U.S.D.A. FOREST SERVICE
RESEARCH PAPER
FPL 101
DECEMBER 1968

U.S. Department of Agriculture • Forest Service • Forest Products Laboratory • Madison, Wis.

STRENGTH EVALUATION OF ROUND TIMBER PILES

• •

SUMMARY

Foundation piles are used to support structures resting on soils having insufficient bearing strength to support footings for any but the lightest loads. Current practice is to design wood piles for loads of 15 to 25 tons when load tests are not conducted and for loads of 40 to 50 tons are justified by the load test. These higher loads produce stresses that approach the allowable stresses for green sawn timbers. Data are needed to verify that the higher design stresses are justified for timber piles.

This study was conducted in two parts. In Part 1, strength properties in compression parallel to the grain and in bending were dertermined for 15 timber piles of each of 3 species--Douglas-fir, southern pine, and red oak. The results of these evaluations indicated the following average tip end crushing strengths: read oak 3,460 p.s.i., Douglas-fir 2,960 p.s.i., and southern pine 1,820 p.s.i. The three species ranked in the same order for modulus of rupture. In Part 2, the effect of kiln-drying of southern pine piles on crushing strength was investigated. Kiln-dried piles had about 12 percent less crushing strength than green piles when both were evaluated at the same moisture content.

The strength values obtained in this study given an indication of the loads for which timber piles may be designed. The results should be useful in the development of timber pile specifications.

STRENGTH EVALUATION OF ROUND TIMBER PILES[1]

By THOMAS LEE WILKINSON, Research Engineer

FOREST PRODUCTS LABORATORY[2]
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

Foundation piles are used to support structures resting on soils having insufficient bearing strength to support footings for any but the lightest structures. Piles are also used to support piers, docks, and trestles. One of the more practical and economical piles is the round, tapered timber pile which has been preservative-treated.

Test loads applied in accordance with procedures established by local code authorities or other governing bodies provide the best means of determining safe loads lor pile foundations. Wood piles in loading tests have sustained loads as high as 100 tons per pile without exceeding acceptable settlement limits and without apparent damage. Experiences of this kind have convinced many engineers that wood piles can be successfully driven and used to support loads of up to 40 or even 50 tons. This contrasts sharply with the past practice of using wood piles with bearing values in the range of 15 to 25 tons only.

Allowable working stresses in compression parallel to grain for green sawn timbers range from about 1,800 pounds per square inch in the highest grades of dense species down to 600 pounds per square inch in the lower grades and less dense species. Fifty-ton bearing values on piles of minimum size can far exceed the maximum stress values if most of the load is carried in bearing at the tip of the pile.

Round timber piles are subjected to impact compressive stress in driving that may exceed the static stresses. At present, little is known about the compressive strength of wood under impact loading. Techniques for observing stresses during driving of piles are complex, and the determination of impact strength of full-size pile sections is difficult; however, the impact strength of 1- by 1-inch small clear specimens is readily determined and can possibly be used to give an indication of the impact strength of full-size piles.

Wood piles in marine structures project above the surface of the ground, where they are subjected to lateral loading from wind, waves, or moving vessels. Wharf or fender piles are designed to absorb the energy of collision of a moving vessel without damage to the piles or the vessel. Piles in many railway or highway bridges also project above ground, where they resist

---

[1] This research was was conducted in cooperation with the American Wood Preservers Institute.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

lateral forces from wind, stream flow, or from the braking or centrifugal forces of moving vehicles. Sometimes piles are driven through strata that provide little or no lateral support, in which case they must be designed as long or intermediate columns. Therefore, to design piles for all possible uses, compression parallel to grain strength, bending strength, and modulus of elasticity in bending are all important qualities.

Published information on the strength of timber piles is extremely limited. Pile specifications do not contain specific or required strength values. Occasionally, codes and design specifications give recommended or allowable working stresses in compression parallel to grain, but these may range from 800 to 1,200 pounds per square inch for the same species and grade of pile.

These circumstances clearly indicated the need for a study of the compressive and bending strength values of round limber piles. Accordingly, the U.S. Forest Products Laboratory, in cooperation with the American Wood Preservers Institute (AWPI), conducted a research program in this specific field.

This report is presented in two parts. Part 1 gives the results of strength tests of three species of round timber piles. Part 2 gives the results of a second study to determine the effect of kiln-drying on the strength of southern pine piles.

BASIC REFERENCES AND SPECIFICATIONS

A basic reference on the design of pile foundations is by Chellis (7).[3] In this text, thefollowing items are discussed--the forces that a pile must withstand, such as direct load, impact, and bending forces; conditions of support in the different soil strata; conditions of fixity due to caps and bracing; the driving of timber piles; and related problems. Recommended working stresses for timber piles, however, are not given.

Alexander (1) discusses the function of a pile, differences in pile specifications, and many other related factors, including: Relative strength and stiffness of various wood species (in static bending) used for piles; vertical or lateral static and impact loading; imposed stresses in bending, tension, and compression: types of support. required for piles; and the effect of preservative treatment on mechanical strength. In an article by Wilson (12), the same general factors are discussed and some recommended limitations on the size of knots and spiral grain are given.

Many load tests, such as those reported by the American Wood Preservers Institute (6) , have been conducted on timber piles. From these tests, design loads of 40 to 50 tons have been determined as safe. Loads up to 150 tons have been imposed on many of the piles before failure.

