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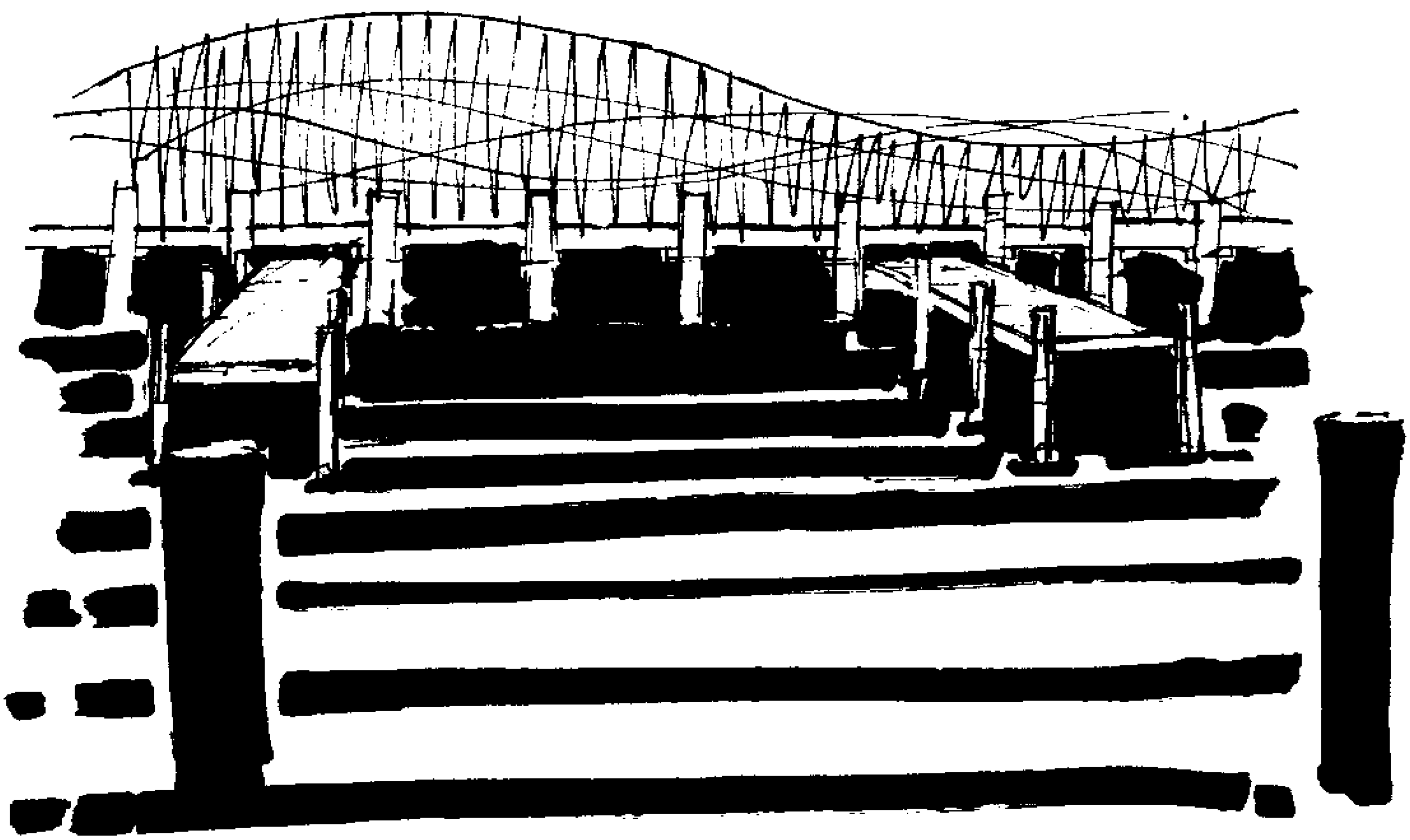
Christopher P. Jones



Florida Cooperative Extension

Marine Advisory Bulletin

DETERIORATION AND REPAIR OF TIMBER AND CONCRETE PILINGS

by

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FOREWARD

This is the first in a series of Marine Advisory Program bulletins and fact sheets dealing with common engineering problems identified in a Florida Sea Grant marina survey. These publications will acquaint marina operators with the causes of the problems they face, and will help in solving them. However, these reports are intended only as guidelines, and cannot replace the assistance of a qualified engineer or marine contractor.

ACKNOWLEDGEMENTS

I would like to thank the following Marine Advisory Agents for their helpful comments on this publication: Frank Dimitroff, Joe Halusky, Leigh Johnson, Anne Marshall, Don Pybas, John Stevely and Don Sweat. I would also like to thank Dr. Ernest Estevez of the Mote Marine Laboratory for his thoughts and comments on marine borers in general and *Sphaeroma* in particular.

