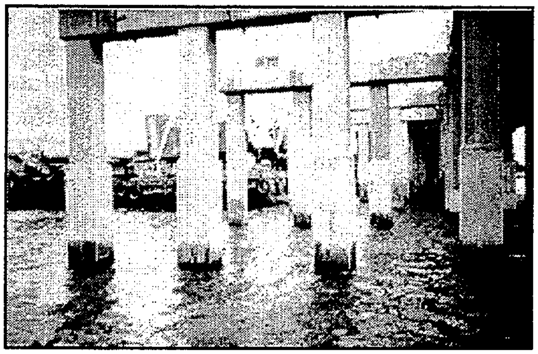
10-93

This particular form system is banded to withstand grout pressures prior to grout curing. A polymer grout is used with a small annulus.



10-94

Example pile bent with forms in place. Note unused form segments on the bank.



10-95

Finished construction with the banding removed. Note that the pile size is enlarged only about 2 inches, and a grout cap was provided.

EPOXY GROUT FILLER

10-96

Note that the last form system had a small annulus around the pile. This is for several reasons:

- Jacket is primarily for protection of the pile substrate, with some added strength.
- For an epoxy filled space the material costs for the grout become high.
- A reduced volume of epoxy grout reduces heat generated by the curing reaction of the epoxies. For thick jackets, low exothermic epoxies are available.

A variety of epoxy products are available and formulated for use as a jacket filler. Materials should be 100 percent solid epoxy and the filled system must be readily pumped. Epoxy components should be of contrasting colors to aid in detecting insufficient mixing and should typically contain at least three parts of filler to one part of liquid. Specific grouts may be required by the form supplier.

BOND
IS
CRITICAL

10-97

In these systems the bond of the epoxy grout filler to both the substrate and jacket (or form) is critical. Loss of bond can mean loss of the form or whole jackets, particularly under wave action. Again, these are jacket systems composed of the form and grout which combine to provide the protective system.

BOND

- CLEAN SUBSTRATE
- CLEAN FORM
- TIMING
- GROUT PLACEMENT

10-98

Several factors effect good bond. Bond strengths of 200 psi between the grout and substrate and between the grout and forms are typical minimum specification requirements.

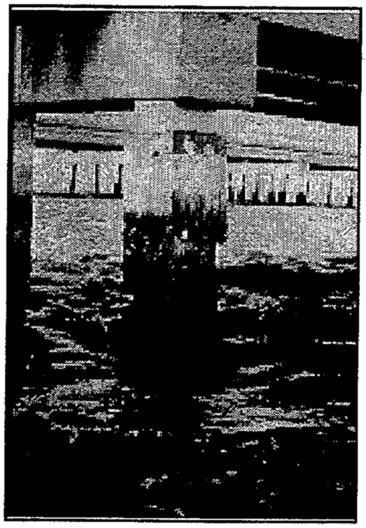
- The substrate must be clean. In warm water especially, algae can begin forming on a surface in a matter of 2 or 3 hours.
- Forms must be clean not only of marine growth or silt, but must not be contaminated with mold wax, dirt, etc. Note that diesel exhaust fumes, such as from trucking, can leave an oily film. Proprietary protective films that peel off or sandblasting may be used by particular vendors to aid bonding to forms.
- Timing of the installation should minimize elapsed time from substrate preparation to final grout placement. Normally, this should occur on the same work day.
- Bond is enhanced by placement techniques which create a shearing or washing action of the grout against the form and substrate. Placement from the bottom up is recommended using inlet ports or a tremie pipe.

10-99

Here we see a missing jacket and grout exposed beneath. Note that the grout is not uniform in placement and does not fill the area. This is the result of grout placed from above into water.

10-100

The effect of poor bond is the loss of the jacket as shown here. Wave action will cause total failure.



10-101

Here the jacket is missing. Note also that the grout filler is gone at the waterline. Bond to the substrate and jacket failed. This was a cement based grout in a thin jacket.

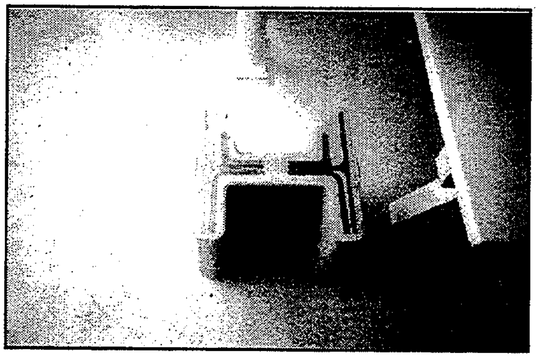
FRP FORM DURABILITY

10-102

The jacket form must be durable to provide long term protection. Fiberglass jackets made up of layers of glass cloth, hand laid up, or by pultrusion have been found to be more durable than those composed of chopper gun material which are less dense and exhibit more absorption. Addition of an added gel coat can reduce these problems. An ultraviolet screening agent should also be added to the form resin.

10-103

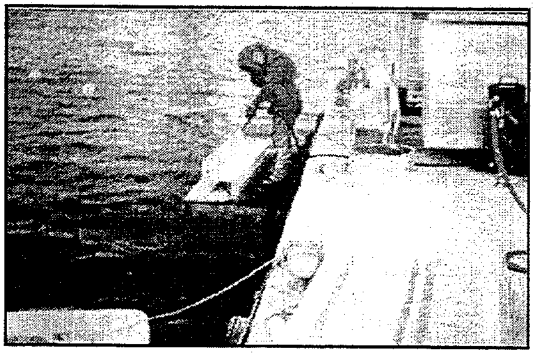
This is an example of a fiberglass jacket/epoxy system on an H-pile. Note the grout injection port. This particular form is clear so that grout placement can be better observed by inspection divers.



10-104

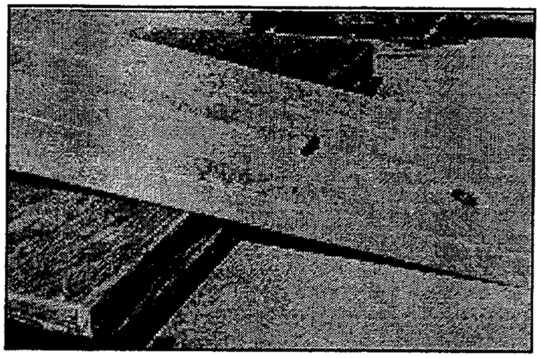
Another, sectional view.

Bond of the systems can be improved by application in periods of warm weather. When the piles later cool, contraction of the system occurs with the jacket shrinking onto the pile.



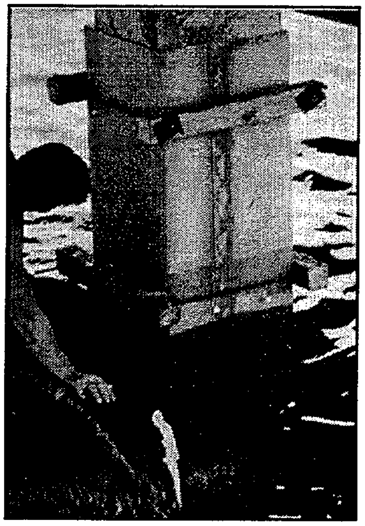
10-105

Example of sandblasting the inside of the form to enhance bond.



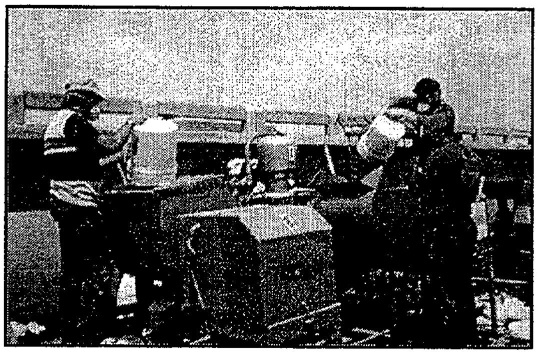
10-106

Here we see a translucent thin fiberglass jacket before installation. The injection port is at the bottom.



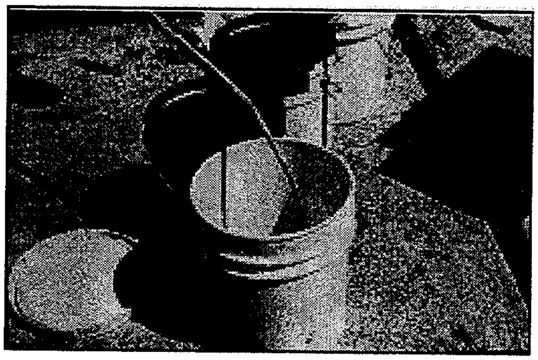
10-107

This shows forms in place with column brackets to secure them. Note the brackets are fairly close together due to the light jacket, and being above water.



10-108

Two grout mixers are shown in use. This provides a continuous supply of grout and gives redundancy to the grout operation. Mixing and pump capability should be generously provided.

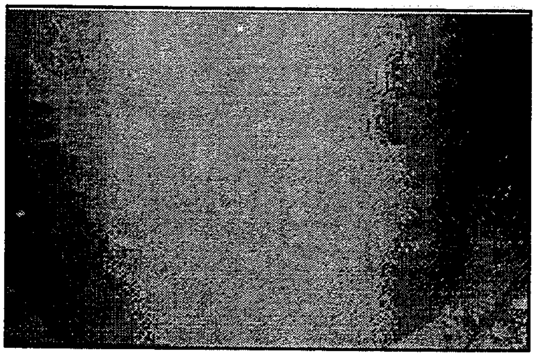


10-109

Grout fluidity tests should be run regularly. Note the high flow of this mix. Grout fluidity can be checked using the Corps of Engineers Flow Cone test.

10-110

Grout is being placed into the jacket. Note the sealant along the seams. The grout is visible rising in the form.



10-111

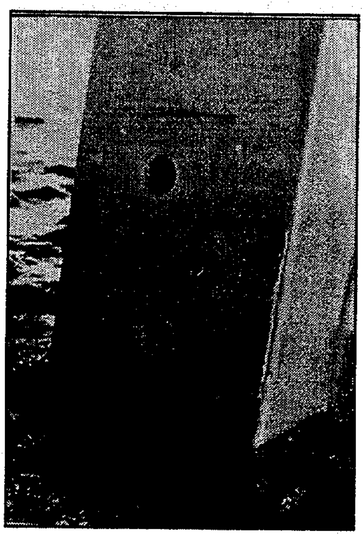
This shows the grout in the form. The dots are form standoffs.

10-112

Bond tests can be run using a modified Elcometer. A core drill is used to separate a disc from the surrounding material.

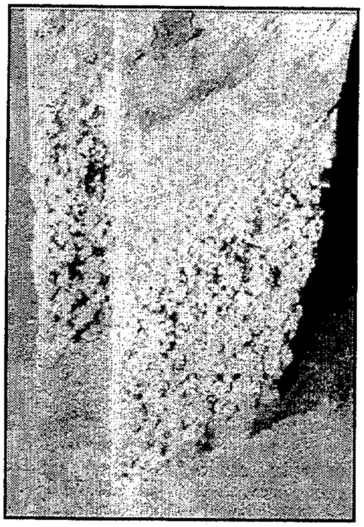
10-113

The discs are then pulled off and the pull off load converted to bond strength. Here the Elcometer is pulling off the discs.



10-114

This shows the discs removed.



10-115

V. COATINGS

Where pile deterioration is minor, hand applied coatings are available that can give corrosion protection, primarily for use on steel piles. The pile should be cleaned before the coating is applied.

Coating life is often quite limited, especially where abrasive materials or debris is present in the water. Periodic recoating should be anticipated.

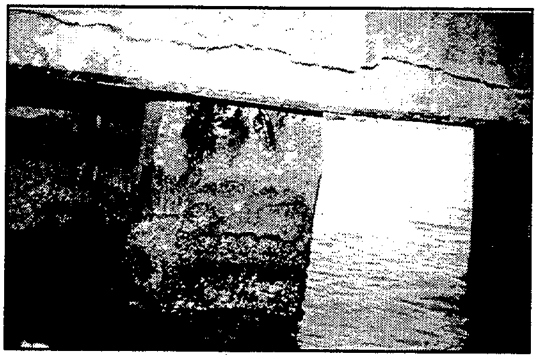
CRACK INJECTION

10-116

VI. CRACK INJECTION

Epoxy crack injection of underwater elements was presented in Session 10. This technique is equally applicable to repair of cracks in piles. Before selecting injection as a repair technique, the cause of cracking must be established. Where cracks are the result of corrosive expansion or reactive materials, injection will not provide an effective repair.

The most common use for injection of pile cracks in to repair cracks due to impact or seismic damage, or resulting from poor construction practices. Such repairs should be made soon after occurrence to preclude the onset of internal corrosion.



10-117

This shows the result of attempting to repair an active crack resulting from reinforcing corrosion by epoxy injection. Continued corrosion refractured the injected crack.

10-118

Injection of cracks may be used in conjunction with jacket installation as shown here, as well as alone.

10-119

VII. REPAIRS TO WRAPS AND JACKETS

Unfortunately, repairs must sometimes be made to previously made repairs. The cause for deterioration must be thoroughly evaluated to preclude a repeat of the same problem.

Here, shotcrete applied pile jackets are deteriorating and starting to re-expose H-piles to further corrosion.

10-120

This shows a void area in a cast concrete jacket as a result of poor concrete placement techniques. The resulting void could be hand packed with mortar, or a local form set and grout pumped into the area.

Repairs to pile wraps are usually made by removing and replacing the wrap. Rewraps with heavier materials and reworked connection details often are made.

Deteriorated jackets can be repaired with an added jacket. Removal of the existing jacket is usually impractical so the new jacket must go over the existing one . This further increases the dead load and hydrodynamic loads to the structure and may lead to strength problems which must be evaluated.

Repair by use of the much thinner epoxy jackets can reduce the adverse loading effects. If this technique is to be used, the general condition and bond strength of the existing repair must be carefully evaluated.

PILE REPAIRS

- REPLACEMENT
- WRAPS
- JACKETS
- COATINGS
- CRACK INJECTION

10-121

VIII. SUMMARY

This Session has covered a variety of options for repairing damaged or deteriorated piles of various materials. In determining the most appropriate repair, an initial evaluation of whether restoration of strength, protection from further deterioration, or a combination of the two is needed.

