CHAPTER 2 MAINTENANCE

2.1 MAINTENANCE PLANNING AND TYPE OF FACILITIES

2.1.1 Maintenance Planning

2.1.1.1 Maintenance Standards and Criteria

The need for and accomplishment of major repairs and rehabilitation of existing berthing/mooring facilities will be based on experience, judgment, and engineering evaluation. The services of qualified technical personnel will be used to assist in the establishment of maintenance programs.

2.1.1.2 Maintenance Program

The maintenance program shall be designed to include prevention of deterioration and damage, prompt detection of deficiencies, and early accomplishment of maintenance and repairs to prevent interruptions to operations or limiting full use of a facility.

(1) Planning and Economic Considerations

In maintenance planning and execution, consider future expected use of each facility, the life expectancy of the facility, and the life cycle cost of periodic repairs versus replacing a facility or major components. The level of maintenance and programming of major repairs should be planned in consonance with the future requirement for the facility and planned replacement. When berthing/mooring structures are in an inactive status, the maintenance policies will be in accordance with the inactivation plan.

(2) Maintenance

Maintenance is the recurrent day-to-day, periodic, or scheduled work that is required for a facility to be used for its designed purpose. It includes routine work undertaken to prevent damage or deterioration of a facility that otherwise would be more costly to restore. The more common concerns in maintenance of waterfront facilities are:

(a) Painting and protective coating.

(b) Routine replacement or mending of fender components (e.g., rub strips) to prevent damage to ships and the pier.

(c) Maintenance of utility systems to prevent outages.

(d) Routine mending of protective plastic wraps.

(e) Routine patching of small concrete spalls and cracks.

(f) Maintenance of the cathodic protection system.

2.2 – Materials and Preventive Maintenance provides details of maintenance procedures in addition to descriptions of materials and deterioration causes.

(3) Inspection

Periodic, rigorous inspections are necessary for an effective maintenance program. Types of inspections and detailed procedures are described in **Part II, Chapter 3 – Planning for Inspection**.

(4) Repair

Repair is the restoration of a facility to such a condition that it can be used for its designed purpose. The repair is done by overhaul, reconstruction, or replacement of deteriorated constituent parts or materials that have not been accomplished through maintenance. The more common repair projects are:

(a) Replacement or reconstruction of fender systems.

(b) Repair of eroded or failing quaywalls.

(c) Repair and resurfacing of pier decks.

(d) Reconstruction of major concrete spalls and cracks.

Part III provides details of repair options. This chapter is organized to guide engineering and maintenance personnel in selecting repairs to the facilities.

2.1.2 Types Of Berthing / Mooring Facilities

The basic facilities to provide berthing support for ships are piers and wharves. These facilities provide a safe space for ships to moor.

2.1.2.1 Piers

Piers are berthing facilities that extend outward from the shore into the water. Piers may be used for berthing on one or both sides of their length.

Open piers are pile-supported platform structures that allow water to flow underneath.

Closed piers, or solid fill piers, are constructed so that water is prevented from flowing underneath. The solid fill pier is surrounded along the perimeter by a bulkhead to hold back fill.

2.1.2.2 Wharves and Quaywalls

Wharves are berthing facilities that are parallel to the shore. They are normally connected to the shore along their full length, and a retaining structure is used to contain earth or stone placed behind the wharf. This retaining structure is often referred to as the quaywall or bulkhead. Ships are moored along the outshore face of the wharf. The wharf types are the same as the basic pier types and include open and closed (or solid fill) configurations.

2.1.3 Components of Structures

Numerous components of basic facilities are present to aid in port operations. These components are integral parts of piers and wharves.

2.1.3.1 Piling

Piling is an integral part of all open piers and wharves. The exposure of piling makes it susceptible to severe environmental attack: corrosion, marine borers, and erosion. Piling is made from steel, concrete, wood, or composite materials and requires protective coatings, preservatives, or wraps to ensure a long life.

There are four functional types of piling: vertical bearing piles, batter piles, fender piles, and sheet piles. Bearing piles are used to support the weight of the pier and loads on the pier. Batter piles provide lateral and longitudinal stability. Fender piles are used to absorb the impact of berthing ships. Sheet piling is used for various waterfront structures, e.g., quaywalls to retain fill.

2.1.3.2 Dolphins

A dolphin is a group of piles placed near piers and wharves, or in turning basins and ship channels. These structures are used to guide vessels into their moorings, to mark underwater structures (shoals or shore), and to support navigational aids.

