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MARINE BORERS

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16. Abstract

The two broad classifications of marine borers are: (1) Crustacea Subfamily with genera such as Limnoria and Chelura which cause exterior deterioration of timber piling; and (2) Mollusca Subfamily with genera such as Teredo and Bankia which cause interior deterioration of timber piling. Periodic inspection of a timber pile is necessary for determining when a jacketing system should be installed. Two ways to properly inspect wood piling: (1) Visually underwater for detecting external deterioration; and (2) Ultrasonic for detecting internal deterioration. Many different methods and materials are available for protecting and restoring timber piling. There is a wide variation in the degree of marine borer attack from one locality to another. Thus the experience of owners of nearby structures should be sought and a preliminary investigation should be made of the harbor where timber is going to be used. Creosote is effective against virtually all borers except Limnoria tripunctata of the Crustacea Subfamily. The presence or absence of Limnoria tripunctata will determine the type of preservative used. The service life of wood can be extended to combat Limnoria by the addition of soluble components of creosote which are both bacteriacidal and toxic to Limnoria tripunctata, by dual treatment or by the removal of the wood from the environment by use of plastic or metal barriers.

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MARINE BORERS

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I. INTRODUCTION

Although the use of concrete and steel piling for the construction of foreshore marine installations is increasing, in many areas of the world wooden piling remains the construction material of choice. Also, most existing harbors, especially older facilities, have timber as the dominant building material for piling and wharf facilities. In this use of wooden piling, prevention of "biological corrosion" is paramount if a long service life compatible with safety is to be assured.

Because of sea life and salinity, hardly any material will last very long when placed in the marine environment without eventual replacement of key parts or continual maintenance. Concrete, steel and wood - man's three traditional building materials - all have their problems in this environment. Since the 1950's, there has been a steady increase of activity in the protection of underwater structures. More recently, the pace has quickened as we are more and more conscious of the problem at hand and the economical, positive means of arresting this wasteful destruction particularly of wood and steel piling. Present day techniques of pile restoration and preventive maintenance systems applied with sound engineering practice can economically extend the service life of waterfront facilities.

This report will concentrate its discussion on timber piling, since it remains the most predominant material used on waterfront facilities, and will include a review of the damage caused by marine borers, a brief biological description of the various borers and the destructive process by each species (Mollusca and Crustacea Subfamilies), and an overview of protective techniques to arrest and/or prevent biological corrosion.

II. DETERIORATION OF WATERSIDE FACILITIES

A. Background

Wood piling in the marine environment is subject to attack and damage by various species of marine borers. Marine borers are an integral part of nature's decomposition cycle, in that they break wood up into small pieces to accelerate bacterial decomposition. All borer species exhibit greater activity during the warm months. Marine timber in tropical regions will be subject to more severe borer attack because of the greater borer activity in warm waters. The type of borers and the degree of attack found will vary widely from one location to another. In the Pacific Northwest, loss of pile bearing strength occurs almost entirely from attack by Bankia setacea and Limnoria lignorum. (See Table 1 on page 6 for classification of marine borers). Teredine borers such as Teredo navalis of antiquity fame and Crustacean borers such as Limnoria tripunctata are very active in more Southern waters.

Sooner or later every harbor engineer and terminal owner must face the realization that many of the creosoted wood piles in his wharf structure are being destroyed by marine borers. To extend the utility of these borer ravaged facilities, the engineer has a choice of the following three (3) methods:

(1) Reconstruct the wharf.

(2) Replace destroyed piles and continue to replace them as they deteriorate, realizing that similarly treated new timber piles are equally subject to attack.

(3) Preserve by any feasible means those timber piles which are attacked, but still retain a major portion of their structural integrity. This latter option will be reviewed in more depth in Section V of this report under "Protective Barriers".

B. Scope and Economic Aspects

Although many techniques have been used to combat marine borers, they cause an estimated $50 million of damage per year to foreshore marine installations in the United States. Figure 1 shows a facility in Los Angeles Harbor that has sustained extensive damage to creosoted piles in less than (7) years, well under the original contemplated thirty (30) years life of the facility.

The survival of a borer colony at any locale will depend on environmental factors such as acceptable salinity and dissolved oxygen (D.O.)

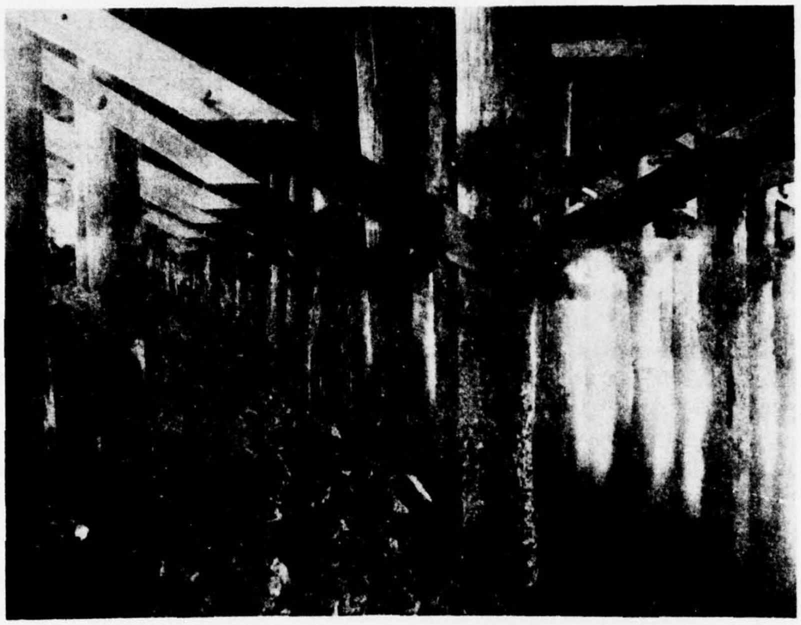
levels, favorable temperature, and a sufficient supply of wood. Salinity requirements will vary among the different types of borers; for example, Teredo navalis requires no less than 9 to 20 parts per thousand. Seasonal changes will cause extreme changes in temperature, resulting in the prevention of year round breeding of marine borers. The optimum sea water temperature ranges between 50 and 70 F (10 and 21.1C). Low levels of D.O. (below two parts per million) are associated with low marine borer activity. The prevention of marine borer attack involves controlling one or more of these essentials.

In New York Harbor during periods of peak marine borer breeding activities, Limnoria and Teredo larvae are generated in response to some cyclic internal or external stimuli. Within a few tidal cycles larvae are transported over the entire harbor, and when conditions are favorable larvae survive to multiply to destructive proportions. Occasionally marine borers are transported by infested driftwood or shipping; however, dispersion by tidal currents remains the dominant means for the distribution of marine borers.

The most destructive borers and also the most difficult to detect are in the Mollusca Subfamily. Results of their actions are shown in Figure 2. The Teredo (Mollusca Subfamily) can destroy an unprotected pile in less than a year, whereas Limnoria (Crustacea Subfamily) may take up to 8 years. The area of attack of the marine borer generally extends from the mud line to the high water line, as shown in Figure 6. In the past it was thought that Limnoria showed the greatest attack at the mean tide and Teredo at the mud line. However, experiments have shown that this is not necessarily the case. In some localities Teredo or Limnoria may show a particular area of concentration relative to the mean tide line of the pile, yet the point of attack on a pile in another locality may be different.

Water pollution, due primarily to industrial waste, has had the effect of keeping borers out of harbors. However, the improvement in ecological quality of the harbor water improves the habitat for marine borers, thereby increasing the attack rate on piles and wharf facilities. Furthermore, water leaching of the impregnant continues throughout the life of the pile making it increasingly vulnerable to borer infestation. Thus, as the harbor environment is cleaned up and as the piling ages the rate of piling failure increases.

With the increasing costs of material and labor and the inconvenience of disruption to a working wharf or warehouse facility, it is often more economical to establish a systematic inspection program and rehabilitate existing piling rather than planning a major replacement or reconstruction. This is made possible due to present day techniques of pile restoration and preventive maintenance systems applied with sound engineering practice.



Extensive Limnoria damage to piles reducing bearing capacity and restricting usage of facility well under expected service life.

Surface gouging effect of Limnoria tripunctata on creosoted pile showing galleries in both the treated and untreated parts of the wood.

Figure 1

Creosote Treated Pile Section with no visible damage.

