Determination of In-Place Timber Piling Strength

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ABSTRACT

A nondestructive inspection procedure that uses the ultrasonic technique to determine the material properties of timber piles above and below water is described, and the equipment developed is presented. The technique is suitable primarily for piles such as those on the Denton Bridge (that collapsed in Maryland in 1976) and others that are immersed in fresh water for long periods of time and sustain damage to the wood microstructure, which can reduce pile capacity by actually changing material parameters, such as strength and density, without a loss of cross-sectional area. This type of destructive action cannot be detected by any existing inspection technique. Laboratory testing of a large number of new and old piles from four different bridges in the state of Maryland were used to establish relationships between the pulse velocity from the ultrasonic testing and the crushing strength of the timber piles. Variables that affect the relationships, such as type of wood, degree of decay, moisture content, and treatment of the wood, were also studied. The relationships developed were verified by determining the pulse velocity of in-place piling in a fifth bridge, then removing the piles, cutting them into sections, and axial load testing the sections to determine the strength of the piles. It has been concluded from the favorable comparison of the calculated and the experimentally determined strength that the technique and equipment developed could be confidently used in timber pile inspection. The quantitative determination of the remaining strength of timber piles in service will lead to appropriate judgments as to the ability of the piles to further support the loads imposed on them.

Federal and state legislation requires periodic inspection and evaluation of highway and railroad bridges and requires that they be rated as to their safe load-carrying capacity. It has been pointed out that 70 percent of the highway bridges in the United States were built before 1935 (1) and that almost 4 out every 10 are defective. Therefore, it is vital that these bridges be effectively inspected in order to predict their remaining life and verify their structural integrity. One aspect of the problem is the existence of a large number of timber piling structures that are old and rapidly deteriorating. Thus their periodic inspection is necessary to ensure the early detection of damage or deterioration and to prevent structural failure. Inspection is also essential for an economical decision with regard to bridge replacement or rehabilitation.

Despite a recent underwater inspection of the piling, an unanticipated failure occurred to a timber-supported bridge at Denton, Maryland, in early 1976. The underwater inspection had indicated reasonable soundness of the timber, but later laboratory tests indicated substantial reduction in material strength during the life of the piling. These deficiencies were undetected by current inspection techniques and were only determined after failure of the bridge. Because wood is a biological material, it is subject to decay fungi, checking, abrasion, insect attack, and other factors that reduce strength with time in service. In addition, below water a variety of marine borers invade the wooden piles and cause loss in wood volume on the surface, or erode away the piling interior. Also, impact, fatigue, and overloading by traffic on bridges cause additional pile damage. Thus it is to be expected that bridge timber pile structural integrity and resistance decrease with time in service.

A research project supported by the Maryland State Highway Administration and FHWA is being conducted by the University of Maryland, the main objective of which has been to develop a nondestructive test for determining the in-place strength of bridge timber piling that has sustained damage to the wood microstructure with or without a loss of area of the pile section (2). Piles such as those in the Denton Bridge and others that are immersed in fresh water for long periods of time can sustain damage to the wood microstructure. This type of damage can reduce pile capacity by actually changing material parameters, such as strength and density, without a loss of cross-sectional area. This type of destructive action cannot be detected by a sonic instrument developed in the early 1960s (3) for inspection of marine piling or by any other method.

The project can be divided into four major tasks:

1. Develop an in-place nondestructive testing (NDT) technique and equipment;
2. Develop a data bank for new and old piles by NDT of pile sections and then determine their strength through testing to failure, thereby allowing the strength of timber piles to be evaluated throughout their service life;
3. Develop relationships between the NDT data and the strength of timber piles (factors that influence the test interpretation, such as type of wood, treatment, moisture content, and so on, were considered); and
4. Develop analytical methods to determine the effect of decay on the stress distribution and on the load-carrying capacity of single piles.

To limit the size of this paper, the fourth task has not been included and is presented elsewhere (4).

In this paper the ultrasonic pulse velocity technique used in characterizing the material properties of timber piles is presented. The equipment developed for above-water and underwater testing of piles are briefly described. The relationships between the wave velocity and the remaining strength, developed through extensive testing, are presented. The technique was further verified by NDT of in-place piling, then removing the piles, cutting them into sections, and axial load testing the sections to determine their strength.

It is concluded that although wood is a natural material with a relatively high variation in inherent strength, the equipment and relationships developed can be used confidently to determine the remaining strength of the pile in-place.

CAUSES AND EFFECTS OF DETERIORATION

Because of the organic composition of wood and the harsh environment in which they are usually located, bridge timber piles are subject to deterioration. The principal causes of deterioration of piles in service are bacteria, fungi, insect attack, fire, mechanical wear, and marine borers. Of primary concern in this work are the determination of the physical and engineering properties of decayed wood. The effects of decay include (a) loss of density--although still retaining its outward appearance, decayed wood generally becomes extremely light in weight; (b) increase in permeability--decayed wood absorbs liquid and becomes waterlogged much more readily than does sound wood; and (c) loss in strength--caused by enzymatic degradation of the wood cellulose and lignin. It has been observed that the toughness or capacity of decayed wood to withstand loading is reduced rapidly. Other strength properties, such as resistance to bending and crushing, are also reduced.