TABLE OF CONTENTS

INTRODUCTION

Approximately 70% of those responding to an engineering survey of Florida's marinas identified the deterioration of pilings (both timber and concrete) as a major problem.[1] It is quite possible, however, that the problem is more widespread than the survey indicated since the deterioration of pilings may go unnoticed until it has reached an advanced stage.

While the key to ensuring a long lifetime of marine structures is prevention of decay, repair and/or replacement will at times be necessary. As a guide for the maintenance and repair of structures, Johnson (1965) outlines the following procedure:

1. find the deterioration
2. determine the cause
3. evaluate the strength of the existing structure
4. evaluate the need for repair
5. select and implement a repair procedure

This publication will provide guidance for following the above procedure where pilings are concerned. As a way of prolonging the lifetime of marine stuctures, whether during repair or replacement, or during initial construction, the marina operator should be sure to specify materials properly and insist on sound design and construction practices.

FINDING DETERIORATION

In order to avoid the replacement of pilings and reconstruction of docks and other structures, finding deterioration in its early stages is critical. Unfortunately, few marinas bother to examine their stuctures where problems are most likely to occur - below the water line. In some cases when deterioration is finally noticed at or above the water line, it may have progressed to the point where damages to the underwater portions are beyond repair.

Thus, periodic underwater inspections of pilings are necessary to find deterioration in its early stages. The frequency of inspection will depend upon the type of piling and the severity of deterioration noted in the past. In the case of concrete pilings or properly treated timber pilings, a yearly inspection will probably suffice. In the event that pilings at a particular marina or in a certain region have experienced rapid decay in the past, or if untreated timber pilings are used, the inspections should be made more frequently.

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[1] "A Survey of Small-Craft Recreation Marinas in Florida," Florida Sea Grant Technical Report 18, by P. V. Rao, et al., 1980.

DETERIORATION OF TIMBER PILINGS

Above water portions of timber pilings should be examined for soft or discolored wood - an indication of decay or rot caused by fungi. Look also for signs of insect attack by ants, beetles and termites. Usually, damages by rot and insects can be avoided if the piling tops and adjacent decking are kept dry and are treated with preservatives.

Portions of pilings in the tidal zone and below should be examined for signs of marine borer activity, undoubtedly the most destructive organisms to attack marine structures. Inspections will require the removal of marine growth from the pilings at a few locations between the tidal zone and mud line. Sounding pilings by tapping with a hammer is required to find damage to interior portions that is not apparent at the surface.

Marine Borers

Marine borers fall into two main groups (Hochman, 1973): Those of the class Crustacea, which are crab-related, and those of the phylum Mollusca, which are clam-related. In Florida, there are five wood borers of importance - two crustacean borers and three molluscan borers.

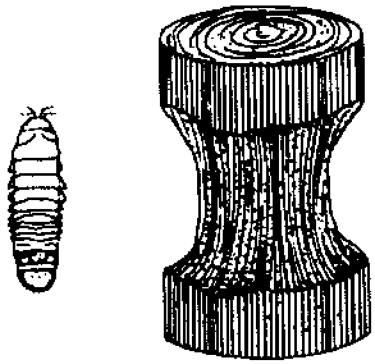
The first of the crustacean species, *Limnoria tripunctata* (also referred to as the gribble) is thought to be the more damaging and consequently, has been studied extensively. The second species, *Sphaeroma terebrans*, has not been studied much, and unfortunately, the work on *Limnoria* is not generally applicable to *Sphaeroma* due to significant biological differences between the animals (Estevez and Simon, 1974).

Limnoria (Figure 1) are about 1/8 to 1/4 inch long and burrow along and just under the surface of the wood. As waves and debris wear away the weakened wood, the animals burrow deeper, resulting in the characteristic "hourglass" shape (Helsing, 1981). They are free swimming and can travel from one piece of wood to another, which they use as both a source of food and protection.

Sphaeroma (Figure 2) are also free swimming, but are larger than the *Limnoria*, reaching 1/2 inch in length. Damage by them has probably been attributed to other borers in many cases (Estevez, personal communication). While the *Sphaeroma* seem to prefer the prop roots of the red mangrove, they have been found in driftwood, pilings and other wooden structures in the intertidal zone. Unlike the *Limnoria*, the *Sphaeroma* do not use the wood into which they burrow as a source of food, but only for protection.