Cross-section of Above Pile showing heavy Teredine damage and loss of cross-section.

Longitudinal Section of Same Pile showing the eccentricity of the voids and extensive loss of cross-section.

Figure 2

III. MARINE BORERS

A. History

The "shipworm's" place in history is well documented. They were the scourge of the Roman galleys, of the sea-going Greeks and Phoenicians, and of the explorers of the New World. In the 1700's they riddled the dikes that the Dutch had built to retain the sea; by so doing, they threatened the very life of Holland. (The first extensive studies of the shipworm were made by Dutch scientists, to whom knowledge of its biology had become a matter of life and death. Snellius, in 1733, pointed out for the first time that this animal is a clamlike mollusk and not a worm). About 1917 the shipworm invaded the harbor of San Francisco. Before its inroads were even suspected, ferry slips had begun to collapse and wharves and loaded freight cars fell into the harbor. During the Second World War, especially in tropical waters, the shipworm was an unseen but powerful enemy.

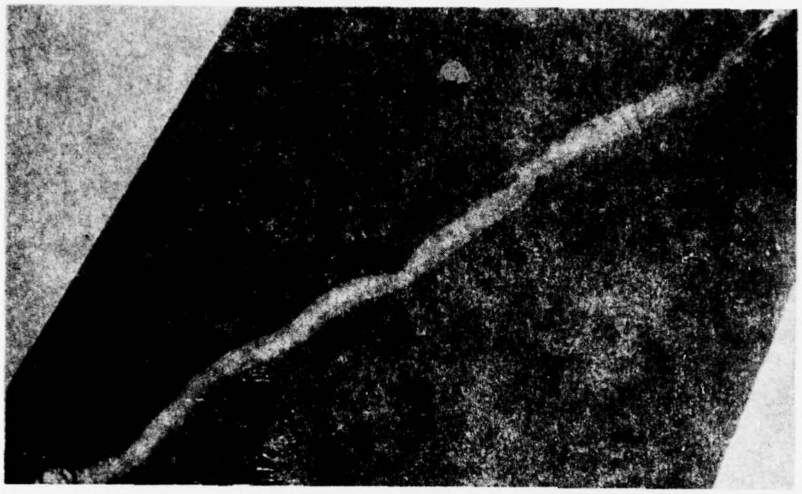
B. Mollusca and Crustacea Subfamilies

For centuries the terms "shipworm" and/or "pileworm" have been applied to various marine boring organisms, especially Teredo or Bankia, (Mollusca Subfamily) which have been observed boring into wood submerged in salt water. The general term "marine borer" is used to designate any of the several hundred species of marine invertebrates which bore into timber, lowgrade concrete, soft stone, bricks or other non-metallic materials in salt water. There are two divisions of these destructive organisms, the Mollusca Subfamily and the Crustacea Subfamily.

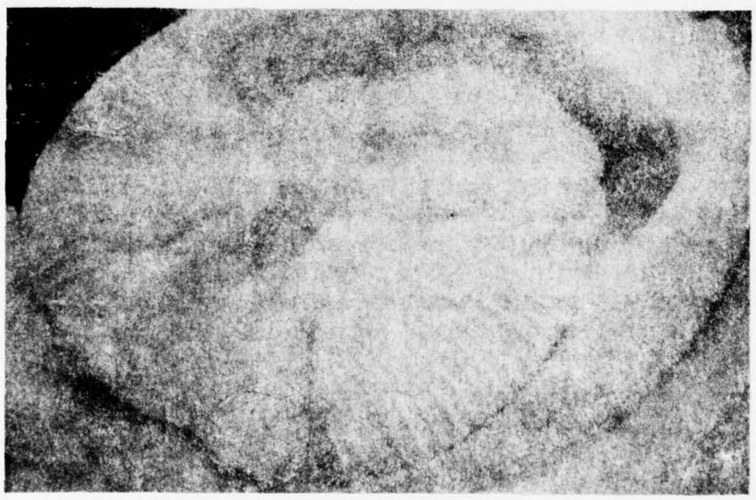
Table 1 - Classification of Marine Borers

Mollusca Subfamily	Crustacea Subfamily
Genera: Teredo Bankia Lyrodus Martesia Hiata Pholas	Genera: Limnoria Chelura Sphaeroma

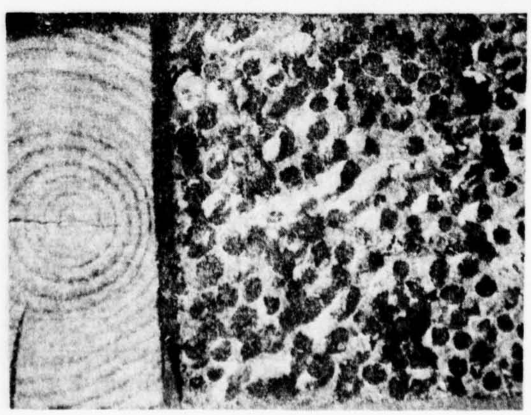
Their methods of attack on timber are somewhat different. Teredo larvae enter the timber through minute holes and destroy the interior of the timber. The minute entrance holes (approximately 0.008 in (0.20 mm) to pinhole size) with associated siphon tubes are difficult to detect by surface inspection. Inspection is performed by cutting or coring timber or by ultrasonic techniques.



Adult Teredine Borer
- Bankia Setacea approximately 18" (45.7 cm) long and ½" (12.7 mm) diameter. Note the clam shell like grinders at the left, anterior end and the "feathery" pallets and siphons at the right, posterior end.



Close-up of Anterior End of Bankia showing the rasp like shells used for grinding wood.



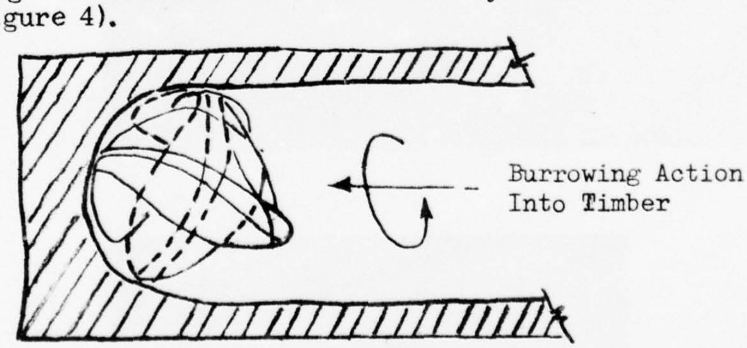
Two inch (5.1 cm) untreated test material before and after teredine attack.

Figure 3

Limnoria are the smallest and most destructive borers in the Crustacea Subfamily. Limnoria tripunctata are normally found in warm waters and will keep away from freshly creosoted timber, but attack creosoted wood after a variable exposure period. Several explanations for this phenomenon have been proposed. Some experts believe that the destructive attack will occur after a sufficient number of creosote resistant organisms have been produced. Other experts have proposed that Limnoria subsist on growth factors produced by micro-organisms. The service life of creosoted piling in Liminoria tripunctata infested water, i.e. Los Angeles/Long Beach Harbor, San Francisco Bay, Pearl Harbor, etc., is about 8 years, since once the creosoted layer is opened, other borers can riddle the piling in a matter of months.

C. Biological Corrosion

1. Molluscan Borers - The genera Teredo and Bankia are part of the Mollusca Subfamily and have similar physical characteristics. The Bankia is illustrated in Figure 3. Teredo has a grayish, slimy, worm-like body and a shell on its head which is used for boring. It is a member of the clam family and although the pattern of the life cycle differs slightly between species, the larva exists as a minute, free-swimming, clam-shaped organism. It has feeble powers of locomotion and is borne by water currents to wood surfaces. Then the young bivalve puts out a slender byssus thread as an anchor, a foot develops and the clam shell-like grinder on its head become modified into efficient cutting tools. The burrowing begins. With a powerful muscle, the animal scrapes the ridged shell against the wood revolving meanwhile so that a smooth, cylindrical burrow is cut (See Figure 4).



Diagramatic View of Teredo Shell in the Burrow, Showing Two Positions in Boring (lateral view).