2.1.3.3 Deck and Mooring Hardware

Various deck and mooring hardware, such as gratings, handrails, bollards, bitts, cleats, chocks and rings, are used on piers and wharves. These items require inspection and maintenance to ensure personnel safety and adequate mooring facilities for ships.

2.2 MATERIALS AND PREVENTIVE MAINTENANCE

2.2.1 General

Common structural materials used for construction and repair are: steel, reinforced concrete, wood, and plastic. Selecting the proper materials and systems can reduce maintenance costs and increase the life of facilities. Cathodic protection, coatings, quality control of the reinforced concrete materials, wood preservatives, and carefully selecting alloys and synthetic materials help extend the life of the materials and structures.

This Section describes types of materials used in the construction and repair; types of deterioration, corrosion, and other problems that may be encountered; and preventive maintenance actions that should be taken. **Table 1.2.1** summarizes preventive maintenance actions that should be a part of all maintenance programs.

Table 1.2.1
Summary of Preventive Maintenance Actions

PREVENTIVE MAINTENANCE ACTION	PARAGRAPH NUMBER
Steel – General	
Design Actions	
Select type of steel for environmental conditions of use	2.3.1
Select proper protective coating for immersed steel	2.3.3 (1)
Provide cathodic protection system	2.3.3 (3)
Concrete - General	
Use Type II or V cement	2.4.3.1 (1)
Avoid marine aggregates	2.4.3.1 (2)
Provide adequate cover over reinforcing steel	2.4.3.2
Use coating on concrete above splash zone	2.4.6
Treat cracks with a flexible elastomeric or with polyurethane injection	2.4.6 (3)
Wood and Timber – General	
Use pressure-treated member	2.5.4 (1)
Treat exposed areas: cuts, bolt holes	2.5.4 (2)
Timber Piles	
Install plastic wrapping or jacket	2.5.4 (3)

2.3 STEEL

Steel is used extensively in construction and repair of facilities. Maintenance of steel structures and components will entail repair or replacement of damaged or corroded steel, periodic coating of steel surfaces for corrosion protection, and maintenance of cathodic protection systems. Although physical damage from impact or loading may occur, corrosion is the major cause of the deterioration of steel structures. The extent or severity of corrosion will vary with the exposure zone of the material; that is, whether it is in the atmospheric zone, the splash or tidal zone, or the submerged zone. The selection of materials must consider each of these varied conditions.

2.3.1 Types of Steel

Carbon steel and carbon steel alloys are the most important types of metals. In general, only low carbon steels with a carbon content less than 0.35 % by weight are used due to welding characteristics.

(1) Carbon Steel

Carbon steel is an alloy of iron and carbon with a carbon content less than 2%. The requirements for structural carbon steel are contained in ASTM A 36 and this grade is suitable for welding.

Carbon steel will corrode in all exposure zones, but the most severe corrosion occurs in the splash zone and just below MLW. Coatings and cathodic protection are necessary to prevent excessive corrosion of steel.

(2) Low-Alloy Carbon Steels

Corrosion resistant, low-alloy carbon steel may be used instead of carbon steel if greater corrosion resistance is required. Low-alloy carbon steels contain small amounts of other elements such as copper, chromium, nickel, molybdenum, silicon, and manganese. Up to 1.5% of these elements is added for increased strength or heat treatment capability. These alloys have a better resistance to corrosion because the rust does not easily break away from the metal surface.

The common low-alloy steels include:

(a) ASTM A 690, *Specification for High-Strength, Low-Alloy Steel H-Piles and Sheet Piling for Use in Marine Environments,* (also called “Mariner steel”).
(b) ASTM A 572, *Specification for High-Strength, Low-Alloy Columbium-Vanadium Steels of Structural Quality.*
(c) ASTM A 242, *Specification for High-Strength, Low-Alloy Structural Steel.*

Steel conforming to ASTM A 690 is recommended for steel H-piles and sheet piling, because of its greater corrosion resistance over plain carbon steel in the splash zone.

The low-alloy steels offer no more resistance to corrosion than ordinary carbon steel, however, when submerged, the low-alloy steels require coatings or cathodic protection, or both.

Composite piles of ASTM A 690 and ASTM A 36, *Specification for Structural Steel* may be used when more resistance in the splash zone is required.

ASTM A 242 steels are not recommended for buried structures, submerged conditions, and marine atmospheres unless they are exposed to the wind, rain, and sun.

