Chapter 8

ACTION OF MARINE BORERS AND PROTECTIVE MEASURES AGAINST ATTACK

R. Horonjeff
Lecturer and Research Engineer
Institute of Transportation and Traffic Engineering
University of California, Berkeley

D. A. Patrick
Lieutenant, Civil Engineer Corps
United States Navy

SUMMARY

A major concern to engineers engaged in the design of timber harbor structures is protection against marine borers. These pests can severely damage these structures in a relatively short time. Attack is concentrated on submerged timbers in the area between the mudline and the water surface. The intensity of attack is dependent on a number of environmental conditions. The most destructive and widely distributed borers are the Teredinidae and the Limnoria. Some forms of borers exist in all oceans. This paper describes the manner in which the borers destroy timber. It summarizes information gathered by various investigators on the conditions which have bearing on the presence of borers and the factors governing rate of destruction. Several methods of protecting timber structures from infestation are described and the costs compared.

INTRODUCTION

Marine borers have been defined as "marine invertebrates which drill into and consequently damage timber and other materials in salt water" - (U. S. Navy, 1950a). Marine borers are responsible for many millions of dollars of damage to harbor structures annually. These damages amounted to $100,000,000 in 1949. The Bureau of Yards and Docks, U. S. Navy, has reported cases where green piling up to 16 in. in diameter was severed in six months and treated timber was replaced in less than two years. An article by Long (1951) relates the story of a crew in a fishing boat which tied up to a pier in San Francisco Bay during lunch hour and returned after lunch to find no sign of either the boat or the pier. Later evidence disclosed that a wave caused by a passing ship had collapsed the pier and both boat and pier floated away on the tide. Both were found the next day, still lashed together. Another example of the destructive effect of marine borers relates to the Navy piers on Guantanamo Bay, Cuba. The piers, constructed during World War II, were of creosoted timber piling--(U.S. Navy, 1951a). The rate of destruction of one of these structures was obtained from an account of several surveys. Originally the minimum allowable pile diameter was 12 inches. A survey in the spring of 1949 showed that the minimum cross-section of the 13 outboard bents

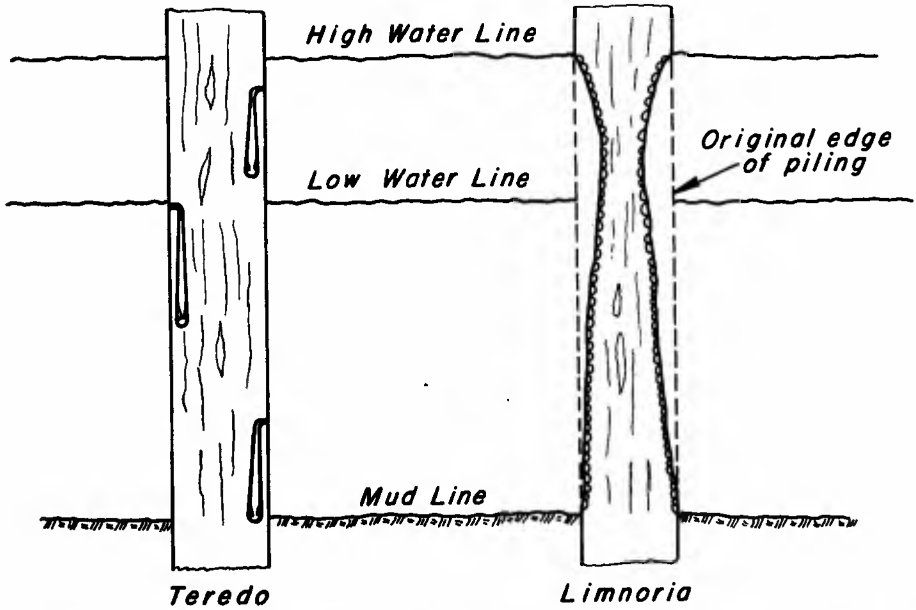

Fig. 1
Idealized cross-sectional sketches of piling showing typical methods of marine borer attack.