Pile replacement may sometimes be needed. Most often, repairs are accomplished using one of many proprietary wrap or jacket systems. Wraps are non-structural, while jackets with reinforcing incorporated can be used to restore or even increase strength. Coatings and crack injection techniques may be used for pile restoration if deterioration or damage is minor.

SESSION 11

CATHODIC PROTECTION

SESSION 11: CATHODIC PROTECTION

TOPICS: **BASIC CORROSION THEORY, PASSIVE SYSTEMS, ACTIVE SYSTEMS**

LESSON PLAN:

DURATION	30 minutes
GOAL	Learn common methods of cathodic protection applicable to marine structures.
OBJECTIVE	Ability to determine potential use of cathodic protection and consult with specialist.
OUTLINE	I. Cathodic Protection Theory II. Materials and Systems A. Galvanic Systems B. Impressed Current Systems III. System Applications IV. Maintenance V. New Cathodic Protection System VI. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 11
CATHODIC PROTECTION

11-1

I. CATHODIC PROTECTION THEORY

Understanding cathodic protection requires an understanding of the process of corrosion.

Cathodic protection (CP) systems have not been used much for bridge substructures in the past, although Florida and Oregon have used CP systems since the early 1990's. CP systems can stop corrosion even in salt contaminated structures.

11-2

Steel in both fresh and salt water will corrode due to an electrochemical reaction. In this reaction there is a flow of electricity from one area of a steel member to another through an electrolyte.

The flow of current can be due to external sources such as strong currents from welders or nearby industrial processes. It may be caused by differences in potential from dissimilar metals in the structure, or even from different areas of the same metal.

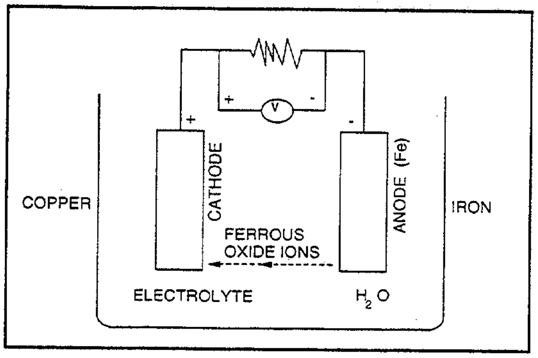
PARTIAL LIST OF ELECTRICAL POTENTIALS

MATERIAL	ELECTRICAL POTENTIAL (V)*
■ ZINC	-1.10
■ CARBON STEEL	-0.68
■ STAINLESS STEEL: 18%Cr. 8% Ni (active)	-0.61
■ COPPER	-0.43

*ALL VALUES WITH RESPECT TO A COPPER-COPPER-SULFATE HALF-CELL

11-2A

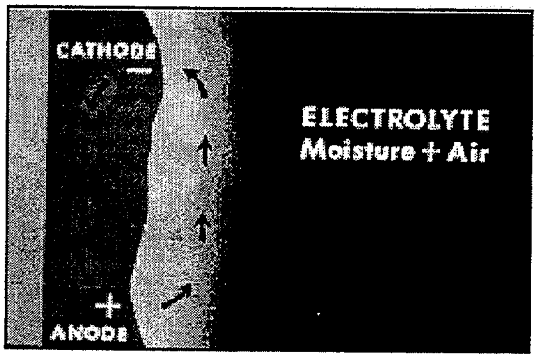
When two dissimilar metals are connected to each other, the metal that has the higher electrical potential will sacrifice itself(corrode) to protect the other metal.



11-3

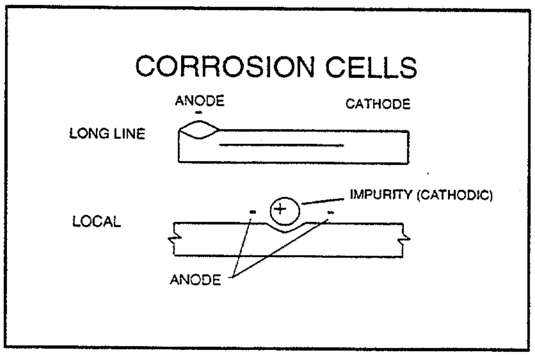
The corrosion process is really like a battery. In this reaction, one area of the steel is considered anodic (corroding portion), the other area cathodic. The flow of current through the electrolyte carries ferrous oxide ions, metal, away from the anode. The flow of current does not have to be very large.

Salt water is conductive and can act as an excellent electrolyte. Even fresh water may be conductive if there are chemicals in it.



11-4

You can even have this reaction between different parts of the same piece of metal. Differences in embedment, coatings, moisture, oxygen and abrasions can set up small corrosion cells.



11-4A

There are two types of corrosion cells: long line and local. Differences in metals or minor imperfection can start the corrosion process. Very low voltages and currents can result in severe loss of metal.

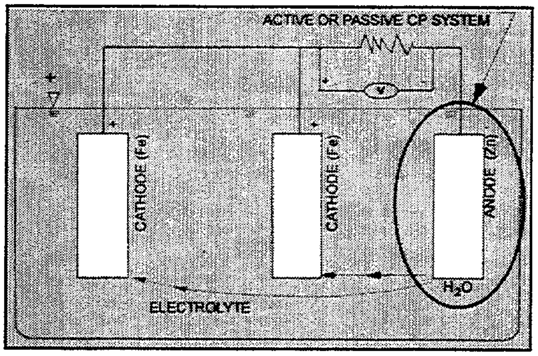
CATHODE: PROTECTED FROM CORROSION

ANODE: CONSUMED BY CORROSION

11-5

Cathodic protection is the reduction or elimination of corrosion by making the entire submerged portion of the steel member a cathode by means of either an impressed direct current or attachment of a sacrificial anode.

To effectively protect a metal structure using cathodic protection, all exposed metal must be made to be cathodic.



11-5A

This is accomplished by adding an element which is more anodic than the existing structure.

CATHODIC PROTECTION SYSTEMS

- **GALVANIC (PASSIVE)**
- **IMPRESSED CURRENT (ACTIVE)**

11-6

II. MATERIALS AND SYSTEMS

There are two basic types of cathodic protection systems: galvanic and impressed current. These are also called passive and active systems.

GALVANIC SYSTEMS

USE A SACRIFICIAL ANODE TO CREATE A DRIVING ELECTRIC CURRENT.

11-7

Now we will look at each system in more detail.

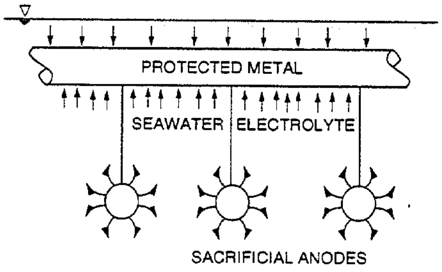
A. GALVANIC SYSTEMS

Whether or not a galvanic anode system will work depends on electric circuit resistance and the current required for protection. The circuit resistance is determined almost entirely by the resistivity of the electrolyte environment. Galvanic systems work best in low resistivity electrolytes such as seawater. (They are also used in fresh water such as in water tanks.)

The advantage of galvanic (passive) systems is that they are low maintenance. A system consists of anodes placed at pre-determined locations along a member. Once in place, the only maintenance required is to periodically check the amount of anode material remaining, and replace as necessary. This can be done as part of the routine inspection of a structure.

It should be noted that the driving potential of galvanic anodes is normally not high enough to provide sufficient current for effective cathodic protection in all cases. This is particularly true when the structure to be protected is surrounded by an electrolyte of high resistivity such as that frequently encountered with steel in fresh water.

A galvanic system (also referred to as a passive system) operates under the "dissimilar metal" principle. When two dissimilar metals are separated by an electrolyte, an electric current will flow between them. If the current is sufficiently high, one of the metals will corrode, until it is used up. The sacrificial anode (the material chosen to corrode) selected must be of sufficient size to effectively protect the metal over a period of time.



SACRIFICIAL ANODE SYSTEM

11-8

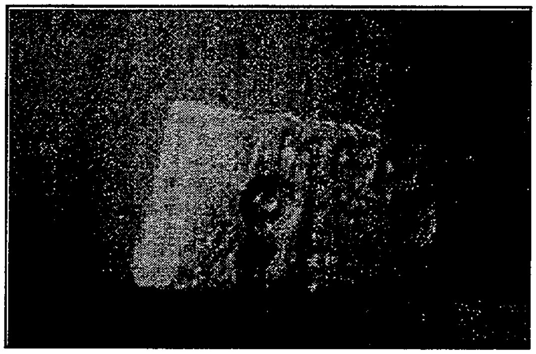
SACRIFICIAL ANODES

- ZINC
- ALUMINUM
- MAGNESIUM

11-9

Sacrificial anodes are typically made from one of three materials: zinc, aluminum, magnesium. Magnesium anodes are not suited for use in seawater due to the tendency of magnesium to self corrode in the low resistivity of seawater electrolyte. Additionally, magnesium has a much higher cost. Zinc is the most common material used in underwater cathodic systems.

Zinc anodes are almost pure cast zinc or may be zinc with aluminum and cadmium. Aluminum anodes are alloyed with zinc. Magnesium anodes are alloyed with aluminum.

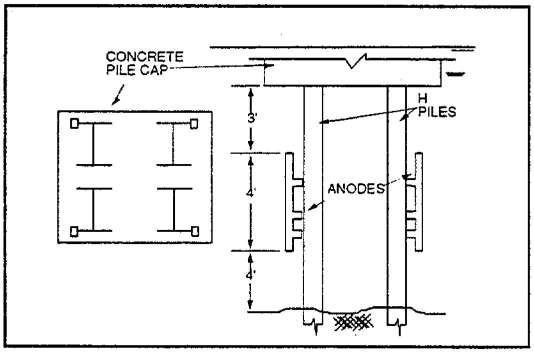


11-10

This is a photo of a typical anode underwater in a passive system.

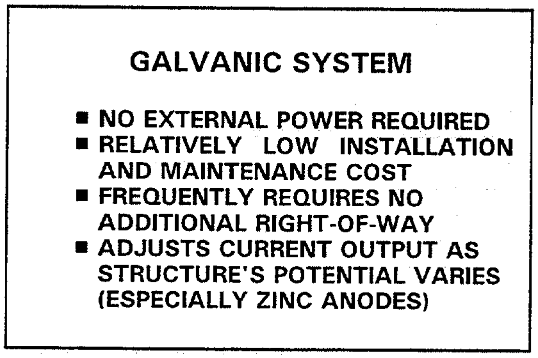
The size needed for a particular structure can be computed and the life of the anode can be estimated.

At some point, anodes may need to be replaced.



11-11

This is a design detail for galvanic protection from the Florida DOT's "Manual for Bridge Maintenance and Repair." This detail is for H-piles in salt water or brackish water. It shows the required placement of anodes along a length of H-piling.

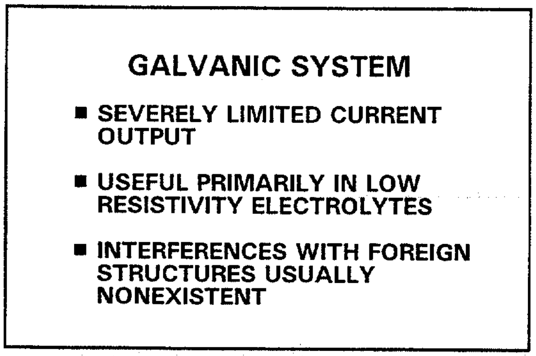


GALVANIC SYSTEM

- NO EXTERNAL POWER REQUIRED
- RELATIVELY LOW INSTALLATION AND MAINTENANCE COST
- FREQUENTLY REQUIRES NO ADDITIONAL RIGHT-OF-WAY
- ADJUSTS CURRENT OUTPUT AS STRUCTURE'S POTENTIAL VARIES (ESPECIALLY ZINC ANODES)

11-12

The characteristics of the galvanic system for cathodic protection are summarized on these two slides. This system is fairly simple, and usually the least expensive. It has been successfully used for many years.

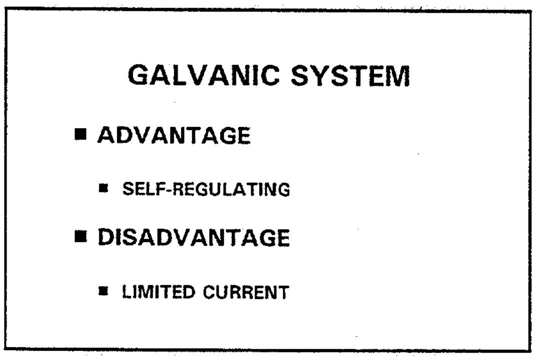


GALVANIC SYSTEM

- SEVERELY LIMITED CURRENT OUTPUT
- USEFUL PRIMARILY IN LOW RESISTIVITY ELECTROLYTES
- INTERFERENCES WITH FOREIGN STRUCTURES USUALLY NONEXISTENT

11-13

Characteristics of the galvanic system continues.

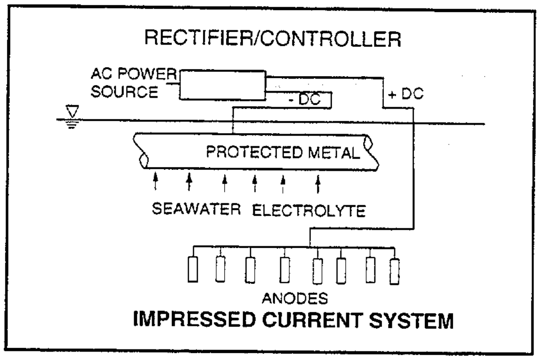


GALVANIC SYSTEM

- ADVANTAGE
  - SELF-REGULATING
- DISADVANTAGE
  - LIMITED CURRENT

11-14

The simplicity of the galvanic system is its main advantage. Its limited current output, especially in electrolytes with low conductivity, is its main disadvantage.