Coatings for, and cathodic protection of, low-alloy steels are the same as for plain carbon steel.

(3) Stainless Steels

Stainless steels have application in the marine environment under certain conditions. They do well when exposed to wind, rain, sun, or high-velocity conditions in seawater. In calm or stagnant waters, salt spray zones, or in buried conditions, corrosion is likely to occur. Stainless steels in the 300 series (302, 304, and 316) are substantially more corrosion resistant than the 400 series stainless steels. Except in certain atmospheric environments, stainless steels should only be used for specialized applications where performance experience has been superior to more commonly used materials to justify the high cost.

2.3.2 Deterioration of Steel

Although exposure to the atmosphere, and wind erosion all contribute to the deterioration of steel, exposure to saltwater is the major concern. Corrosion rates of metals exposed to seawater are much higher than those of similar metals exposed to freshwater.

Biological fouling, the growth of marine organisms on steel, also contributes to increased corrosion. This type of fouling can be decreased by using antifouling coatings.

The other major causes of deterioration are: wave and current effects, abrasion from objects, and elements in the seawater.

2.3.3 Preventive Maintenance for Steel

The primary preventive measures available to increase the life of steel are protective coatings and cathodic protection. The decision of which approach to use is a function of location on the waterfront structure (submerged or not) and economics. The use of cathodic protection is restricted to submerged or buried structures.

(1) Protective Coatings for Steel

Steel in a marine environment will corrode freely if left unprotected and without a coating system. Coating systems are designed according to three marine zones:

(a) Constantly submerged
(b) Intertidal and splash zone
(c) Above the splash zone

Steel in the submerged zone is best protected through a combination of a coating system and cathodic protection. Maintenance coating systems are employed as follows:

(a) Overcoats on sound coatings
(b) Repairs to coating systems with spot failing
(c) Complete reapplication where coating systems have failed

Surface preparation of previously coated steel may consist of the following sequential procedures:

(a) 100% removal of biological growth
(b) Removal of unsound coatings and rust
(c) Removal of surface contamination such as oil, grease, dirt
(d) Removal of surface chloride contamination
(e) Brush-off blasting of sound coatings
(f) Abrasive blasting of uncoated steel to produce an angular anchor profile between 0.05 to 0.08mm.

(2) Coating Systems

The below coating systems have displayed high performance and may be used for either spot repairs or complete reapplication. It is recommended that a coating specialist be contacted prior to specifying one of the below coating systems for over coating sound coatings.

(a) Submerged

- Underwater cure, two-component, 100% solid liquid epoxy: 1 to 2 coats at 0.2 to 0.3mm DFT
- Underwater cure, two-component, 100% solid epoxy putty: 1 coat at 3 to 6mm DFT

(b) Intertidal/Splash Zone

- Two-component, coal tar epoxy: 1 to 2 coats at 0.2 to 0.4mm DFT
- Single-component, coal tar urethane: 1 to 2 coats at 0.1 to 0.3mm DFT
- Three-component, aggregate-filled epoxy: 1 coat at 3 to 6mm DFT

(c) Above Splash Zone

- Two-component epoxy polyamide primer followed by two coats of a two-component, aliphatic urethane topcoat: 3 coats at 0.25mm DFT (0.15mm primer, 0.1mm topcoat, 0.1mm topcoat)
- Single-component, zinc-rich urethane primer followed by two coats of a single-component, aliphatic urethane topcoat: 3 coats at 0.2mm DFT (0.1mm primer, 0.1mm topcoat, 0.1mm topcoat)
- Two-component epoxy polyamide primer followed by two coats of a flexible acrylic topcoat: 3 coats at 0.5mm DFT (0.15mm primer, 0.2mm topcoat, 0.2mm topcoat)

(3) Cathodic Protection of Steel

The natural corrosion of steel structures immersed in water or buried in soil can effectively be controlled by using anodes and direct current systems to minimize or stop the corrosion process, by establishing the steel as a cathode. Cathodic protection systems are best installed when the structure is constructed, but can be added to existing structures. They can effectively stop corrosion but cannot restore the material already lost by corrosion.