Specifications for timber piles are given in the American Society for Testing and Materials (ASTM) Standard D 25-58 (3). Dimensions for classes A, B, and C piles are presented, as well as limitations on knots, spiral grain, and crook. However, methods to determine allowable stress are not given.

A few of the building codes give allowable stresses for timber piles but values vary among the individual codes. For example, the National Building Code (2) allows 850 pounds per square inch in compression for such species as Douglas-fir (Mountain region) and western hemlock, and 1,200 p.s.i. for Douglas-fir (Coast region), oak, and southern pine; the Uniform Building Code (8) allows 60 percent of the basic stresses as presented in ASTM D 245 with a maximum of 1,000 p.s.i.; and the Southern Standard Building Code (9) allows 1,200 p.s.i. for Douglas-fir, southernpine, and oak.

PART 1: STRENGTH EVALUATIONS

Objective of Study

This research was designed to evaluate the static and impact compressive strength parallel to grain on small clear specimens and the compressive strength, static bending strength. and modulus of elasticity in bending of creosote-treated Douglas-fir, southern pine, and red oak piles.

---

[3] Underlined numbers in parentheses refer to Literature Cited at the end of this paper.

Specimen Material

The species selected lor this study--Douglas-fir, southern pine, and red oak--were chosen as being the more popular of the species used for timber piles. Fifteen class B piles, 50 feet in length, were evaluated for each of the three species. All were pressure-treated with creosote, and had a moisture content above fiber saturation. The Douglas-fir, southern pine, and red oak piles were obtained from commercial treating plants in Washington, Mississippi, and Illinois, respectively.

Quality

Upon receipt, the piles were checked to assure conformance with the requirements for class B piles as set forth in ASTM Standard D 25-58 (3). Table 1 gives class B size requirements for 50-foot piles, and measurements of the average and range of diameters of the specimens. All of the Douglas-fir, 13 of the oak, and 12 of the southern pine met or exceeded the size requirements for class B piles.

The Douglas-fir and southern pine piles were clean-peeled (machine-peeled) and had a fairly uniform taper. The red oak piles were rough-peeled (hand-peeled) and had a rather ragged appearance and nonuniform taper. All piles met the requirements for straightness.

All knots were measured. In class B piles, 50 feel or less in length, sound knots shall be no larger than 4 inches or one-third the diameter of the pile at the point where they occur, whichever is the smaller; also, the sum of all knots in any foot of pile length shall not exceed twice the size of the largest permitted single knot.

The largest single knot and the largest sum of knots for each pile are given in table 2. Ten of 15 southern pine, all the Douglas-fir, and only 5 of the 15 red oak piles met the requirements for single knot size. At times, the extent of a knot was difficult to determine for the oak piles because of the rough peeling. Fourteen of 15 southern pine, 4 of 15 Douglas-fir, and 13 of 15 red oak piles did not meet the requirement for summation of knot sizes. In most instances, the large knots were located in that portion of the length toward the tip end. ASTM D 25-58 permits larger knots in this portion of the length in piles over 50 feet in length; thus, the piles used in this study were on the border between two different requirements as to knot sizes.

The piles were also examined for spiral grain and were found to conform to the requirements of ASTM D 25-58 in this regard; thus, spiral grain was not considered to have any effect on the results of this study.

Preservative Treatment

According to the records furnished by the preservative treating plants, all piles were creosote-treated in accordance with the American Wood-Preservers' Association specification AWPA C3-64 (5). The treating, records indicate

Table 1.--Diameters of 50-foot pile specimens compared to the requirements of ASTM D 25-58 for Class B piles

Species	Tip diameter			Diameter 3 feet from butt			
	Specification	Actual		Specification		Actual	
	Minimum	Average	Range	Minimum	Maximum	Average	Range
	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Douglas-fir	7	8.36	7.51 to 9.54	12	20	12.42	12.06 to 12.75
Southern pine	7	7.22	6.68 to 7.67	12	20	13.17	12.26 to 14.56
Red oak	6	8.66	7.45 to 10.17	13	20	14.06	12.40 to 16.80

Table 2.--Summary of knot sizes in 53-foot piles[1]