The extent of decay is difficult to assess by visual inspection. This is because the timber pile may be completely decayed internally while the external appearance indicates soundness of material.

METHODS OF INSPECTION

Because the causes of timber pile deterioration are many and varied, and because the protective measures used to guard against this deterioration (although extremely useful in some cases) are no guarantee that deterioration will not occur, it is therefore necessary to periodically inspect timber piles. The inspection procedures are to determine if damage is occurring and to what extent the stability and safety of the piles have been affected. The availability of this valuable information would assist the engineer in establishing a schedule for the replacement of any unsafe piles. There are two basic groups of testing--destructive and nondestructive methods. Destructive testing (DT), as the name implies, increases the loss of cross-sectional area of the tested pile. Some of the destructive testing methods in use are probing and core sampling. In general, all destructive tests have been known to impose undue strain on the tested pile, and they imply a sampling process in which the tested pieces are assumed to represent the entire population not tested. Nondestructive testing is the name given to all test methods that permit inspection of material without impairing its usefulness. The methods include visual inspection, sounding, radiography, resonance methods, and ultrasonic methods.

ULTRASONIC TESTING OF WOOD

In the NDT of wood-based materials and structures various pulse-measuring instruments have been developed, producing varying degrees of success as a means of evaluating the soundness of wood structures in service. Lee (5) used the ultrasonic test technique for the examination of decayed timbers forming the roof structure of an 18th century mansion. Muenow (6) also used the ultrasonic test for inspecting 11 sections of wooden utility poles from the Commonwealth Edison Company. McDonald et al. (7) and McDonald (8) used ultrasonics to determine the quality of lumber for automated production of clear cuttings for better use of timber resources. Pellerin (9) indicated that the wave velocity in wood gave a good indication of the quality of the interior of the wood, because the progress of a wave is slowed by an increasing number and size of defects. Vanderbilt et al. (10) used the ultrasonic test technique for evaluating the strength and stiffness of large timber piles. Lanius et al. (11) presented a procedure for examining wood joists in an existing structure. In the procedure the stress-wave technique was performed to determine the allowable working stresses for the joists.

For timber piles, studies were initiated in 1955 at B.C. Research in Vancouver, British Columbia, Canada, that developed an underwater sonic-probe as a nondestructive method of testing in-place underwater piling (3). The instruments are used to locate marine borer damage and to evaluate the extent of cross-sectional loss of wood. It should be mentioned here that this sonic testing method, as developed, deals with the gross dimensions of the pile and changes caused by marine borers or mechanical damage in these dimensions. However, Scheffer et al. (12) have shown that a pile immersed in fresh water for long periods of time can sustain damage to the wood microstructure. This type of damage can reduce pile capacity by actually changing material parameters such as modulus of elasticity. This type of destructive action is not detected by the sonic instrument developed and is the primary concern of the equipment developed in this work (as in the case of the Denton Bridge collapse).

WAVE PROPAGATION IN WOOD

It can be shown that the velocity of propagation of the waves parallel to the grain V_L and in the radial direction V_N (normal to the grain) in an orthotropic material with a Poisson's ratio for transverse strain in the longitudinal direction when stress is applied in the radial direction in the range of 0.02 to 0.04 is approximately

$$V_L = (E_L/\rho)^{1/2} \quad (1)$$

and

$$V_N = (E_N/\rho)^{1/2} \quad (2)$$

where

- E_L = dynamic modulus of elasticity in the longitudinal direction,
- E_N = dynamic modulus of elasticity in the radial direction (normal to grain), and
- ρ = material mass density.

Hearmon (13) and others showed that these equations are reasonably true for wood. The equations made it possible to calculate the dynamic modulus of elasticity of a material if the velocity of the stress wave and the material mass density are known.

EQUIPMENT DEVELOPED

Ultrasonic waves, particularly pulsed waves, were used for the quantitative inspection of timber piles. A commercial testing apparatus constitutes the basic instrument, which provides a means of generating and transmitting pulses of ultrasonic sound through the pile and electronically measures the time of transmission of the sound from the face of the transmitter to that of the receiver. From the measured transit time for the pulse to traverse a known path length, the propagation velocity can be determined.

A short description of the equipment developed for the in-place testing of timber bridge piling is presented. A detailed description of the equipment and the field procedures for testing are presented elsewhere (14,15).

Two pieces of equipment were developed, one to be used above-water and the other underwater, to determine the pulse velocities in sections along the in-place timber pile. Two basic measurements are obtained at regular depth intervals: transit time and path length. The transit time is obtained in digital form. The distance between the two faces of the transducers (path length) is determined either by direct reading on a scale as in the case with the above-water equipment or by measuring the distance the transducers travel as in the case of the below-water equipment. The above-water equipment is simply a scissors-type piece of equipment that is used to hold the transducers in place and measure the distance between them, as shown in Figure 1. The underwater equipment is composed of a sensing unit that is mounted on a special gear to lower and raise it along the length of the pile for the inspection. The measurements are collected through a monitoring unit at the surface. The equipment developed can be used without the aid of a scuba diver. Figure 2 shows a side view of the equipment during testing in a tank that was built to study the operation of the equipment underwater.

