

DISCUSSION

*W. A. Norum*¹ (*written discussion*)—The author has detailed much information on codes that should prove helpful. It is to be hoped that his paper will prove to be a stimulus for engineers and encourage them to get more involved in code writing activities. They will add greatly to the value of building codes and code writing organizations, such as Building Officials and Code Administrators International (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International (SBCCI). These organizations write and publish the model codes that greatly influence the content of local codes and, consequently, all building construction. It is estimated that the model codes directly control 80 percent of building construction in the United States. As stated by the author, these codes are titled Basic Building Codes (BOCA), Uniform Building Code (ICBO), and Standard Building Code (SBCCI).

On the subject of the role of codes in pile foundation design and construction, I agree that codes should be written as a combined prescriptive and performance regulation, with the performance regulation allowing freedom in design based on substantiation by a qualified engineer. All model codes are written in this manner, and the reason is well known to both soils and structural engineers. We just don't know how to write a code to recognize all the variables that can be experienced with pile foundations, such as soils, driving equipment, personnel qualifications, and pile materials. We do know something about all of these variables, and possibly some engineers know just about all there is to know about all of them. The important question is, What can be written in performance terms rather than be written in the form of specifications? This is the challenge of the professional engineers and building officials. In my opinion, we should always improve codes by writing more and more in performance terms whenever possible. Getting rid of specified load limits on piles would be my first objective. All model codes fortunately have been rid of that archaic method of design, but some local codes continue. Engineers should be given more credit for knowledge. To shackle them by such a restriction is an insult. Performance criteria should be adopted that are based on soils investigation, pile strength properties, interaction of piles with soils, and technique of installation. Proof loading or test loading may be necessary as part of the standards for special situations to justify the design.

I take exception to the author's remarks directed at the role of trade

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associations in code and standard writing activities and his specific criticisms of ASTM Establishing Design Stresses For Round Timber Piles (D 2899). Indirectly, the author is taking issue with ASTM procedures and in the specific case made of ASTM Method D 2899; he in reality is taking issue with the federal government. Membership on ASTM committees are selected so as to balance the consumer, producer, and general interest groups, which leaves little room for control by trade associations. In the case of ASTM Method D 2899 or any other ASTM standard on wood products, there is an additional strong influence exercised by the public interest through representatives of the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory (FPL). Representatives of the FPL are recognized authorities in wood technology, so there is no doubt that proposed standards have little chance for advancement to standard by ASTM without their acceptance. More important, however, is the question, Does the standard stand up satisfactorily to a critical review? The answer will come from ASTM Committee D07.07 membership who are examining the criticisms expressed in papers presented for this symposium by Armstrong and Diekmann and in my discussions of their papers.

Fuller has also made some critical comments directed to round timber piles that need response. His specific comments and my response to each are set forth below:

1. The author said, "The actual load duration reduction factor used in the ASTM Method D 2899 formula is only 66 percent according to Norum,² which represents a continuous or cumulative loading of about 1.5 years."

As a matter of factor, I said "it includes a factor for duration of load so that now it relates to normal loading conditions, which means 10 years of accumulated time at maximum stress conditions."

It is obvious that a conflict exists between these two statements. Apparently, the author neglected to take certain facts into consideration when drawing a conclusion that the ASTM Method D 2899 formula derives stresses for short-term loading only. Probably he overlooked a need to compensate for a difference in the effect time has on the results of full-size pile tests, which averaged 20 min. Instead, he referred only to the 2 min test period applicable to small clear specimens when interpreting the meaning of the 0.66 or 1/1.52 coefficient explained in my discussion of Diekmann's paper.

2. The author said, "In the final analysis the formula in ASTM Method D 2899 actually solves for the ultimate stress of the pile material under the 1.5 years duration of loading and the other reduction factors used."

²Norum, W. A., Discussion on "Timber Piles in Standards, Codes, and Practice," by E. F. Diekmann, this volume.