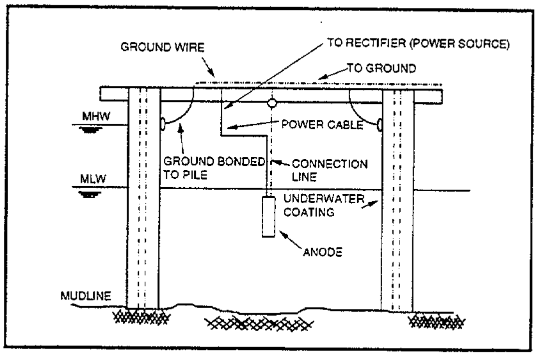


11-15

B. IMPRESSED CURRENT SYSTEMS

An impressed current system (also referred to as an active system) exists when a limited electrical output current is used to create a driving potential. Common impressed current anode materials are cast iron, graphite and special alloys.

Initially, a higher current may be necessary to polarize the structure, but if current is too high, there is a potential for hydrogen to be produced from the reduction of water into hydrogen and oxygen. Hydrogen embrittlement can cause steel to crack.



11-16

This is a sketch of an impressed current system.

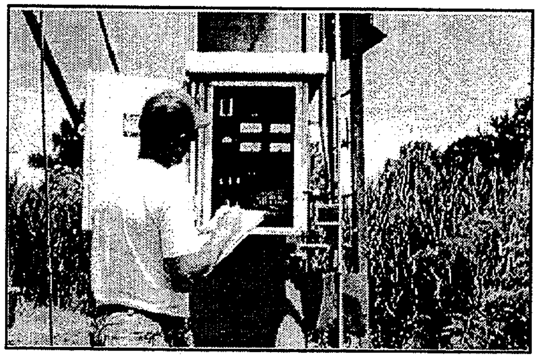
It's important to note that the system is only effective for the submerged parts of the structure. Coatings should be used above and below water in conjunction with the CP system.

Impressed current systems differ from galvanic systems in three important respects:

1) The galvanic potential difference between anode and protected substructure is of no importance.

2) The impressed current anode should be as inert as possible, i.e., have a very low consumption rate for long life.

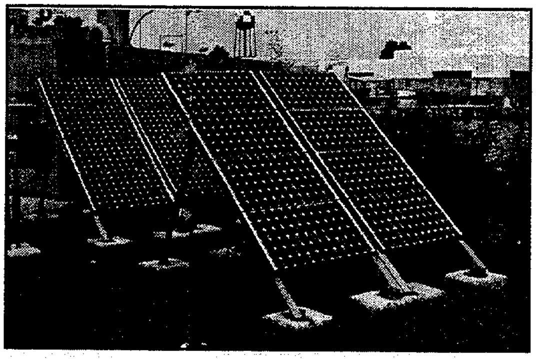
3) Impressed current systems require an external direct current (DC) electrical source to serve as a driving potential to make the structure being protected completely cathodic.



11-17

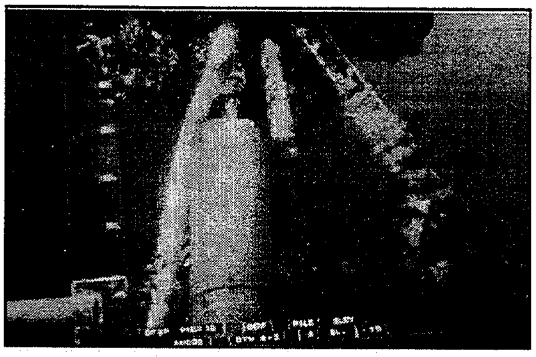
This is a power source for an active CP system. The positive side of the source is connected to the anode and the negative side to each of the protected elements.

This system incorporates voltage meters, current meters and reference electrodes so the systems can be monitored and adjusted. The source of power is generally an AC power line.



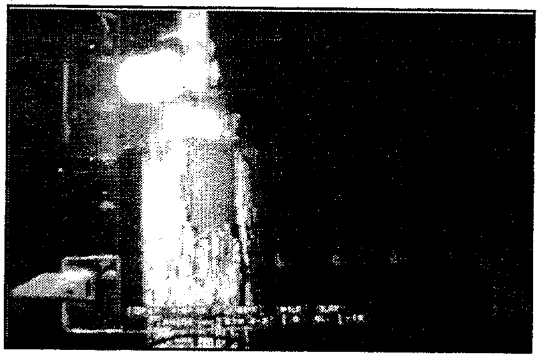
11-17A

Power can also be provided by solar panels. This is an installation of the U.S. Navy used to protect a seawall..



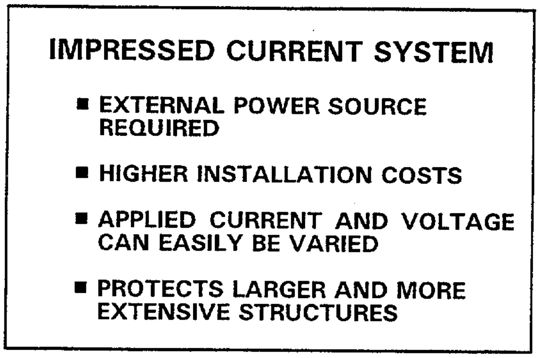
11-17B

This is a cast iron-graphite anode.



11-17C

This anode has had too much current applied through it, resulting in carbonation.

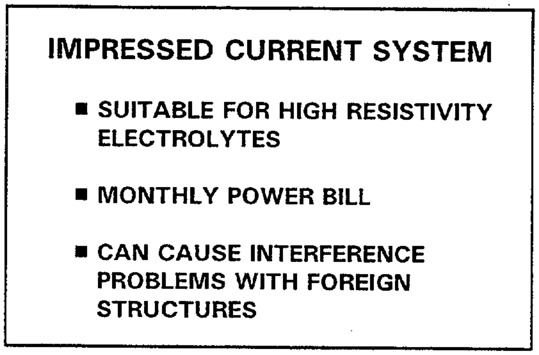


IMPRESSED CURRENT SYSTEM

- EXTERNAL POWER SOURCE REQUIRED
- HIGHER INSTALLATION COSTS
- APPLIED CURRENT AND VOLTAGE CAN EASILY BE VARIED
- PROTECTS LARGER AND MORE EXTENSIVE STRUCTURES

11-18

The impressed current system is summarized in the next two slides. Like the galvanic system, this is a "tried-and-true" method for protecting structures by an active means. While these systems are more complex than the galvanic system, this complexity allows more variation in the system's applications and capabilities.



IMPRESSED CURRENT SYSTEM

- SUITABLE FOR HIGH RESISTIVITY ELECTROLYTES
- MONTHLY POWER BILL
- CAN CAUSE INTERFERENCE PROBLEMS WITH FOREIGN STRUCTURES

11-19

Summary of the impressed current system continues.

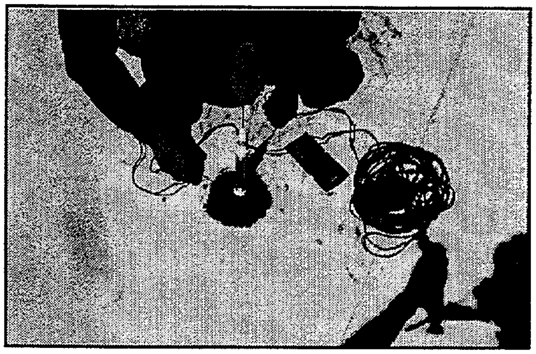
IMPRESSED SYSTEM

- ADVANTAGES
  - FEWER ANODES REQUIRED
- DISADVANTAGES
  - ROUTINE MAINTENANCE REQUIRED
  - POWER SUPPLY REQUIRED

11-20

The advantage of an impressed system is that fewer anodes are required. This can, in some instances, be more cost-effective, especially for larger structures.

A disadvantage of active systems is that more frequent maintenance is required than for a passive system. In addition, a power source is needed which means there is periodic expense.



11-21

Testing should be performed to verify whether a system is working. A waterproofed copper-copper-sulfate half cell is commonly used to measure the potential of CP protected members. A silver/silver chloride electrode may also be used. This system consists of a waterproofed half cell with a long wire lead, a volt meter and a grounding lead.

The half cell is lowered next to the member being tested, within 1.5 feet. The other lead is grounded to the member above water and the difference of potential is read on the voltmeter.

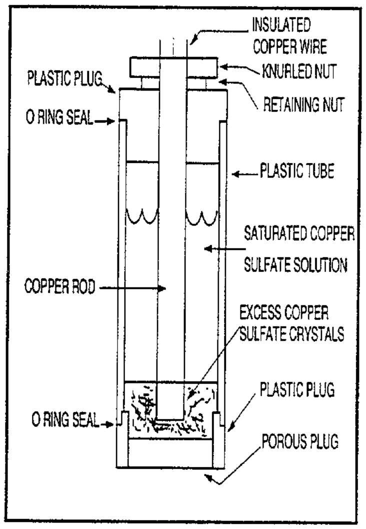
CORROSION VOLTAGES*

- <0.20vdc - NO CORROSION
- 0.20vdc - 0.35vdc - POSSIBLE CORROSION
- >0.35vdc - CORROSION

*RELATIVE TO COPPER COPPER SULFATE REFERENCE CELL

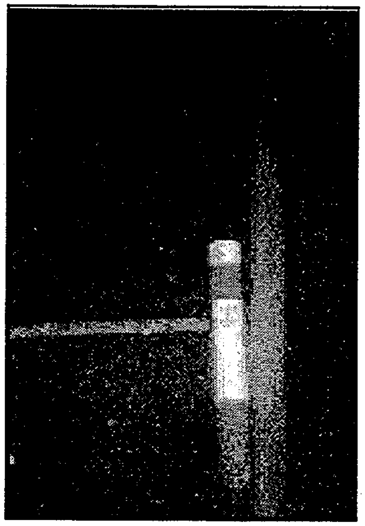
11-22

A corrosion survey, with a reference electrode, and no CP system operating, can indicate if corrosion is occurring. It can also be used for concrete structures where corrosion is not evident.



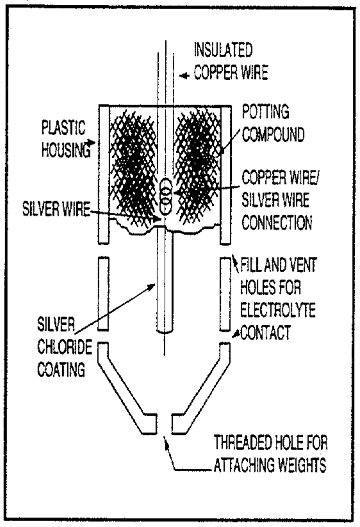
11-23

This is a schematic of a half cell. It consists of a solution of copper-copper sulfate, a center copper conductor, and a porous tip. This is commonly used in fresh water.



11-24

The photo shows an impressed current reference anode in place below water on a structure.



11-25

This is a schematic of a silver/silver chloride electrode. This is commonly used in salt water.

DESIGN CONSIDERATIONS TO PREVENT CORROSION

- **COAT IF POSSIBLE**
- **NO INTERFERENCE FROM OTHER STRUCTURES (DISSIMILAR METAL CORROSION)**

11-26

III SYSTEM APPLICATIONS

Ideally, design for cathodic protection should be a part of the original design of the structure. Placing an existing substructure under cathodic protection can be expensive. Some considerations that should be addressed during the design phase are:

- If coating is feasible, use a high quality coating and apply it properly with minimal bare areas or discontinuities. A well-applied coating is good protection against corrosion.
- Be sure that there are no metallic contacts with other subsurface structures such as pipelines, pipeline casings, or cables.
- Provide CP system to protect against breaks in coating system.

SYSTEM CHOICE

- REQUIRED CURRENT
- ELECTROLYTE RESISTIVITY
- POWER AVAILABLE

11-27

Whether to use a galvanic or impressed current system to protect a given substructure normally will depend on several factors.

- Amount of protective current required.
- Resistivity of the contacting electrolyte.
- Electric power availability.

Current requirements can be calculated or, preferably, determined by actual tests. If it is calculated, the total exposed area must be determined.

FRESH WATER

- PROTECTIVE COATING
- IMPRESSED CURRENT SYSTEM

11-28

In general, steel pile supported bridges over fresh water should not require cathodic protection if an effective protective coating has been applied. If the coating of an existing structure has failed, an impressed CP system may be effective in controlling corrosion below water.

SALTWATER - BRACKISH WATER

- GALVANIC SYSTEM
- IMPRESSED CURRENT SYSTEM

11-29

In coastal waters, cathodic protection is often critical to preserve the condition of submerged steel members. Active and passive systems can be used.

MAINTENANCE OF GALVANIC SYSTEM

- ANODE CONDITION
- LOOK FOR CORROSION
- REPAIR IMMEDIATELY

11-30

MAINTENANCE OF IMPRESSED CURRENT

- MEASURE VOLTAGE DIFFERENTIAL
- INSPECT WIRES
- CONDITION OF ANODES
- RECTIFIER

11-31

IV. MAINTENANCE

The consumption rate of an anode will vary from structure to structure. Each system will require a different inspection frequency depending on system design. In general, the following items should be inspected:

Galvanic System

- Inspect the condition of all the anodes to insure they are installed correctly and that they have sufficient section to effectively protect the structure until the next inspection.
- Inspect the steel member for any areas of corrosion. Corrosion will indicate that the protection system might not be functioning properly.
- Any missing or broken anodes should be repaired immediately.

Impressed Current System

- Measure the potential difference to insure it is at least -.85 volts which is required for protection. Take measurements at numerous locations on the structure.
- Visually inspect the wires to insure the insulation is in good condition and that the wires are securely connected to the structure and anodes. (If the insulation is not in good condition, the wire could corrode.)
- Inspect the condition of the anodes. If the anodes are located near the bottom, insure they have not been covered by bottom material.
- Inspect the rectifier to insure it is operating correctly.
- Correct any deficiencies or defects in the system.