EXPERIMENTAL TESTS FOR DATA BANK

In this study the ultrasonic testing technique is used in characterizing the material properties of wooden piles. The results of the ultrasonic testing are correlated with the strength values from the compression parallel to grain test. The developed relationships can then be used for establishing the in-place strength of bridge timber piling. To accomplish such an objective, a data bank is needed that encompasses all variables that affect the strength of timber piles.

Various combinations of the following factors were considered in the testing program, including type of wood, effect of treatment, direction of grain, density of wood, degree of decay, moisture content, and the effect of testing above and below water. The results of some of the tests performed are summarized here but are presented in detail elsewhere (4,14).

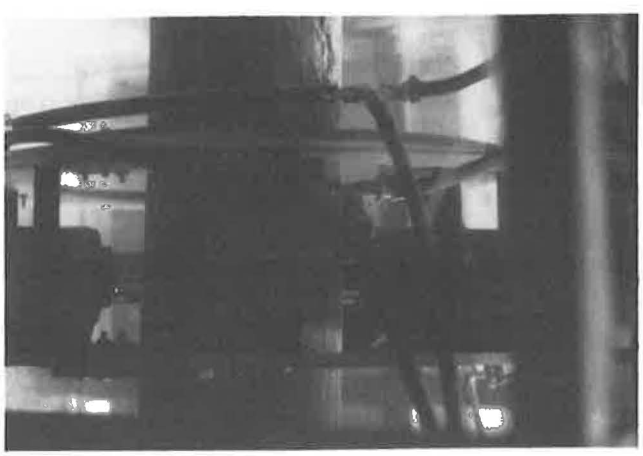

FIGURE 1 Above-water equipment.

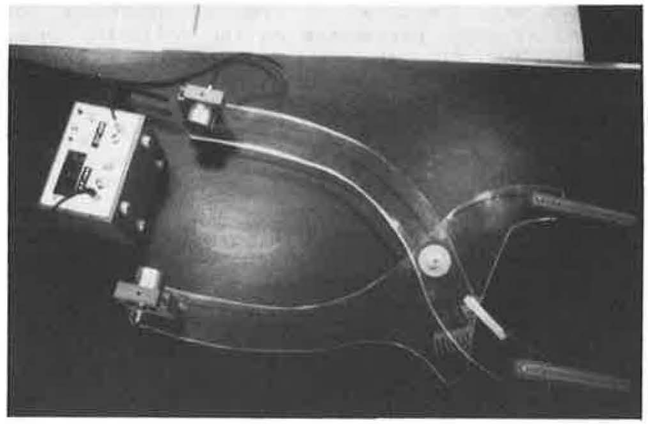

FIGURE 2 Side view of underwater equipment in laboratory testing.

Scope of Testing

Tests on specimens prepared from sections of piles and tests on sections themselves were comprehensive and complete in scope. The statistical evaluations for the test results were based on a 95 percent confidence limit. The tests included different types of new and old wood piles. In all cases, NDT was performed first, followed by either a compression strength test or a bending test.

Sections Tested

Tests were conducted on sections from new and old piles. The new piles were both treated and untreated Southern Yellow Pine. For the old piles, sections were obtained from the following bridges.

1. Bridge No. 0404 on Sandyfield Road, crossing Nine Pin Branch (Worcester County, Maryland): Twenty-one sections of treated Southern Yellow Pine, submerged 25 years in water and taken from three different piles of the bridge, were obtained. Creosote treatment of 16 lb/ft^3 was used.
2. Bridge No. 9015 on MD-392 over Marshyhope Creek (Dorchester County): Thirty-four sections of treated Southern Yellow Pine were obtained from 12 different piles removed after 25 to 30 years of service. Creosote treatment was 12 lb/ft^3.
3. Denton Bridge at Denton, Maryland (Caroline County): This bridge collapsed in 1976. Laboratory tests by the Maryland Highway Department indicated substantial reduction in strength of the piles during their service life. For this study, 32 sections of Red Pine were taken from four different piles after a service life of 60 years.
4. Piles from relieving platform at Fort McHenry Tunnel Project: This platform, being removed for the purpose of constructing a tunnel, is located in Baltimore. Thirty-four sections of untreated Southern Pine from piles from the platform were obtained. The platform is about 18 years old.

Specimens Tested

Tests were conducted on prepared specimens for crushing strength parameters on the following types of wood: Douglas Fir (50 specimens), Red Oak (30 specimens), new untreated Pine (30 specimens), new treated Pine (30 specimens), and old treated Pine (395 specimens).

Tests were conducted on prepared specimens for bending strength parameters on the following types of wood: Red Oak (40 specimens), untreated Yellow Pine (25 specimens), treated Yellow Pine (25 specimens), and Yellow Pine from Marshyhope Bridge sections (42 specimens). As in the case of the crushing strength testing, the ultrasonic tests were followed by the bending strength test on the same specimens.