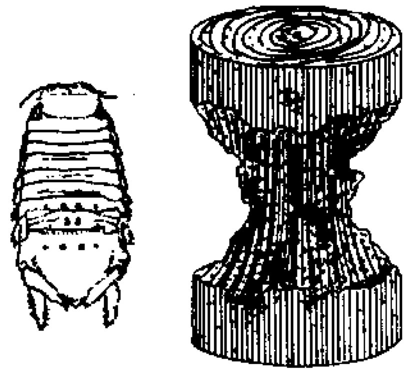
The three molluscan borers of importance are the *Bankia*, *Teredo* and *Martesia*. The *Bankia* and *Teredo* are of the same family and are both referred to as shipworms. *Martesia* are referred to as pholads. Unlike the crustacean borers, the pholads and shipworms are free swimming only in the larval stage. Once the larvae attach themselves to a piece of wood, they burrow inside, spending the rest of their lives there.

Pholads (Figure 3) have a clam-like appearance in the adult stage and can reach 2 1/2 inches in length and 1 inch in diameter. Their burrows are generally perpendicular to the wood surface and are pear shaped, with a small



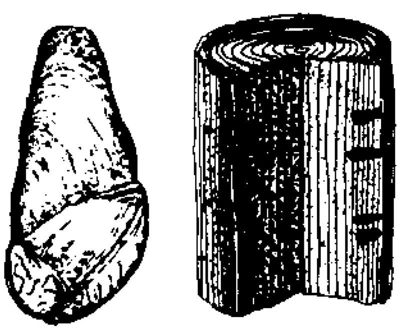
Limnoria and typical damage

Figure 1



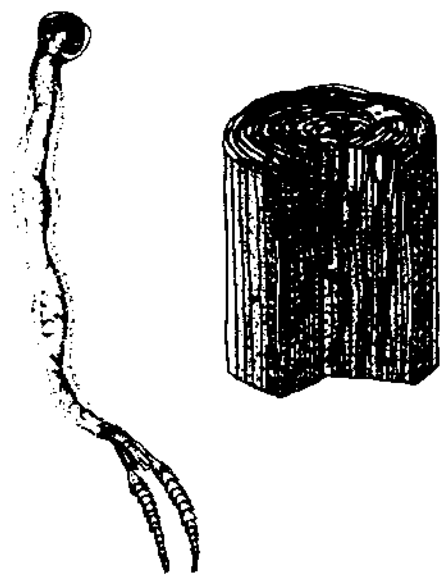
Sphaeroma and typical damage

Figure 2



Pholad and typical damage

Figure 3



Shipworm (*Bankia*, *Teredo*) and typical damage

Figure 4

(Figures 1, 3 and 4 adapted from Helsing, 1981; Figure 2 adapted from Estevez and Simon, 1974).

opening (1/16 to 1/8 inch) at the surface where the larva entered. As the animal grows it enlarges its burrow only to accommodate its size; it does not digest the wood fragments. Even though pholads have been known to bore into wood, rock and concrete, they are not judged to be as damaging as the shipworm due to their limited burrow size and restricted range.

Adult *Bankia* and *Teredo* are more worm-like. While the pholads develop so that their soft tissues are contained within a pair of shells, the shipworms develop with two shells at the head (for rasping) and a long soft body (Figure 4). *Teredo* typically grow to several inches in length, but have been known to reach one to two feet; *Bankia* have been known to reach several feet in length. As the animals grow, the lengths of their tunnels increase while the entrance holes at the surface remain small-about 1/16 inch in diameter. For this reason shipworm attack is difficult to find without sounding the piling; the inside can become completely riddled with attack and go unnoticed at the surface.

Which Borers Are Active In Your Area?

Surveys have shown that heavy *Teredo* attack can be expected along the entire coastline of Florida, while moderate to heavy *Limnoria* attack will be found (Beach Erosion Board, 1955). *Sphaeroma* have been reported along most of Florida's coastline and in many estuarine areas; they seem to prefer waters of intermediate salinities (Simon and Estevez, 1974). Pholads have also been reported along most of Florida's coastline. Fortunately, most places where borer attack takes place are affected only by one or two dominant species. Determining the exact species that are present in your area can be accomplished by a careful examination of pilings in the vicinity or by placing test blocks in the water body of interest. These test blocks should be of untreated wood and held in place by use of a weight and line.

Water temperature, salinity, food supply and dissolved oxygen levels are all important in determining whether or not marine borers will thrive in a certain area. Relatively cool water temperatures, low salinities and heavily polluted waters will generally inhibit populations. For this reason, waters of low salinity in upper portions of estuaries (which do not typically experience marine borer attack) may during drought conditions find marine borers present as salinities rise. Waters which were at one time heavily polluted but are now becoming cleaner as a result of pollution abatement programs may see a sudden increase in borer attack as water quality improves.