Figure 4

As the burrow is extended, usually with the grain of the wood, the body of the "shipworm" grows. One end remains attached to the wall near the minute point of entrance. This bears the siphons through which contact with the sea is maintained. The animal lives the rest of its life inside its wooden burrow, the size of the burrow corresponding to its size. The burrow is lined with a smooth nacreous lining. Although a timber may be infested with hundreds of larvae, the burrows never interfere with each other. If an animal finds itself coming close to another burrow, it invariably turns aside. As it bores, it passes the loosened fragments of wood through its digestive tract. The maximum size of the borer is limited generally by the quantity of wood available in the vicinity. The size of the mature common species ranges from 3/8 inch (9.6 mm) in diameter and 5 or 6 inches (127 to 152 mm) in length. Some species of Bankia in the Pacific Islands reach sizes up to 48 inches (1219 mm) in length and burrow diameters up to 3/4 of an inch (19 mm).

Another borer that uses its shell for boring is the Pholad, but its body is enclosed by the shells and there is no lining in the burrow. Some species of this group bore in soft concrete and rock as well as mud. They make entrance holes somewhat larger than those made by the Teredo, (See Section III-B) but the holes are still small and hard to find by surface inspection. Species of this genus are found in all parts of the world, but in general, are fewer in number than the Teredo and are responsible for much less damage, even though their attack is more difficult to prevent.

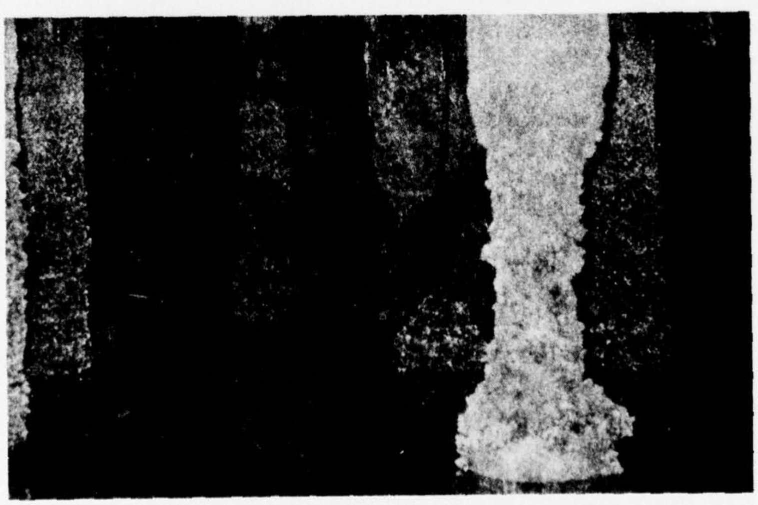
2. Crustacean Borers - There are three important Crustacean borers: Limnoria, Sphaeroma and Chelura. Limnoria, the most widely distributed of the genera, is illustrated in Figure 5. The Limnoria are surface gougers which resemble small lobsters or wood lice about 1/8 inch (3.2 mm) in length and a width of about 1/3 the length. The mouth of the Limoria contains a pair of strong, horney-tipped mandibles with which the boring is done. Its body has numerous pairs of legs ending in sharp, hooked claws so that it can move freely and cling to timber. It uses its gill plates for swimming. Limnoria destroy timber by producing a lacy network of tunnels at the wood surface, seldom penetrating more than a 1/4 of an inch (6.4 mm). As these lacy networks of tunnels are eroded away by wave action the animal penetrates deeper into the wood. As many as 400 borers per square inch (645 sq. mm) have been counted on timber under heavy attack. The points of greatest concentration are found near the mud line and mean tide level (See Figure 6) but they may be either distributed uniformly or concentrated anywhere between these limits.

The Limnoria is able to leave its tunnels and migrate to new wood surfaces, although this migration is normally associated with the release of the young animals at certain periods of the year. They are found in tidal waters from the Arctic Circle to the Tropics.

Sphaeroma are very much like Limnoria in appearance except that they are generally larger, a large specimen being 1/2 inch (12.7 mm) in length and 1/4 inch (6.4 mm) in width. Sphaeroma are widely distributed geographically but are not as noted for destruction of timber as are the Limnoria.

Surface Borer Limnoria Lignorum approximately 2-3 mm in length.

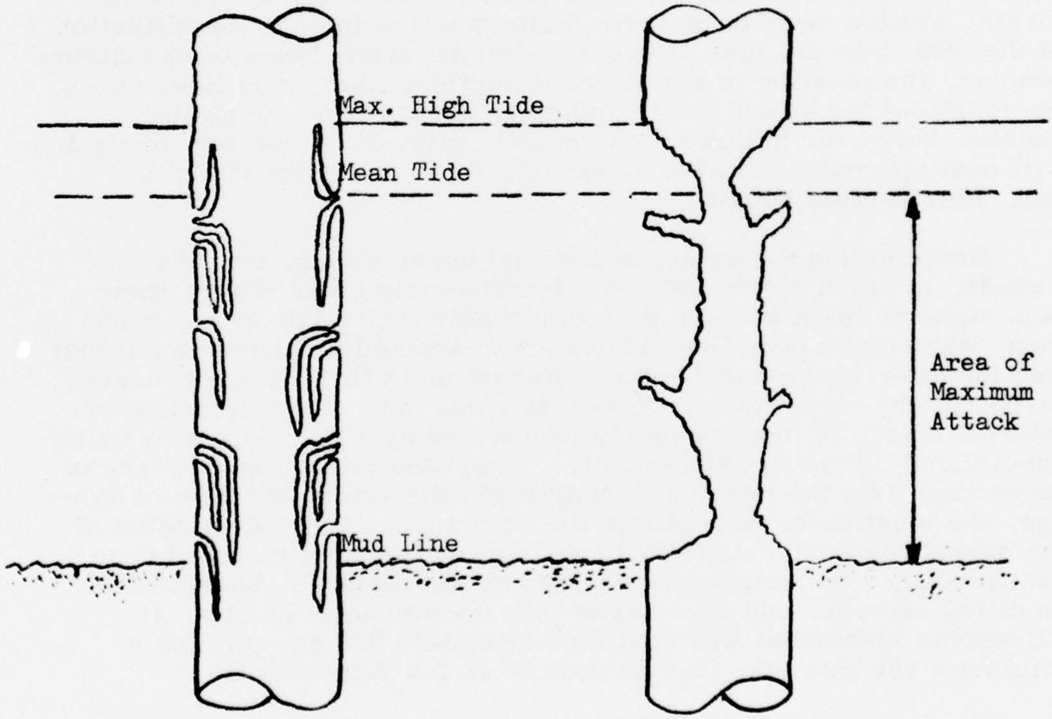
Test material before and after Limnoria attack.



Pile in forground with classic Limnoria 'hourglassing', two other piles completely destroyed.

Figure 5

Chelura are slightly larger than the Limnoria and are found in the same localities. When present in great numbers, they seem to drive out the Limnoria. The body at the joints, the antenna and the legs are heavily feathered with long hairs. This borer is destructive in European waters and in many Pacific Island Harbors. They had not been found in important numbers in the Continental United States until 1935, when they appeared in enormous numbers in Boston and several other New England harbors. Until recently Chelura had been considered as destructive as the Limnoria. However, recent studies seem to indicate that this species has been overrated in its destructive ability, possibly because Chelura are frequently discovered occupying abandoned Limnoria burrows.