Sample Preparation and Testing Methods

New pine piles were selected in accordance with ASTM D25-79. Specimens were cut from the sections of piles in accordance with ASTM D143. The size of the specimens prepared for compression parallel to grain testing was 1 x 1 x 4 in. This was in compliance with ASTM D143, Part II. For static bending tests the procedure followed was ASTM D143-79, Part II, Sections 245-252. For the compression parallel to grain tests the procedure followed was identical to ASTM D143-79, Part II, Sections 253-259, with the exception that load compression curves were not taken because only the maximum crushing strength was of interest.

For the ultrasonic tests, time readings were taken across the grain in three directions and parallel to the grain in three locations: at the pith, in the middle of the section, and on the outer rings of the section. The wave velocities were calculated, and the dynamic modulus was then determined.

Correlation Between Specimen and Section Results

The ultrasonic test was conducted on sections to measure the wave velocity parallel to grain (V_L). Sections with height-to-diameter ratios between 1 and 3 were tested. The test was also conducted on specimens prepared from the same sections. The dimensions of the specimens were 1 x 1 in. in cross section and had a length of either 4 or 16 in. The results indicate that the average wave velocity parallel to grain for the sections is about 0.885 of the specimen, and for the crushing strength the ratio between the crushing strength of sections of piles to small specimens at 12 percent moisture content for Southern Pine was found to be 0.92. [Wilkinson (16) showed that this ratio is 0.90 at the pile tip and 0.97 at the butt of the pile.] Thus the wave velocity and crushing strength for sections can be determined if only small specimens are tested. However, this is only true for new piles.

Relation Between Dynamic and Static Modulus

The modulus determined from ultrasonic testing is referred to as the dynamic modulus. Most of the data reported indicated that the dynamic modulus of elasticity is higher than the modulus of elasticity evaluated in the static bending test E_S by 5 to 15 percent (17). It has been suggested that the difference is caused by the rate of loading. Figure 3 shows the relationship determined for Red Oak specimens.

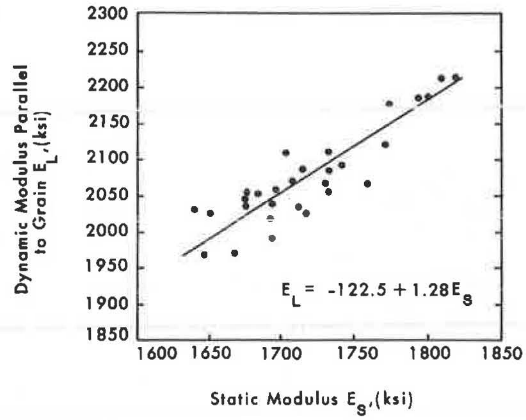

FIGURE 3 Static and dynamic moduli for Red Oak specimens.

are the more popular species used for timber piles. The properties from all test results at air dry are presented elsewhere (14).

Variables Considered

The following variables were considered in the testing program because of their influence on the reliability of the assessment of the inspected piles.

Type of Wood

The species selected in this study--Douglas Fir, Southern Pine, and Red Oak--were chosen because they are the more popular species used for timber piles. The properties from all test results at air dry are presented elsewhere (14).

Effect of Treatment

Various procedures have been developed to help ensure lasting protection of timber piles by preventing the growth of deterioration agents around and within the piles. The basic protective barrier method for wood piling is impregnation by chemical preservatives. Creosote is the most widespread preservative in use on timber piles. Processes associated with the treatment can lead to reduction in strength of the wood. The primary strength reduction appears to be controlled by the conditioning process used before pressure treatment (18).

To study the effect of treatment on piles used in the state of Maryland, untreated Southern Yellow Pine sections were tested ultrasonically and then sent to a company for creosote treatment, after which the sections were retested. The treatment applied was the same as for other piles used in the state; thus the effect of treatment was studied on the same sections. In addition, both treated and untreated sections were tested for strength determination. The data in Table 1 give the average properties of crushing strength, wave velocity, density, and dynamic modulus for sections of treated and untreated Pine. It can be concluded that treatment reduced the crushing strength by 20 percent.

Direction of Grain

Wood is characterized by three mutually perpendicular axes of symmetry, corresponding to the longitudinal, radial, and tangential directions of the wood structure. The strength and elastic properties of wood differ in these three different directions. In

TABLE 1 Properties of Treated and Untreated Pile Sections

Type of Wood	Crushing Strength, σ_{cr} (psi)	Wave Velocity (ft/sec) V_L	V_N	Density, γ (lb/ft^3)	Dynamic Modulus, E_L (ksi)
Untreated Yellow Pine	6,227	15,740	6,340	34.9	1,880
Treated Yellow Pine	5,005	14,435	6,010	43.2	1,980

most properties, however, the major differences are denoted by strength and elastic values parallel and perpendicular to the grain, as the differences between these properties of wood in the tangential and radial directions are, in general, relatively small.

To study this factor, specimens and sections were prepared for ultrasonic testing in the tangential and radial direction for the following types of wood: Douglas Fir, untreated Pine, treated Pine, and Red Oak. The results indicated that the velocity in the radial direction is higher by about 10 percent than the velocity in the tangential direction. In addition, for all types of wood, it was found that the wave velocity parallel to grain (V_L) is 2 to 3 times the wave velocity normal to grain (V_N). However, for old piles the relation between V_L and V_N no longer varies from 2 to 3 and is as shown in Figure 4. It was also found that the ratio between the longitudinal and normal to grain velocities is a function of the wood unit weight, as is shown in Figure 5.