Pile No.	Single knot		Sum of knots in 1 foot of length	
	Largest knot diameter	Pile diameter at knot	Largest sum of knot diameters	Pile diameter at knots
	Inches	Inches	Inches	Inches
		SOUTHERN PINE		
1	2.50	7.8	6.75	8.9
2	2.50	10.3	9.50	8.6
3	3.50	9.6	10.50	7.0
4	2.00	8.4	4.50	8.0
5	2.25	8.4	6.00	8.4
6	2.75	7.6	7.25	7.6
7	2.50	8.0	8.00	10.8
8	2.50	8.2	8.50	9.1
9	2.75	10.2	7.00	7.8
10	3.00	7.6	6.75	8.7
11	2.75	9.3	8.25	9.7
12	2.75	9.6	6.75	9.6
13	2.50	12.2	5.50	7.9
14	4.00	8.7	6.50	8.8
15	3.50	8.1	5.75	7.7
		DOUGLAS-FIR		
1	1.50	8.6	5.75	10.0
2	2.00	8.3	9.00	8.3
3	1.25	9.0	4.25	9.6
4	.75	9.8	2.75	9.8
5	2.00	9.0	7.50	9.0
6	1.00	9.6	2.75	11.0
7	1.75	8.6	7.00	8.6
8	1.00	8.5	4.50	8.9
9	1.00	7.9	5.25	8.2
10	.75	9.1	3.00	9.1
11	1.25	8.9	5.00	11.4
12	.75	9.3	2.50	9.9
13	2.00	8.8	8.50	8.8
14	1.50	9.9	6.50	10.7
15	1.50	8.3	5.25	9.8
		RED OAK		
1	4.00	9.7	10.00	9.7
2	3.50	11.3	9.00	11.3
3	2.00	8.9	6.00	8.9
4	3.00	7.4	8.00	7.4
5	2.50	8.0	6.25	7.8
6	3.50	9.4	6.50	9.4
7	5.00	10.3	16.00	10.3
8	2.50	7.8	5.50	8.2
9	2.50	7.5	5.50	7.6
10	4.00	10.8	13.25	10.8
11	5.00	8.0	7.38	8.0
12	3.00	8.7	5.50	8.7
13	6.00	10.7	8.50	9.1
14	3.25	9.3	8.50	9.6
15	3.50	9.6	8.50	9.6

---

[1] The requirements for knots in Class B piles, 50 feet in length, as established in ASTM D 25-58 are: (1) Sound knots shall be no larger than 4 inches or one-third the diameter of the pile at the point where they occur, whichever is the smaller; and (2) the sum of sizes of all knots in any foot of length of the pile shall not exceed twice the size of the largest permitted single knot.

that the southern pine piles were steam conditioned at 245° F. for 15 hours. This conditioning has been shown to reduce the modulus of rupture of southern pine (13). The piles were treated at a pressure of 200 p.s.i. and at a temperature of 200° F. for 3 hours. This resulted in a net creosote retention of 12.25 pounds per cubic foot, compared to a required retention of 12 pounds per cubic foot. The sapwood was completely penetrated.

The Douglas-fir piles were conditioned in the preservative at a temperature of 190° F. and 22 inches of vacuum for 14 hours. Treatment was at 180° F. and 140 pounds per square inch pressure for 3.25 hours. The net retention was 12.55 pounds per cubic foot, as compared to a required relention of 10 pounds per cubic foot. The depth of treatment was at least 0.75 inch, and penetration was fairly uniform.

The oak piles had a net retentionof 11.3 pounds per cubic foot, as compared to the required retention of 6 pounds per cubic foot. The sapwood was completely penetrated. No record of treatment was obtained for this group of piles.

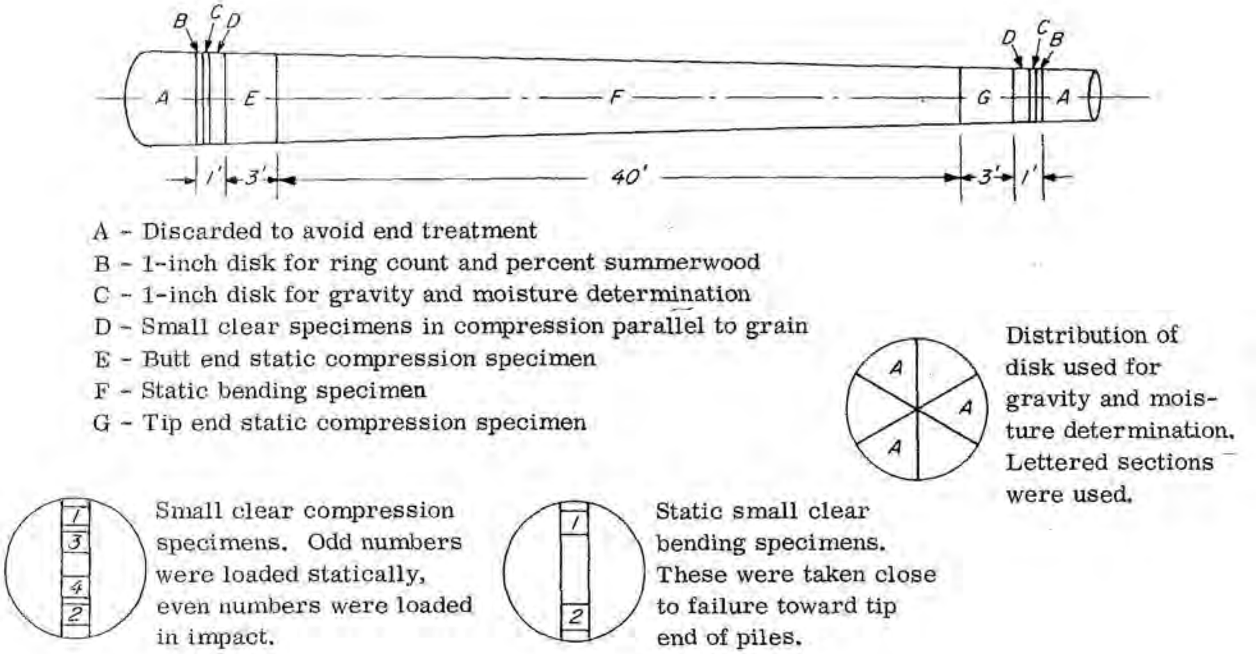
Specimen Preparation

Figure 1 shows the cutting diagrams for obtaining specimens from the piles. A 3-foot compression specimen was obtained from both the butt and tip end of each pile. The center 40 feet of each pile was evaluated in static bending. Before testing, the location and size of knots were determined, specimens weighed, and moisture readings taken with an electrical-type moisture meter to make sure that each specimen was at a moisture content above the fiber-saturation point.