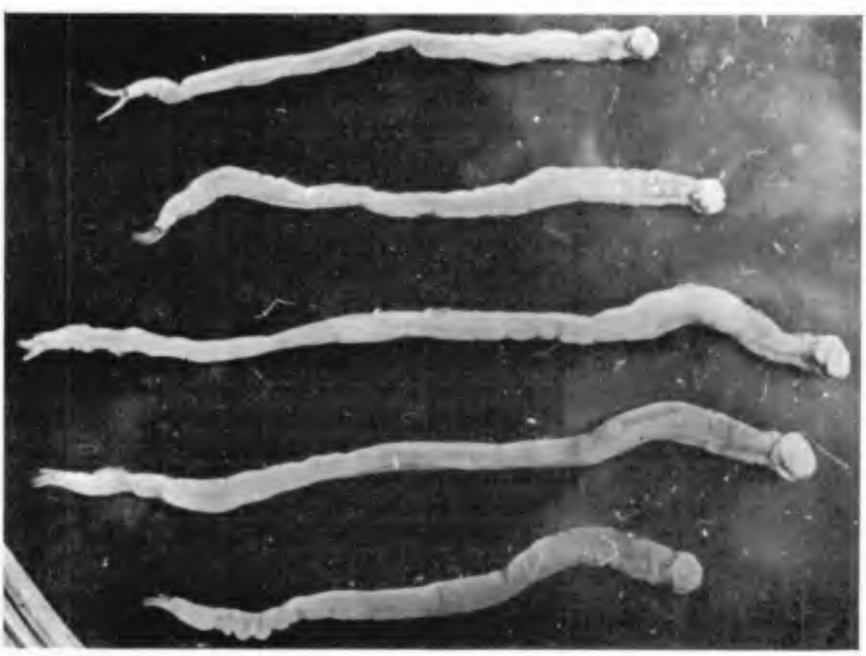

Fig. 2
Teredo Navalis.

average only 37 percent of the original section. By November 1949 these same bents showed only 17 percent of the original section. By February 1950, only 9 percent remained and observers concluded that because of honey-combing in the interiors of the piling probably only 50 percent of this 9 percent could be considered effective.

In the past few years the increased cost of the production and protection of timber has resulted in a considerable decrease in the use of wood for harbor structures. Nevertheless, there are many situations where the use of concrete is not justifiable, particularly in structures of rather temporary nature, as the case may be in defense installations. Therefore, continued study of the action of marine borers is certainly justified.

PRINCIPAL TYPES OF BORERS

Virtually all investigators agree that marine borers most damaging to harbor structures are (1) mollusks, of which the Teredo and its immediate relatives are the most destructive and widely distributed, and (2) crustaceans, of which the Limnoria is the most destructive and widely distributed. Another mollusk of importance is the Martesia; other crustaceans are the Chelura and Sphaeroma.

MANNER OF ATTACK

Borers of the molluskan and the crustacean groups attack the wood by different methods. Mollusks enter through very small holes bored when young and grow to size inside. This destruction can only be detected by cutting the wood or by careful inspection of the surface. The crustaceans, on the other hand, destroy the surface of the wood; thus attack is readily visible from the surface. The manner of attack of both groups is sketched on Fig. 1.

The Teredo usually enters the wood as larvae by boring holes as small as 0.008 in. in diameter which increase to about 0.03 in. --(Chellis, 1948). After a larva enters, it starts to grow. Normally the adult size is of the order of 3 to 6 in. in length with a diameter approximately that of a lead pencil; but occasional specimens have been reported in excess of 3 ft. in length, boring holes 3/4 in. in diameter or larger. The Teredo navalis is shown on Fig. 2. The head is equipped with two small shells similar to clam shells. The burrowing is performed by the back and forth motion of these shells. The tail part consists of two pallets, attached to a muscular collar, which in turn is attached to the wall of the burrow over the entrance. The shells and body grow in diameter as the burrow is made longer. The animal can seal the burrow entrance at will with the pallets and is thus able to withstand for some time unfavorable external conditions. With favorable conditions a single animal can bore as much as 14 in. per year--(U. S. Navy, 1950a). The average rate for the larger animals in San Francisco Bay is shown on Fig. 3. The life span of a Teredo does not often exceed one year.