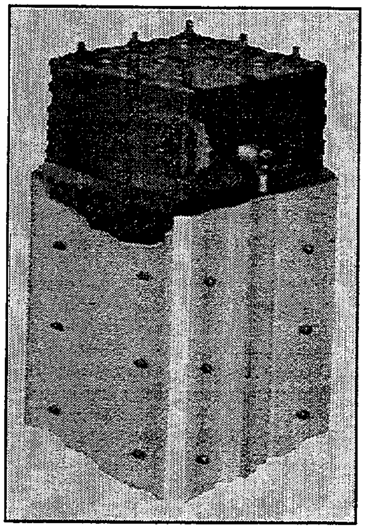
NEW CATHODIC PROTECTION SYSTEMS

- **BUILT INTO JACKETS**
- **WIRE ON SURFACE**
- **FLAME SPRAYED ZINC**
- **WRAP SYSTEM**

11-32

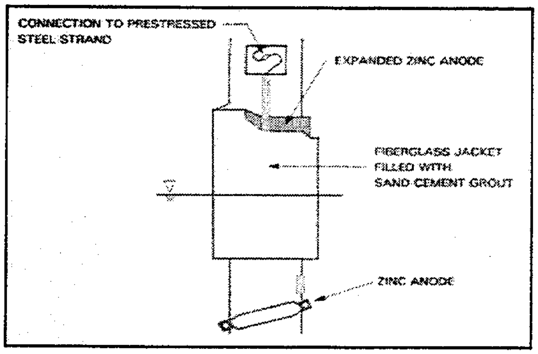
V. NEW CATHODIC PROTECTION SYSTEMS

There are a number of new types of systems being developed. Florida, for example, has used a number of new jacketing systems for use on concrete piles in recent years which they have developed in conjunction with cathodic protection.



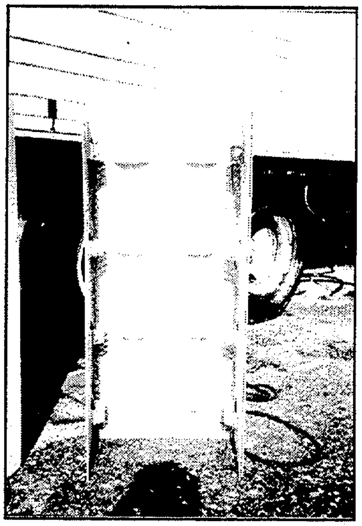
11-32A

This is a galvanic system that Florida has installed on concrete piles in the splash zone and also below water. It consists of an expanded zinc mesh anode embedded in a portland cement mortar within a stay-in-place fiberglass form. The zinc is bonded to the reinforcing steel through the junction box. The entire system has an estimated life of more than 45 years.



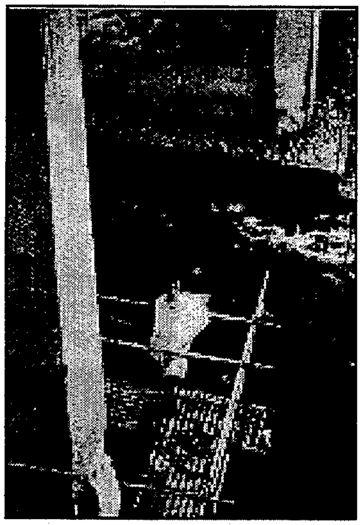
11-32B

The system also includes a 45 pound bulk zinc anode so that the mesh is not consumed in protecting the entire pile.



11-33

This is an example of the mesh anode built into a jacket to be installed on the concrete pile. The standoffs are also visible.



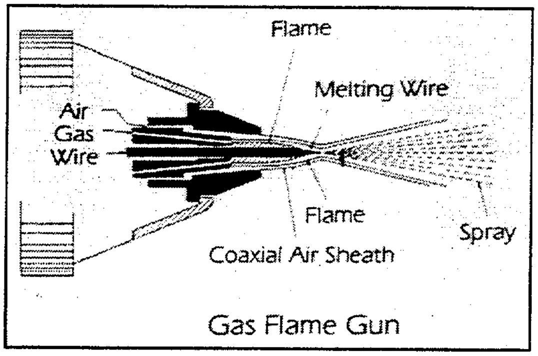
11-34

This is an impressed current system of titanium wire electrodes attached to the surface of the concrete piers.

11-35

This is an example of flame spraying zinc onto the surface of the concrete above the low water line. The system can be either an active or a passive system. The zinc is generally sprayed on in a thickness of 15 to 20 mils.

Surface preparation is critical to good bond.



11-35A

This an example of a gas flange spray gun.

SACRIFICIAL WRAP SYSTEM

- **ZINC FOIL ANODE - 10 MILS**
- **HYDROGEL CONDUCTIVE ADHESIVE - 30 MILS**

11-36

A sacrificial wrap has also been developed. It consists of a zinc foil anode and a hydrogel, i.e., an ionic conductive adhesive.

SUMMARY

- CORROSION IS AN ELECTRO-CHEMICAL PROCESS
- PASSIVE SYSTEMS PROVIDE A SACRIFICIAL ANODE TO SAVE THE STRUCTURE
- ACTIVE SYSTEMS IMPRESS A CURRENT TO OFFSET CORROSION PROCESS
- CATHODIC PROTECTION IS PART OF CORROSION PROTECTION SYSTEM
- SYSTEM MUST BE INSPECTED AND MAINTAINED

11-37

VI. SUMMARY

Cathodic protection systems can be used to reduce, or possibly eliminate, deterioration of metals due to corrosion. Both passive and active systems can be used on below water structure elements. All systems require at least some maintenance to perform properly. While cathodic protection systems have been designed and used for many years, new techniques for use in a marine environment, particularly on reinforced concrete are continually evolving.

Florida DOT has an extensive corrosion testing program. The accompanying video summarizes the corrosion problem in concrete piles and one galvanic system.

SESSION 12

SCOUR COUNTERMEASURES

SESSION 12: SCOUR COUNTERMEASURES

TOPICS: **RIPRAP ARMORING, GROUTED RIPRAP, FORMED CONCRETE, SHEET PILE CONTAINMENT, JET GROUTED UNDERPINNING, AND COUNTERMEASURES FOR STREAM MIGRATION**

LESSON PLAN:

DURATION	30 minutes
GOAL	Understand overview of scour conditions and repair methods.
OBJECTIVE	Participant should recognize general scour countermeasures and their application.

OUTLINE

I. Introduction
II. General Considerations
III. Techniques at Piers
    A. Riprap Armoring
    B. Sheet Pile Containment
    C. Jet Grouted Underpinning
    D. Bottom Paving
IV. Flow Control Countermeasures
V. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

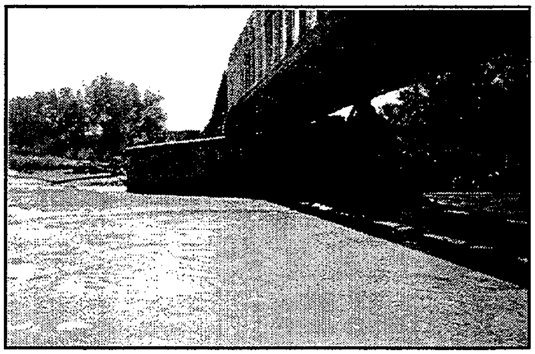
SESSION 12
SCOUR COUNTERMEASURES

12-1

I. INTRODUCTION

Bridge failures such as Schoharie Creek, Hatchie River and the recent failure of an I-5 bridge in California have received considerable news coverage and increased awareness of the potential for bridge failure through scour. Indeed, many bridge failures have occurred due to scour, though fortunately few have been large structures or caused a loss of life.

Hydraulic Engineering Circular No. 20, "Stream Stability at Highway Structures" (HEC-20) defines a scour countermeasure as "... a measure incorporated into a highway - stream crossing system to monitor, control, inhibit, change, delay, or minimize stream and bridge stability problems or action plan for monitoring structures..." Countermeasures may be a part of initial construction, or may be a retrofit.



12-2

This railroad bridge pier has settled approximately two feet and moved downstream nearly three feet due to scour. Repair techniques for undermining of the pier were presented in Session 10.

This session presents a brief overview of several techniques for providing scour protection which may be evaluated as a part of an underwater repair program, focusing on the area near the bridge.

GUIDANCE

- HEC-18
- HEC-20
- HIGHWAYS IN THE RIVER ENVIRONMENT

12-3

Guidance or detailed analysis and design of these and other techniques is available in the following publications available from the FHWA.

- Hydraulic Engineering Circular (HEC) No. 18, "Evaluating Scour at Bridges".
- Hydraulic Engineering Circular (HEC) No. 20, "Stream Stability at Highway Structures".
- "Highways in the River Environment".

SCOUR MONITORING AND INSTRUMENTATION

DEMONSTRATION PROJECT 97

12-4

Scour monitoring and instrumentation are presented as a separate module in Demonstration Project 97. This is an one and one-half day companion program to this class available through the Office of Technology Applications (Contact Tom Krylowski at (202) 366-6771).

Detailed information on scour processes and calculating scour depths is presented in NHI Course No. 13046, "Stream Stability and Scour at Highway Bridges".

GENERAL CONSIDERATIONS

12-5

II. GENERAL CONSIDERATIONS

Scour effects at the bridge may be the result of a combination of long term stream bed elevation changes (aggradation/degradation), contraction scour (scour throughout the bridge cross section due to contraction of flow area caused by the bridge), and local scour (scour in the immediate vicinity of piers and abutments).

STREAM STABILITY

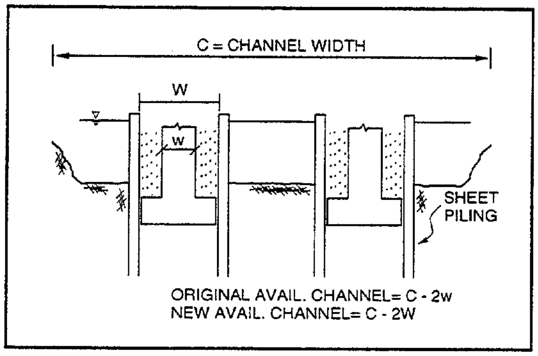
- LATERAL
- VERTICAL
- LOCAL

12-6

Foundation problems due to loss of river bed support material can occur from stream instability in any of several forms.

- Lateral movement of the river may undercut abutments or move flows into banks with shallower footings than at the previous main channel piers (as at Hatchie River).
- Reduction in the vertical elevation of the river bed causes a loss of lateral and also, perhaps, vertical pier support. Though less often considered, an increase in the river bed elevation due to material deposition could also result in problems such as bridge over topping or increased debris build up.
- Local scour at piers and abutments is often the most critical case for pier stability and perhaps most easily addressed by local remedial measures to be presented in this session.

It is extremely important to understand what conditions caused the scour and quantify the maximum possible scour before selecting any remedial measures.



12-7

Repairs can have both desirable and undesirable effects. The adverse effects must be alleviated by careful design. For example:

- A widening of piers can cause deeper scour.
- Armoring an area or construction of flow training structures can cause scour at an area previously not experiencing scour.

As shown in this slide, adding sheet piling to protect a footing from undermining and extending that sheeting above the footing results in a pier widening. This widening reduces the available channel width, thus increasing flow velocity and potential scour.

For some projects it may be more appropriate to monitor scour activity and have an emergency action plan than make very costly repairs. This is addressed in the Demonstration 97 project.

TECHNIQUES AT PIERS

12-8

III. TECHNIQUES AT PIERS

Various scour repairs and countermeasures take place at or very near the piers or abutments.

RIPRAP ARMORING

- RESISTS SHEAR
- RESISTS WAVES
- SIZING EQUATIONS

12-9

A. RIPRAP ARMORING

Riprap armoring consists of sizing and placing large enough stone in scour susceptible areas to resist the flow induced shear stresses or wave induced impact and turbulence on the waterway boundary. Riprap can be used as either a scour preventative measure or as a scour repair material.

There are a number of empirical mathematical relationships in existence for sizing riprap. These equations yield stone size or weight and include stone density and water velocity (to the second power) as two parameters. However, because of extreme turbulence and severe flow conditions near bridge piers it is difficult, if not impossible, to design and place riprap that will provide permanent protection. Therefore, riprap at piers should be considered a temporary scour countermeasure and should be periodically inspected or monitored. Details in calculating riprap sizing, are contained in the referenced publications.

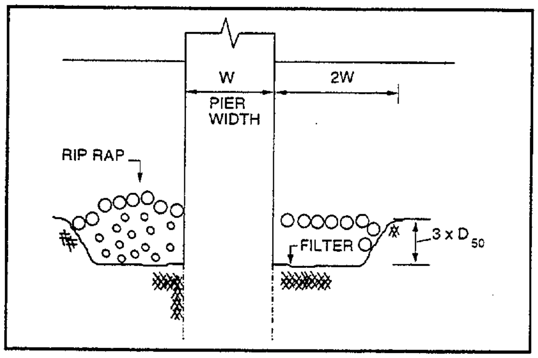
DESIGN PARAMETERS

- THICKNESS
- EXTENT
- GRADATION
- PREVENT MIXING

12-10

Design parameters that are important to proper performance include those shown here.

HEC-18 recommends that the minimum thickness of a riprap placement should be greater than three times the size of the average stone (the D_{50} stone).



12-11

Determining the area requiring riprap protection is very subjective. Current practice for pier armoring varies, protecting the channel bottom out to a distance of between 1 and 6 pier widths away from the pier face. HEC-18 recommends a minimum distance of twice the pier width. For abutments, armor is typically placed out to a distance equal to the depth of design flow.

Stone must be graded such that the riprap interlocks, is not washed out, and bottom material is not washed out through the stone. Riprap gradation criteria which help the individual stones interlock are:

$$1.26 \times D_{50} \le D_{100} \le 1.71 \times D_{50}$$

$$0.5 \times D_{50} \le D_{15} \le 4 \times D_{85}$$

Where D_{85} = equivalent diameter of underlying material for which 85% is smaller.

Gradation criteria can be satisfied by using multiple layers of different size stones, geotextiles, or replenishing riprap periodically to replace stones which have settled into the substrate. Placement of filter fabric under riprap is difficult in flowing water, and may be impossible to place properly. Poorly graded materials without a filter layer may be mixed with the bed materials and become ineffective.

ALTERNATIVES TO RIPRAP

- **GABIONS**
- **GROUT BAGS**
- **GROUT MATTRESSES**
- **INTERLOCKING CONCRETE SHAPES**

12-12

There may be situations when there is a lack of acceptable riprap. In those situations it may make economic sense to armor areas susceptible to scour with gabions, grout bags, grout filled mattresses, or commercially available mats composed of interlocking concrete shape. Their function would be the same as the riprap, which is to resist the shear stresses caused by flow patterns in susceptible areas.