Small clear straight-grained specimens, 1 by 1 by 4 inches, were obtained from a portion of the pile adjacent to the pile compression specimens (fig. 1). Those obtained from one side of the pith were loaded statically to obtain their crushing strength and modulus of elasticity. Specimens from the other side of the pith were evaluated under impact loading.

Small clear bending specimens, 1 by 1 by 16 inches, were then from each pile after failure.

Figure 1 .--Cutting diagrams for obtaining specimens from piles. M 130 961



A - Discarded to avoid end treatment
B - 1-inch disk for ring count and percent summerwood
C - 1-inch disk for gravity and moisture determination
D - Small clear specimens in compression parallel to grain
E - Butt end static compression specimen
F - Static bending specimen
G - Tip end static compression specimen

Distribution of disk used for gravity and moisture determination. Lettered sections were used.

Small clear compression specimens. Odd numbers were loaded statically, even numbers were loaded in impact.

Static small clear bending specimens. These were taken close to failure toward tip end of piles.

They were obtained as close to the failure as possible, usually toward the tip end of the pile. One specimen was taken from the tension side of the pile and one from the compression side, as shown in figure 1.

Test Methods

The development of special procedures and test methods was necessary to determine the strength properties of full-size pile sections in compression parallel to the grain and in bending, because standard test methods have not as yet been established. The procedures and test methods used in this study for determining compressive and bending strengths, and also specific gravity and ring count, are described fully in the following three subsections.

Compressive Strength

In developing a method for testing full pile sections in compression parallel to grain, a series of exploratory tests was made to study test variables that could affect the strength. The possible effect of lateral earth pressure was studied first. Using small clear specimens (11), it was found that lateral pressures of the magnitude to which piles are subjected had no significant effect upon the maximum crushing strength, proportional limit fiber stress, or modulus of elasticity in compression parallel to the grain for either Douglas-fir or red oak. The investigation of the effect of different end-bearing conditions on the test specimen indicated that placing a hard rubber mat on each end tended to cause a separation between the summerwood and springwood, resulting in a reduction in the compressive strength. More realistic failures and higher strength values were obtained using steel bearing plates on each end. From these exploratory studies it was decided to evaluate the pile sections without lateral pressure and with steel bearing plates. Before loading, the specimens were banded on both ends with 3/4-inch steel strapping (fig. 2).

The method of loading pile sections for evaluation of compressive strength parallel to the grain is shown in figure 3. The 16-inch-square rockers were installed at 90° to each other to compensate for any nonparallelism of the ends

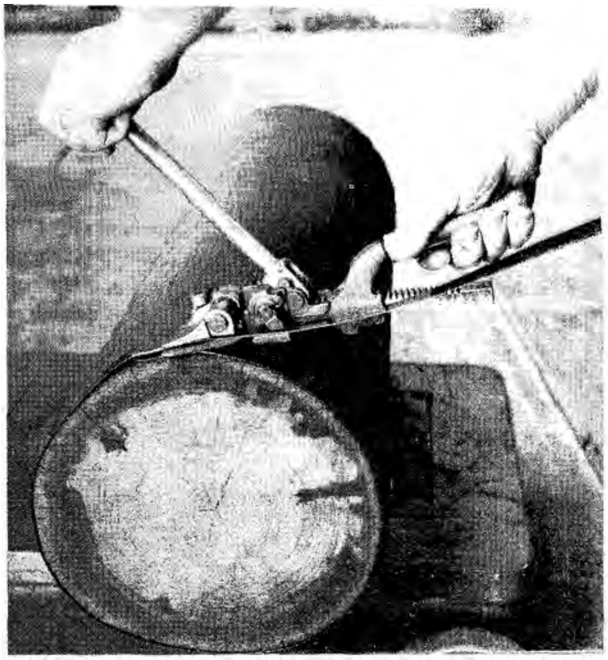
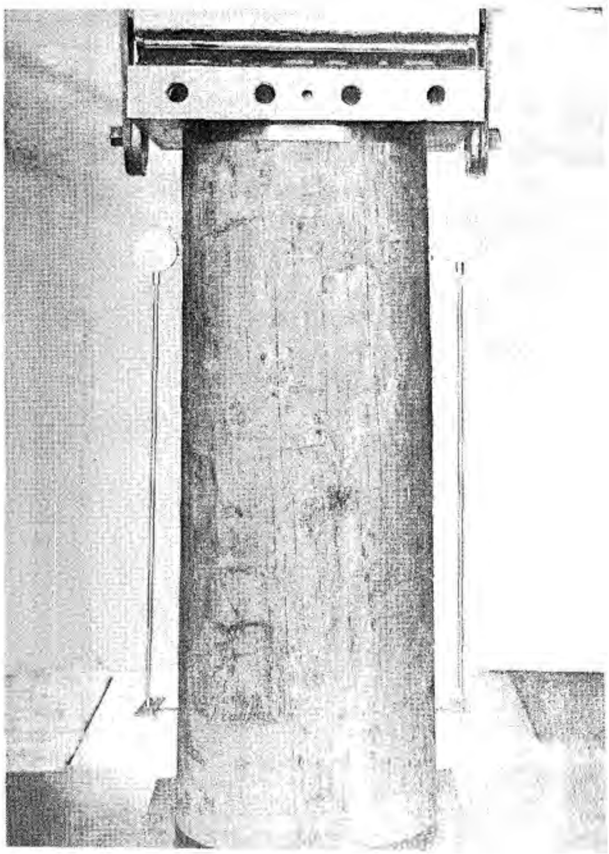


Figure 2.--Banding of pile compression specimens with 3/4- inch steel strapping to prevent brooming of ends during loading.