(a) Galvanic Anode

Galvanic anode cathodic protection systems rely on the corrosion of active metals such as zinc, magnesium or aluminum to generate the electrical current needed to protect buried or submerged steel structures. Since these anodes are sacrificed to protect the structure, they are known as sacrificial anodes. The anodes must be buried or submerged near the structure to be protected and electrically connected to it with a low resistance bond. As the anodes are consumed, they must be periodically monitored and replaced when over 80 % of the metal is consumed, or when they will be consumed before the next scheduled inspection. The level of protection provided can be determined by measuring the potential of the structure being protected by comparison with a standard reference electrode.

(b) Impressed Current

Impressed current cathodic protection systems use an external source of electrical alternating current, and a rectifier, to provide the protective direct current to be impressed across the system. This system also requires anodes buried or submerged in the vicinity of the structure being protected, but these anodes can last much longer than galvanic anodes, since they only conduct the protective current into the water or soil and are not the source of the current. Impressed current cathodic protection systems also require periodic inspection and maintenance to ensure effectiveness in controlling corrosion.

2.4 REINFORCED CONCRETE

2.4.1 General

Reinforced concrete is the predominant construction material due to its durability, strength, and economy as a bulk construction material. Steel and wood do not have the bulk properties and adaptability of concrete. In addition, basic components to make reinforced concrete are readily available at most locations.

2.4.2 Deterioration

Deterioration of reinforced concrete near or in seawater is due to corrosion of the reinforcement. This corrosion can be accelerated due to improper concrete mix, insufficient concrete cover (thickness of concrete over the reinforcing steel), improper curing, operational loads, chemical attack, and volume changes. Using well established mix designs and construction practices, however, will enhance reinforced concrete durability.

2.4.3 Components of Reinforced Concrete

2.4.3.1 Concrete

Concrete is a mixture of portland cement, coarse and fine aggregate, and water. Various admixtures and pozzolans may be used to improve the strength, workability, and service life.

(1) Cement

Five types of portland cement are described in ASTM C 150A, Cement Portland. For concrete structures exposed to seawater, Types II and V should be used. Type II is a sulfate-resisting cement. Type V, however, is no longer being produced. Low alkali cements should be used with potentially reactive aggregates.

Do not use any product containing sodium or calcium, as it will likely accelerate the onset of rebar corrosion.

(2) Aggregates

Aggregates are used in concrete mixtures to improve durability and reduce costs. They usually make up 60 to 80% of the volume of concrete. The shape and size of the aggregate should meet the requirements specified in ASTM C 330. Aggregates are a mixture of sand and rock. Marine aggregates, such as coral, should not be used. However, if marine aggregate is the only available material, it must be washed thoroughly with freshwater to remove the salt.

In some applications, special aggregates may be used to make lightweight concrete for lightweight structures. Most lightweight concretes have a density between 1,280 and 1,760 kg/m^3 compared to 2,400 kg/m^3 for normal weight concrete. Lightweight aggregate concrete is generally more durable in the marine environment than concrete made with normal weight aggregate.

(3) Water

Water quantity and quality will affect the durability, strength, and workability of concrete. In practice, use water equal in quality to drinking water. The ratio of water to cement has a direct effect on the strength of the concrete and its permeability. A maximum water-to-cement ratio of 0.40 by weight is crucial for concrete used in a marine environment. Seawater should never be used for making concrete because the salts will dramatically increase the corrosion rate of reinforcing steel.

(4) Admixtures

Various chemical admixtures are used to give specific properties to the concrete to improve durability, finishability, or workability. If admixtures are required, they should meet the appropriate ASTM or ACI specifications.

(a) Water Reducing

Water-reducing admixtures are available to allow a reduction in the water-to-cement ratio while maintaining a workable slump. Normal range water reducers and super plasticizers are admixtures that permit the reduction of the water-to-cement ratio.

(b) Accelerator

Accelerator admixtures are available for rapid setting products. These increase the early strength of concrete but have little effect on the final strength. Accelerators containing excessive chloride should not be used since they increase corrosion of reinforcing steel.

(c) Pozzolan Minerals

Pozzolan minerals (fly ash Class F) are highly recommended as a replacement of 25% of the portland cement. The ash reduces permeability, eliminates alkali-silicon reactions, and improves workability. Silica fume can reduce permeability but may cause finishing problems and surface cracks. Avoid silica fume dosages about 5% by weight to concrete.