Effect of Density on Wave Velocity

The air-dry weight density (γ) for sections of old piles obtained from different bridges are plotted with the wave velocity (V_N) in Figure 6. The data in the figure indicate that the relationship is strongly dependent on the amount of treatment the pile received when it was new. The figure could be used to estimate an approximate value of γ when the velocity (V_N) is known; however, it should only be used if there is no other means of determining the air-dry unit weight.

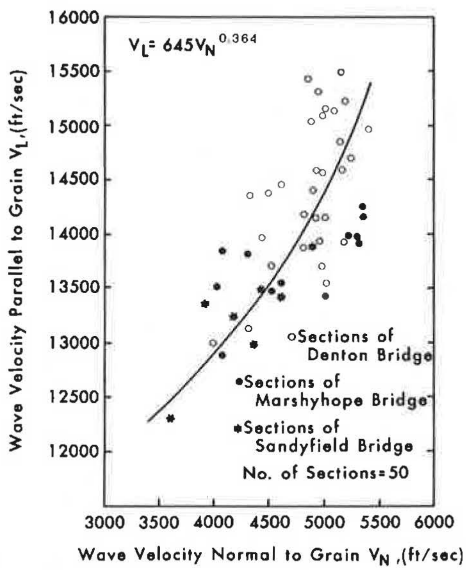

FIGURE 4 Relationship between V_L and V_N for old piles.

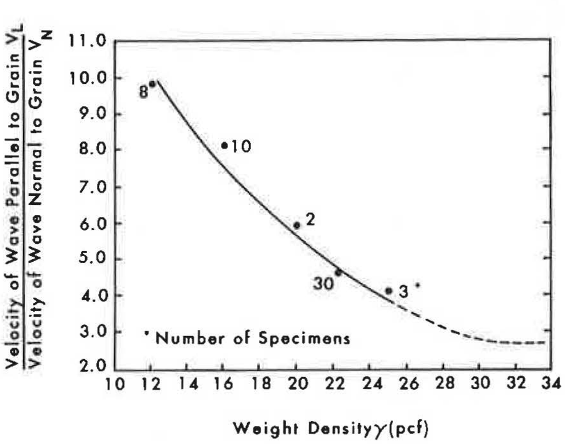

FIGURE 5 Effect of weight density on V_L/V_N.

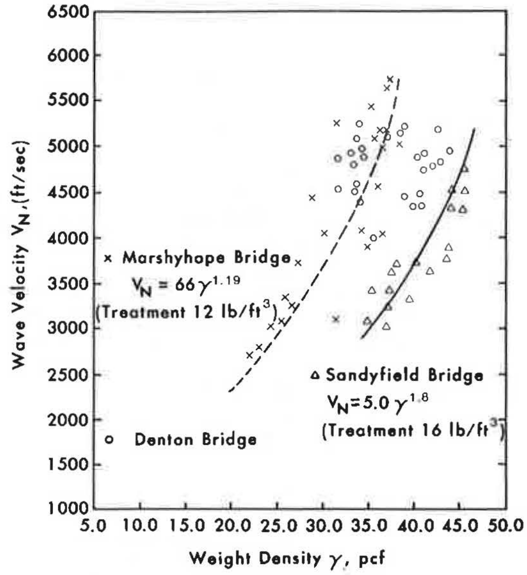

FIGURE 6 Relationships between wave velocity and weight density.

Effect of Degree of Decay

Scheffer et al. (12) noted from studying piles removed from the Potomac River in Washington, D.C., after 62 years of service that the crushing strength of small specimens prepared from the pile above the mudline has been reduced by 60 percent and of that below the mudline by 20 percent. In a similar study of bridge piles after 85 years in the Milwaukee River, Bendtsen (19) reported that the average modulus of rupture of the Red Pine was 32 percent, the modulus of elasticity 27 percent, and the specific gravity 12 percent lower, respectively, than the published values in ASTM.

To study the effect of the degree of decay on the ultrasonic and crushing strength tests, piles from four different bridges of different service lives were used. Both sections and specimens were tested.

For the specimens, the results of ultrasonic tests and compression tests for small specimens prepared from sections above and below water level indicated the following reduction in comparison to specimens prepared from new treated piles:

Properties	Avg Reduction (%)
Crushing strength, σ_{cr}	69
Dynamic modulus, E_L	60
Wave velocity, V_N	55
Density	55

For sections in which cavities were present, the dynamic modulus in the longitudinal direction was corrected for such loss in area. The reduction in the engineering properties in all bridges (no sections from the platform at the Fort McHenry Tunnel

TABLE 2 Reduction in Engineering Properties of Pile Sections

	Avg Reduction (%)			
Pile Sections From	Crushing Strength, σ_{cr} (psi)	Dynamic Modulus, E_L (ksi)	Wave Velocity, V_N (ft/sec)	Density (lb/ft^3)
Sandyfield Bridge	40	22	37	16
Marshyhope Bridge	73	67	59	43
Denton Bridge	36	16	20	18

were tested) caused by decay are summarized in Table 2.