A. Typical Teredo Damage B. Typical Limnoria Damage

Figure 6 TYPICAL PILE DAMAGE BY MARINE BORERS

IV. INSPECTION AND TESTING

A. Discussion

There are two ways to correctly inspect wood piling:

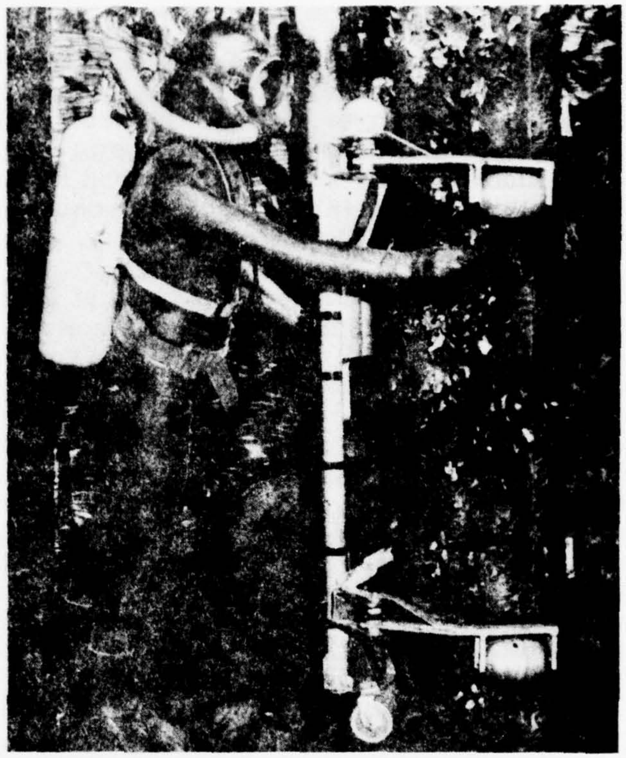
(1) Visually underwater for detecting external deterioration caused by Crustacean borers (Limnoria) and (2) Ultrasonic for detecting internal destruction caused by Molluscan borers (Teredo). The distinctive hour glass shape caused by Crustacean Borers can be easily seen or felt and reasonably accurate estimates of strength reduction by reduced bearing area can be obtained by surface inspection at low tides, scuba divers, and/or hard hat divers. "Qualified divers who routinely inspect wood piles for external deterioration furnish written reports on their findings which include identification of the pile, percent loss of cross-sectional area, types of organisms present, the location of the attack (intertidal zone, mud line, etc.), the length of the attack area, and other defects such as splits, checks, holes, or hollowed out areas". (Ref. 2) Visual pile inspection will cost approximately $5.00 per pile for a minimum 100 pile job. (See Section VII B)

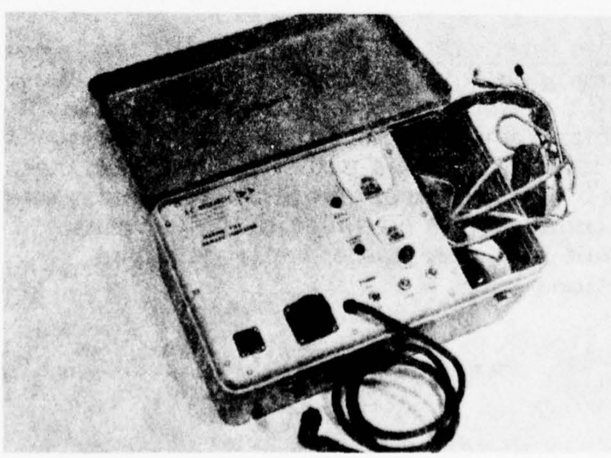
Determining the extent of internal borer attack, typified by Teredo, is much more difficult. In extremely clear water, their twin siphons might be seen by a thoroughly trained diver but even then, when disturbed, the siphons are retracted and can remain that way for several days without any disruption in their living process. Inspection by visual means or feel is ruled out. Thus detection of internal attack is most properly performed by a two man crew using specialized ultrasonic equipment. "A written report on this type of inspection lists the residual strength and the extent and type of damage, the location of each pile in the structure, and an evaluation of the overall project. Appended information includes marine borer background, a description of equipment and methods, background on piling service, and methods of pile maintenance". (Ref. 2) Ultrasonic inspection will cost approximately $30 per pile for a minimum 100 pile job. (See section IV B.2 & Appendix C)

B. Inspection Instruments

(1) Coring - Core samples can be effective in determining the presence of Teredine borers only if the inspector is lucky enough to intersect a tunnel. Where internal destruction is just getting underway and before the pile is seriously damaged, the chances of locating Teredine borers in this manner are obviously very slim. Coring has the disadvantage of reducing the cross-section of the pile, and, because the protective barrier has been penetrated, provides an ideal entry point for young borers if not properly treated and sealed.

Scuba diver scans surface with sonic probe and provides visual inspection.





Sonic probe test set monitored by a surface technician.

Figure 7

(2) Sonic Testing - Various sonic inspection methods have been tried and one successful technique is that developed by British Columbia Research, Vancouver, B.C., Canada. One limitation of the sonic technique is that the sonic wave shows all the wood defects including borer tunnels, ring shake in the wood itself and other timber defects. Also, a highly specialized team is required to operate the equipment and evaluate the information.

In 1955, studies were initiated at British Columbia Research to develop instruments for nondestructive testing of in-place marine piling. It was found that the velocity and strength of sound waves passing through wood varied inversely with voids in wood caused by marine borers. Based on this principle, instruments were developed which use magnetostrictive transducers to produce an ultrasonic "scan" of the pile. The plane waves from the transmitting transducer which penetrate the wood initiate transmission of secondary sonic patterns in the direction of the wood grain. As these wave trains transmit along the axis of the pile, they produce radial sets of waves which are picked up by the transducer. Undamaged wood is an excellent transmitter of these waves whereas damaged wood attenuates the sound. A direct meter read-out is provided showing the percentage of sound wood remaining.

The testing crew consists of two men, a scuba diver who provides visual observations and scans the entire surface of the pile with the sonic "probe" and a surface technician who monitors the observations and readings produced on the meter (See Figure 7). Removal of fouling is not required for operation of the unit. Under average conditions of water depth, current, and visibility, one two-man crew can test approximately 100 piles per day.

(3) Radiography - Radiography using "X" or Cobalt rays has been tried with some laboratory success and the method shows promise as a future inspection tool.

C. Testing and Inspection Intervals - The intervals of testing and inspections will vary depending upon environmental fluctuations, degree of known harbor infestation by marine borers and usage of the facility. Generally, a sustained systematic program of 2 to 5 year evaluations should be practiced based on local conditions and sound engineering practices. "Local conditions" may be based on economic constraints or budget restrictions which conflict with engineering judgements and which ultimately may result in higher costs due to deferred maintenance policies or practices.

V. PROTECTIVE BARRIERS

Protective pile barriers are of two types: those which protect damaged piling from further damage and strength loss and those which restore strength in severely damaged piling.

A. Preservative Chemicals - "No wood is immune to marine-borer attack, and no commercially important wood of the United States has sufficient marine-borer resistance to justify its use untreated in any important structure in areas where borers are active. The heartwood of several foreign species, such as turpentine, greenheart, jarrah, azobe, totara, kasikasi, manbarklak, and several others, has shown resistance to marine-borer attack. Service records on these woods, however, do not always show uniform results and are affected by local conditions." (Ref. 5) The basic protective barrier for wood piling commences with impregnation of selected preservative chemicals under pressures on the order of 200 psi (1.4 MPa). The timber piles are placed into hermetically sealed, cylindrical retorts, and are immersed in the preservative chemical. The pressure forces the preservatives deep into the wood to help assure long lasting protection. "The life of treated piles is influenced by the thoroughness of the treatment, the care and intelligence used in avoiding damage to the treated shell during handling and installation, and the severity of borer attack. The treatment must be thorough, the penetration as deep as possible and the retention high to give satisfactory results in heavily infested waters. It is best to treat such piles by the full-cell process "to refusal", that is to force in all the preservative the piles can hold without using treatments that cause serious damage to the wood". (Ref. 5) Thus maximum protection against marine borers can be obtained when as much preservative as practical is injected into the pile. The piling should be air dried before treatment to insure the highest retention possible.

For maximum effectiveness the preservative should be matched to the borers expected to be present. Creosote is the most widely used preservative and is highly effective against virtually all borers except Limnoria tripunctata, which is creosote resistant. Apart from its own destructive activity, Limnoria tripunctata can expose the untreated areas of a pile to Teredine attack by destroying the protective creosoted layer. Teredine larvae do not settle on well creosoted timbers; however, a mature Teredo or Bankia could penetrate the creosote layer of a pile via a firmly attached untreated dapped piece of wood, brace or strut.

Many new preservatives are developed each year. The United States Navy Civil Engineering Laboratory's (NCEL) research on improved preservatives for marine piles has shown that an effective preservative system should be a combination treatment. "One component of the treatment must be toxic to Limnoria and the other toxic to Teredo. Three types of combination treatments were found to be effective:

1. A compound which is toxic to Limnoria is dissolved in creosote, which is toxic to Teredo.

2. A compound which is toxic to Limnoria and a compound which is toxic to Teredo are dissolved in an inert solvent.

3. A compound which is water soluble and toxic to Limnoria, and which becomes insoluble in the wood after impregnation is used to treat the wood. After drying, the wood is given a conventional creosote treatment (this procedure is called dual treatment by the wood preserving industry)." (Ref. 1) For economic reasons the wood preserving industry has adopted only treatment 3.