2.4.3.2 Reinforcing Steel

Reinforcing steel for concrete should conform to ASTM A 615, *Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*; ASTM A 616, *Specification for Rail-Steel Deformed and Plain Bars for Concrete Reinforcement*; or ASTM A 617, *Specification for Axle-Steel Deformed and Plain Bars for Concrete Reinforcement*. Place 100mm concrete cover, which is critical for durability, over the plain steel. If 100mm concrete cover is not possible, then a barrier coating on the rebar should be considered to isolate the steel from these corrosive agents. ASTM A 934, *Specification for Epoxy-Coated Reinforcing Steel Bars* should be specified for new reinforcement.

2.4.4 Special Types of Concrete Mixtures

Special concrete mixtures include polymer concrete and polymer-portland cement concrete. Concrete mixtures containing polymers are useful for repairing concrete and may provide improvements over conventional concrete mixtures when used and applied correctly.

(1) Polymer

Polymer concrete does not contain portland cement. Epoxy concrete is one common type of polymer concrete that is readily available and possesses excellent bond and tensile strength qualities. Use extreme caution when using polymer concrete for structures subject to thermal resistance due to a high coefficient of thermal expansion that often results in repair failure.

(2) Fiber Reinforced

Fiber reinforcements may improve the tensile strength, toughness, and ductility of concrete. In general, steel fibers should not be used in the marine environment. Polypropylene fibers avoid the corrosion problem of steel fibers and improve impact resistance. Fiber should not be considered as a replacement for the reinforcement.

2.4.5 Causes of Concrete Deterioration

Cracking and spalling of concrete are the results of chemical attack and rebar corrosion.

(1) Chemical Attack

The most common chemical attack is from sulfates in seawater that cause a softening of cement paste. Other causes of chemical attack are poor quality aggregates reacting with alkali in the cement (alkali--aggregate reaction). The alkali-aggregate reaction expands the aggregate and results in cracking throughout the concrete in the presence of moisture. Use of 25% Class F fly ash is extremely effective in reducing chemical attack.

(2) Corrosion of Reinforcing Steel

The high alkalinity of cement paste protects steel from corrosion. With improper mix designs, chloride contamination and carbonation eventually reduce the alkali film around the steel. Corrosion will then occur if sufficient moisture and oxygen are present. In the splash zone, the wet and dry cycles provide conditions for the chloride and oxygen to corrode the steel. Accordingly, steel corrosion in concrete is most severe directly above the mean low water (MLW).

When steel corrodes, the rust product increases in volume many times over its original volume. Expansion of the rust causes cracking of the concrete. These cracks run parallel to the reinforcement. Eventually, concrete covering the reinforcing steel spalls off.

(3) Cracking of Concrete

As concrete dries it shrinks, which in turn, can cause cracks. These cracks may increase in size as the internal water is lost over time and the concrete cannot contract freely. Temperature change, overload conditions, uneven settlements of structures can also cause cracking.

Shrinkage cracking can be minimized by proper curing and using a minimum amount of cement and water in the mix. Temperature cracking can be controlled in concrete by using expansion joints and temperature reinforcement.

Prevention and control of cracking may be improved by proper design of the concrete structure and measures taken during construction.

2.4.6 Preventive Maintenance for Concrete

Measures to minimize deterioration of reinforced concrete must be taken during design of the structure and during construction.

The main objectives of preventive maintenance are to:

(a) Keep water out of the concrete.
(b) Protect the reinforcing steel.
(c) Prevent and control cracking.
(d) Prevent chemical actions.

The primary preventive maintenance measure that should be considered for existing reinforced concrete structures is the application of a surface coating. Coatings should be reapplied periodically to concrete that was coated when new. This measure can be applied to old concrete but rebar corrosion, the principal cause of concrete deterioration and the reason these preventive maintenance measure are applied, will not likely be inhibited.

The treatment of cracks, described briefly in this Chapter, is best considered as a repair technique and is presented in detail in **Part III, Chapter 2 - Repair of Concrete Structures**.

(1) Surface Coatings for Concrete

Sound concrete piles and other concrete structures are generally left uncoated and provide years of excellent service. Existing concrete structures, above the splash zone, however, may be successfully coated for aesthetics, for marking purposes, and for protection against wind driven rain and sand, and salt spray. The application of a coating over a penetrating sealer is not recommended because the sealer reduces the bond strength of the coating to the concrete.

It is both difficult and labor intensive to coat immersed concrete and concrete in the splash zone. These areas require using either cofferdams or divers to apply “splash zone mastics,” high performance coatings that cure underwater and other specialty coatings. The benefit of applying these coatings, however, may not warrant the high cost.