Figure 7 shows the relationship between the dynamic modulus (E_L) and the crushing strength for one of the bridges, and Figure 8 shows this single variable relationship for all the bridges. Figure 9 presents the correlation between crushing strength and wave velocity normal to grain, and weight density (i.e., a multivariables relationship). In the multivariables equation, the first parameter represents the effect of the velocity across the pile section, whereas the second term represents the contribution of the average weight density. The predicted crushing strength from the single-variable model is higher by about 8 percent than that of the multivariables model for the same unit weight.

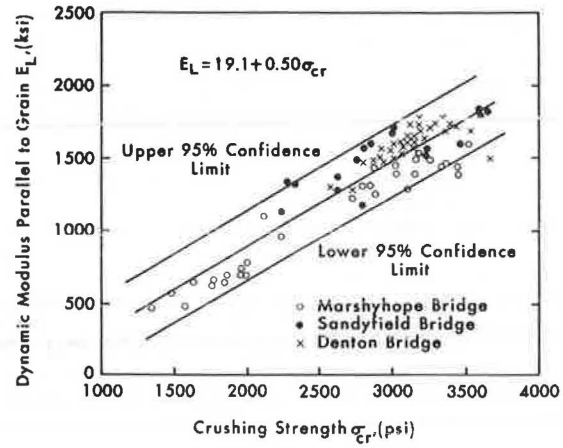

FIGURE 8 Relationship between E_L and σ_{cr} for all bridges.

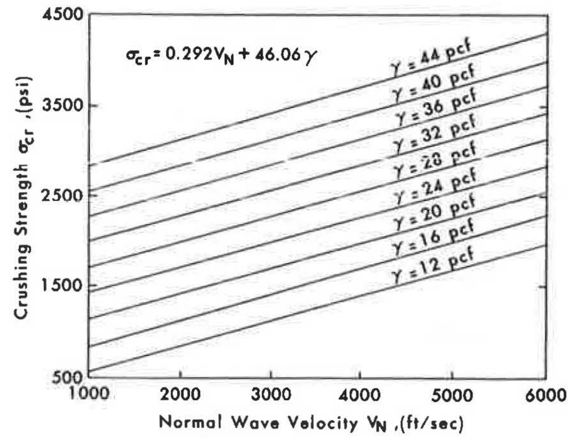

FIGURE 9 Crushing strength and normal wave velocity as a function of weight density.

Effect of Moisture Content

The moisture content of air-dry wood in most wood represents an average of about 12 percent. In using the green strength values, it is important to use the value that corresponds to the fiber saturation point, above which the strength is the smallest and is approximately constant. This moisture content value is assumed to be about 24 percent. For NDT, James (20), Burmester (21), and Gerhards (22) all studied the effect of moisture content on the longitudinal wave velocity.

In this study the effect of moisture content on the wave velocity has been determined for Red Oak, and untreated and treated Pine. Figure 10 shows the effect of the moisture content on the wave velocity parallel to grain. The figure shows that the wave velocity decreased by about 9 percent between the moisture content at air-dry condition and at the fiber saturation point.

The compression test parallel to grain was also conducted on sections of treated Pine obtained from different piles. Two sets of sections were prepared from the same pile for the purpose of testing one set at air-dry condition and the other set at wet

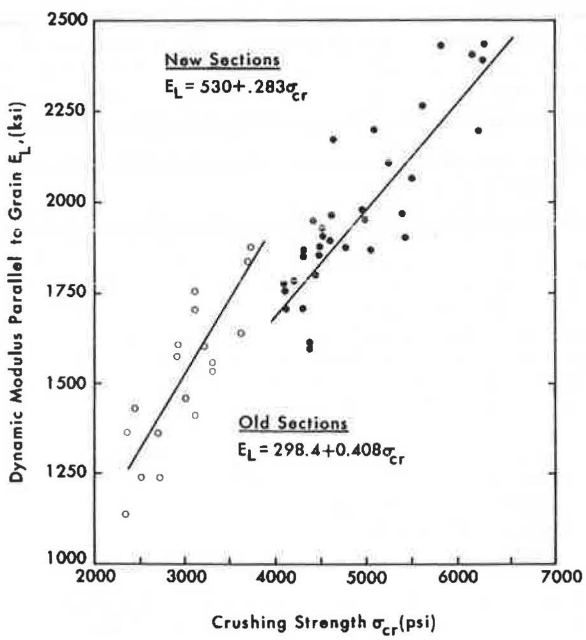

FIGURE 7 Relationships between E_L and σ_{cr} for Sandyfield Bridge.

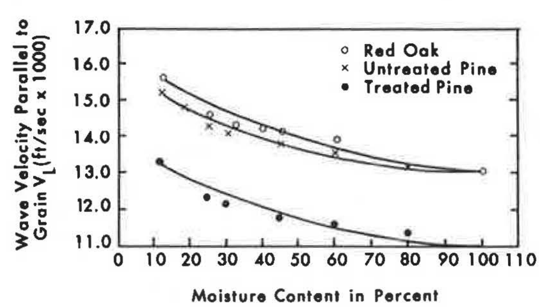

FIGURE 10 Effect of moisture content on V_L.

condition. It was found that the crushing strength of the sections at air-dry condition is 1.48 times that of the sections at wet condition (i.e., a pile underwater loses about 33 percent of its strength).