As previously explained, the 1.5 years should read 10 years of accumulated time at maximum stress conditions. This is not the only exception I take, however, with the author's comment. He introduces the thought that stress values derived under procedures of ASTM Method D 2899 represent ultimate values. This is wrong! The conventional engineering use of the word "ultimate" refers to breaking values, which is obviously not the case under ASTM Method D 2899. If the values derived under ASTM Method D 2899 represent ultimate values, then the pile tip parallel to grain values for Douglas fir would be about 2960 psi. This figure is the average crushing value experienced by FPL in their test program. On the other hand, the value of 1250 psi is being recommended by ASTM Method D 2899.

3. The author said, "ASTM Method D 2899 does state that no formal safety factor is included in the formula for determining the allowable stress in compression parallel to the grain."

It is a misleading statement as presented by the author. His statement implies that the derived stresses are crushing values, which is not correct. A factor of safety is inherent in the procedure used for deriving stresses for round timber piles similar to procedures used satisfactorily for deriving stresses for lumber (ASTM Method D 245). It is a multivalued factor of safety that is accountable by use of mathematical techniques that predict probability of risk.

4. The author said, "The important fact, however, is that the current version of ASTM Method D 25 (1973) permits twice as many knots for a given length of pile than allowed in the 1958 version for Class A and B piles."

It is a misleading statement as presented by the author. It implies that the growing characteristics of trees will adjust to a change in ASTM Method D 25. The fact is that man can only select trees for acceptance under ASTM Method D 25 and that the growing characteristics of trees prevents the occurrence of a radical change in knot patterns. Changing the standard to allow the same size and number of knots to occur along a 6-in. pile length that previously was limited to a 1-ft length does not actually double the amount and size of knots. Please refer to my discussion of Armstrong's paper for more details and reasoning in support of my comments. Fuller's conclusion based on the premise that the allowable knot sizes and numbers in ASTM Method D 25-73 are not adequately considered in ASTM Method D 2899 is wrong. The standard reflects these knot limits, as explained in my discussion of Armstrong's paper.

5. The author said, "He does mention the higher impact strength of timber but unfortunately this beneficial property is offset by low-cycle fatigue effects just as stated by Gamble³ for concrete."

The facts are that the U.S. Forest Products Laboratory *Wood Handbook*

³Gamble, W. L., "Capacity of Reinforced and Prestressed Concrete Pile Sections," this volume.

reveals that fatigue need not be a design consideration for wood construction until repetitions of design stress or near design stress are expected to be more than 100 000 cycles during the normal life of a structure. It is apparent to me that this physical property of timber does not justify being classified "low-cycle fatigue".

Conclusions reached by Fuller, at least as they relate to timber piles, are very questionable. Much of his rationale is based on papers presented by Armstrong and Davisson, both of whom have arrived at conclusions related to timber piles that are judgmatical and without documentation. The several areas of disagreement with these authors are covered in my discussions of their papers.

F. M. Fuller (author's closure)—The discussor has made a valuable contribution to the general subject of allowable stresses for timber piles as determined by ASTM Method D 2899 by bringing out for further discussions some very important considerations to which the writer will respond. A more comprehensive discussion is essential for an understanding of these controversial issues.

Design versus Ultimate Stress

The discussor emphatically denies that the stress values derived under procedures of ASTM Method D 2899 result in ultimate values. The proper terminology for such stresses is "failure stress at the 5 percent exclusion value under normal load duration." This is a type of "ultimate" stress and regardless of what this stress value is called, it is not a working or design stress, although identified as such in ASTM Method D 2899.

The development of a true design stress for 10-year loading at the tip of an untreated timber pile, starting with the short-term crushing strength of a small clear specimen is illustrated in Fig. 3. To obtain a design stress for treated piles, an additional strength-reduction factor must be applied to design stress in Fig. 3, depending upon the type of conditioning used. To obtain a long-term design stress (for more than 10-year loading) the load duration reduction factor must be increased.