M 129 886

Figure 3.--Method of loading pile sections for evaluation of compressive strength parallel to the grain.

M 129 885



of the specimens. This insured full bearing on both ends of the specimens. Load was applied at a constant head movement rate of 0.028 inch per minute. Strains were measured over a 24-inch gage length, using two dial indicators reading to 0.0001-inch.

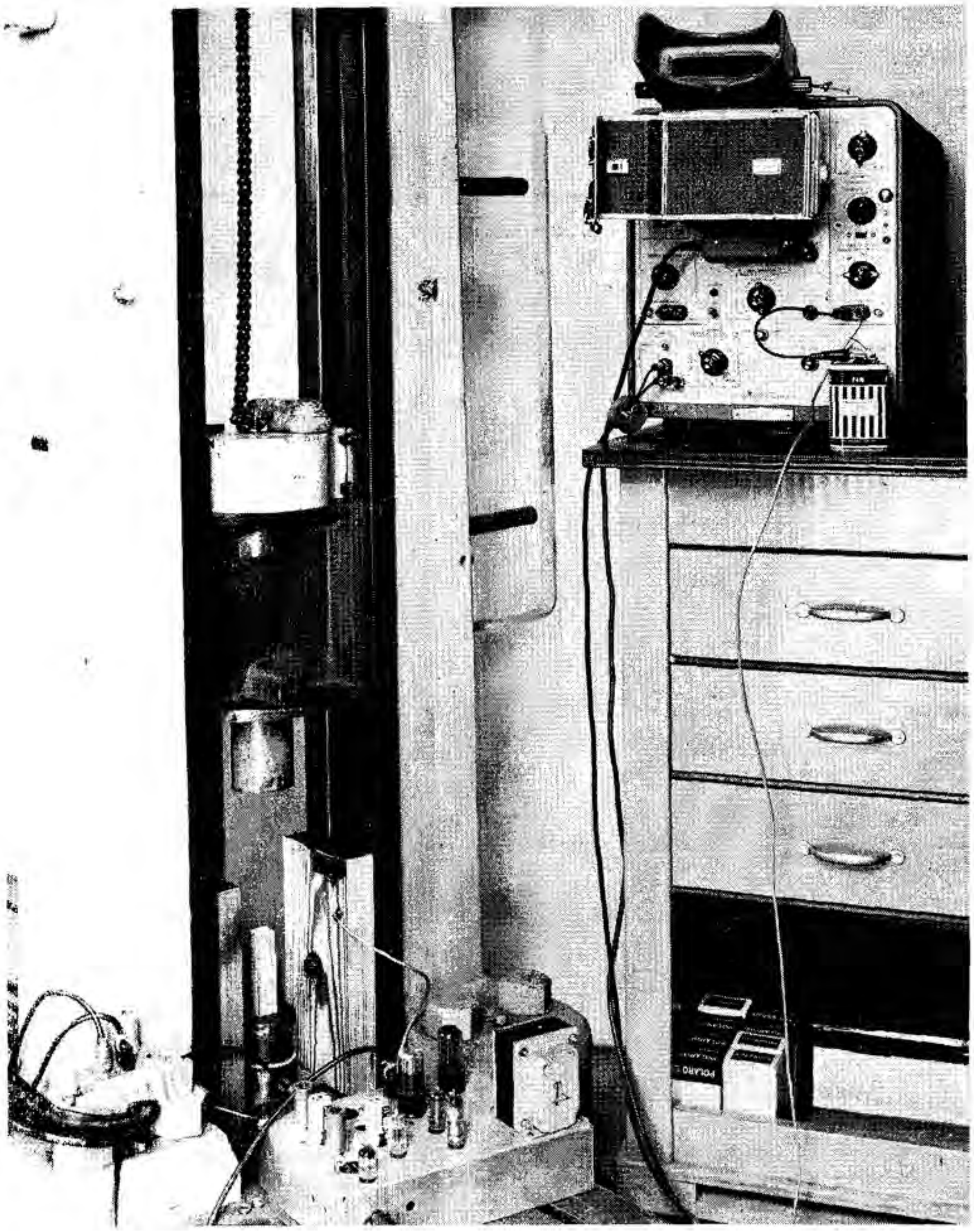
The arrangement of equipment for impact loading of 1- by 1-inch specimens is shown in figure 2. A 51-pound weight was dropped from a height sufficient to cause failure of the specimen with a single drop. Load was measured with a capacitance-type load cell. The oscilloscope trace of load versus time was recorded on film.