REPAIRING DAMAGED TIMBER PILINGS

If deterioration of a timber piling is noticed before it has lost much of its cross-section to borer attack (say 20% or less) then it can probably be repaired. Bear in mind though, the costs of repair may be greater than replacement.

Repairing a damaged timber piling is accomplished by placing a watertight barrier between the piling and the water. The barrier, whether sheet metal, plastic or concrete, should extend from above the high water mark to below the mud line, and should have no openings in joints or seams. Each type of barrier has advantages and disadvantages: metal barriers may be susceptible to galvanic corrosion or puncture; flexible PVC sheets may provide adequate protection, but they too are subject to puncture; concrete encasements or grout-filled pile jackets can provide protection but may be too heavy for some structures. For these reasons consult an engineer or a qualified marine contractor when considering repairs to timber pilings. Remember, unless repairs are done correctly, replacement will be required.

SPECIFICATION OF TIMBER PILINGS FOR MARINE USE

The best way to minimize marine borer damage to a structure is to select materials resistant to their attack. While some species of wood (Greenhart, for example) are reputed to be naturally resistant to borer attack, this is not always the case. Thus, the best solution is to specify pressure treated pilings (pressure treatment is simply the forcing of preservatives into wood at high temperatures and pressures). The preservatives render the wood fibers toxic, or at least unpalatable, to boring organisms and reduce or prevent their attack. Since borers show a preference for damaged wood in which to begin their attack, and since cuts and holes made during construction and damage during handling may expose untreated wood fibers, any damaged areas, cuts and holes should be carefully field-treated with preservatives.

Preservatives recommended for use in marine piles can be divided into two groups: creosote (and creosote-coal tar) and waterborne salts. Of the many waterborne salt preservatives available, two are recommended for marine use: ammoniacal copper arsenate (ACA) and chromated copper arsenate (CCA). Other preservatives that are used for land and fresh water applications (creosote-petroleum solutions and oil-borne preservatives, such as pentachlorophenol) should not be used.

In order to specify the proper treatment for pilings, both the type and amount of preservative must be given. These are determined by the type(s) of borers expected. Details concerning preservative treatments are given in Appendix 1.

DETERIORATION OF CONCRETE PILINGS

The deterioration of concrete pilings in marine environments is a very common occurrence. Several factors may contribute to the problem, including: design errors, damage during handling and construction, impact, abrasion, chemical attack of the concrete, corrosion of the embedded reinforcing steel, or a combination of the above. Probably the most frequent cause is the corrosion of the reinforcing steel, either placed in poor quality concrete or too close to the piling surface.

Chemical Attack

Deterioration due to chemical attack can be divided into two types: internal and external. Internal attack is due to ingredients in the concrete mix reacting with each other to produce swelling and gradual deterioration. External attack arises when there are aggressive agents in the surrounding waters that attack the piling surface.

Impurities or high concentrations of salts in the concrete mixing water, alkali-reactive aggregates and improperly washed aggregates can lead to internal attack. Fortunately, these problems can be avoided through the proper selection of concrete ingredients (see the section on SPECIFICATION OF CONCRETE PILINGS FOR MARINE USE and Appendix 2).

The different types of cements used in concrete are to a varying degree susceptible to attack from dissolved salts found in seawater, particularly magnesium and calcium sulfates (Portland Cement Association, 1975). Sulfate attack on concrete may produce cracking, swelling and softening of the concrete surface. The more inert pieces of concrete aggregate will be left protruding from the surface of the piling.

Corrosion of Reinforcing Steel

Identifying deterioration due to the corrosion of the embedded reinforcing steel is not difficult, but unfortunately, noticing the problem at the piling surface means that the corrosion of the steel is at an advanced stage. The first visible sign of corroding reinforcement will be cracks on the surface, running parallel to the steel. As the corrosion progresses the cracks will widen and rust will stain the surface. Eventually, pieces of concrete will be broken off, exposing the corroded steel.

The process just described above, whereby pieces of concrete break away from the surface because of corrosion of the reinforcing steel (or because of internal swelling or expansion of the concrete itself) is called **spalling**. Figure 5 illustrates this process: as the steel corrodes it expands in volume, setting up stresses in the concrete which lead to the cracking and eventual failure of the concrete surface.