As Armstrong⁴ states, the basic reference strength or 5 percent exclusion strength for small clear timber specimen ($S - 1.645SD$) (or product of the first two terms in Fig. 3) can be considered as comparable in nature to the design strength f'_c used in concrete design under ACI 318 Building Code Requirements for Reinforced Concrete. To this basic reference strength, whether for timber or concrete, are applied various appropriate strength reduction factors and an appropriate factor of safety (load factor) to arrive at a design or working stress.

⁴ Armstrong, R. M., "Structural Properties of Timber Piles," this volume.

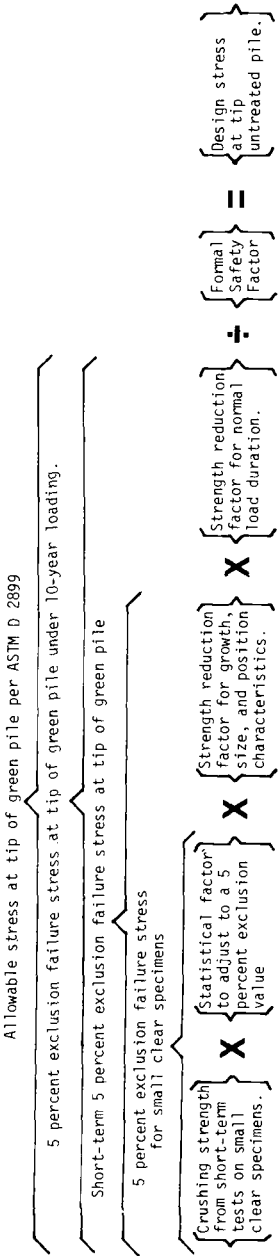


FIG. 3—Development of a true design stress for 10-year loading at the tip of an untreated timber pile, starting with the short-term crushing strength of a small clear specimen.

A recent study by Randolph⁵ indicates that the 5 percent exclusion failure stress for treated southern pine piling under normal load duration (10 years) is about 5.5 MPa (800 psi). When the ASTM Method D 2899 recommended factor of safety of 1.25 is applied to this "failure stress," the resulting allowable design or working stress is about 4.4 MPa (640 psi). This is of the same order of magnitude as that recommended by Armstrong (see footnote 4) and is far less than the so-called design or working stresses computed by ASTM Method D 2899.

In defense of his stand that the application of procedures in ASTM Method D 2899 does not result in an "ultimate" stress, the discussor compares the average crushing value of 20.4 MPa (2960 psi) resulting from Forest Products Laboratory (FPL) tests on treated Douglas fir pile tips as reported by Wilkinson⁶, with an allowable design stress value of 8.6 MPa (1250 psi) which the discussor claims is derived from ASTM Method D 2899 for treated Douglas fir piles.

The value 20.4 MPa (2960 psi) from the FPL tests is the average short-term crushing strength, whereas the 8.6 MPa (1250 psi) from ASTM Method D 2899 is a 5 percent exclusion stress under reportedly 10-year (normal) load duration as shown in Fig. 3. Because of the difference in load duration and statistical considerations, the two values cannot be compared directly. In order to make a valid comparison, the reportedly 10-year 5 percent exclusion strength, 8.6 MPa (1250 psi), must be converted to a short-term average strength.