Dual treatment as specified by the American Wood Preservers Bureau Standard MP-1 (AWPB-MP-1) requires:

1. Applying no less than 1.0 lb/cu ft (16.02 kg/cu m) retention of ammoniacal copper arsenite or chromated copper.

2. Applying no less than 20 lbs/cu ft (320.4 kg/cu m) retention of creosote.

The Technical Note, 1976 Inspection of Experimental Marine Piling by T. Roe of NCEL evaluates various timber piles impregnated with either creosote containing a toxic additive, a selected single treatment, a solution containing two toxic compounds, or a dual treatment. Experimental piles are located at Coco Solo, Canal Zone and Pearl Harbor. Douglas fir dual treated piles (ammoniacal copper arsenite followed by creosote) after 13 years have performed better than all other treated piles at Coco Solo. Experimental piling at Pearl Harbor treated with creosote containing a toxic soluble additive such as chlordane or tributyltin oxide and dieldrin in general performed better than piling treated only with creosote.

"Each additional year of exposure increasingly supports the opinion that dual treatment piles are superior to creosote alone as a wood preservative in warm water harbors. The extent of the superiority cannot yet be determined, but it is sufficient to warrant using the more costly dual-treated piles for bearing purposes. Their use in fender systems is questionable because there is evidence that suggests that treatment with water-borne salts embrittles wood and decreases its energy absorbing capacity." (Ref. 4)

Research on preservative treatments at the Forest Products Laboratory, Madison, Wis. indicates that a reduction from the present standard of 1.0 lb/cu ft (16.02 kg/cu m) salt in dual treatment is possible without a great reduction in marine borer resistance. For example, panels dual treated with 0.60 lb/cu ft (9.612 kg/cu m) marine grade crosote have remained free from marine borer attack after 78 months exposure at Key West, Fla. Wood can be expected to lose 5% of its strength and experience about 15% increase in brittleness for every 1.0 lb/cu ft (16.02

kg/cu m) of the salt retention. The pile design should allow for this condition. NCEL has contracted the Department of Forest Products, Oregon State University to evaluate the effect of salt retention on the energy absorbing capacity of wood. (See Appendix E-3).

In addition to embrittling wood, dual treatment means double pressure treatment which is time consuming and expensive. Thus, the search for more effective treatments against marine borers is necessary for the wood-preserving industry to remain competitive with the concrete and steel piling industry. "A successful treatment should be resistent to the various kinds of marine borer attack, be economically feasible to the buyer, and fulfill federal and state environmental regulations." (Ref. 3). For this purpose the William F. Clapp Laboratories, Inc., is investigating in the laboratory and in the natural environment, the addition of chemical toxicants to creosote before impregnation into wood. (See Appendix E-4).

In conclusion the service life of wood can be extended to combat Limnoria by the addition of soluble components of creosote which are both bacteriacidal and toxic to Limnoria tripunctata; by dual treatment, first with an aqueous solution of a material toxic to Limnoria followed by creosote; or by the removal of the wood from the environment by the use of plastic or metal barriers.

B. Flexible Barriers - The prevention of further pile damage and strength loss is achieved by encasing the piling with a protective jacket. The purpose of this jacket is to create a lethal environment in which the borers cannot live, by eliminating dissolved oxygen in the water under the wraps. This is often referred to as the "stagnation principle". To achieve this effect, it is necessary to have the jacket or barrier fit the general contour of the pile tightly.

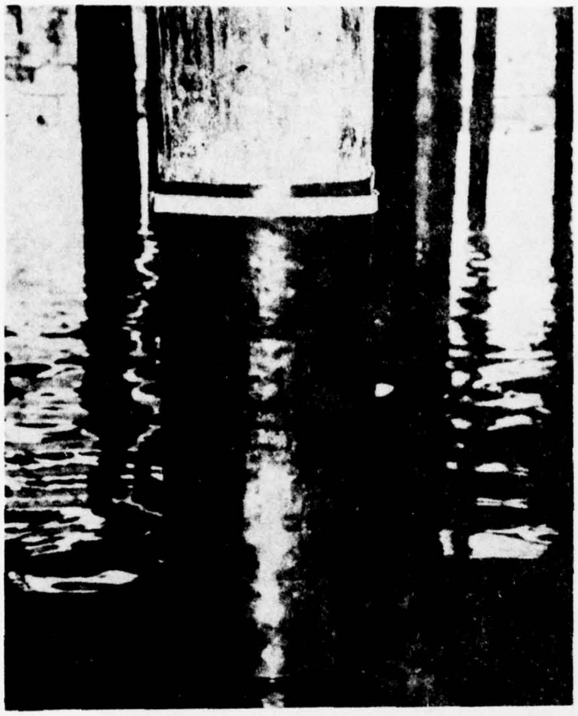
Bearing piles which encounter more than 5% and up to 15% reduction in cross sectional area may be jacketed with a flexible wrap. These percentages may be adjusted to meet local conditions. For example, the Port of Los Angeles had an inspection policy of wrapping those piles with a 10% reduction in section. However, recent improvements in the ecological quality of the harbor water has resulted in increased dissolved oxygen (D.O.) levels leading to increased marine borer attack. Thus, the protection policy has been revised to wrap all the piles as soon as practical and maintain inspections to verify the integrity of the protected piles. NAVFAC Specifications TSM-B10A recommend the installation of a flexible barrier system on bearing piles which have lost 10 to 15 percent of their cross sectional area. A 5 percent reduction in area can be chosen as a minimum to take into account the progressive attack occurring during a lengthy delay between inspection and installation of flexible barriers. In many harbors a 5 percent reduction in area will progress to near 10 percent in one year. The installation of a flexible barrier system is not recommended in areas where piling inspections indicate a destructive erosion of timber piling due to the abrasive action of ice or other objects. The following are examples of flexible barriers:

(1) Polyvinyl Chloride (PVC) - Sections of 30 mil (0.76 mm) PVC sheathing are prepared on land and then fitted around the piling in situ and tightened into position, with the encasement usually extending from a point below the mud line up to above the level of the highest anticipated tide. (See Figure 8). An underjacket of 6 mil (0.15 mm) polyethylene is incorporated into the wrap since creosote softens PVC and could result in damage to the wrap. An aluminum alloy band with an intertidal seal is installed at the plus 8 foot (2.4 meters) and minus 2 foot (0.6 meters) points of the tidal zone. The balance of the wrap is secured with aluminum alloy nails. PVC sheathing has demonstrated resistance to impact from floating objects such as log rafts, free floating logs, empty oil drums, crates, and moderate ice action. PVC has been used within ambient temperature range of 0 to 100 F (17.8 to 37.8 C). A Naval Civil Engineering Laboratory study at Port Hueneme, California, has proven the feasibility of using a PVC barrier plus a metal shoe on timber fender piling. The metal shoe is a metal cylinder or similar metal armor installed over the PVC barrier at the tidal zone to prevent mechanical damage to the PVC. The installation of a camel system is recommended for preventing scouring of the ship's hull due to the ship's motion against the metal shoe.

(2) Rigid Polyvinyl Chloride - Rigid split tube PVC material in 60 mil (1.52 mm) thickness has been thermoformed in such a manner that it can be opened longitudinally and snapped around a pile in situ to produce a snug fit. (See Figure 9) It is then nailed and/or banded with aluminum or copper-nickel alloy type material.