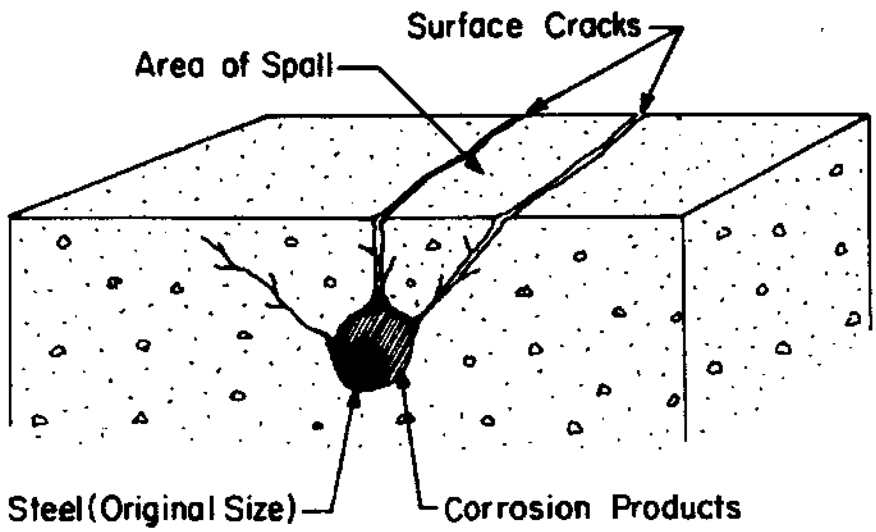


Figure 5. Spalling

The most likely place to encounter piling deterioration due to the corrosion of reinforcing steel is in or just above the tidal zone. This is where the concrete is subject to repeated wetting and drying, leading to a build-up of salts, which then diffuse into the concrete, attacking the steel. The chloride ion is responsible for the attack by reducing the pH of the concrete and destroying the protective oxide layer that covers the steel. Chloride attack is not limited to concrete structures placed in seawater, however. It is a major problem in many buildings and other reinforced concrete structures located along the coast (Hartt and Martin, 1981).

REPAIRING DAMAGED CONCRETE PILINGS

Repairs to damaged concrete pilings can be made except during cases where extensive damage has occurred during a collison or where obvious deterioration has been neglected for a long time. The factor limiting chances for repair of a concrete piling is not usually the condition of the concrete but that of the reinforcing steel. The steel is the part of the piling that enables bending and other forces to be resisted (concrete alone is strong in compression but relatively weak in tension and bending). When the steel has corroded and lost a significant portion of its cross-section, then the piling's ability to resist bending and impact is reduced. When this happens, either new steel must be spliced in or the piling must be replaced.

Repair procedures will be dictated to a large extent by the nature of the deterioration. Regardless of the repairs though, cleaning and preparation of the area to be repaired is essential. All marine growth should be removed by wire brushing, scraping or by use of a high-pressure water jet. Any poor quality or damaged concrete should be chipped away.

Small Surface Defects

These include minor cracks and small cavities in the piling surface (up to a few inches across) that are not due to corrosion of the reinforcing steel. These may be caused by shrinkage, impact, damage during driving or by improper patching of cut-off lifting rings.

Small cracks can be sealed with epoxies or cement patching compounds. Small cavities can be filled with hydraulic cement or with mixtures of epoxy and sand. For best results, the cavity should be enlarged slightly, undercutting the sides to hold the patch in place (Figure 6).

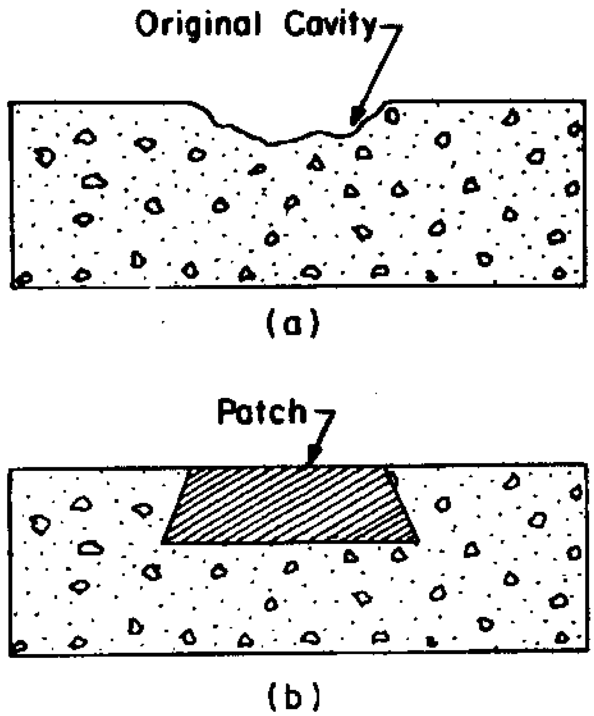


Figure 6. Correct Method for Patching Small Cavities.