The value 8.6 MPa (1250 psi) is converted to a short-term strength by applying as follows the load duration factor used in the ASTM Method D 2899 formula 1 [Norum (see footnote 2)]

$$1250 \times 1.52 = 1900 \text{ psi} \quad 5\% \text{ exclusion, short-term}$$

For compression parallel to the grain, the standard deviation SD according to ASTM Method D 2555 is approximately 18 percent of the average crushing strength S . Hence, the 5 percent exclusion value is approximately 70 percent of the average strength:

$$(S - 1.645 \times 0.18 S) = 0.70 S$$

Therefore, the 5 percent exclusion short-term value 13.1 MPa (1900 psi) can be adjusted to an average short-term crushing strength as follows:

$$1900/0.70 = 2714 \text{ psi} \quad \text{average short-term}$$

⁵ Randolph, M. W., "Application of Monte-Carlo Method to Strength of Timber Piles," Special Problem, Civil Engineering Department, University of Illinois, Urbana, Ill., April 1979.

⁶ Wilkinson, T. L., "Strength Evaluation of Round Timber Piles," U.S. Department of Agriculture Forest Service Research Paper FPL 101, Forest Products Laboratory, Madison, Wis., Dec. 1968.

Thus, the only valid comparison between the results of the FPL tests (see footnote 6) on treated Douglas fir pile tips and the "allowable" stress from ASTM Method D 2899 is 20.4 MPa (2960 psi) versus 18.7 MPa (2714 psi). This comparison indicates a difference of only about 8 percent. However, for the FPL tests only 15 Douglas fir pile tips were tested, which is too small a data base to make an accurate comparison.

A better comparison can be made between the ASTM Method D 2899 design stress 8.6 MPa (1250 psi) and results from the Oregon tests⁷ on untreated Douglas fir piles, for which many more samples were tested giving a much broader data base. Armstrong (see footnote 4) shows (his Fig. 8) that the short-term 5 percent exclusion crushing strength for the 114 untreated Douglas fir pile tips from the Oregon State University tests was 13.6 MPa (1975 psi). The 8.6 MPa (1250 psi) stress from ASTM Method D 2899 represents a 5 percent exclusion value for treated piles under reportedly normal load duration. Therefore, to compare the results of the Oregon tests with the allowable stress 8.6 MPa (1250 psi) from ASTM Method D 2899, that allowable stress must be converted from "normal" load duration to short-term loading and from a treated to untreated condition.

The allowable stress 8.6 MPa (1250 psi) is converted from normal load duration to short-term loading by applying as follows the load duration factor which according to Norum (see footnote 2) was used in deriving formula 1:

$$1250 \times 1.52 = 1900 \text{ psi} \quad 5\% \text{ exclusion, short-term, treated}$$

To convert the resulting short-term 5 percent exclusion value for treated piles, 13.1 MPa (1900 psi), to that for untreated piles, the strength reduction factor for the Bolton process per ASTM Method D 2899 is applied as follows:

$$1900/0.90 = 2111 \text{ psi} \quad 5\% \text{ exclusion, short-term, untreated}$$

The resulting stress, 14.6 MPa (2111 psi), is basically comparable to the stress 13.6 MPa (1975 psi) from the Oregon tests; both are short-term 5 percent exclusion failure stresses for untreated piles. It should be noted that using the enlarged data base from the Oregon tests as a comparison, the stresses resulting from ASTM Method D 2899 are about 7 percent higher.

It is quite evident in analyzing both the FPL and the Oregon tests that the ultimate stress levels obtained in both cases are of the same order of

⁷ Peterson, J., "Final Report—WWPI Pile Tests," Report on testing project funded by the Western Wood Preservers Institute, Civil Engineering Department, Oregon State University.

magnitude as the so-called design stress derived by ASTM Method D 2899 when the proper adjustment factors are applied; there is no wide difference, as claimed by the discussor. In developing and supporting his arguments, the discussor drew only upon the FPL test and totally ignored the results of the extensive testing done at both Oregon State University as reported by Peterson (see footnote 7) and Mississippi State College (Forest Products Utilization Laboratory) as reported by Thompson⁸. Wilkinson⁹ points out that while the FPL test program was one of those used in developing ASTM Method D 2899, it was not used as heavily as other studies.

Considering the above, especially Fig. 3, the only conclusion that can be reached is that the procedures in ASTM Method D 2899 result in a type of "ultimate" stress and not a working or design stress.