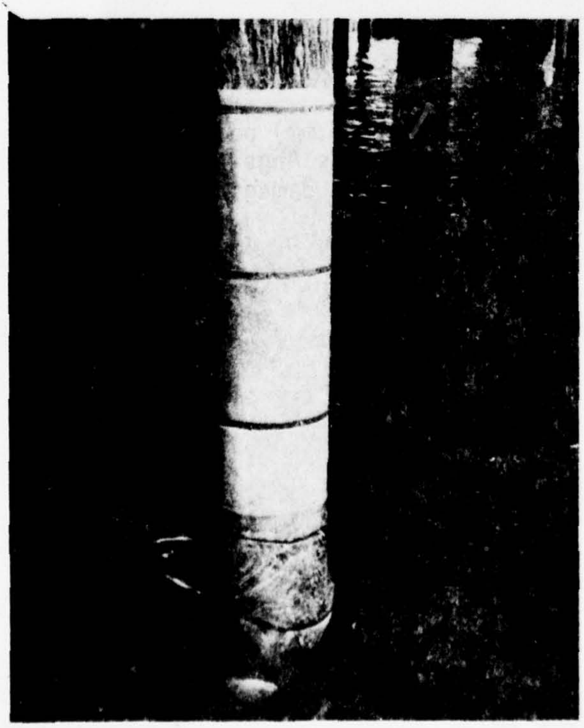
(3) Heat Shrink Polyethylene to Timber Piling - Port of Los Angeles Engineering personnel have developed a unit for the application of 20 mil (0.51 mm) polyethylene by heat shrinking directly onto the pile before it is driven. The unit consists of an annular windscreen enclosing a ring of propane fired ceramic burners. (See Figure 10) The polyethylene is applied in 10' 6" sections (3.2 meters). As the unit passes over the polyethlene film, it shrinks circumferentially and tight against the pile and at the same time makes a heat seal at the overlapped portion. The result is a one-piece continuous film of 20 mil (0.51 mm) polyethylene tightly shrunk to the pile. About 5 to 7 feet (1.5 to 2.1 meters) is left uncovered at each end so that the pile may be handled without damaging the film. After driving, all areas of the pile exposed to seawater immersion are protected with polyethylene.

(4) Metallic - Various metallic barriers such as copper, copper-zinc and copper-nickel alloys have been used for a great many years as an effective barrier against marine borer infestation. The mechanical difficulties of application and costs of material have made



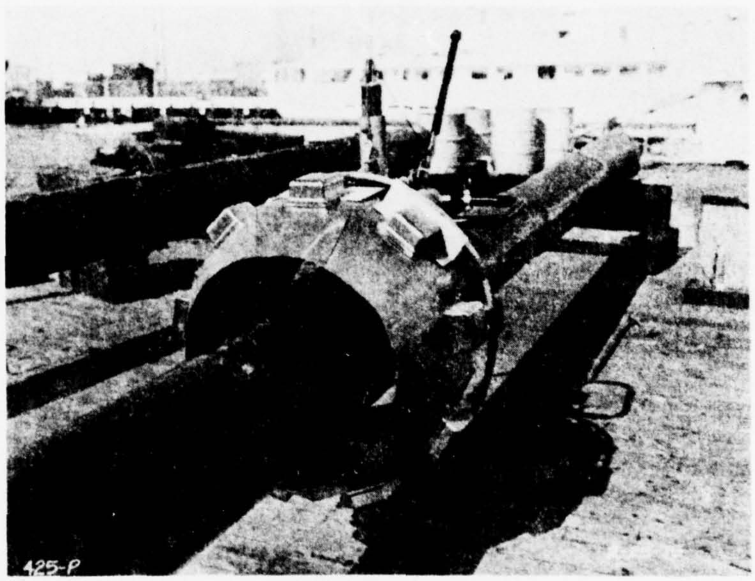
Polyvinyl chloride sheathing wrapped around pile, tightened into position and secured with aluminum bands and nails.

Figure 8



Rigid polyvinyl chloride "snapped" around pile for tight fit.

Figure 9



Heat Shrinking Unit shrinking 20 mil (0.5 mm) polyethylene film tightly to the pile. The Port of Los Angeles has handled and driven numerous piles without damaging the film.

Figure 10

the overall cost of metal sheathing expensive. In certain cases, however, where localized cavities exist in piles, grouting and/or application of metal patches is an effective maintenance technique.

C. Strength Restoration - Various innovative techniques have been employed to restore strength to piling by methods other than replacement of the severly damaged pile. Strength restoration is normally required when a pile has lost 15% to 50% of its cross sectional area. When 50% or more of the piling cross sectional area has been destroyed, the repair procedure involves cutting out the damaged area and replacing it with a sound section. Strength restoration methods include the following:

(1) Precast Shotcrete - Prefabricated, 3 inch (76 mm) concrete half cylinders with projected reinforcing mesh on the sides and ends of each modular unit were successfully used by the Port of Long Beach to protect wood piles. The split cylinders were placed around the piles above the water line and the projecting reinforcing mesh twisted to make a complete enclosure. End and side joints were shotcreted and the completed unit lowered into the water. A second section was placed on the first and the process continued until a completed encasement was jetted several feet below the mud line and the annular space filled with concrete grout. (See Figure 11)

(2) Stubbing Method - This process consists of exposing the pile at the mudline below the area of deterioration, and the damaged area is removed. A pin is driven into the exposed sound stump and a lightweight tube housing reinforcement bars is attached to the stump and cap. Concrete is pumped into the tube and allowed to harden, after which the bottom and top tube attachments are removed. The loads are transmitted from the cap to the sound pile stub in the mudline by the new reinforced concrete pile section.

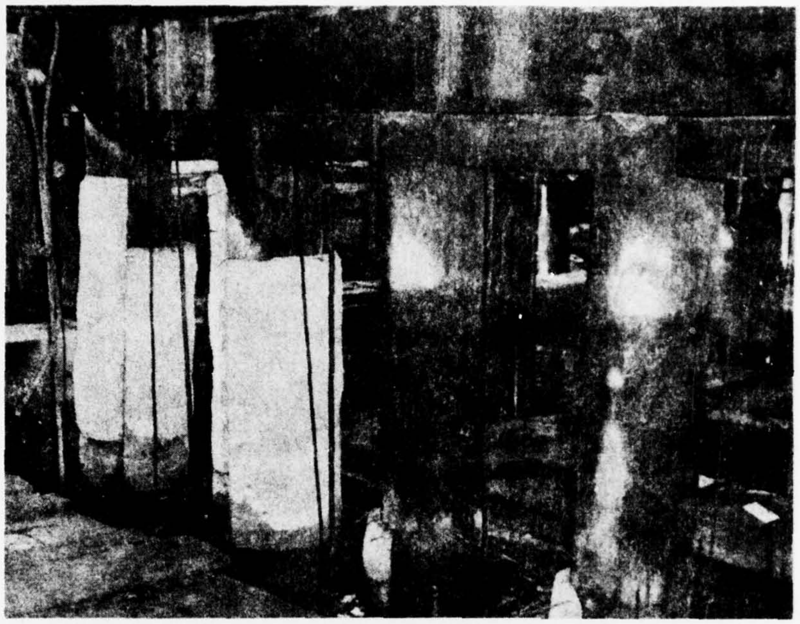
(3) Oil Drum Method - This method is also used in splicing of stubbed piles or in replacing the major portion of pile's length. In the first case, the damaged section of a pile is removed and replaced with a treated wood pile section. A 50 gallon (0.189 cu m) steel oil drum with a hole, the size of the pile, cut in its bottom is fitted around the joint and filled with concrete. A variation on this method is achieved by simply placing the drum around the old stump and additional drums are added in chain sequence as required. Reinforcing can be added, if desirable and the mold, consisting of oil drums, is then filled with tremie concrete. The pile is normally wrapped with polethylene prior to placing concrete in order to get a tight oxygen-free seal adjacent to the pile surface. The Port of Oakland has successfully used this as a standard method of repair for a number of years. (See Figure 12)

(4) Concrete Jacket - This process is used when 20% or more of the pile cross-section has been damaged or lost. A fabric "sock"

is installed as a mold around the length of a damaged pile, reinforcing mesh or rods are placed around the pile inside the sock and the sock is pumped full of concrete. (See Figure 13). This process has been used successfully even on piling which are subjected to considerable lateral bending.

This process requires careful control and inspection, especially on battered piles, to assure correct placement of the pumped or tremie concrete and to verify that there has been no separation of cement and aggregate in the mix due to water saturation.

(5) Numerous other innovative techniques are available, however, application of any of these will be determined by suitability of the method in solving a problem at a given location and overall economic factors.



Precast concrete split shells around deteriorated creosoted wood piles. The vertical and horizontal joints are being sealed by means of shotcrete prior to lowering the hardened unit in the water. More shells are then added, shotcreted together and lowered until the mudline is reached.