Chemical Attack

In cases where deterioration is due to internal attack, i.e., the concrete ingredients reacting with one another, there is usually little choice but to chip away the concrete and to form a new piling in place, or to replace the piling.

When external attack is encountered, repairs can be made by chipping away all soft or damaged concrete and encasing the piling with concrete not susceptible to the attack. Surface sealing of the new concrete with one of a number of materials (expoxies, bitumastics, etc.) may be required in especially aggressive conditions.

Cracking and Spalling

When repairing cracking and spalling caused by corrosion of reinforcing steel, the first step is to determine the extent of corrosion. This is accomplished by chipping away all damaged concrete, exposing the steel and cleaning it of all rust and corrosion. The diameter of the bars should be measured and compared with the original diameter; new steel should be spliced in as necessary.

It is not good practice to have the joint between original and new concrete in the same plane as the reinforcing steel since differences in the concrete mixes may result in a potential cleavage plane by which moisture can reach the steel. Thus, it is best to chip away concrete until the existing bars are exposed on all sides, leaving at least 3/4 inch between the bars and the nearest concrete (Johnson, 1965). By doing so the steel will be completely surrounded by new concrete when repairs are completed.

In instances where cracking and spalling are not extensive, the area to be repaired can be filled with concrete after the above mentioned steps are taken. For more extensive repairs, best results are obtained by proper cleaning, followed by encasing or jacketing the piling. This is accomplished by forming a new piling around the old (Figure 7). The diameter of the encasement is typically eight to twelve inches larger than that of the original piling, and the length of the encasement may vary from a few feet to the entire length of the piling between the superstructure and mudline.

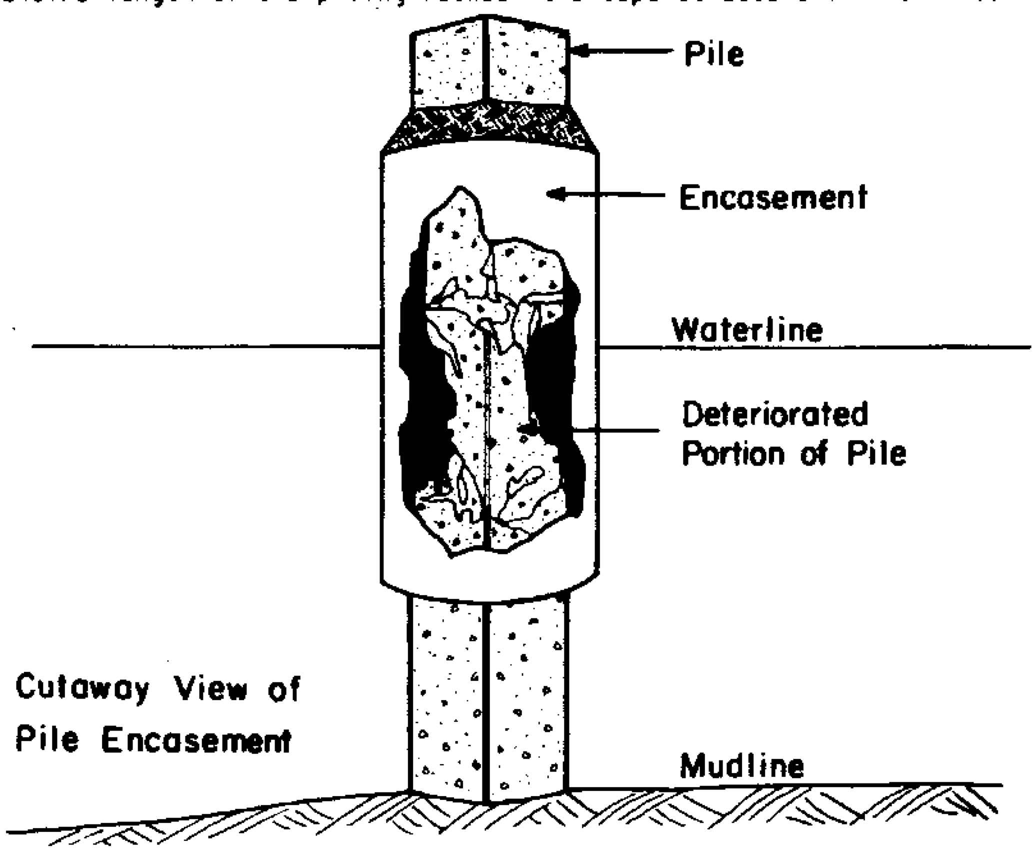


Figure 7 (Adapted from Symons, 1980).

Until a few years ago one of the most difficult tasks involved was placing the required formwork around the piling, but this has been solved by using nylon or reinforced fiberglass fabric sleeves which remain in place after repairs are complete.