Load Duration Factor

The discussor objects to the writer's statement that the 66 percent load duration reduction factor, used according to Norum (see footnote 2) in deriving formula 1 from ASTM Method D 2899, relates to a continuous or cumulative loading of about 1.5 years and claims that the factor used represents normal 10-year loading. To justify the 66 percent factor, he also claims that the duration of tests on full-size piles averaged 20 min.

The strength ratio versus load duration curve in Fig. 2 (from ASTM Methods D 2899 and D 245) was developed based upon results of bending tests for which the test duration under load ranged from 5 to 10 min; the index line of 100 is plotted at approximately 5 min. Although the curve in Fig. 2 is supported by studies in bending, ASTM Method 245 suggests that the same relationship of strength versus load duration may be used for other allowable stresses (including compression parallel to the grain). An examination of the curve in Fig. 2 shows that the duration of load corresponding to the 0.66 factor used in the ASTM Method D 2899 formula is about 1.5 to 2 years as stated. The general definition in wood terminology of "normal load duration" is a duration of 10 years under the maximum service load stresses either continuous or cumulative. Long-term loading is considered as loading in excess of 10-years (factor = $0.90 \times$ normal load duration factor).

If the tests on full pile sections averaged 20 min, as claimed by the discussor, this would have the effect of moving the 100 percent index line (Fig. 2) to the right, thus raising the curve and justifying the use of a 0.66 factor for 10-year loading.

⁸Thompson, W. S., "Results of Strength Tests on Piling Sections," Report submitted to American Wood Preservers Institute by the Forest Products Utilization Laboratory, State College, Miss.

⁹Wilkinson, T. L., Discussion on "Timber Piles in Standards, Codes, and Practice," by E. F. Diekmann, this volume.

However, there is no indication in the test data upon which ASTM Method D 2899 was based that the test loads were applied to full pile sections for a duration of 20 min. These data resulted from tests at the University of Wisconsin (Forest Products Laboratory) Oregon State University (see footnotes 6 and 7) and Mississippi State College (see footnote 8). Although actual load durations were not reported, information reported on the strain to failure and the rate of loading can be used to calculate the load duration. Armstrong and Davisson¹⁰ show that such calculations lead to the following load test durations on full pile sections:

FPL tests	1.5-5 min
Oregon tests	2.2 min
Mississippi tests	2.1-5.1 min

These load durations are far less than the 20 min claimed by the discussor, and it is obvious that the index line as currently plotted in Fig. 2 at 5 min duration is compatible with the actual load duration of tests on full pile sections. Thus, the load duration factor of 0.66 used in the ASTM Method D 2899 formula does in fact relate to a load duration of from 1.5 to 2 years as stated by the writer and does not represent 10-year loading as claimed by the discussor. The recognized load duration factor is 0.625 ($5/8$) for normal load duration (10 years) and is 0.5625 ($9/16$) for long-term loading as indicated in Fig. 2 and as shown by Diekmann,¹¹ Armstrong (see footnote 4), Wood,¹² Gurfinkel,¹³ and others.

Factor of Safety

The discussor claims that a factor of safety is inherent in the procedures used for deriving "long-term" allowable stresses for timber piles in accordance with formula 1 from ASTM Method D 2899.

Norum (see footnote 2) shows the basic derivation of formula 1 for design compressive stress parallel to the grain from ASTM Method D 2899. The basis for the ASTM Method D 2899 formula is also illustrated in Fig. 3. It should be noted that the adjustment factors are intended to convert the crushing strength of small clear specimens to a comparable 5 percent exclusion crushing strength for full-size pile tips under normal load duration. Section 13.1 of ASTM Method D 2899 recommends a safety factor of 1.25 for compression parallel to the grain "if a formal factor of safety is

¹⁰ Armstrong, R. M. and Davisson, M. T., "Review of Some Factors Controlling Allowable Loads on Timber Piles," unpublished critique and analysis of test data on which ASTM Method D 2899-74 was based, Urbana, Ill., July 1976.