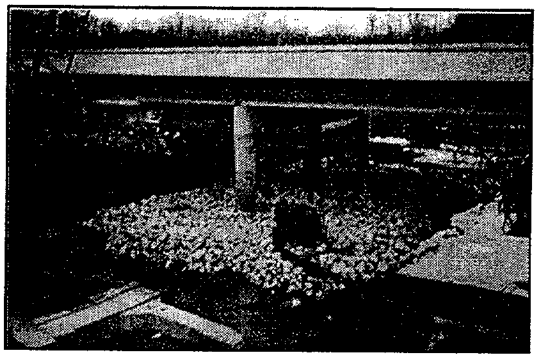
These materials should be placed tightly against the pier to prevent loss of bottom material up along the pier and undermining of the mats. Mats may also require anchoring to the channel bottom to prevent uplift at the leading edge, where failure is most likely.

Note that there may be situations for which riprap protection is not appropriate. In these situations the entire bed of the water course is in a state of motion or transport and the riprap will move into the bed material and downstream.

STONE QUALITY

12-13

Where riprap extends up embankments and may be exposed to freeze-thaw action, stone quality must be high. The Corps of Engineers criteria for durability of breakwater stone can be used for these cases if other department specifications are not available. For stone that is constantly submerged, material standards can be lower and result in cost savings.



12-14

This shows riprap placement at a bridge footing as part of scour protection work. Note the extent of stone placement.

12-15

Placement of stone riprap may be difficult due to overhead restrictions.

Here, grout filled bags are used as riprap to ease placement.

SHEET PILE CONTAINMENT

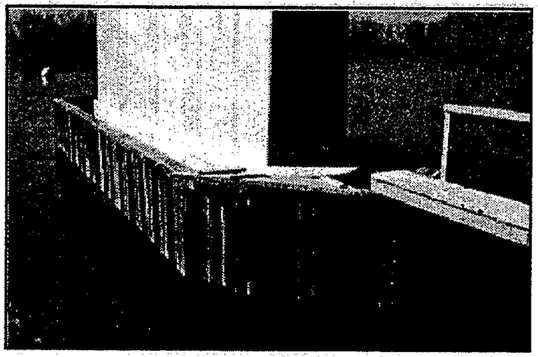
12-16

B. SHEET PILE CONTAINMENT

For some situations, a sheet pile containment structure may be appropriate or cost-effective. Usually steel sheeting is used and no special corrosion protection required. This should be evaluated, however. Z-pile sections are recommended for drivability, and can be hot or cold rolled sheets. Sheet piling can be used as part of remediation of a scour problem, particularly where undermining has taken place and the sheets serve to contain concrete placed into the undermined area.

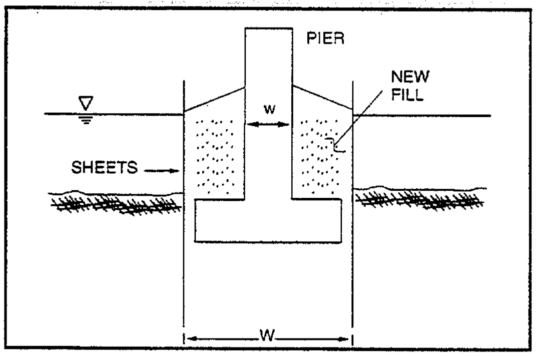
It is also used where undermining has not occurred but may be expected. In this case usage is preventative. The sheeting containment does not prevent scour from occurring, but rather protects the foundation from being adversely effected by it.

In both cases, the piling must extend deep enough to yield a stable structure under maximum scour where it may behave as a gravity structure subjected to large lateral water pressures. For pile supported structures, the scour will cause larger vertical pile loads which, for friction piles, may be being resisted by a reduced embedment length. Additional bearing piles could be required.



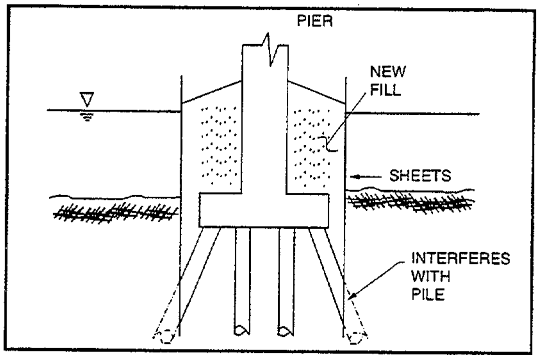
12-17

In some cases piles may extend to the surface, as shown here.



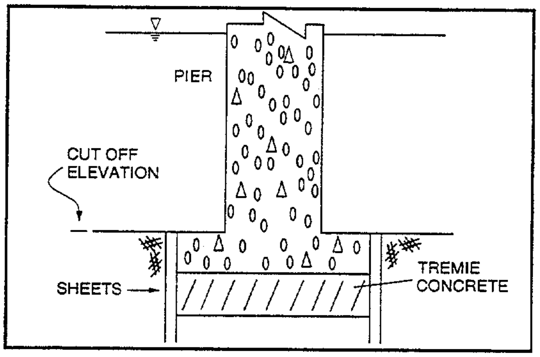
12-18

Note that by extending these sheets to the surface the effective pier width was increased from w to W which will increase scour.



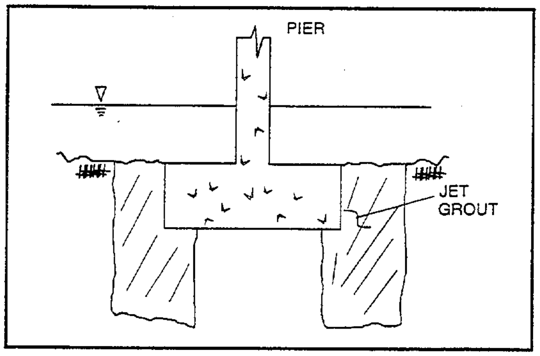
12-19

Driving sheet piling to required depths may also be a problem where battered piles must be cleared by the sheeting.



12-20

Cutting the sheets off at the top of the footing is an obvious choice to reduce the problem of added pier width.

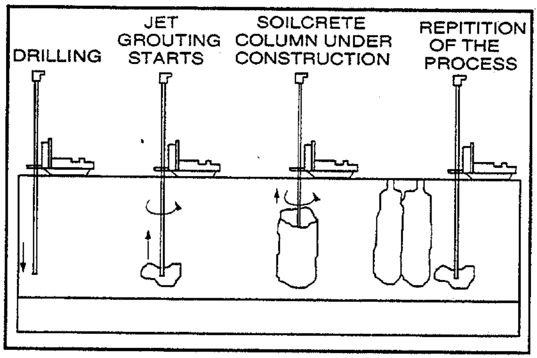


12-21

C. JET GROUTED UNDERPINNING

In special situations where underpinning may be appropriate, such as severe scour where clearances preclude sheet pile installation, jet grouting offers a convenient, although expensive, repair procedure.

Jet grouting can increase the load carrying capacity of the soil around the foundation and reduce its susceptibility to scour by its cementing action.



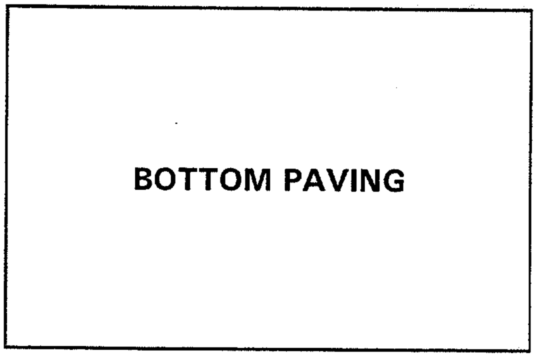
12-22

This diagram shows a flow chart for the jet grouting process. Jet grouting consists of drilling a hole with a hollow stem drill and while withdrawing and rotating the drill stem, "spraying" a water cement, or chemical, slurry under approximately 6000 psi pressure perpendicular to the hole. The slurry mixes with the insitu material, forming an embedded mortar column. The columns can be located intermittently, or so they intersect and form a solid mortar mass.

The drilling and underpinning can be performed vertically, angled, and even horizontally. It is possible to drill through a pier or abutment to install a mortar column beneath it.

12-23

This shows a series of jet grouted soil columns exposed as part of a verification test of the integrity and consistency of the grouted columns.



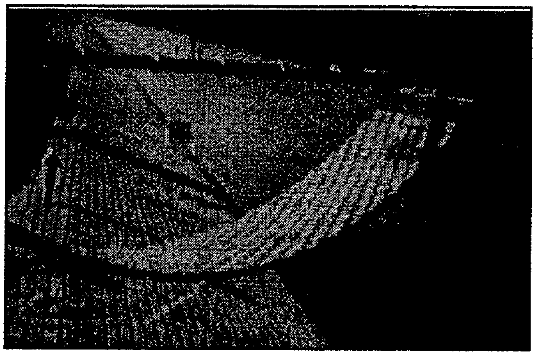
BOTTOM PAVING

12-24

D. BOTTOM PAVING

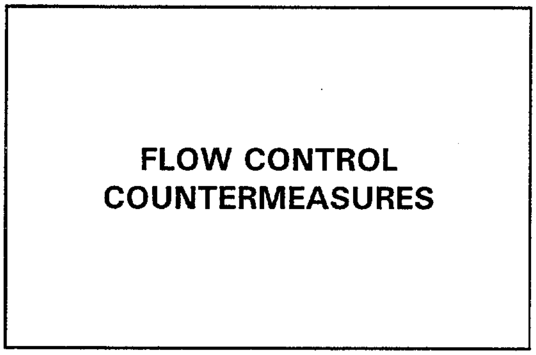
Where scour extends across the waterway opening, paving of the channel has sometimes been used. This may consist of riprap, gabions, grouted fabric mattresses, articulated concrete mattresses, or actual concrete cast-in- place slabs. Woven willow mats have also been used for this purpose and are perhaps one of the oldest methods of protecting footings.

Such systems must be designed against undercutting at the upstream end and downstream toe and may include cutoff walls.



12-25

This shows cabled-articulated concrete blocks being set. They can extend across the channel as well as provide bank protection.

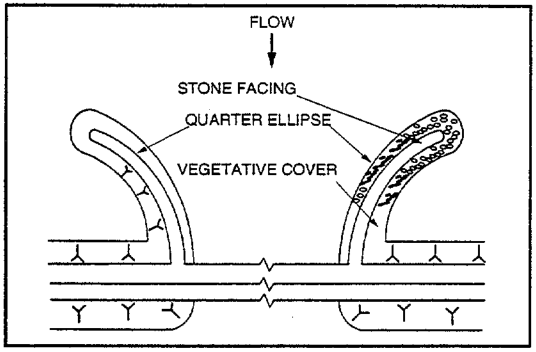


FLOW CONTROL
COUNTERMEASURES

12-26

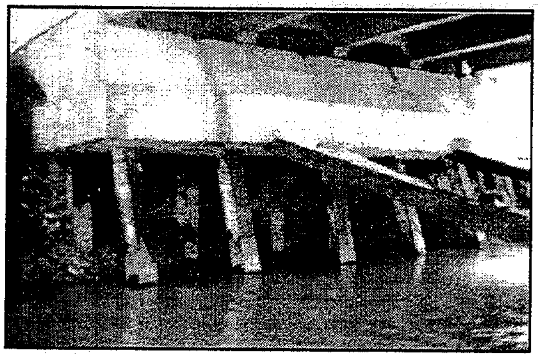
IV. FLOW CONTROL COUNTERMEASURES

Flow control countermeasures serve to steer a river in a desired direction or modify the river flow to correct an erosion problem. Here we will simply note a few possibilities. Detailed design guidance can be found in previously cited references.



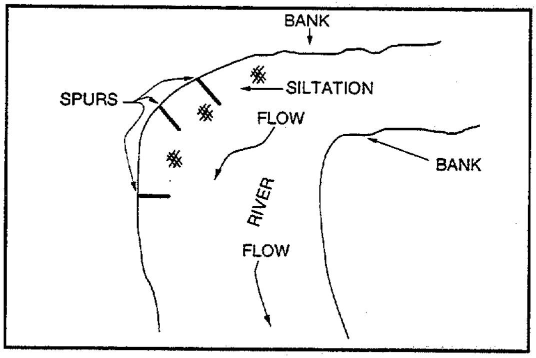
12-27

Guide banks are used to: 1) improve flow alignment and hydraulic performance, and, 2) to reduce abutment scour and transfer the location of potential scour away from the bridge. Guide banks typically extend for 100 to 250 feet, with 150 feet a good estimating average. The banks should be properly protected by riprap and vegetation.



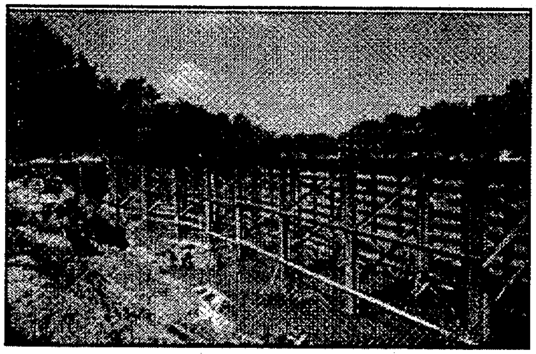
12-28

Lateral erosion can cause severe abutment problems as shown here. The use of spurs and silt fences can aid in reducing the lateral bank movement.



12-29

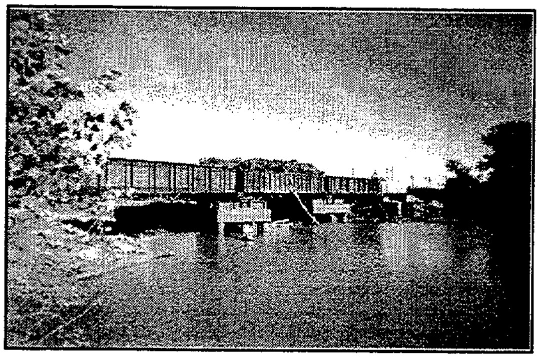
Spurs project out from the bank and serve to slow flow and create dead current areas in order to cause siltation. Spurs are often constructed from rock or may be fence type structures with filter cloth or closely spaced slats to impede flow.



12-30

Fence retarder structures, sometimes called silt fences, are also constructed to reduce velocities and create deposition near the bank. They generally are placed parallel to the stream bank.