The Limnoria is a relatively small lobster-like animal 1/8 to 1/4 in. in length and one-third to one-half as broad; about the size of a grain of rice. A Limnoria is shown on Fig. 4. It has horny boring mandibles, two sets of antennae, and seven sets of legs with sharp hooked claws. The mandibles are large denticulated organs which cut into the wood and crush it. The body is firmly held in position by the legs and claw-like feet. The Burrows are .025 to .50 in. in diameter. A large number of Limnoria reduce the surface of the wood to a network of burrows. To the casual observer the surface has the appearance of a sponge. Limnoria are the primary cause of the characteristic hour-glass shape of piling shown in Fig. 1. In contrast with the Teredo which must locate wood on which to settle while in the larval stage, Limnoria are able to swim short distances throughout their life and therefore can change habitat at any time. It is reported that they can burrow into soft woods such as pine to a depth of about one inch per year--(Chellis, 1948).

AREA OF ATTACK

The main area of attack of the borers extends from the mudline to the high water line. Previously many engineers thought that Limnoria attack was greatest at the surface and Teredo greatest at the mudline. However, one of the earliest results of the Navy research program was to show that such is not necessarily the case. In Florida, attack by both Teredo and Limnoria was on the average three times more intense near the mudline than at the surface, although at two locations in water of high salinity the greatest attack was at the surface. The observers concluded that buoyancy was probably responsible; the area of attack being higher in denser water. The San Francisco Bay Marine Piling Committee found that borer action is greater in deep than in shallow water; Teredo attack being greatest towards the mudline and Limnoria attack greatest between tide levels--(Hill and Kofoid, 1927).

ENVIRONMENTAL INFLUENCES

Salinity, temperature, abundance of food, current action, pollution, dissolved oxygen, hydrogen-ion concentration, and the amount of dissolved hydrogen sulfide all may have some bearing on the presence and the amount of activity of marine borers. Investigators have found that the first three are the most important. Various attempts have been made to relate intensity of attack with these factors. Geographic ranges have been difficult to establish since places which are relatively safe from attack at one time may suffer severe attack at another. A report on marine borer activity in 56 important harbors was compiled by the U. S. Navy--(1951b). Particular species sometimes are predominant in an area. Absense of borers in an area is no assurance that future attacks will not occur. Also borer populations may change rapidly over a period of a few years. For example, along the North Atlantic coast of the United States from 1939 to 1941, the borer population was estimated at 100 times what it was a few years earlier--(Chellis, 1948).

Salinity--Changes in salinity as small as 10 parts per 1000 may have a marked effect on borer activity. Ocean salinity is about 30 to 35 parts of salt per 1000. Teredo navalis activity decreases rapidly in salinities of less than 9 parts per 1000 and the threshold of lethal salinity has been placed at about 5 parts per 1000. Limnoria seem to require higher salinities; about 30 parts per 1000 for full activity; there is a decided retardation in salinities of 12 to 16 parts per 1000; and 6.5 to 10 parts per 1000 appears to be lethal.

Temperature--The breeding period of the Teredo is influenced to a great degree by the temperature of the water. For the free swiming larvae to survive the water must be warm. Warm water is also a stimulus for the parent to expel the egg or larva as the case may be. Therefore, it follows that the breeding season is much longer in the southern coasts of the United States than in the north. In general, the breeding season and the period of heaviest attack for Teredo navalis include the summer and autumn months of the year. Temperature has very little effect on Teredo after it has embedded itself in the wood and it will continue to attack unless the temperature falls to slightly above freezing, when it lies dormant.

Investigators have found that Limnoria is not affected to the same extent as the Teredo by temperature. Limnoria is constantly present in regions as far north as Kodiak, Alaska. In San Francisco Bay breeding occurs when the temperature is as low as 46°F. At Kodiak the water temperatures are considerably below 46 degrees Fahrenheit. As for Teredo, attack will continue until water temperature decreases to a point just above freezing.