¹¹ Diekmann, E. F., "Timber Piles in Standards, Codes and Practice," this volume.

¹² Wood, L. W., *Journal of the Structural Division*, American Society of Civil Engineers, Vol. 84, No. ST7, Nov. 1958.

¹³ Gurfinkel, G., *Wood Engineering*, Southern Forest Products Association, New Orleans, La., 1973.

considered to be required," but no formal factors of safety are included in the formulas used to calculate working stresses.

Armstrong (see footnote 4) recommends a formal factor of safety for compression parallel to the grain of 1.2 based upon a load duration factor of 0.60. This is comparable to the factor of safety of 1.25 recommended in ASTM Method D 2899 combined with a 10-year load duration factor of 0.625. If the load duration factor of 0.66 currently in ASTM Method D 2899 is retained, the comparable required factor of safety would be 1.32.

These factors of safety are considerably lower than those used for structural design of other pile types; generally, the structural factor of safety is about 2.2. However, a formal factor of safety of 1.25 (for a load duration factor of 0.625) is considered satisfactory for timber piles because of the informal safety factor inherent in the load duration factor. However, if the pile is subjected to the full design stress either continuously or cumulatively over the load duration period reflected in the reduction factor used, this informal safety factor disappears and only the formal safety factor (if used) is left. As the actual load duration period under full design stress continues to increase, any formal factor of safety used continues to be eroded. As pointed out in the case of the ASTM Method D 2899 formula, the load duration factor actually used reflects only a 1.5 to 2 year total load duration. After the expiration of this full-load duration period, there is no safety factor left.

Knot Limitations

The discussor claims that the revision to ASTM Method D 25-58 resulting in the current specification ASTM Method D 25-73 did not increase the amount and size of knots permitted in timber piles and contends that the allowable knot sizes and sum of knot sizes permitted in ASTM Method D 25-73 are adequately considered in ASTM Method D 2899.

Table 1 shows a direct comparison of the knot limitation requirements in both the 1958 and 1973 versions of ASTM Method D 25. It will be noted that

1. Specific limitations for maximum-size single knot and maximum sum of knots in a given length of pile were included in the 1958 version for piles of various qualities or lengths. These specific maximum sizes could not be exceeded regardless of the pile diameter.

2. The 1973 version does not contain any such specific limitations. Thus, the permitted knot size or sum of knot sizes in a given length of pile can increase with the increasing pile diameter.

3. In the 1973 version, the maximum allowable knot size and sum of knot sizes in a given pile length for all piles are equivalent to or greater than those for class C piles in the 1958 version.

TABLE 1—Comparison of knot limitations between ASTM Methods D 25-58 and D 25-73.

Knot Property		Knot Limitations ^a	
		1958	1973
Maximum-size single knot	Class A and B piles < 50 ft	$\frac{1}{3}D$ max 4 in.	All piles $\frac{1}{2}D$
	Class A and B piles > 50 ft		
	$\frac{3}{4}L$ from butt	$\frac{1}{3}D$ max 4 in.	
	$\frac{1}{4}L$ from tip	$\frac{1}{2}D$ max 5 in.	
Maximum sum of diameters all knots per length indicated	Class C piles	$\frac{1}{2}D$ max 5 in.	All piles $\frac{1}{3}C = D$ in 6 in. length
	Class A and B piles < 50 ft	$\frac{2}{3}D$ max 8 in. in 12 in. length	
	Class A and B piles > 50 ft	$\frac{2}{3}D$ max 8 in. in 12 in. length	
	$\frac{3}{4}L$ from butt	D max 10 in. in 12 in. length	
	$\frac{1}{4}L$ from tip	D max 10 in. in 12 in. length	
	Class C piles	D max 10 in. in 12 in. length	
Clusters of knots	Class A and B piles	not permitted	All piles permitted up to single knot size $= \frac{1}{2}D$
	Class C piles	not permitted	

Conversion factors

1 ft = 0.30 m

1 in. = 2.54 cm

^a D = pile diameter, C = pile circumference, L = pile length.