Bending Strength

A nearly constant stress between the load points was desired for the bending strength determination. This was accomplished by making the loads proportional to the section modulus at each load point. The section moduli were based on the

Figure 4.--Arrangement for impact loading of 1- by 1-inch specimens. A I51-pound weight was dropped from a height sufficient to cause specimen failure with a single drop. Load was measured with a capacitance-type load cell.

M 130 505



average taper of all the piles. This proportioning resulted in the theoretical stress distribution from imposed loading shown in figure 5.

The loading arrangement for the static bending test of 40-foot pile sections on a 36-foot span is shown schematically in figure 5. The quarter-point loads were applied through double I-beams 20 feet in length. The load from the testing machine was applied to the I-beams at a distance of 6.65 feet from the load point nearest the butt end of the pile. This resulted in the proper proportioning of the loads. An upward counterbalancing force was applied to the long portion of the I-beam, thus eliminating the need for considering the weight of the I-beam in pile strength calculations. Allowance was made for the shortening of the span as the pile was loaded by providing for horizontal movement at both reactions and at one of the load points. Load was applied through continuous motion of the movable head of the testing machine at a rate of 0.773 inch per minute. The tip reaction of the pile was accurately measured by a hydraulic load cell reading to the nearest 5 pounds. Deflections were measured at each of the load points with scales and a taut wire as outlined in ASTM D 198-67 (4).

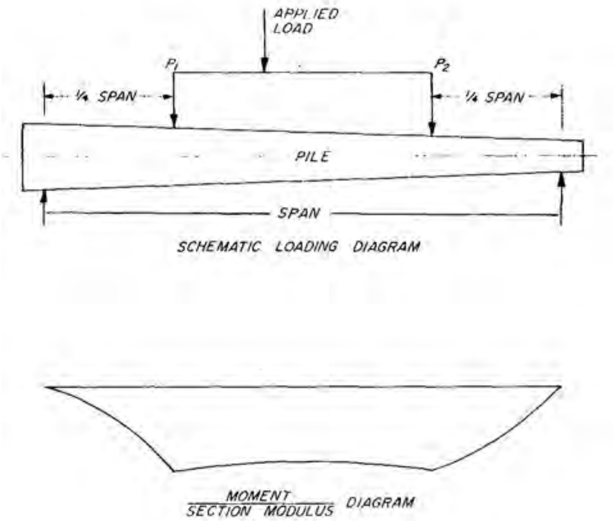


Figure 5.--Theoretical stress distribution from imposed loading in pile bending test. P_1 was made larger than P_2 according to the average section modulus at each load point.

M 130 962

Specific Gravity and Ring Count

Two 1-inch disks were obtained from each end of the piles. One of the disks was used to measure percent summerwood and ring count. The other disk was divided into six pie-shaped sections (fig. 1); alternate sections were used for specific gravity determinations. Volumes were obtained by immersion, and weight of wood substance was determined by extracting the creosote and water from the specimens.

Discussion of Results

Compressive Strength Parallel to the Grain

The results of the parallel to the grain strength tests of 3-foot sections from the butt and tip ends of each pile are presented in tables 3 through 8. The three species had these average crushing strengths:

	Tip (p.s.i.)	Butt (p.s.i.)
Red oak	3,460	3,620
Douglas-fir	2,960	3,590
Southern pine	1,820	2,950

There was considerable difference between the crushing strengths of the butt and tip ends of the piles. The average difference ranged from 1,130 p.s.i. for the southern pine to 160 p.s.i. for the red oak. The butt ends were always the stronger. This difference can be attributed partially to the difference in specific gravity between the butt and tip ends of the piles, The average specific gravity values for each species were:

	Tip	Butt
Red oak	0.67	0.62
Douglas-fir	.47	.51
Southern pine	.48	.53

The tip sections of red oak piles had higher specific gravity values on the average than the butt ends. In general, this is characteristic of hardwoods.

Table 3.--Results of compression parallel to grain tests of 3-foot sections from the butt end of southerrn pine piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
PB 1	53	75	0.56	148	11.36	12.65	154	3,040	1,960
PB 2	40	92	.54	168	11.91	12.76	157	2,830	1,540
PB 3	48	97	.50	198	13.22	13.65	186	2,720	1,550
PB 4	42	100	.54	185	12.45	13.10	174	2,860	1,610
PB 5	41	93	.54	185	12.75	13.30	198	3,100	3,080
PB 6	36	104	.52	164	12.40	12.55	180	2,980	1,990
PB 7	41	91	.52	196	13.66	14.00	237	3,230	1,660
PB 8	30	81	.56	166	12.40	13.01	170	2,820	1,220
PB 9	31	98	.41	172	12.35	13.02	158	2,650	1,420
PB 10	32	94	.54	197	12.69	14.12	149	2,360	700
PB 11	43	105	.50	185	13.02	13.15	200	3,000	2,160
PB 12	43	107	.49	190	12.92	13.87	207	3,160	2,190
PB 13	46	94	.52	194	12.95	13.80	187	2,840	1,960
PB 14	35	75	.60	176	12.00	13.15	181	3,210	2,010
PB 15	43	92	.58	172	12.00	13.15	191	3,390	2,050
Average	40	93	.53	180	12.54	13.28	182	2,950	1,810