Food--The Teredo gets its main supply of food from plankton. It requires proteins for growth and receives this diet from plankton; however, energy for the boring process is provided principally by the carbohydrates of the wood. This energy can be supplied from the protein material of the plankton but much less efficiently since nitrogenous products must be eliminated in the process-(Hill and Kofoid, 1927). More recent studies--(U. S. Navy, 1950a) show that this early conclusion was essentially correct. In laboratory studies where the Teredo were left in the wood but deprived of plankton, they showed very little change after 7 days. However, when removed from the wood and placed in a plankton-rich environment, only one animal in an extensive series of tests survived more than 7 days. Chemical tests in this series showed that the wood was used to sustain carbohydrate metabolism. The important fact is that the Teredo cannot live on plankton alone. Consequently, the impregnation of wood is a rational method of introducing toxins into the animal's system. In contrast, the Limnoria derives all its food from the timber it attacks and does not require plankton.

Pollution and Sewage--Heavy pollution in many cases seems to prevent action by marine borers. Yet numerous wooden sewer outlets have been completely destroyed by Teredo. Investigations by the Marine Laboratory, University of Miami, indicate that domestic sewage is

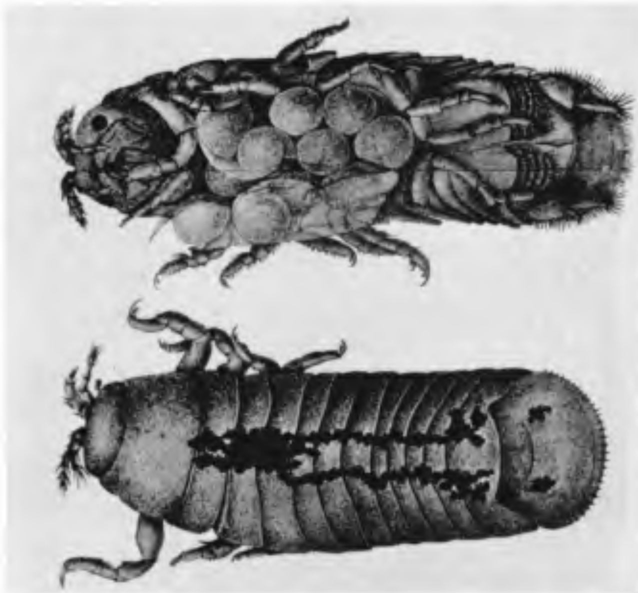

Fig. 4
Limnoria.

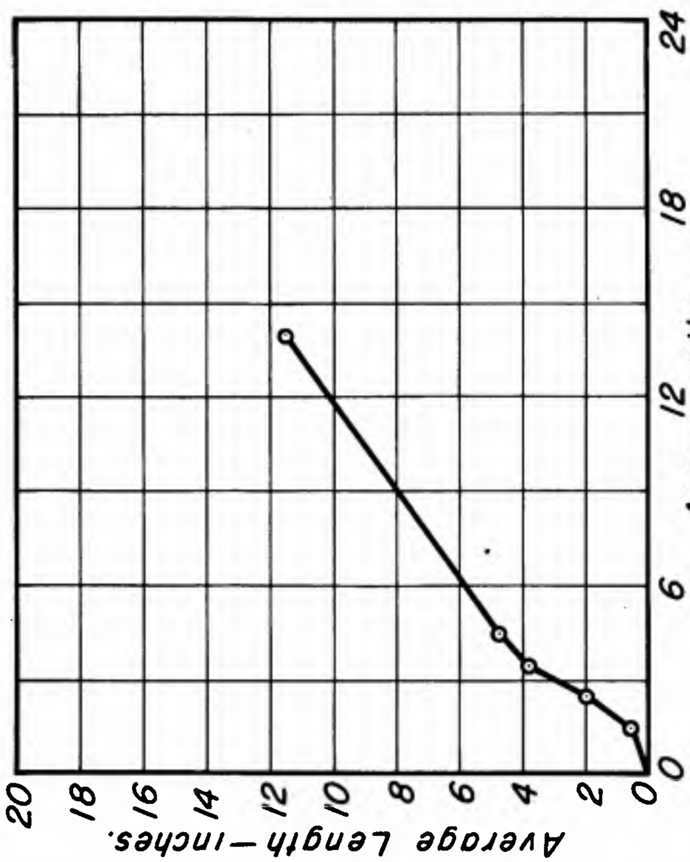

Fig. 3
Rate of boring of Teredo Navalis in San Francisco Bay.

beneficial rather than harmful to marine borers. It is the opinion of many of the investigators that it is industrial waste rather than domestic sewage that provides conditions unfavorable for borers.