Wire mesh is placed between the piling and the sleeve, and then the sleeve is filled with concrete or **cement grout** (a fluid mixture of cement, sand and water). There are several ways to fill the sleeve, depending upon the size of the job, availability of equipment and whether or not repairs are above or below the waterline.

If the area to be repaired is above the waterline, fresh concrete or grout can be placed by conventional means. If all or a portion of the area to be repaired lies below the waterline, more specialized placement procedures must be used. Concrete should not be allowed to fall freely through water in the forms; if it does, the mix can separate, leaving layers of **laitance** throughout the repaired areas. **Laitance** is a weak material, consisting primarily of lime, that forms when excess water mixes with concrete (Myers, 1969).

Two accepted methods of placing concrete or grout in forms that lie below the waterline are: pumping through a hose connected to a one-way valve at the bottom of the form, and placing through a **tremie tube**, which is inserted at the top of the forms. The latter is a tube with a concrete receiving funnel at the top. The bottom of the tube is placed initially at the bottom of the form and the tube and funnel are filled with concrete. As concrete flows from the tube into the forms the bottom of the tube is raised so as to always keep it immersed in fresh concrete. This prevents the formation of laitance by gradually displacing the water in the forms with concrete.

SPECIFICATION OF CONCRETE PILINGS FOR MARINE USE

The two most important requirements for concrete pilings in a marine environment are:

1. the concrete mix should be dense and impermeable, and should be made with the proper ingredients

2. the design must provide for adequate concrete cover over the reinforcing steel.

The first requirement will be satisfied if the proper type of cement, sound and clean aggregates, clean water and a few percent air are used in the concrete mix. The second requirement varies, depending upon where the piling is cast (i.e., plant or job site). Details concerning these requirements are included in Appendix 2.

APPENDIX 1

SPECIFICATION OF PRESERVATIVE TREATMENTS FOR MARINE TIMBER PILINGS

The material in this appendix is taken from standards of the American Wood Preservers Association (AWPA, 1979).[2] Where *Teredo* is written, it includes *Bankia* as well (personal communication, B. Haldeman, AWPI). *Sphaeroma* are not covered in the standards.

In those areas where *Teredo* and pholad attack are known or expected and where *Limnoria tripunctata* attack is not expected, specify a creosote or creosote-coal tar preservative. In areas where *Limnoria tripunctata* and pholad attack are known or expected, specify dual treatment (waterborne salts treatment followed by creosote or creosote-coal tar treatment). In areas where *Limnoria tripunctata* attack is known or expected and where pholads are absent, specify either dual treatment or waterborne salts preservatives. This is summarized in the table below.

Marine Piling - Specific Requirement of Use for Treated Wood Subject to Exposure of Marine Borers

Marine Boring Organism	Type of Treatment		
	Creosote and Creosote-Coal Tar Solutions	Waterborne Preservatives (CCA and ACA)	Dual Treatment
Teredo	S	S	S
Pholads	S	X	S
Limnoria tripunctata	X	S	S

S - Satisfactory for use where the particular boring organism is present.
X - Maximum service life will not be obtained when waterborne salts are used where pholads are known to attack and when creosote and creosote solutions are used where *Limnoria tripunctata* are known to attack.

[2] Available for a nominal charge from the American Wood Preservers Institute, 1651 Old Meadow Road, McLean, Virginia 22101.

It is not sufficient to specify the type of preservative treatment alone. In addition, the retention of the preservative in the pile (expressed in pounds of preservative per cubic foot of wood) and the depth of penetration of the preservative into the pile should be specified. In the case of southern pine, the following requirements should be met during pressure treatment:

Type of Treatment	Requirements
Creosote and Creosote-Coal Tar Solutions	minimum retention 20.0 lb/ft^3 in the first 3.00 inches from the pile surface; minimum penetration 4.00 inches, or into 90% of the sapwood
Waterborne Salts (ACA or CCA)	minimum retention 2.50 lb/ft^3 in the first 0.50 inch from the pile surface, and 1.50 lb/ft^3 between 0.50 and 2.00 inches from the pile surface; minimum penetration 3.50 inches, or into 90% of the sapwood
Dual Treatment[3]	minimum retention 1.00 lb/ft^3 of ACA or CCA in the first 1.00 inch from the pile surface, followed by minimum retention 20.0 lb/ft^3 of creosote or creosote-coal tar in the first 1.00 inch from the pile surface; minimum penetration 3.50 inches, or into 90% of the sapwood

To be sure that pilings have received the above specified treatment, look for the mark of the American Wood Preservers Bureau (AWPB). The mark MP-1 signifies dual treatment, MP-2 signifies creosote or creosote-coal tar treatment, and MP-4 signifies waterborne salts treatment.