This is a photo of a large silt fence constructed of steel and timber.



12-31

Where other attempts to mitigate scour are unsuccessful or impractical, new foundations extending to below scour depth can be constructed. Here deep drilled shafts have been used to bypass the original scoured bridge piers. This is obviously an expensive proposition.

SUMMARY

- **WELL PUBLICIZED FAILURES**
- **INTERDISCIPLINARY EFFORT**
- **VARIETY OF TECHNIQUES**
- **DEMONSTRATION PROJECT 97**

12-32

V. SUMMARY

Methods for scour countermeasures require a joint effort of hydraulic, structural, and geotechnical engineers. Designs must be well tempered by judgement and experience. Many techniques, such as riprap or sheeting, are used at the pier. Others techniques attempt to favorably alter the river flow. Much research work is currently underway related to scour prediction and protection. Demonstration Project 97 is one educational tool available to provide in-depth information on this topic.

SESSION 13

MISCELLANEOUS STRUCTURES REPAIR TECHNIQUES

SESSION 13: MISCELLANEOUS STRUCTURES REPAIR TECHNIQUES

TOPICS: **PROTECTION CELLS, SHEAR FENCES SHEET PILE WALLS, TIMBER CRIBS AND CULVERTS**

LESSON PLAN:

DURATION	30 minutes
GOAL	Familiarity with selected repair techniques for miscellaneous structures.
OBJECTIVE	Ability to select appropriate repair scheme.
OUTLINE	I. Introduction II. Protection Cells III. Shear Fences IV. Sheet Pile Walls V. Timber Cribs VI. Culverts VII. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 13
MISCELLANEOUS STRUCTURES REPAIR TECHNIQUES

13-0

I. INTRODUCTION

Bridge engineers are responsible for a variety of structures built in conjunction with bridges and roadways. In some states they may also be concerned with ferry terminals. These facilities are also often in need of repair.

MISCELLANEOUS STRUCTURES

- PROTECTION CELLS
- SHEAR FENCES
- SHEET PILE WALLS
- TIMBER CRIBS
- CULVERTS

13-1

Various types of structures such as protection cells, shear fences and sheet pile walls may be constructed to supplement bridges. Bridge piers are sometimes founded on timber cribs. In addition, other structures such as culverts may be fully or partially submerged, where underwater methods of repair become appropriate.

PROTECTION CELLS

- SHEET PILE
- PILE CLUSTERS

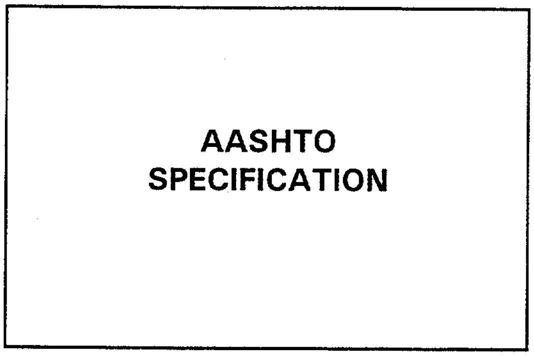
13-2

II. PROTECTION CELLS

Protection cells are used to protect bridges from vessel or barge impact damage. Usually they are constructed of:

- Sheet pile cell with fill
- Pile clusters, usually timber or steel pipe

Cells are considered navigation aids and must be maintained in serviceable condition. These structures are subject to material deterioration as well as physical damage from vessel collision.

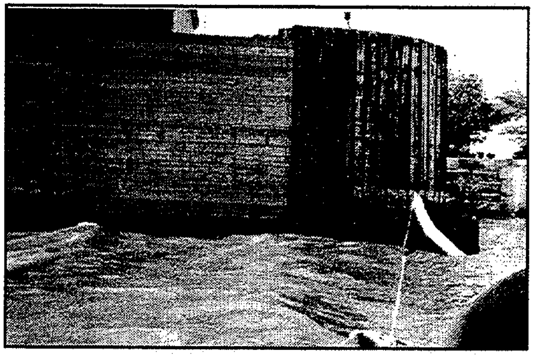


AASHTO SPECIFICATION

13-3

The "AASHTO Guide Specification and Commentary for Vessel Collision Design of Highway Bridges" should be consulted where extensive repair or replacement of bridge protection devices is necessary.

This publication provides extensive information on the mechanics and dynamic design methods to handle vessel impact loads.



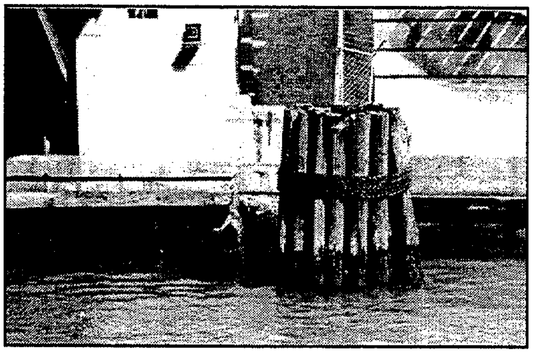
13-4

This slide shows a typical sheet pile cell. Timber pier protection is provided between the cells at either end of the pier. Cells are normally constructed of driven flat sheeting. The cells may have internal bands or driving templates and are filled with granular material.

Cells usually have concrete caps and navigation lights.

Several design procedures are available for the design of a cell for a given lateral loading.

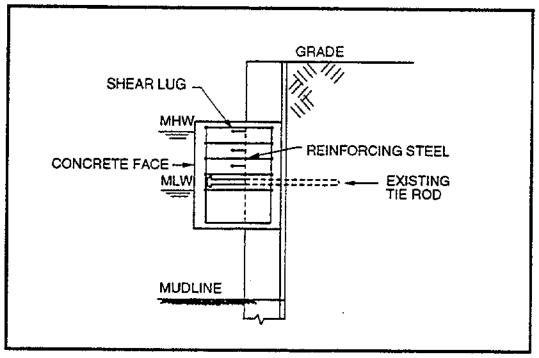
Navigation lighting requirements are contained in U.S. Coast Guard regulations.



13-5

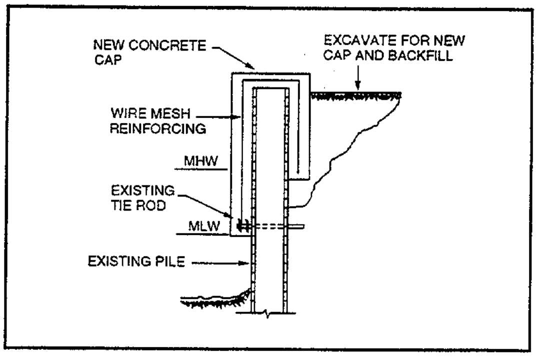
This shows a pile cluster used as a protection device. Timber piles and pipe piles are commonly used. The piles are driven in a group and tied together above water with cables, bands, caps, or other means.

Sizing of pile clusters has often been by rule-of-thumb and department standards. U.S. Navy guidelines limit lateral loads on a 19 pile timber pile cluster driven at a one to ten batter to a maximum of 30 tons.



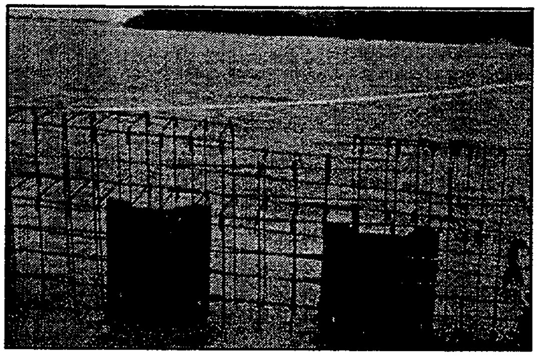
13-26

Where deterioration is more extensive, such as shown here between high and low water, a concrete facing can be used. Shear connectors are fixed to the old sheets and then the new facing is cast in forms. It is often possible to do virtually all of this work from the top at low water. The facing thickness should be kept to a minimum, and may incorporate a precast stay-in-place form.



13-27

For more extensive repair the cap can be carried over the top of the pile and even down the back, as shown in this drawing. This eliminates the need to install shear studs on the piles.



13-28

Here, reinforcing cages are being placed over a heavily deteriorated steel sheet pile wall which is to receive a concrete cap to restore wall integrity.

Walls may lose toe embedment due to scour. This is usually repaired with dumped riprap. If this is severe, new sheets are driven with a deeper toe.

The ability of a protection device to absorb the energy from a vessel impact is related to the structure's lateral stiffness. While this is only implicitly a part of many "designs", it is a computed property with major implications for behavior of other structures, typically those more recently designed or designed for major bridges. Thus, repairs to a structure which will alter its stiffness, such as a new line of sheeting outside the original, should be carefully evaluated. A stiffer structure must be able to carry a larger load and could increase vessel damage upon a collision.

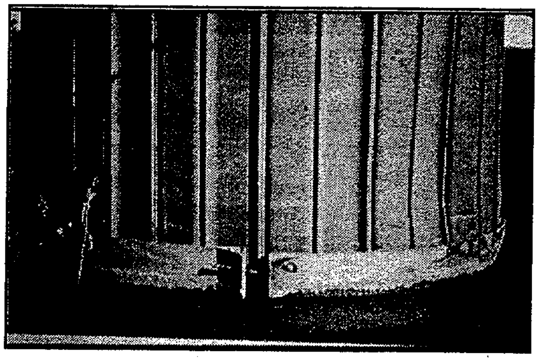
REPAIR TECHNIQUES

- **ADD SHELL**
- **PULL AND REDRIVE**
- **PATCHES**

13-9

Repair techniques for protection cells and clusters include:

- Driving a new sheet pile shell around the old structure. New fill and cap are added. Adequate navigation clearance must be maintained which may limit this option.
- The existing cell is partially removed and replacement sheets may be spliced if deformations are small. Temporary cable bands may be needed for cell stability during repair.
- Pile clusters may have individual piles pulled and replacement piles driven.
- If damage is local, steel patch plates can be installed or a full band placed. Voids behind the patch can then be grouted. For pile clusters, a reinforcing band of plate can be used to strengthen local pile damage.



13-10

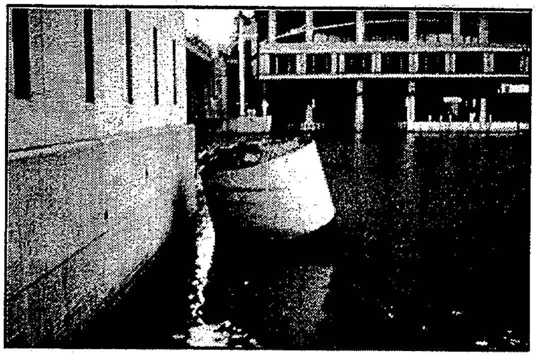
Reinforcing bands added to cells can be wide and add not only reinforcing for cell tension forces but added local impact resistance. Reinforcing may be needed due to cell damage or where extensive corrosion has occurred. Depending on the condition of the sheets, those bands and their connections should be capable of carrying the full interlock tension of the sheets. Bands are usually set in two sections and, if needed, lowered below water for diver tightening of connection bolts.

Repair plans may require damaged sheets to be removed and new sheets driven. Sheets can be burned off underwater for partial length sheet replacement. Splice locations should be staggered. Interior tension bands may also need repair and can serve as a partial template for driving new sheets.

Mating to existing sheets can be difficult as suppliers and hence interlock details and sheet profiles have changed over time.

Vertical pile splices normally take very little load and can be made with welded splice plates whether above or below water. "Hair Pin" splices are also sometimes used, consisting of a plate on either side of the new pile such that they slip down over the existing pile.

Local repairs to interlock splits or tears are also made by welding, above or below water, of either the interlock itself or, more often, small plates over the torn area.

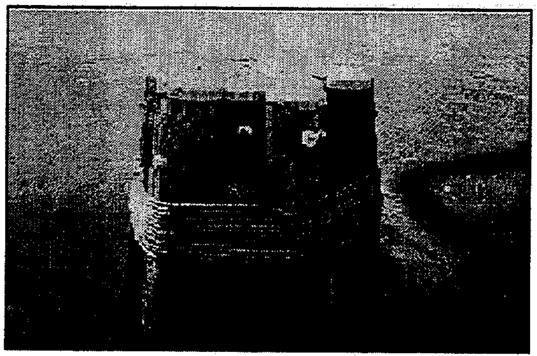


13-11

As previously noted, repairs to pile clusters usually involve removal of damaged piles and redriving. New wrapping is often installed and possibly a concrete cap, particularly to protect timber pile tops.

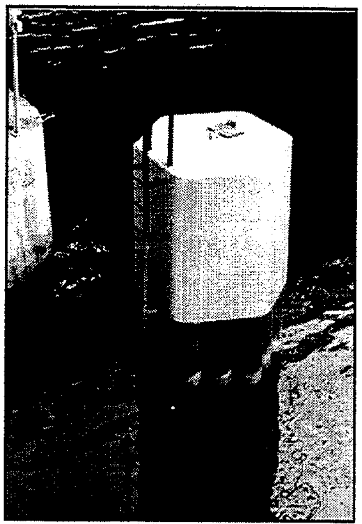
This shows a badly damaged cluster for which total replacement is recommended.

Pile replacement, either selective or total, is usually needed where pile material deterioration has occurred since installation of pile wraps or jackets is virtually impossible with a pile cluster.



13-12

Sometimes the cluster is enlarged with new piles and wrapping and the old piles left. Note here the metal caps placed atop each timber pile to protect the end grain from rotting. These caps may be metal or plastic and should be bedded in roofing cement and well fastened with galvanized or copper nails.



13-13

This slide shows a replacement pile cluster using steel pipe piles. A welded steel cap and top banding is provided to help the piles act as a group. The replacement cluster should be in precisely the same location as the cluster it replaced. This may be complicated if old piles break off during removal.

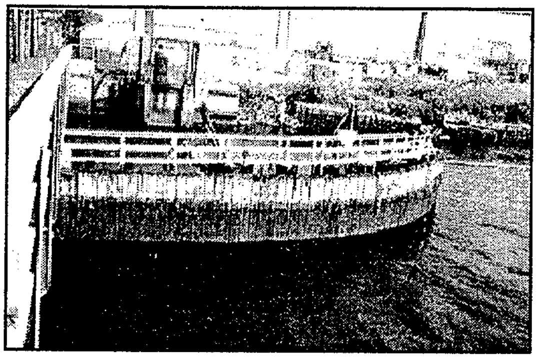
SHEAR FENCES

13-14

III. SHEAR FENCES

Shear fences, usually of timber, are frequently damaged by impact and may also decay. Repair normally consists of removing damaged members and replacement in kind.