Dissolved Gases and Hydrogen-ion Concentration--Marine borers seem to be adaptable to wide variation in the amount of dissolved oxygen and dissolved hydrogen sulfide, and in the hydrogen-ion concentration of the sea water. The amount of dissolved oxygen in normal sea water is of the order of 5.5 cc per liter. The San Francisco Bay Marine Piling Committee found that the average hydrogen sulfide content in San Francisco Bay was .13 cc per liter and the maximum was .42 cc per liter. The hydrogen-ion concentration is a measure of acidity or alkalinity. Normal sea water is slightly on the alkaline side and has a pH value of 7.5 to 8.5. At the present time sufficient information is not available to establish specific lethal values for these factors.

Current Action--Experiments conducted by the Marine Laboratory, University of Miami, to determine the effect of current velocity upon the attachment and growth of several borers, including Teredo and Limnoria, indicated that currents of the order of two knots seemed to preclude attack in Florida waters. Fig. 5, obtained from data collected by the University of Miami, indicates the effect of current action on intensity of borer attack.

PROTECTIVE MEASURES

There are many schemes for protecting piles from marine borer attack. The choice of method depends to a great extent upon the availability of protective materials, their cost, and the economic life of the structure to be protected. Care in application of protective measures is vital. Minute openings offer entrances for many of the most destructive types of borers. This paper describes three methods which have been in recent use in the United States; these are (1) creosote pressure treatment, (2) gunnite jackets, and (3) precast concrete jackets.

CREOSOTE PRESSURE TREATMENT

Inventors have been busy for years endeavoring to find ways and means of protecting wood against decay and marine borers. It was not until 1838, when John Bethel patented the "Full Cell Process", that real progress in wood preservation in this country began. This process effects a deep penetration of the preservative; the depth being dependent upon a number of factors, chief of which are the kind of wood, character of growth, its condition as to seasoning, the method of treatment, and the preservative used. Non-pressure processes are not recommended for piles to be used in salt water as the depth of penetration, even under the most favorable conditions, is extremely small. Either green or seasoned timber can be treated by the pressure process. Green timber is often seasoned by means of live steam before treatment.

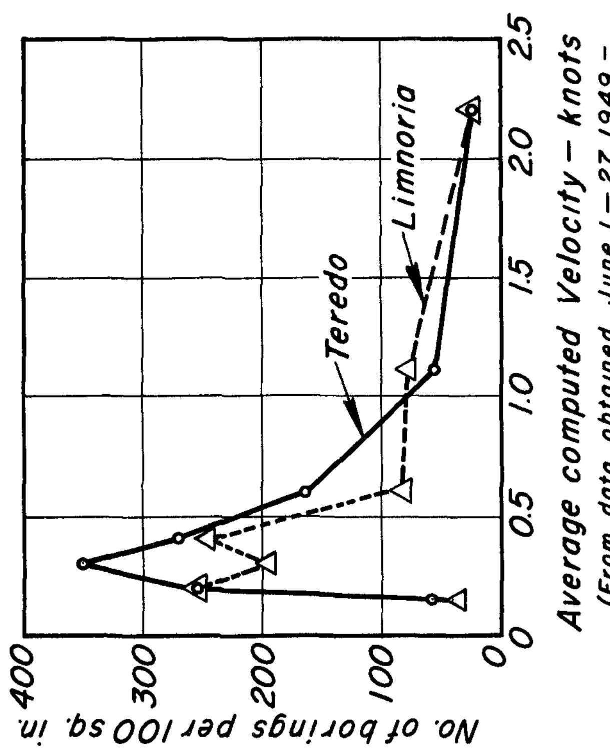

Fig. 5
An indication of intensity of borer attack vs. water current velocity.