[3] The Florida Department of Transportation recommends a minimum retention of 2.00 lb/ft^3 of CCA in the first 1.00 inch from the pile surface, followed by the creosote treatment.

APPENDIX 2

SPECIFICATIONS FOR REINFORCED CONCRETE MARINE PILINGS

The most important requirement of concrete for marine use is that it be as dense and impermeable as possible. This is accomplished by specifying a mix rich in cement (over 752 lb. per cubic yard of concrete) with a water - cement ratio less than 0.45 by weight and by requiring that the mix be workable and consolidated properly (Gerwick, 1974).

The type of cement used in the concrete is also of importance. Concrete made with a cement low in tricalcium aluminate, C_3A, is better at resisting sulfate attack than a mix made with a high C_3A content cement. On the other hand, concrete made with a cement of high C_3A content is better at reducing chloride penetration and corrosion of reinforcing steel. Hence, a cement of moderate C_3A content, such as ASTM Type II cement, is generally recommended for marine applications. ASTM Type I cement (normal cement) has a slightly higher C_3A content than Type II cement, and all other things being equal, will be slightly better at resisting corrosion of the steel, but slightly more susceptible to sulfate attack of the concrete.

The entrainment of 4% to 8% of air in the concrete mix will help to reduce cracking of the piling in the tidal zone. It is essential for concrete subject to freezing and thawing in the marine environment and helps reduce chemical attack (Gerwick, 1974).

The aggregates for concrete should be sound, non-reactive and resistant to abrasion. All aggregates should be washed thoroughly with fresh water to remove any salts and other impurities (Portland Cement Association, 1979).

Mixing water for concrete should be fresh water (seawater is not recommended for use in reinforced concrete), with concentrations of chlorides, sulfates, alkalies and solids limited.

Much discussion has been given to the amount of concrete cover needed over reinforcing steel (the distance between the outside face of the concrete and the surface of the steel). Cover of 3 inches is recommended by many authorities for reinforced concrete cast in place in a marine environment, although less coverage has been used successfully in some instances. The key seems to be the quality of the concrete. A piling or member precast (at the plant) with dense impermeable concrete may perform well with less than 3 inches cover; prestressed pilings have been cast with as little at 1 1/2 inches cover and performed well (Gerwick, 1974).

Concrete mixes for in-place repairs should be designed with the above mentioned requirements in mind. However, one difference is that when it is pumped or placed by tremie it should be a more fluid mix - not as stiff as that used at the plant for precasting pilings. The reduction in size of aggregates and the use of special admixtures can help achieve this.

REFERENCES

American Wood Preservers Association, Standards, 1979.

Beach Erosion Board, "Factors Affecting the Economic Life of Timber in Coastal Structures," Technical Memorandum 66, U.S. Army Corps of Engineers, 1955.

Estevez, E. D. and Simon, J. L., "Systematics and Ecology of Sphaeroma (Crustacea: Isopoda) in the Mangrove Habitats of Florida," in Proceedings of the International Symposium on Biology and Management of Mangroves, edited by G. E. Walsh, et al., University of Florida, 1974.

Gerwick, B. C., Jr., "Marine Structures," in Handbook of Concrete Engineering, edited by Mark Fintel, Van Nostrand Reinhold, New York, 1974.

Hartt, W. H. and Martin, P. E., "The Environmental Deterioration of Concrete Construction," Florida Environmental and Urban Issues, January 1981.

Helsing, G. C., "Recognizing and Controlling Marine Wood Borers," Oregon State University Sea Grant Poster SG-49, 1981.

Hochman, Harry, "Degredation and Protection of Wood from Marine Organisms," in Wood Deterioration and Its Prevention by Perservative Treatments, Volume 1, ed. by D. D. Nicholas, Syracuse University Press, 1973.

Johnson, Sidney M., Deterioration, Maintenance and Repair of Structures, McGraw Hill, New York, 1965.

Myers, J. J., et al., Handbook of Ocean and Underwater Engineering, McGraw Hill, New York, 1969.

Portland Cement Association, Principles of Quality Concrete, John Wiley and Sons, New York, 1975.

Portland Cement Association, Design and Control of Concrete Mixtures, 1979.

Rao, P. V., Einerson, J. A., Einerson, J. J., and Mehta, A. J., "A Survey of Small-Craft Recreational Marinas in Florida," Florida Sea Grant Technical Paper 18, August 1980.

Symons Corporation, "Pile Restoration and Preservation System," Form No. 80-1, 1980.