(2) Coatings for Deck Marking

For use in identifying walkways and traffic lines, the following marking paints may be applied to clean/dry concrete decks.

(a) 54% volume solids, solvent-based, chlorinated rubber: 1 coat at 0.2 to 0.25mm DFT

(b) 50% volume solids, solvent-based alkyd: 1 coat at 0.2 to 0.25mm DFT

(c) 60% volume solids, waterborne acrylic (water-based): 1 coat at 0.2 to 0.25mm DFT

(3) Treatment of Cracks

Cracks in concrete are typically caused by shrinkage during curing, thermal expansion and contraction, rebar corrosion, operational loading, or structure settlement. Cracks are routed out and repaired using a flexible elastomer over bond-breaker tape. Hairline cracks may be repaired by pressure injecting polyurethane or methyl methacrylate through injection ports. **Part III, Chapter 2 - Repair of Concrete Structures** provides details of materials and procedures to use to repair both static and dynamic cracks in concrete.

2.5 WOOD AND TIMBER

2.5.1 General

Wood and timber members have been used for construction and maintenance of older piers, wharves, bulkheads, quaywalls and pile dolphins.

2.5.2 Maintenance

Maintenance of wooden structures involves replacing decayed or damaged wood with properly treated wood or other suitable material. If repairs are to be reduced in the future, exposed wood and pile caps must be treated with an effective preservative to retain its strength and longevity against destructive fungi, marine organisms, insects, and bacteria attack.

2.5.3 Wood Deterioration

Biological and physical deterioration of wood can bring about rapid destruction of facilities. Improper design and construction procedures that lead to biological deterioration include:

(a) Inadequate preservative treatment.
(b) Improper handling of treated wood.
(c) A design that promotes retention of water.
(d) A design that unnecessarily places wood timbers below water.

Major design deficiencies, which promote physical deterioration, include:

(a) Insufficient strength of piles resulting in overloading (loss of strength and embrittlement caused by treatment with salts and other preservatives are an important design considerations).
(b) Improper connection hardware or pile connections that restrict load transfer to other parts of the structure.
(c) Inability of sheet pile walls to retain backfill or insufficient strength in the soil foundation that results in sheet pile movement.

(1) Biological Deterioration

Wood-destroying organisms infest wood structures both above and below the waterline. Marine borers are the principle cause of deterioration in the immersed zones and are found in harbors and estuaries worldwide. Marine fouling organisms found on the wood surface do not cause wood deterioration and may even serve to retard marine borer damage. Insects and fungi are the main wood-destroying organisms above the waterline.

(2) Physical Deterioration

Physical deterioration of timber piles and other wood structures is generally due to the following causes:

(a) Abrasion

Abrasion of timber piles occurs principally in the intertidal zone. The rate at which piles are destroyed by abrasion depends on the amount of floating debris in the harbor, the velocity of water moving past the piles, and the action of marine borers.

(b) Overload

Overloading of piles may result from a continuous heavy load or infrequent, severe loads. Overloading may be caused by vertical and horizontal loads. Failure of one pile requires the adjacent piling to carry the extra load. Continual overloading can lead to collapse of the entire structure.

(c) Connection Failure

When a timber pile connection fails, the structure is free to move and will eventually fail. If untreated wood is exposed, connection failure may first allow the entry of marine borers if below the waterline, or insects and fungi if above the waterline.

(d) Timber Wall Movement.

Outward wall movement can result from horizontal loading of the backfill material caused by excessive loading behind the structure or failure of tie-backs. Loss of backfill material can result in movement in the opposite direction. If either condition continues, the structure will fail.

2.5.4 Preventive Maintenance for Wood and Timber

The primary preventive maintenance measure is to select the type of wood best suited for the particular use and to purchase wood products and timber piles that have been treated with quality preservatives and methods. Field techniques should be used to eliminate or minimize cuts and holes made in the members at the site, particularly for those members to be placed below water. If cuts and holes must be made, special field preventive maintenance preservative treatment is required. In addition, there are other preventive maintenance measures applicable to timber piles using encasements and retardants. The most important field preventive maintenance for the exposed wood is the application of paint and other coatings.

(1) Pressure Treatment

Pressure treatment of the outer sapwood of timbers with preservatives is the most important and effective method of protecting wood. Using pressure treatment allows the preservative to uniformly penetrate deeper and allows closer control of retention levels. The preservative penetrates the wood from 10mm to 100mm, depending on the type of wood, and provides protection from fungi, marine borers, insects and bacteria.