Tests Above and Below Water

Ultrasonic tests were conducted on treated and untreated solid sections of new Yellow Pine piles in air and in water at different moisture contents. The results indicated that the difference between the ultrasonic velocities for solid sections tested in air or in water at the same moisture content are small and may be neglected. In the case of treated sections of old Yellow Pine piles that were tested in air and also in water at air-dry and at wet conditions, again no difference existed between the values measured in the air or water at the same moisture content.

Figure 11 presents the relationship between the ratio (RA) of the velocity at air-dry condition to wet condition, and the weight density γ in pounds per cubic foot for good and decayed pile sections. Because the greater the decay in the wood the more water it will absorb, the ratio RA will therefore be higher for those values of small γ and lower for high values of γ, as shown in Figure 11.

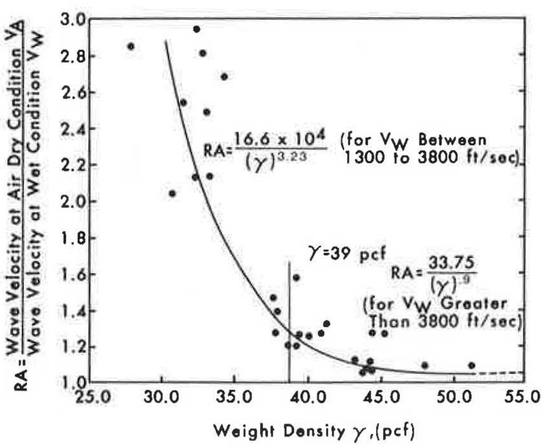

FIGURE 11 Ratio RA as a function of weight density.

Summary

From knowledge of the wave velocity that is obtained from field inspection, the dynamic modulus and the crushing strength can be determined. It should be noted here that the values obtained for the crushing strength have to be corrected for any of the factors that were discussed previously, such as treatment, whether the reading was taken above or below water, and so on.

CONDITION OF PILES IN-PLACE

Ultrasonic testing was performed on sections from piles from all bridges, followed by compression testing of the sections, except for Bridge No. 9015 on MD-392 over Marshyhope Creek, where ultrasonic testing was also performed in-place before the pilings were removed. By using the ultrasonic data, the correlation curves for some sections, and the crushing strength determined from testing of other sections, the crushing strength distribution along the length of the piles was plotted. Figure 12 shows an example of such a plot. The data from all the piles indicated that along the pile length a reduction in strength between 10 to 40 percent had occurred; however, at the water line (between high and low tide) a larger reduction took place in two of the bridges (up to 80 percent reduction in strength in one of the piles tested). This means that there existed a severely decayed part at the water line in some piles and the degree of decay decreased going either up or down along the pile.

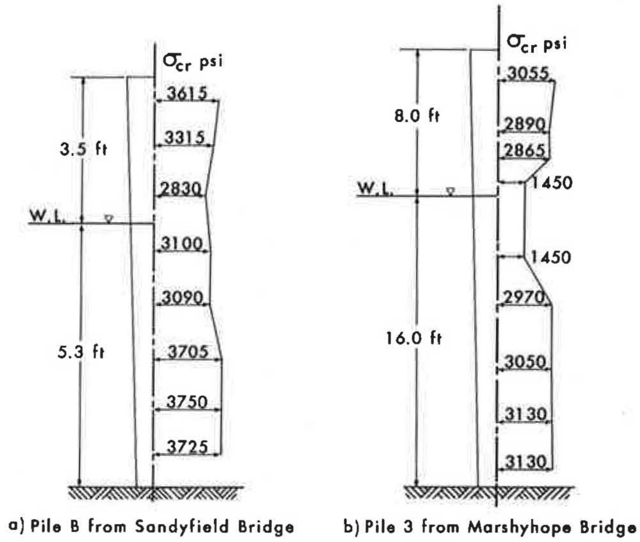

FIGURE 12 Crushing strength along length of pile.

It is interesting to note that in some cases, piling whose external appearance suggested no damage and appeared to be in satisfactory condition indicated no wave transmitted by the equipment developed. When these piles were removed it was found that a large decay pocket was present at the center, surrounded by extensive internal decay with a shell of sound wood 2 to 3 in. thick remaining in the pile. In general, it was found that decay had occurred at the pith of the section while the treated outer ring was in a better condition.

VERIFICATION OF CORRELATION CURVES

The correlation curves developed were verified and checked by comparing the crushing strength calculated by using those curves and those that were determined experimentally. The ultrasonic tests were first conducted on piles from a highway bridge on MD-715 over US-40. The bridge had the advantage in that it included two sets of piles, one original and the other added later to strengthen the bridge. When the bridge was removed to be replaced by a larger bridge, 9 piles were taken to obtain 32 sections. The results of the ultrasonic tests were substituted in the developed correlation curves to determine the crushing strength of the pile sections. These values were then compared with the crushing strength obtained from the compression parallel to grain tests on the same sections. The results of these tests and the comparison are presented elsewhere (4).

The results indicated that the calculated average crushing strength is different by only about ±11 percent from the actual measured strength. This percentage is close to the acceptable limit (7 percent) of the probable variation in the crushing strength in random trees of the same type.