4. In the 1958 version, the maximum allowable sum of knot diameters is based on any 12-in. length of pile; for the 1973 version, it is based on any 6-in. length of pile. The possibility of having an increased sum of knots exists.

5. In the 1958 version, cluster knots were prohibited for all piles, including class C piles.

6. In the 1973 version, cluster knots are permitted for all piles up to the maximum size allowed for single knots.

It is quite obvious that when ASTM Method D 25-58 was revised in 1970, the knot restrictions were substantially liberalized. As noted above, the quality of piles permitted in the current specification, as far as knots are concerned, is that which would be classified as class C piles or poorer in the 1958 specification. Class C piles were identified as suitable for use in foundations that will always be completely submerged or for cofferdams, falsework (temporary construction), or light construction. Thus, in today's market for timber piles, all piles, regardless of what type structure they are to support or what loads they are to carry, could be of class C quality or poorer as far as knots are concerned.

Formula 1 from ASTM Method D 2899 was derived principally from results of tests on timber piles conducted at the University of Wisconsin

(Forest Products Laboratory), Oregon State University, and Mississippi State College. Armstrong (see footnote 4) shows that of the total piles tested under these three programs, approximately 60 percent were of class A or B quality as far as knots are concerned. Thus, the majority of piles used in tests on which ASTM Method D 2899 was based were of higher quality than those allowed in today's market and to which ASTM Method D 2899 is being applied. For this reason, and because the strength of a pile is reduced as the size and number of knots increase, the allowable stresses determined by ASTM Method D 2899 do not adequately reflect the poorer quality of piles permitted under the current specification ASTM Method D 25-73.

Low-Cycle Fatigue

The discussor objects to the writer's use of the term "low-cycle fatigue" in discussing the physical driving limitations of timber piles, and discusses "fatigue strengths" on the basis of more than 100 000 repetitions of the design stress or near design stress during the normal life of the structure. For a life of 20 to 30 years, this is equivalent to about 1 cycle for each 10 to 16 min. The "fatigue strength" to which the writer refers, relates to dynamic driving stresses, which are considerably higher than design stresses and are applied at the rate of about 60 or more cycles per minute.

A timber pile will not stand up under sustained hard driving. At high point resistance, it does not take many hammer blows to break down the cellular structure of the wood and leave broomed fibers. Norum¹⁴ recognizes this by stating "It has been proven that banding timber piles reduces the amount of fiber separation experienced during hard driving." This phenomenon of brooming exists whether it is called "low-cycle fatigue" or something else.

Conclusions

Conclusions regarding the items of controversy can be summarized as follows:

1. The procedures of ASTM Method D 2899 do not result in a design or working stress as indicated in the standard.
2. The load duration factor in the ASTM Method D 2899 formula 1 represents a load duration of 1.5 to 2 years and is not justified; it should be at least 0.625 (1.60) for normal 10-year loading.
3. The ASTM Method D 2899 formula 1 does not contain a factor of safety (load factor) in accordance with conventional timber design.

¹⁴Norum, W. A., Discussion on "Stress in Piles," by M. T. Davisson, this volume.

4. The revision to ASTM Method D 25-58 resulting in the current ASTM Method D 25-73 did substantially liberalize the knot limitations for timber piles.

5. ASTM Method D 2899 does not adequately reflect the size and extent of knots permitted under the current pile material specification, ASTM Method D 25-73.

6. Timber piles are subject to a type of "low-cycle fatigue" resulting in the breakdown of wood structure (brooming) under repetitively high impact stresses often occurring during pile driving.