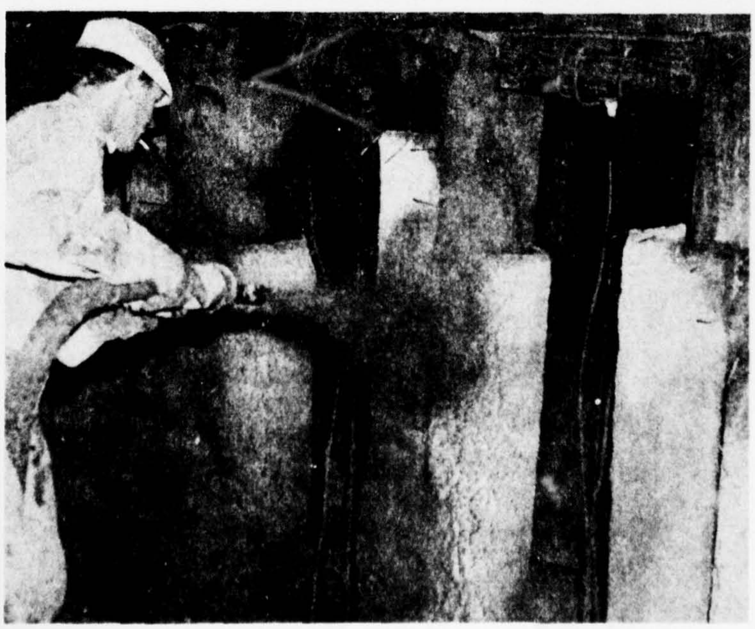


Figure 11

Oil drums used to splice a stubbed pile or as shown, in chain sequence as a form and filled with concrete to repair a deteriorated pile.

Figure 12

Fabric "sock" or bag installed as a mold around length of damaged pile, reinforcing steel placed and bag pumped full of concrete. Works well on steel H-beam, pipe and pre-stressed concrete pilings as well as on wood.

Figure 13

VI. SUMMARY

A. Wood pilings in the marine environment are subject to attack and damage by various species of marine borers.

B. Although many techniques have been used to combat marine borers, they cause an estimated $50 million of damage per year to waterfront properties in the United States.

C. There are two primary divisions of marine borers, the Mollusca Subfamily, which enter the timber through minute holes and destroy the interior of the timber, and the Crustacea Subfamily, which destroy the outside of the timber through surface erosion.

D. A sustained systematic inspection program is required to identify pile deterioration and establish remedial measures. In areas where Crustacean attack is dominant, a qualified diver should visually inspect piles to determine the degree of surface deteroriation. In areas where Molluscan attack is dominant, ultrasonic inspection is recommended for determining the condition of pile interior.

E. Sonic testing requires specialized equipment and operative personnel, however, residual strength of an equivalent undamaged pile can be obtained.

F. Improvement in the ecological quality of the harbor water improves the habitat for marine borers thereby increasing the attack rate on piles and wharf facilities.

G. The basic protective barrier for wood piling commences with the impregnation of selected preservative chemicals for the marine environment such as creosote and/or waterborne toxic salts. For maximum effectiveness the preservative should be matched to the borers expected to be present. An unbroken shell of preservative should be maintained in the underwater part of the pile. Whenever possible all framing, cutting, boring, or trimming should be completed before treatment. When field frabrication becomes necessary all exposed timber should be treated in accordance with AWPA Standard M4-74.

H. Dual treatment in accordance with the American Wood Preservers Bureau Standard MP-1 is recommended on timber piling in warm-water harbors highly infested with marine borers especially, Limnoria tripunctata. The metal salt component of the treatment will reduce the strength of the piling and the design should allow for this condition.

I. Flexible barriers are normally installed after a pile has lost 10 to 15% of its cross sectional area and can still support the design load. Strength restoration is normally required when a pile has lost 15% to 50% of its cross sectional area. When 50% or more of the piling cross sectional area has been destroyed, the repair procedure involves cutting out the damaged area and replacing it with a sound section or replacing the piling.

J. The acknowledged methods to protect damaged piling from further damage and strength loss consists of ensheathing the pile in polyvinyl chloride, polyethylene or metallic copper-zinc/nickel alloys tight against the pile. The principle of this method is to protect against borer activity by cutting off water circulation and thereby restricting the supply of oxygen to the borers.

K. Various innovative techinques have been used to restore strength to damaged piles (other than replacement). Some of these techniques are precast concrete shells around the piles, stubbing replacement of the damaged pile section, oil drum forms filled with tremie concrete and fabric "sock" or bag mold with reinforcing mesh or bars pumped full of concrete.

L. Construction malpractices can accelerate the deterioration of piling. Such malpractices include: opening of cracks in piling by over-driving, the drilling of subsurface bolt holes, the exposure to sea water of untreated cut ends of piling and brace planking and the unprotected attachment of this lumber to piling.

M. Abrading of the protective barrier, preservative chemical and/or jacket, by ships, barges or floating debris can result in exposure of unprotected piling surfaces which can accelerate marine borer deterioration. Expendable fender piles, shoe protective devices and floating bumpers to restrain driftwood from reaching piles beneath the wharf should be maintained in good order.

N. Sea-water leaching of the impregnant continues throughout the life of the pile making it increasingly vulnerable to marine borer attack. Thus, as a pile ages, the rate of piling failure increases.

O. Due to the wide variation in marine borer attack from one locality to the next, a preliminary investigation should be made of the harbor where timber is going to be used. The experience of owners of nearby structures may be helpful in selecting among the many materials and methods available for pile protection.

VII. APPENDICES

A. Glossary of Terms

(1) Bankia - Is a genus of the Mollusca Subfamily.

(2) Barriers - Protective pile barriers can be classified into two main categories; those which protect damaged piling from further damage and strength loss and those which restore strength in severely damaged or destroyed piling:

(a) Chemical barriers are preservatives injected into the wood to make the wood toxic to marine borers.

(b) Flexible barriers are plastic or metallic barriers used to remove the wood from the environment.

(c) Strength restoration involves removal of deteriorated pile section and replacing it with a sound section or reinforcing damaged section to restore strength.

(3) Chelura - Is a genus of the Crustacea Subfamily.

(4) Creosote - Creosote is the most widely used preservative and is highly effective against virtually all borers except Limnoria tripunctata, which is creosote-resistant. Creosote is relatively insoluble in water and has good penetration properties.

(5) Crustacea - Limnoria, Chelura, Sphaeroma are genera within this subfamily. They resemble a sow bug and inhabit tunnels just below the surface of the wood. The borer gnaws along the softer rings of the wood. Myriads of borers penetrate the surface causing destroyed wood to break away exposing a new surface of attack. The exterior destruction is charactorized by an hourglass shape.

(6) Dapped - Refers to cutting and forming a recess in timbers to form joints.

(7) Dual Treatment - Dual treatment is the most efficient method for protecting against all types of marine borers. Dual treatment involves the application of a waterborne copper - containing salt preservative followed by coal tar - creosote.

(8) Full-Cell Process - "Is any process for impregnating wood with preservatives or chemicals in which a vacuum is drawn to remove air from the wood before admitting the preservative. This favors heavy absorption and retention of preservative in the treated portions." (Ref. 5)

(9) Limnoria - Is a genus of the Crustacea Subfamily, and includes

Limnoria lignorum, Limnoria tripunctata, and Limnoria quadripunctata.

(10) Mollusca - A phylum of unsegmented invertebrate animals which resemble worms and form a shell exoskeleton. Teredo, Martesia, and Bankia are genera within this subfamily which cause internal destruction of timber floating or submerged in the sea. The borers enter the wood as a larva and burrow into the timber with their rasp like shells. The borer eats away at the timber center leaving a thin outer shell intact until the cross-sectional area is sufficiently reduced to cause failure.

(11) Preservative Chemicals - Preservative chemicals are used to make the wood toxic to aggressive organisms. The degree of preservation achieved is a function of the type of preservative used and the retention of chemicals. For maximum effectiveness the preservative should be matched to the borers expected to be present.

(12) Sphaeroma - Is a genus of the Crustacea Subfamily.

(13) Sonic Testing - A sonic probe test set is used to non-destructively test wood for deterioration due to marine borers. Magnetostrictive Transducers produce an ultrasonic "scan" of the pile. The weakest cross section of the timber pile is used to estimate the remaining strength in the pile and is determined from the sonic readings and visual inspection.

(14) Teredo - Is a genus of the Mollusca Subfamily.

(15) Waterborne Salts - Waterborne salts include standard wood preservatives such as ammoniacal copper arsenite and chromated copper arsenate used in solution with water.