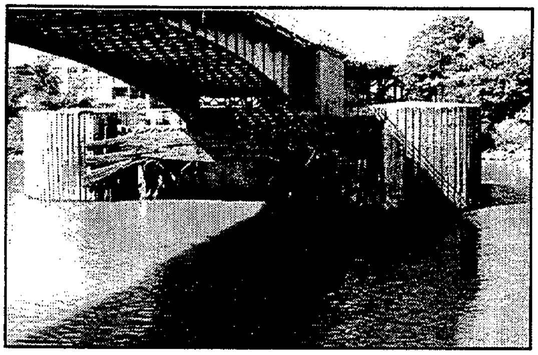
In some cases of material deterioration, access is good enough that individual piles may be repaired using the techniques presented in Session 10.



13-15

Shear fences are considered aids to navigation and vessels expect to and do use them. Single side shear fences as shown here typically include vertical and batter piles with a facing. Minor impact and abrasion damage should be expected and will require periodic repairs. Major repairs may be required following a vessel collision.

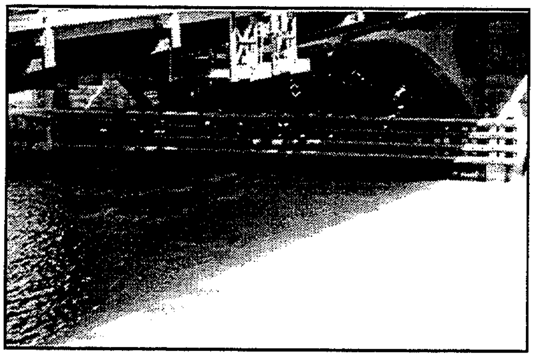
Comments regarding legal issues for protection cells apply to shear fences as well.



13-16

This is an example of a shear fence of timber piles and sheeting where sheeting and pile damage has occurred from a vessel impact. Pile breaks below the mudline may occur, and NDT techniques used to determine in situ pile lengths have shown promise in locating such breaks.

Generally, vessel damage should be restored to original condition, even if minor, so that any subsequent damage is readily identified.



13-17

This shows a repaired fendering area. New members should be treated after fabrication and new hardware, galvanized, used in assembly.

Panalized sections may make underwater replacement easier.

During repairs, upgrading the structure to include resilient fenders may aid in a longer facility life and should be considered. Either marine fendering systems may be used, or a plastic "timber" can used. These typically last longer that a timber member.

SHEET PILE WALLS

- **STEEL**
- **TIMBER**
- **CONCRETE**

13-18

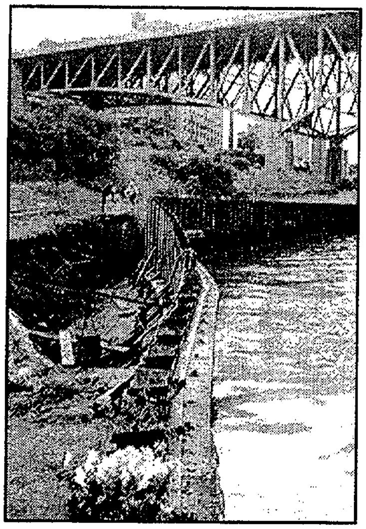
IV. SHEET PILE WALLS

Sheet pile walls may be used as extensions to wingwalls or as river walls near bridges. Steel, concrete, and timber walls are found. Walls may be anchored using drilled and grouted tie-backs, or deadmen.

Deteriorated walls can allow loss of material from around abutments and adversely effect local flow conditions.

13-19

Deterioration is usually from weathering and corrosion. Here a steel sheet pile wall is badly corroded from marine exposure.



13-20

Overall wall failure as shown here is usually due to geotechnical factors and will not be considered here.

REPAIRS

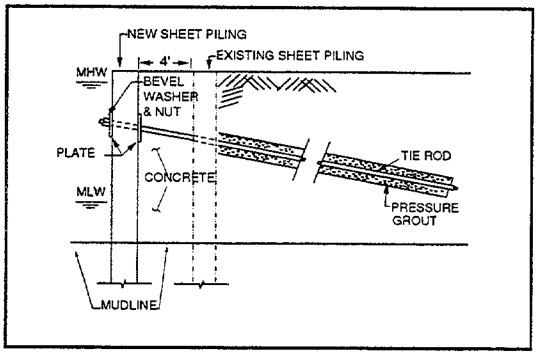
- ADD WALL
- LOCAL PATCHING
- REFACING

13-21

Several repair options are available.

Adding a replacement wall may be necessary in cases of severe material deterioration, but is more often used where geotechnical factors are a cause of failure or distress. Local patching is used for isolated areas of repair.

Where repair areas are numerous, overall refacing is usually undertaken. This also adds protection against further deterioration.

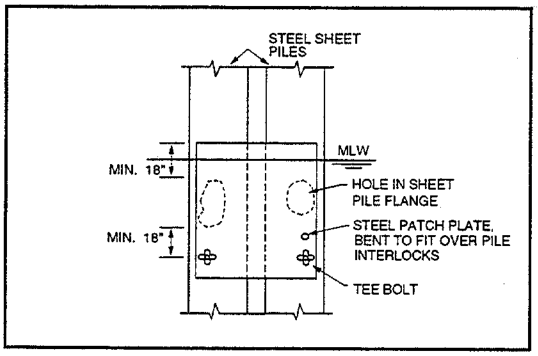


13-22

A new wall can be driven, usually outboard of the existing wall. If the existing wall has anchors, interconnection of the walls is usually made, and sufficient space between the walls is needed to execute the connection. Anchors may also be added to the wall. The annulus between the walls should be filled with granular material, or preferably with concrete.

13-23

If deterioration of the wall occurs in small areas, as shown here, local repairs can be made to the affected area. Often these repairs are in the splash zone. Before undertaking such repairs the overall wall should be evaluated to assure that the small areas are not symptomatic of more extensive deterioration.



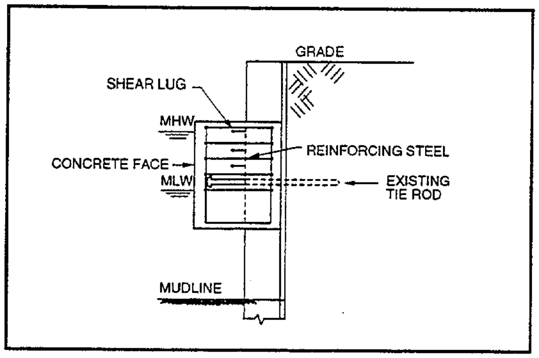
13-24

Local repairs to timber sheeting usually are made by splicing or lag bolting a timber or steel patch over the effected area. Sometimes holes are packed with cement mortar.

13-25

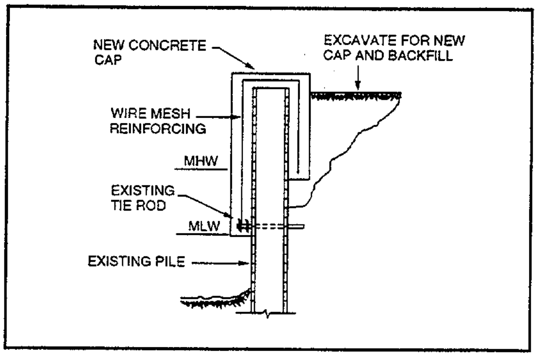
Steel sheets can have patch plates welded in place, or holes packed with cement mortar. Welded plates are also used to seal split interlocks.

Concrete sheets or cast-in-place walls can be repaired with techniques discussed in Section 9.



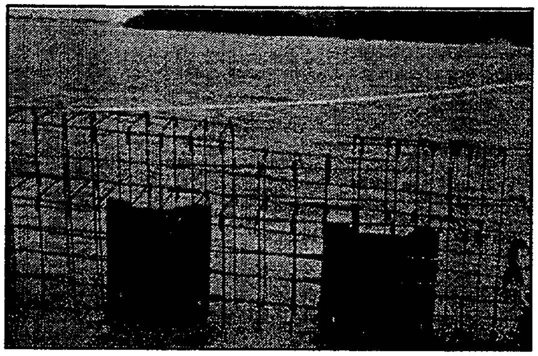
13-26

Where deterioration is more extensive, such as shown here between high and low water, a concrete facing can be used. Shear connectors are fixed to the old sheets and then the new facing is cast in forms. It is often possible to do virtually all of this work from the top at low water. The facing thickness should be kept to a minimum, and may incorporate a precast stay-in-place form.



13-27

For more extensive repair the cap can be carried over the top of the pile and even down the back, as shown in this drawing. This eliminates the need to install shear studs on the piles.



13-28

Here, reinforcing cages are being placed over a heavily deteriorated steel sheet pile wall which is to receive a concrete cap to restore wall integrity.

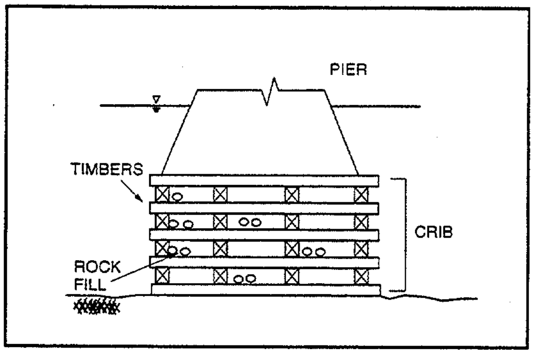
Walls may lose toe embedment due to scour. This is usually repaired with dumped riprap. If this is severe, new sheets are driven with a deeper toe.

TIMBER CRIBS

13-29

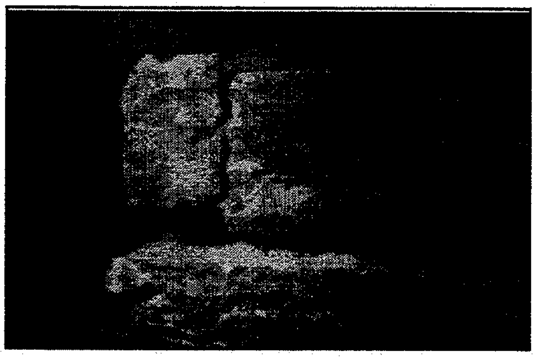
V. TIMBER CRIBS

Timber cribs are wood grillages, often constructed ashore and floated into position, filled with stone and sunk. They are sometimes used to support bridge piers, primarily in northern states.



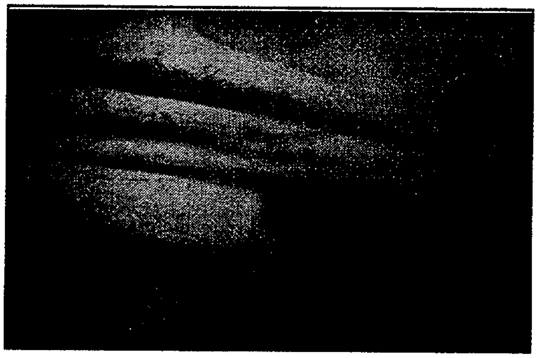
13-30

Crib problems usually stem from loose connections, resulting broken members and subsequent loss of fill.



13-31

In this structure connections are bolted, and drift pins are probably also present as vertical connectors.


13-32

The timbers in this crib are connected with half-lap joints as found in timber framing. Note overall timber deterioration and the outward displacement of the timbers.

A common repair method is to fasten plywood sheeting around the crib, install grout pipes from above, and pressure grout with a sand-cement or neat cement grout. This effectively solidifies the rock mass and locks the timbers in place as well. Steel sheets can also be driven around the crib and used as forms where more extensive deterioration is present.

Crib grouting has recently also been accomplished using a carefully sequenced series of chemical grout injections. Grout viscosity is controlled to limit leakage. This method may be difficult to use in areas of high currents, or very large voids.

Where lateral strength of the mass is suspect, a circular ring of sheet piling may be used around the crib to provide ring tension as a confining force.

CULVERTS

13-33

VI. CULVERTS

Though culverts can usually be repaired in the dry during periods of low flow, occasionally a flooded or partially flooded culvert may need repair where dewatering is impractical.

Where a reduction in culvert diameter is possible, a liner can be set and grout pumped between it and the existing culvert. Use of plastic liners, with small roughness coefficients may be necessary to maintain culvert capacities.

If culvert problems are due to loss of fill through cracks or seams, pipe nipples can be set in the wall and grout placed outside the culvert, thus maintaining hydraulic capacities.

Repair techniques for concrete box and pipe culverts are similar to those used for pier repairs.

Undermining of the toe is usually repaired by placing riprap or grout bags.

SUMMARY

- **STRUCTURE TYPES VARY**
- **NAVIGATION AIDS**
- **VARIED REPAIR SCHEMES**
- **PROMPT REPAIR FOR NAVIGATION**

13-34

VII. SUMMARY

A variety of structures, including protection cells, shear fences, sheet pile walls, cribs, and culverts are often built in conjunction with bridge projects. These are subject to deterioration and damage and can present unique repair problems. Since many of these structures aid navigation, prompt and proper repair is especially important.

SESSION 14

UNDERWATER REPAIR CONTRACTING

SESSION 14: UNDERWATER REPAIR CONTRACTING

TOPICS: **SOURCES OF CONTRACTORS**
DRAWINGS
SPECIFICATIONS
SAFETY
INSURANCE

LESSON PLAN:

DURATION	30 minutes
GOAL	Learn differences between above and below water contracts.
OBJECTIVE	Ability to prepare underwater repair contracts.
OUTLINE	I. Introduction II. Drawings and Specifications A. Drawings B. Specifications C. Payment III. Underwater Contractors A. Advertising B. Prequalifications IV. Insurance V. Construction Inspection VI. Summary

Demonstration Project 98
Underwater Evaluation
and
Repair of Bridge Components

SESSION 14
UNDERWATER REPAIR CONTRACTING

14-1

I. INTRODUCTION

Construction of underwater repairs involves equipment and personnel often unfamiliar to bridge owners. Many contracting firms, large and small, are available nationwide to perform these repairs.