---

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

Table 4.-.-Results of compression parallel to grain tests of 3-foot sections from the tip end of southern pine piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
PT 1	25	65	0.54	48	7.05	7.50	37	1,940	1,200
PT 2	15	96	.47	50	6.72	7.74	29	1,660	840
PT 3	20	111	.45	54	6.85	7.62	25	1,380	890
PT 4	25	100	.52	64	7.56	8.05	42	1,910	1,130
PT 5	24	110	.50	61	7.41	7.80	43	2,030	1,310
PT 6	17	106	.46	51	7.50	7.80	43	1,970	1,230
PT 7	22	88	.52	64	7.65	8.37	50	2,200	960
PT 8	17	76	.47	58	7.98	8.36	50	2,000	1,380
PT 9	17	110	.42	50	7.37	8.18	36	1,730	1,190
PT 10	18	96	.48	56	7.53	7.97	36	1,640	960
PT 11	20	118	.43	46	6.94	7.47	32	1,730	1,090
PT 12	23	117	.45	62	7.75	8.19	49	2,090	1,140
PT 13	25	125	.45	64	7.68	8.14	46	2,010	1,050
PT 14	21	76	.58	71	8.54	8.85	47	1,660	1,080
PT 15	24	110	.47	52	6.95	7.43	40	1,400	1,090
Average	21	100	.48	57	7.43	7.96	40	1,820	1,100

---

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

Table 5.--Results of compression parallel to grain tests at 3-foot sections from the butt end of douglas-fir piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
DB 1	54	56	0.49	110	11.90	12.10	184	3,310	2,580
DB 2	33	87	.42	117	12.11	12.70	167	2,900	1,770
DB 3	81	55	.51	102	12.08	12.37	163	2,860	1,360
DB 4	100	69	.53	126	12.00	12.42	224	3,970	2,900
DB 5	96	61	.49	118	12.16	12.72	214	3,690	2,270
DB 6	88	59	.53	126	12.18	12.35	248	4,260	2,710
DB 7	84	71	.48	118	12.42	12.75	212	3,510	2,040
DB 8	44	27	.64	116	11.90	12.27	210	3,780	2,140
DB 9	52	58	.56	134	11.87	12.67	229	4,150	2,840
DB 10	90	69	.50	117	12.25	12.60	222	3,770	2,160
DB 11	46	61	.46	101	11.50	12.27	189	3,640	1,930
DB 12	96	48	.56	127	11.85	12.40	243	4,420	2,340
DB 13	47	54	.52	128	12.45	12.62	201	3,300	1,720
DB 14	57	65	.47	118	11.95	12.52	173	3,090	2,420
DB 15	48	51	.51	117	12.30	12.50	191	3,220	1,820
Average	68	59	.51	118	12.06	12.48	205	3,590	2,200

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

Table 6.--Results of compression parallel to grain tests of 3-foot sections from the tip end of Douglas-fir piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
DT 1	36	95	0.52	56	8.58	8.62	65	2,270	1,540
DT 2	17	122	.38	54	8.09	8.55	65	2,330	1,400
DT 3	48	52	.38	52	8.94	9.15	89	2,850	1,760
DT 4	76	74	.42	64	9.75	9.84	129	3,460	1,880
DT 5	73	57	.50	61	8.84	9.20	100	3,280	1,770
DT 6	62	69	.47	73	9.55	9.72	144	3,420	1,870
DT 7	51	70	.42	49	7.82	8.51	66	2,090	1,080
DT 8	24	56	.51	54	8.25	8.70	75	2,810	2,010
DT 9	29	75	.57	50	7.80	8.07	79	3,320	1,750
DT 10	66	53	.44	58	8.95	9.30	99	3,160	1,830
DT 11	30	58	.43	43	7.90	8.30	85	3,490	1,790
DT 12	68	62	.48	64	9.22	9.38	110	3,300	2,250
DT 13	25	89	.45	50	7.65	8.20	59	2,580	1,560
DT 14	44	89	.60	61	8.65	8.85	97	3,310	1,650
DT 15	26	85	.42	57	8.03	8.64	66	2,630	1,480
Average	45	74	.47	56	8.53	8.94	88	2,960	1,710

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

Table 7.--Results of compression parallel grain tests of 3-foot sections from the butt end of red oak piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
OB 1	35	78	0.63	248	14.50	15.60	299	3,630	2,090
OB 2	43	78	.63	212	13.68	14.05	249	3,400	1,890
OB 3	38	77	.63	198	13.38	14.55	257	3,620	1,680
OB 4	37	78	.61	182	12.27	14.75	219	3,700	2,160
OB 5	38	73	.63	176	12.55	14.10	220	3,560	1,870
OB 6	39	82	.59	190	12.80	13.60	236	3,680	1,910
OB 7	38	85	.60	314	16.20	17.21	367	3,570	1,980
OB 8	39	81	.62	168	12.05	13.00	220	3,870	2,100
OB 9	43	75	.63	186	12.22	13.12	199	3,400	2,340
OB 10	45	75	.60	254	14.52	16.00	297	3,600	1,760
OB 11	44	69	.64	183	12.15	13.50	221	3,810	2,200
OB 12	39	83	.62	216	13.32	14.30	242	3,470	2,300
OB 13	39	69	.64	238	14.25	15.50	321	4,030	3,460
OB 14	38	62	.69	200	12.95	14.25	231	3,520	2,200
OB 15	44	83	.59	222	13.75	14.87	252	3,400	1,920
Average	40	77	.62	212	13.37	14.56	255	3,620	2,120