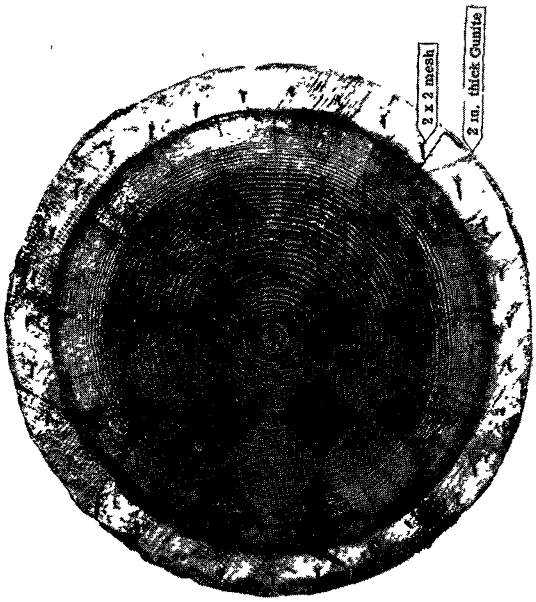

Fig. 6
Cross-section of gunite jacketed pile.

Of the available preservatives, creosote remains the most dependable means of reducing marine borer attack. Creosote is produced by high temperature carbonization of bituminous coal; to increase fluidity, coal tar or petroleum are often added. These admixtures are not toxic to marine borers, therefore their use is not recommended where borers are present.

Although the amount of creosote and the depth of penetration vary considerably, depending on the character and the density of the timber, the American Wood Preservers Association specify the following for Southern Pine and Pacific Coast Douglas Fir subject to borer attack.

	Retention lb per cu ft (minimum)	Penetration (inches)
Southern Pine	16 to 24	4
Douglas Fir	12	3/4, 7/8, and 1 for 12, 14, and 16 lb retentions for full cell process.

Although the AWPA allows the use of either the full-cell or empty-cell processes, the full-cell process is preferred, because it not only coats the wood cells but fills the void spaces between them; the empty cell process only coats the cells. By filling the voids the full cell process assures the complete coating of the cells and provides a greater reservoir against leaching.

It will be noted that the protective coating for Douglas Fir is quite thin, hence extreme care is required against damage to the surface by abrasion. Whenever possible all bolt holes and notches should be cut prior to treatment.

Creosote treatment does not result in complete resistance to borer attack but the progress in creosoted piles is at a much slower rate. In Carribean waters an average life of 8 to 10 years is all that can be expected; in San Pedro Harbor from 20 to 30 years; in San Francisco Bay, 15 to 25 years on the San Francisco side and 20 to 30 years elsewhere.

GUNITE JACKETS

Gunite or pressure-applied concrete has been used successfully on wood piles for some years. The gunite jacket is applied before driving, over that portion of the pile which is exposed to attack by marine borers. The jacket protects the pile from decay, rust, erosion, and fire. It is extended a few feet below the anticipated depth of scour. The average thickness of jackets is 2 inches; a cross section

Fig. 7. Gunite being placed on wood pile.