SUMMARY AND DISCUSSION OF RESULTS

The testing technique employed was that of the ultrasonic wave propagation method. It used the relationship between the wave velocity in a material and its properties. In ultrasonic testing, pile sections were subjected to rapidly alternating stress waves of low amplitudes. Undamaged wood is an excellent transmitter of these waves, whereas damaged and decayed wood delays transmission. The method, therefore, required accurate measurements of the velocity of the propagated stress wave.

The NDT was followed by extensive axial load testing of pile sections and a correlation was then established between the wave velocity or dynamic modulus and the strength of new piles. In addition, old piles from four different bridges in the state of Maryland were obtained to provide the opportunity to follow the NDT procedures through from field in-place measurements in one bridge (before they were removed from service) to laboratory NDT and finally to tests to failure for strength determination in all bridges. The results of the ultrasonic tests were correlated with the strength values from the destructive tests. In addition, small specimens were cut from new and old piles and both NDT and DT were conducted to determine the mechanical properties of wood and the correlation between NDT and DT. In both testing programs all variables that influence the results were considered. The relationships developed were verified and checked by comparing the crushing strength calculated by using these curves and those determined experimentally from a fifth bridge. It has been concluded from the favorable comparison that the relationships can be used successfully to predict the remaining strength of a pile in-place.

Following the inspection of the piles, an analysis should be undertaken by using the existing condition of the pile to determine if the pile can still perform as intended in its original design. A preliminary study, where the decay was represented by assuming a loss in the cross-sectional area or a reduction in the modulus of elasticity, indicated that the additional stresses developed in decayed piles caused by static and dynamic loading are substantial and should be considered (4).

CONCLUSION

Equipment was developed for the NDT of in-place timber piling below and above water. A testing program was used to develop a correlation between the NDT results (wave velocity) and the remaining strength of in-place timber piles. Verification of the correlation was carried out by testing in-place piling by using NDT then removing the piles, cutting them into sections, and axial load testing the sections to determine the remaining strength of the pile.

The technique is suitable primarily for piles that sustain damage to the wood microstructure, such as those immersed in fresh water for long periods of time. From the substantial reduction of strength obtained, it can be concluded that the use of equipment such as developed here are not merely sophisticated techniques for pile inspection but are essential ones.

The study provided an adequate inspection procedure to determine if damage is occurring or has occurred and to what extent, thus predicting the true performance of the pile. The quantitative determination of the remaining strength of timber piles in service with any degree of decay will enable the engineer to make appropriate judgments as to the ability of the pile to further support the loads imposed on it. It will also provide information on which to base a maintenance plan to meet the current or anticipated loading demands, affect decisions on new installations, and aid in projecting the service life of the bridge based on a predictable safety level.

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Production and Testing of Calcium Magnesium Acetate in Maine

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ABSTRACT

The search for an effective substitute for the deicing agent sodium chloride has led to the development of calcium magnesium acetate (CMA). However, CMA is not commercially available. A project for the production of CMA using resources in Maine was carried out at the Maine Department of Transportation. After the product was made, other physical and chemical tests were also performed. The results indicated that CMA can be made in Maine from an apparent abundant source of high magnesium limestone and acetic acid (cider vinegar). A 10 percent solution of acetic acid with 10 min of agitation with the magnesium limestone coarse aggregate provides the best production of CMA for this grade. A commercial production of CMA should consider the constant reflux method with constant monitoring of the pH. Evaporation of the solution by solar energy is not effective because of the large amount of rainfall in Maine. Bituminous concrete batch plants have waste heat, which might be able to aid in this evaporation need. The field trial of CMA as a deicing agent demonstrated both advantages and disadvantages. A major concern is its dustiness. Outdoor uncovered storage of CMA is not practical. The corrosion effect of CMA solution toward metal or concrete needs further study.

The use of sodium chloride (NaCl) as a deicing agent on highways has been under scrutiny for some time. The chief concern is environmental compatibility. Sodium chloride is corrosive in nature and it affects the water-absorbing capability of soil (1,2).

Many research agencies have been searching for an effective substitute for sodium chloride. In March 1980, Dunn and Schenk (3) of Bjorkste Research Lab, Inc., published their findings on their study for a salt substitute. Their project was sponsored by FHWA. The results indicated that calcium magnesium acetate (CMA) was a promising alternative for NaCl. This new deicing agent would react at about the same melting rate as NaCl in the temperature range of common activity, but CMA also had the advantage of being a corrosion inhibitor. The run-off from melting action would be beneficial to most soils, and there is an insignificant effect to water supplies.

Realizing the potential of CMA use and the knowledge that CMA is not produced commercially, FHWA initiated a pooled fund project for CMA in May 1981 to find an efficient manufacturing process and to establish an evaluation procedure for the product. Ultimately a production contract was awarded to SRI International, and an environmental study contract was awarded to the California Department of Transportation. Both research programs began in October 1981, and many interim reports have been published since then. The work undertaken at SRI International has been to produce acetic acid by using Clostridium Thermoaceticum to ferment biomass-derived sugars. The acetic acid was then combined with dolomitic lime to produce CMA.