The choice of preservative treatment depends on how and where the wood is to be used. Wood preservatives are classified in three categories: creosote preservatives, oil-borne preservatives, and water-borne preservatives.

(a) Creosote

Creosote preservatives have been the most commonly used preservatives because they are not easily leached from the wood and are not corrosive to metals. Creosote and creosote-coal tar solutions, both derived from bituminous coal, can be used for immersed wood. Creosote is commonly diluted with petroleum oil for treatment of wood not subject to immersion. An important disadvantage of creosoted piling, however, is that it is readily attacked by the marine borer. In addition, creosote and creosote solutions cannot be used where it may come in contact with people or where local environmental concerns have restricted its use in the marine environment.

(b) Oil-Borne

Oil-borne preservatives are dissolved in a petroleum solvent and include pentachlorophenol, copper naphthenate, tributyl tin oxide, and copper-8-quinolinolate. Oil-borne preservatives are suitable for wood members out of the water for protection against insects and fungi but does not provide adequate protection against marine borers and, thus, cannot be used for immersed wood. Treated wood can be painted, does not swell and distort, is easily handled, and will not corrode metal. Before the solvent evaporates, it is more flammable than untreated wood. Pentachlorophenol is the most effective of these preservatives but is also highly toxic.

(c) Water-Borne

Water-borne preservatives are toxic metallic salts dissolved in water for easier application. The water-borne preservatives include chromated copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), and ammoniacal copper arsenate (ACA). Wood treated with one of these waterborne preservatives can be used either above or below the waterline (wood used below the waterline is treated at higher retention levels). In addition, these salts in combination with creosote (dual treatment) are more effective in preventing marine borer damage than any single treatment. Other water-borne preservatives for use above the waterline include acid copper chromate (ACC), ammoniacal copper citrate (CC), and ammoniacal copper quat (ACQ)-Type B.

(d) Negative Aspects

All preservative treatments have drawbacks that should be considered. Metallic salts, for example, will seriously embrittle wood. More importantly, these toxic chemicals present environmental and personnel safety concerns. All treated wood should be supplied with a Consumer Information Sheet that provides use, handling, and disposal precautions. Proper safety procedures should be carefully followed.

(2) Field Treating Exposed Areas of Wood Before Installation

Cut surfaces of wood members, pile cutoffs, bolt holes, and any other exposed surfaces of treated wood members must be treated in the field before installation. Treat holes for bolts and wood plugs inserted in piles and timbers with the same general type of wood preservative originally used for the member. Bolt holes should be treated under pressure with a mechanical bolt hole treater, if available, or thoroughly saturated.

(3) Protection of Timber Piles

All timber piling in the marine environment, including piling properly treated, are eventually attacked by wood destroying organisms. Pilings are also commonly subjected to abrasion. As a result, protection with plastic wraps is often used.

The use of plastic wrapping to protect piling against marine borer damage, at and below the waterline, does offer considerable economic benefit by effectively eliminating borer damage, reducing future repair costs.

2.6 SYNTHETIC MATERIALS

Synthetic materials are versatile in application and serve as a structural material or coating material. In general, these materials do not corrode in the marine environment, but deteriorate due to other reasons, such as water absorption and swelling and degradation by ultraviolet light. One of the common synthetic materials is FRP.

Deterioration of these synthetic materials, other than physical damage, increases with aging; plastics crack or separate, some become brittle. In general, no preventive maintenance measures are performed other than inspection. Certain materials and components can be economically repaired when damaged.

2.7 FIBER-REINFORCED PLASTICS (FRP)

FRP are used for applications requiring high strength-to-weight ratios and resistance to deterioration, such as pile jackets for steel, concrete, and timber piling to reduce corrosion or erosion; for reinforcement; and to prevent marine borer attack.

Carbon fiber sheets, strips, and rods are used to upgrade existing pier decks. The sheets and strips can be used by bonding them to the underside of the deck and the rods embedded into the top deck for negative reinforcement. These techniques can increase the shear capacity of the deck to permit greater loads.

FRP are a composite of resin and fibrous material. The common resins are polyester and epoxy. Polyester resins are general purpose resins that cost less than epoxy. Epoxy resins have superior strength properties, greater resistance to chemical and water degradation, and lower shrinkage during curing.

Materials used as reinforcement for FRP include: continuous strands, woven cloth, chopped fibers, and in some cases, glass flakes.