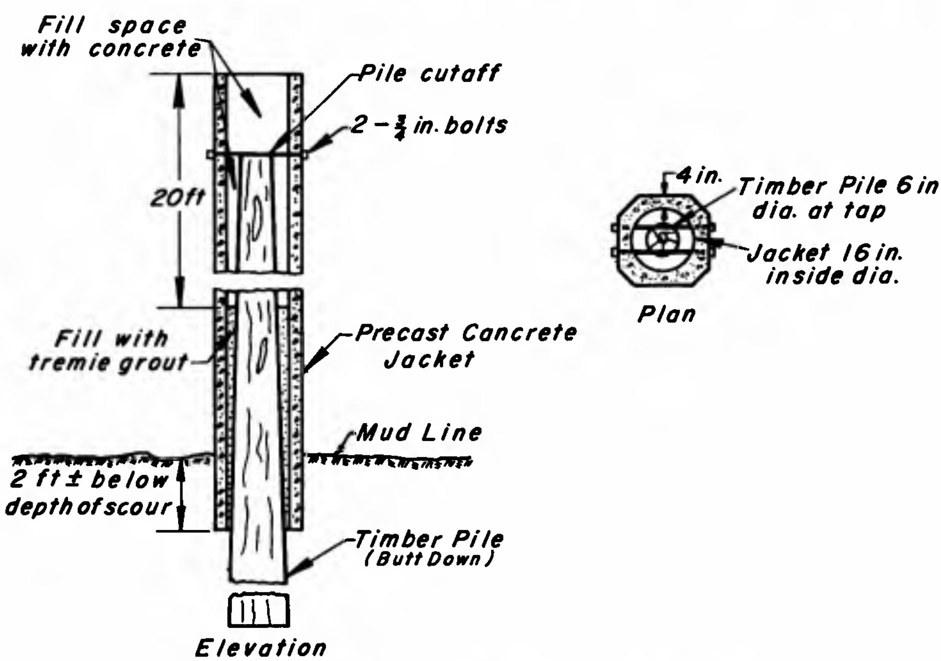

Fig. 8. Details of precast concrete jacket.

is shown on Fig. 6. The steel reinforcement usually consists of galvanized electrically-welded fabric of No. 12 gauge (.1055 in. diameter), 2 x 2 in. mesh. The mesh is placed approximately one inch from the surface of the pile. In order to prevent injury to the protective jacket, the top 3 to 5 ft at the butt end is left uncoated until after driving. Fig. 7 shows gunite being placed on a wood pile. On the average, it takes approximately one week to apply the jacket and cure it.

PRECAST CONCRETE JACKETS

There are several forms of precast concrete jackets; they differ only in detail. A precast concrete jacket developed by the Board of State Harbor Commissioners for the Port of San Francisco is described herein. The jacket consists of a circular inner face and a square outer face with beveled corners. The inside diameter of the jacket is 16 in. and the thickness of concrete 4 in. The green wood pile is driven butt down and cut off square at a predetermined elevation--usually about two feet below the elevation of the deck. The jacket is placed over the pile and lowered or driven into the bottom material. It is supported on the timber pile by two 3/4 in. bolts which pass through the jacket (see Fig. 8). The precast jacket is extended a few feet below the anticipated depth of scour. The space between the pile and the jacket is sealed by grouting through a tremie pipe to 20 feet below the top of the jacket. The remaining space between the jacket and the pile is dewatered and filled with concrete.

COSTS

Comparative costs for creosoting, guniting, and precast jackets will vary depending on local sources of material, labor, contractors' equipment, and experience. Assuming that materials, labor, and equipment are readily available, the cost will depend largely on the length of the pile and the portion which requires protection. Because of the numerous factors involved, each job must be estimated in detail on its own merits. Since the increase in cost of timber in recent years has been disproportinate to the increase in cost of concrete, and because of the scarcity of long timber piles, there are many situations in which the concrete pile compares favorably in cost with protected timber piles.

Unit Costs--In San Francisco creosoted Douglas Fir piles 100 ft in length cost about $2.05 per lineal foot exclusive of driving. Likewise, untreated fir piling of the same length are in the order of $0.75 to $0.90 per foot. Gunite jackets approximate $2.25 per lineal foot. Precast concrete jackets in San Francisco (Fig. 8) were estimated at approximately $199,000 for 58,661 feet of jacket resulting in a unit cost of $3.40 per foot.

Sample Cost Comparison for 100 Foot Pile--Assuming that 35 feet of pile requires protection against marine borers, the following are estimated costs for furnishing and driving 100 ft piles.

Creosote Pile - -	Furnishing (100 x 2.05)	$205
	Driving	15
	Total	$220
Gunite Pile - - -	Furnishing Green Pile (100 x 0.80)	$ 80
	35 ft Jacket (35 x 2.25)	79
	Driving	15
	Total	$174
Precast Jacket -	Furnishing Green Pile (100 x .80)	$ 80
	Precast Jacket (35 x 3.40)	119
	Grouting and Filling Jacket	24
	Driving and Placing Jacket	18
	Total	$241

Reinforced Concrete Pile - Furnishing and Driving (100x4.20) $420.

RESEARCH

There are many investigators currently conducting research on marine borer activity. The two recent conferences on this subject; the Meeting to Discuss Marine Borer Situation (1949) at San Francisco, and the Marine Borer Conference (1951) at Port Hueneme, California are an indication of the interest in this field. The question of wood preservation is not only one of economics, but also one of conserving an important natural resource. Methods of improving present practices and the search for new treatment and protection are being sought through research. In order to advance such a program, considerable data of a basic nature must be collected such as marine borer physiology, habits, distribution, commensals and parasites, etc.