Some areas unique to underwater work are of concern in contracting for this work and are presented in this session.

DRAWINGS AND SPECIFICATIONS

14-2

II. DRAWINGS AND SPECIFICATIONS

Drawings and specifications form the primary communication between the engineer and contractor. Of special concern in underwater repairs are the following:

- Contract documents require careful thought as few "standard" details are usually available.
- The type and extent of repairs must be based on recent inspection data.
- Specifications should allow for expectation that underwater inspection data is less exact than normal above water data as to defect dimensions.

DRAWINGS

- **INFORMATION**
- **DETAILS**

14-3

A. DRAWINGS

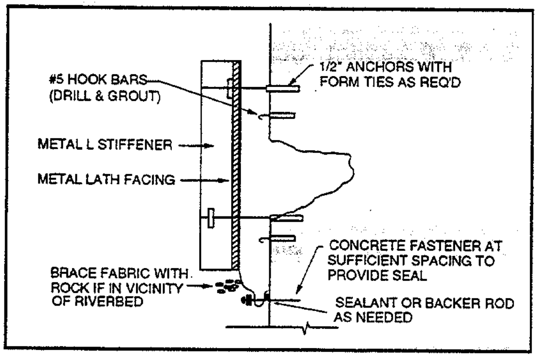
Drawings should provide all available information to the contractor as to insitu conditions. In addition to the structure, this can include:

- Water depth ranges
- Current data
- Debris accumulation

DETAILS

14-4

Underwater repair details are normally more general in nature than used above water. Drawings should be "end result" oriented giving the contractor options on how to execute the work.



14-5

In this case both rigid and flexible form details were shown in the bid drawings for contractor selection. The flexible form detail is shown.

The contractor should be required to submit details not shown on the engineer's drawings required for executing his work for the engineers' approval.

SPECIFICATIONS

- SPECIAL PROVISIONS
- PAYMENT

14-6

B. SPECIFICATIONS

In addition to provisions in standard department specifications, special provisions are required for much underwater repair work. These may become quite extensive.

SPECIAL PROVISIONS

- AREAS NOT IN STANDARDS
- MODIFY STANDARD
- CONSTRAINTS

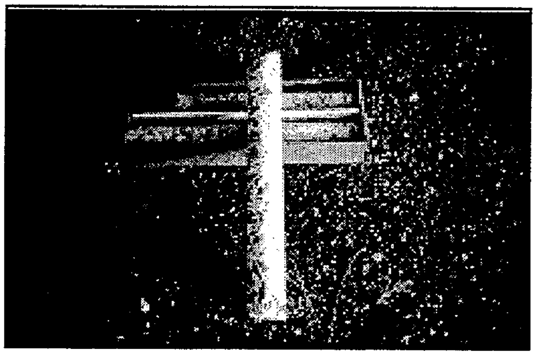
14-7

Existing standard items used for above repair, such as concrete, may not be suited for underwater usage. Care must be taken in using above water repair provisions without careful review by staff knowledgeable in underwater requirements.

Specialized constraints can also effect the work such as:

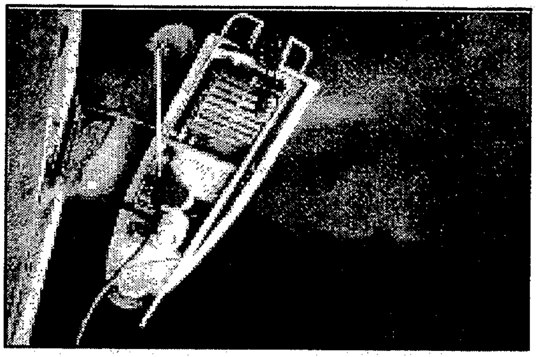
- Water quality may constrain the type of repair materials and require special monitoring
- Fish migration, breeding may limit work time frames and construction techniques
- Adjacent dam operations may be able to be partially controlled to expedite construction.

These areas should be addressed to provide for the most competitive pricing and reduce the potential for future claims.



14-8

This shows concrete cores extracted as part of the quality assurance portion of an underwater repair project. The construction work was closely monitored for environmental degradation.



14-9

Note, however, that in grouting the core holes, shown here, significant grout is being discharged into the river. Obviously enforcement of the special provisions could have been better.

PAYMENT

14-10

C. PAYMENT

Payment provisions should minimize potential areas for dispute and reduce contractor (and owner) risk. As with above water work various payment methods are possible with the most common being unit price and lump sum.

UNIT PRICE

LUMP SUM

14-11

Keeping track of unit price work underwater is time consuming and requires diving staff from the owner or his representative. Relying on the construction contractor for measured units is discouraged. Use of units which can be measured prior to placing below water such as cubic yards of concrete may be used to "measure" work if payment items are carefully defined.

The use of lump sum pay items to the maximum extent possible is recommended.

RISK

14-12

Marine and underwater work carries substantially more risk than work on land. Factors which can have major impacts on contract work include:

- Weather
- Water visibility
- Currents

Ability to predict these factors varies from site to site. Where considerable variability is expected, allowances for job interruptions can be developed in job pricing to reduce contractor costs due to risk which is outside expectation. This can be partially addressed by allowing ample construction time duration.

UNDERWATER CONTRACTORS

- **SPECIALTY FIRMS**
- **HEAVY CONTRACTORS**

14-13

III. UNDERWATER CONTRACTORS

Many firms perform underwater repair work.

For smaller jobs, work may be completed by construction diving contractors.

For large jobs, work is often undertaken by larger heavy contractors or marine contractors who will use divers or local diving contractors for those portions of the work.

ADVERTISING FOR DIVE/MARINE CONTRACTORS

- **LOCAL CONSTRUCTION PUBLICATIONS**
- **PREQUALIFICATION LIST**
- **COMMERCE BUSINESS DAILY**
- **ENGINEERING NEWS RECORD**

14-14

A. ADVERTISING

There are many qualified contractors available. However, their distribution is not uniform across the country, and hence advertising underwater construction contracts will vary.

As tradesmen, divers work over large areas. Many dive contractors, even small ones, work over extensive areas due to work specializations.

Government agencies advertise projects in local publications and these will be used for underwater repair contracts, as required by agency purchasing regulations.

Some agencies maintain lists of prequalified contractors, or require prequalification submittal data with bids, for specially work such as underwater repair. This provides a ready source of bidders and can aid in obtaining good contractor performance.

Where local firms are too few to provide a competitive bid field or acceptable expertise, the Commerce Business Daily (CBD) and Engineering News Record (ENR) are good places to advertise projects. Both of these publications reach wide market areas.

PREQUALIFICATIONS

- **FIRM EXPERIENCE**
- **FOREMAN EXPERIENCE**
- **EQUIPMENT**
- **FINANCIAL CAPACITY**
- **SAFETY RECORD**

14-15

B. PREQUALIFICATIONS

Because of the somewhat specialized nature of underwater construction and increased difficulty of owner inspection of construction, establishing a Prequalification list is recommended.

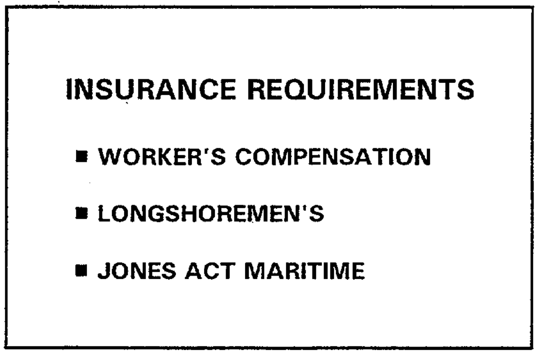
Prequalification submittals should follow normal agency requirements. The following areas are among those of concern:

- Firm Experience
- Foreman Experience
- Equipment
- Financial Capacity
- Safety Record

The increased possibility of unexpected problems occurring in underwater repair places an added importance on the problem solving capabilities of the contractor's foreman.

Along with a firm's safety record, a copy of their OSHA mandated Safe Dive Practices Manual should be filed with the owner. It is not recommended that the owner "approve" this manual. For underwater repair, this manual may run to several volumes.

IV. INSURANCE REQUIREMENTS

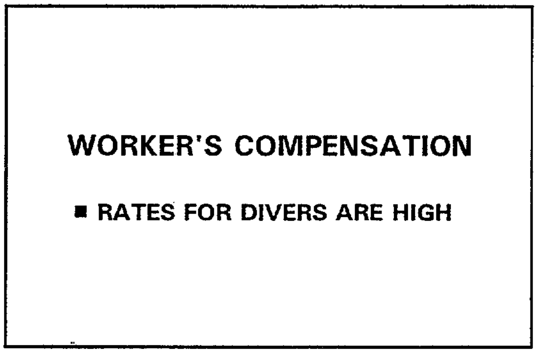

INSURANCE REQUIREMENTS

- WORKER'S COMPENSATION
- LONGSHOREMEN'S
- JONES ACT MARITIME

14-16

Standard agency insurance requirements for construction projects apply to underwater construction.

In addition to standard worker's compensation, other insurances relating to diving or marine operations include Longshoremens and Harborworkers coverage and Jones Act Maritime.


WORKER'S COMPENSATION

- RATES FOR DIVERS ARE HIGH

14-17

Worker's Compensation is required for all workers. In reviewing costs, it should be realized that coverage for divers is much higher than most other trades and typically ranges around $45/$100 of salary. This represents added cost.

**LONGSHOREMENS
AND
HARBORWORKERS**

14-18

Longshoremens and Harborworkers insurance (LSHW) is similar to worker's compensation and covers workers in or over navigable waterways.

Benefits payable under LSHW usually exceed Worker's Compensation amounts. The insurance coverage can be obtained as an endorsement to Worker's Compensation or as a separate policy.

JONES ACT MARITIME

14-19

Jones Act Maritime insurance is again similar to worker's compensation but covers crews of vessels. Among factors in obtaining Jones Act Martime insurance are:

- Debate as to who is a crew member.
- What constitutes a vessel?
- Endorsement or separate policy.

Disputes over which of the above insurance coverages apply in a given instance are not uncommon, and the legal issues are complex. It is probably best to require all coverages.

CONSTRUCTION INSPECTION

- **CONTRACTORS**
- **OWNER**

14-20

V. CONSTRUCTION INSPECTION

As with all construction projects, especially repair, good construction inspection is needed. This inspection can be provided either by the contractor or by the owner.

The inspection process may also include construction of mock-ups on land to help verify procedures and materials.

CONTRACTOR AS INSPECTOR

14-21

Because of a need for diving capabilities in order to conduct underwater construction inspections, some agencies have allowed the contractor to inspect his own work. Photography or video may be used to document his inspection, but this may not provide sufficient detail to assure conformance with contract documents. Such a practice, particularly if measurements for unit price quantities are to be made, are opportunities for substandard work and inflated quantities.

Inspection of work by the construction contractor can unfortunately give the impression of impropriety even if done with great integrity.

OWNER INSPECTIONS

- **IN-HOUSE**
- **CONTRACT**

14-22

It is preferable that in-house staff or an independent contractor/consultant retained by the owner conduct the construction inspection. This is consistent with common practice for above water work.

For agencies with underwater bridge inspection teams, construction inspection can become an added area of responsibility, normally without significantly expanding their equipment or training.

INSPECTION SCOPE

- **FULL-TIME**
- **PART-TIME**

14-23

In above water construction, the work is typically overseen by a resident engineer and additional inspectors as required by job size and complexity. A similar approach can be used for below water work.

The use of a full-time inspection team is obviously desirable, and is used. If this team is to perform diving inspection then its size, and hence cost, can become large. Since many repair projects are not large dollar projects, full time inspection cost is even more significant.

INSPECTION MILESTONES

- EXISTING CONDITIONS
- CONCRETE REMOVAL
- SURFACE PREPARATION
- FORMWORK AND REINFORCING
- MATERIAL PLACEMENT

14-24

Another approach is to use part-time inspection. This can include a part-time or full-time topside resident who is supplemented by an underwater inspection team at critical points during the project's construction. The extent, and hence cost, of the diving inspection can be tailored to the project complexity and size and even the agencies' past experience with the construction contractor's work.

For part-time underwater construction inspection, milestones should be established that reflect critical aspects of the repair process. While these will vary, the milestones shown are representative of a typical project.

- It is important that the contractor and the owner's inspectors examine existing conditions at the start of the project for any differing conditions.

- For concrete, or other material removal, the extent of removal and overall member condition after removal should be checked. This can usually be done early in the removal process to establish acceptable work, and at the end of removal to verify completeness and measure quantities (if needed).

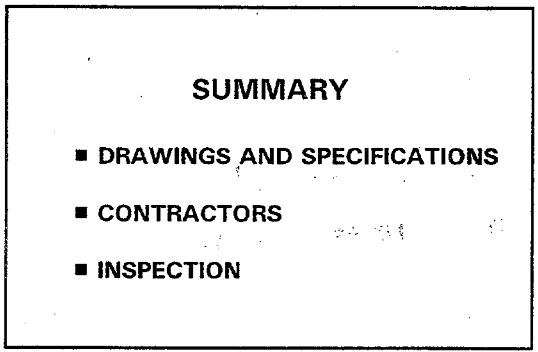
- After surface preparation is complete a verifying inspection should occur.

- Formwork and reinforcing should be checked prior to deposition of concrete. Often this can be done all at once.

- Placement of concrete or other repair material should be continuously monitored above water and, at least at the start, below water.

A final underwater acceptance inspection should be performed and a punch list prepared if necessary. This also gives a base line inspection for future routine underwater inspections.

VII. SUMMARY



SUMMARY

- DRAWINGS AND SPECIFICATIONS
- CONTRACTORS
- INSPECTION

14-25

Because the underwater repair work environment differs markedly from that above water, normally used procedures for construction contracting require alteration to minimize owner and contractor costs and risk while producing a sound structure.

Drawings and specifications should be prepared for each specific project allowing for maximum flexibility and contractor ingenuity.

While numerous underwater contractors are available, they are not well distributed geographically and broader job advertising may be necessary to service competitive price.

Inspection of underwater repairs is best accomplished by the owner and is critical to a good project. Part-time inspection, carefully structured, can be very cost-effective.