B. List of companies qualified (through private industry) to do underwater inspection with divers. (Ref. 2)

(1) Crescent Enterprises, Inc.
P.O. Box 3551
Corpus Christi, Texas 78404
Phone 511/882-2949

(2) Logan Engineering & Contracting Co.
5731 St. Augustine Road
Jacksonville, Florida 32207
Phone 906/731-0000

(3) Marine Interface, Inc.
15900 Sonoma Highway
P.O. Box J
Sonoma, California 95476
Phone 707/966-4866

(4) Miami Marine Research Inc.
547 West Avenue
Miami Beach, Florida 33139
Phone 305/534-0100

(5) Dolphin Marine, Inc.
3947 LaCresta Drive
San Diego, California 92107
Phone 714/222-3189

(6) Atlantic Diving Co., Inc.
Parker Street
Gloucester, Massachusetts 01930
617/283-9500

(7) General Construction Co.
P.O. Box 3845
Seattle, Washington 98124

(8) RAMCON
1121 Huff Road
Burlington, Washington 98233

(9) Industrial Underwater Services, Inc.
3906 East 11th Street
Tacoma, Washington 98421
Phone 206/572-7865

(10) Acquatic Marine Divers, Inc.
3317 Pacific Avenue
P.O. Box 8158
Tacoma, Washington 98408
Phone 206/475-2964

(11) Al Hanson Diving Service
26327 Zephyr Avenue
Harbor City, California 90710
Phone 213/547-4394

(12) Can Cive Oceaneering
250 East Esplanade
North Vancouver, B.C.
Canada V7L 1A3
Phone 604/984-9131

C. Only company known by US Navy CEL that is qualified to do ultrasonic inspections. (Ref. 2)

(1) B. C. Research
3650 Westbrook Crescent
Vancouver, Canada V6S 2L2
Phone 604/224-4331

D. Recommended Reading List.

(1) Buzzati-Traverso, A. A., editor, "Perspective Marine Biology, Published by University of California Press, Berkeley, 1958.

(2) Chellis, Robert D., "Pile Foundation", Published by McGraw-Hill, 2nd Edition, 1961.

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(4) NAVDOCKS-MO-311, "Marine Biology Operational Handbook", Published by Bureau of Yards and Docks, May, 1965.

(5) NAVFAC-M0104, "Maintenance of Water Front Facilities," by Navy Facilities Engineering Command.

(6) Nicholas, Darrel D, editor, "Wood Deterioration and its Prevention by Preservative Treatments Vol. I & II," Published by Syracuse University Press, 1973.

(7) Ray, Dixie L., editor, "Marine Boring & Fouling Organisms," Published by University of Washington and U.S. Office of Naval Research, Seattle, Washington, 1959.

E. Experimental Marine Piling and Laboratory Research

1. Project: Longevity Study of Wood Species Noted for Natural Resistance to Biological Degradation

Starting: July, 1977
Completion: Within approximately 5 years

Description: The International Paper Company will install 24 to 30 timber experimental piles in Trumbo Point Annex NAS Naval Air Station, Key West, Florida. The performance of French Guiana timber species noted for their natural resistance will be compared to test control specimens such as greenheart, brownheart, Ocotea, and dual treated timber. Licania, Esschweilera, Lecytchis, Epera, Dicorynia, and Vouacapoua are French Guiana species to be tested. Licania and Esschweilera are of particular interest because these species have demonstrated resistance to marine borer exposure in the Canal Zone. Scientists from the U.S. Forest Products Laboratory at Madison, Wisconsin, will inspect the specimens in June and December of each year.

Project Coordinators:

Mr. Bruce Johnson
U.S. Forest Product Laboratory
P.O. Box 5130
Madison, Wisconson 53705
608/257-2211

Mr. Bruce Thoman
International Paper Company Cooperate Research
Tuxedo Park, New York 10987
914/351-2101

2. Project: Test at Roosevelt Roads Naval Base (RRNB) Puerto Rico, of Piling Treated with High Naphthalene Content in Special Marine Grade Creosote Solutions.

Starting: July, 1977
Completion: 1992

Description: Approximately 460 piles treated with creosote coal tar containing 10%, 20%, 30%, or 40% naphthalene are to be driven in marine borer infested waters at RRNB. The piling will be inspected periodically during the 15 year test period.

The success of naphthalene-creosote-coal-tar treatment could eliminate the need for dual treatment which is the currently recommended treatment for piling to be located in marine waters with a high prevalence of Teredine and Limnoria borers.

Project Coordinators:

Mr. Arthur Branan
Atlantic Division-Naval Facilities Engineering Command
Norfolk, Virginia 23511
804/444-7121

Mr. Peter Fish
Northern Division-Naval Facilities Engineering Command
U.S. Naval Base Building 77
Philadelphia, PA 19112
215/755-3656

3. Project: Effect of Salt Retention on the Energy Absorbing Capacity of Wood Used for Navy Construction.

Starting: 1976
Completion: 1978

Discussion: U.S. Navy Civil Engineering Laboratory has contracted the Department of Forest Products, Oregon State University to evaluate the effect of salt treatment on the structural properties of timber for U.S . Navy construction.

40 Southern pine and 35 Douglas fir samples will be tested. The Southern pine specimens will consist of the following:

5 - untreated piles.

5 - dual treated piles with ammoniacal copper arsenite (ACA), creosote, and air drying.

5 - dual treated piles with ACA, creosote, and kiln drying.

5 - dual treated piles with chromated copper arsenate (CCA), creosote, and air drying.

5 - dual treated piles with CCA, creosote, and air drying.

5 - piles treated with 2 1/2 lbs/cu ft (40.1 kg/cu m) of ACA.

5 - piles treated with 2 1/2 lbs/cu ft (40.1 kg/cu m) of CCA.

The Douglas fir tests will follow the same format as the Southern pine tests with the exception that the 2 1/2 lbs/cu ft (40.1 kg/cu m) ACA and CCA salt treated specimens will not be included.

Project Coordinators:

Dr. Helmuth Resch
Department of Forest Products
Oregon State University
Corvallis, Oregon 97330
503/754-2017

Mr. T. Roe, Jr.
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043
805/982-4772

4. Project: Laboratory Screening Assays of Treated Wood Samples Exposed to Limnoria Tripunctata.

Started: 1970
Sample test period: 12 to 24 months

Description: The objectives of this study are: (1) to evaluate chemical additives to creosote which prevent Limnoria tripunctata attack (2) to compare the degree of borer attack found in laboratory specimens to large specimens exposed to the natural environment.

"High percentages (2.0-5.0%) of Endrin, tributyl tin oxide plus Endrin, and Kepone added to creosote proved very effective against Limnoria tripunctata attack over a 24 month period. Combinations of tributyl tin oxide with Malathion, tributyl tin oxide with Kepone, and Furfurol alcohol were also effective as was tributyl lead acetate." (Ref. 3)

Dual-treated specimens have continued to resist Limnoria attack. More testing is planned using additional additives in creosote treatments. Information is being compiled comparing the intensity of borer attack in laboratory specimens to exposure of larger specimens in the natural marine environment.

Project Coordinator:

Mrs. Beatrice Richards
Battelle
Columbus Laboratories
William F. Clapp Laboratories, Inc.
P.O. Box A. H.
Duxbury, Massachusetts 02332
617/934-5682

5. Project: Comparative Values of Dual-Treatment and Waterborne Preservatives for Long-Range Protection of Wooden Structures from Marine Borers.

Started: 1964

Discussion: The objective of this study is to compare the effectiveness of dual-treated coupons with high salt retention and creosote versus coupons treated only with high retentions of waterborne preservatives.

The study has been in progress 12 years. The performance of dual-treated coupons and waterborne salt treated coupons in a natural seawater environment are similar. Both types of treatment have remained free of Limnoria attack. Creosote-treated controls were heavily attacked by Limnoria. Untreated controls experienced severe marine borer attack in six months or less.

Project Coordinator:

Mrs. Beatrice Richards
Battelle
Columbus Laboratories
William F. Clapp Laboratories, Inc.
P.O. Box A. H.
Duxbury, Massachusetts 02332

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(6) Figure Credits

(a) Figures 2, 3, 5 and 7	British Columbia Research Vancouver B.C., Canada
(b) Figures 4, 6 and 8	OSMOSE Marine Division, Madison, Wisconsin
(c) Figures 1, 9, 10, 11 and 12	Port of Los Angeles
(d) Figure 13	Aquatic Marine Divers Inc., Tacoma, Washington