Advance in the fight against marine borers must be based on scientific research rather than trial and error tests. As one of the largest single users of timber in waterfront structures, the U. S. Navy through its Bureau of Yards and Docks is sponsoring a relatively broad research program. It includes studies in borer habits and distribution throughout the world, carried on by Dr. William F. Clapp, of Duxbury, Massachusetts; physiological studies under direction of Dr. F. G. Walton Smith, Director of the Marine Laboratory, University of Miami, Coral Gables, Florida; and study and evaluation of present and proposed methods of protection at the Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California. Some of the independent investigations are being carried on at the Bernice P. Bishop Museum on observations and surveys of marine borers in the Central and Western Pacific; at the California Academy of Science on ecological conditions affecting distribution of wood-boring mollusks along the Pacific Coast of North America, and on the effects of salinity on Bankia Setecea; at Southern California Marine Borer Council and the University of Southern California working jointly on fouling organisms, Chelura, cellulose utilization by Limnoria, predators and commensals of Limnoria; by Taylor-Colquitt Company on a solvent recovery process for use in wood treating; at University of California, Davis, on ingestion and digestion of wood by marine borers; at University of Washington on occurence of cellulose in Limnoria Lignorum.

ACKNOWLEDGEMENTS

The Authors wish to express their appreciation to the San Francisco Bay Marine Piling Committee; the U. S. Navy; the William F. Clapp Laboratories; the Marine Laboratory, University of Miami; and to Robert D. Chellis, Structural Engineer of Stone and Webster Engineering Corporation for the use of their material concerning borers and their activity.

Thanks are also extended to Mr. H. E. Squire, Chief Engineer, Board of State Harbor Commissioners for the Port of San Francisco and the Ben C. Gerwick Co. Inc., contractors, for their information on protective measures, and to Dr. Robert C. Miller, Director of the California Academy of Sciences for his review of the manuscript.

REFERENCES

Chellis, Robert D., (1948) "Finding and Fighting Marine Borers", Engineering News-Record, Part I, pp. 64-67, Mar. 4; Part II, pp. 94-96, Mar. 18; Part III, pp. 73-76, Apr. 1; Part IV, pp. 73-76, Apr. 15.

Hill, C. L. and C. A. Kofoid (1927) (Editors in Chief) "Marine Borers and Their Relation to Marine Construction on the Pacific Coast", Final Report of the San Francisco Bay Marine Piling Committee.

Jelley, Joseph F., (1951), "More Basic Research Vital in Fight Against Costly Marine Borers", Civil Engineering, Vol. 21, No. 4, pp. 200-201, Apr.

Long, J. E., (1951), "Subversives of the Sea", U.S. Naval Institute Proceedings, Vol 77, No. 2, pp. 171-173, Feb.

Marine Borer Conference (1951), U.S. Naval Civil Engineering Research and Elevation Laboratory, Port Hueneme, California, May 10-12.

Meeting to Discuss Marine Borer Situation, (1949), San Francisco, California, jointly sponsored by the California Academy of Sciences and the National Research Council, July 20.

U.S. Navy (1949), "The Wayward Worms", Civil Engineering Corps Bulletin, Vol. 3, No. 35, pp. 279-282, Oct.

U.S. Navy (1950a), "Harbor Reports on Marine Borer Activities", Bureau of Yards and Docks, Research Division, P-43, June.

U.S. Navy (1950b), "Marine Borer Technical Report", Technical Digest, Bureau of Yards and Docks, No. 13, Special Issue.

U.S. Navy (1951a), "Mobile One Seabees Raze Guantanamo Pier", Civil Engineers Corps Bulletin, Vol. 5, No. 50, pp. 3-9, Jan.

U.S. Navy (1951b), "Report on Marine Borers and Fouling Organisms in 56 Important Harbors and Tabular Summaries of Marine Borer Data from 160 Widespread Locations", Navy Docks, TP - Re - 1, April.