---

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

Table 8.--Results of compression parallel to grain tests of 3-foot sections from the tip end of red oak piles

Specimen No.	Number of annual rings (from pith to bark)	Moisture content[1]	Specific gravity[2]	Weight	Diameter Top	Diameter Bottom	Maximum load	Crushing strength[3]	Modulus of elasticity
		Percent		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
OT 1	25	61	0.72	109	9.62	9.72	134	3,700	1,450
OT 2	28	64	.71	91	8.55	9.00	106	3,710	1,490
OT 3	25	78	.63	87	8.80	8.90	95	3,150	1,420
OT 4	24	79	.62	60	7.34	7.62	68	3,240	1,370
OT 5	26	76	.63	69	7.70	8.60	75	3,220	1,730
OT 6	26	64	.69	99	8.75	9.75	114	3,800	1,460
OT 7	23	76	.66	130	10.20	10.42	130	3,200	1,420
OT 8	27	59	.72	72	7.40	8.30	80	3,760	1,670
OT 9	30	79	.63	68	7.40	7.80	70	3,290	1,430
OT 10	30	61	.71	127	10.15	10.88	136	3,370	1,490
OT 11	32	64	.69	82	7.77	8.30	80	3,380	1,860
OT 12	25	68	.68	94	8.58	9.51	103	3,570	1,850
OT 13	25	57	.72	96	9.00	9.80	116	3,650	1,740
OT 14	25	67	.58	85	8.60	9.10	108	3,720	1,780
OT 15	32	70	.66	106	9.50	9.80	113	3,210	2,060
Average	27	68	.67	92	8.62	9.17	102	3,460	1,610

---

[1] Moisture content was determined by extraction.

[2] Specific gravity was based on green volume and ovendry weight of extracted specimens.

[3] Crushing strength was determined using the area of the small end of the specimen.

The remainder of the difference in crushing strength between butt and tip sections may be related to the difference in size and number of knots. As previously stated, the largest concentration of knots was found toward the tip end of the piles. The averages of the largest single knots and the averages of summation of knots in 1 foot of length for the pile compression specimens of each species are given in table 9. The effect of knots on the crushing strength of the red oak piles was partially counteracted by the higher specific gravity of the tip sections; thus, the red oak butt and tip sections had crushing strengths that were nearly equal.

Table 9.--Average knot sizes for pile compression specimens

Species	Average of largest single knot diameters		Average of largest summation of knot diameters in 1 foot of length	
	Tip	Butt	Tip	Butt
	Inches	Inches	Inches	Inches
Douglas-fir	1.25	0.50	4.50	1.5
Southern pine	2.25	0	5.75	0
Red oak	3.25	.75	7.75	1.75

The values of crushing strengths for the southern pine piles were considerably less than those for the other two species. The lower values may be due to the 15 hours of steam conditioning at 245° F. In the ASTM wood pole research program (13), compression parallel to grain tests of small clear specimens from longleaf pine poles showed that this conditioning caused a 15 to 25 percent loss in strength. An increase of 25 percent in the crushing strength values of the southern pine piles would make them compare quite favorably to those for the Douglas-fir piles. Under most conditions, these two species have similar strength properties.

Modulus of elasticity in compression parallel to the grain was obtained for each of the pile specimens. Again, as with the crushing strengths, the butt sections had higher values than the tip sections. The average values for the three species were:

	Tip (p.s.i.)	Butt (p.s.i.)
Red oak	1,610,000	2,120,000
Douglas-fir	1,710,000	2,200,000
Southern pine	1,100,000	1,810,000

Modulus of elasticity value of a few of the specimens were difficult to obtain because of the lack of a linear portion in the load compression curve. This nonlinearity could possibly be attributed to the knots, which act as semihinges. A typical load-compression curve for 3-foot pile sections is shown in figure 6.

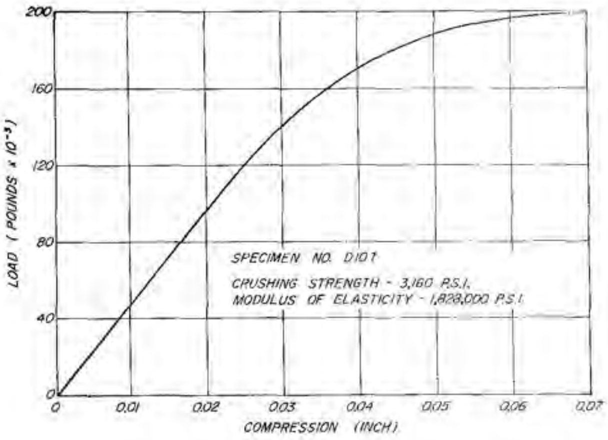


Figure 6.--Typical load-compression curve for 3-foot pile sections.

M 130 963

The number of annual rings from the pith to the bark was obtained for each compression specimen and is given in tables 3 through 8. The number of rings shows that the Douglas-fir piles came from older trees than did the piles of the other two species; also, that the Douglas-fir piles had a greater difference in the number of rings in the butt and tip sections. The Douglas-fir piles had an average of 68 rings for the butt sections and 45 rings for the tip sections. Red oak piles averaged 40 rings for the butt sections and 27 rings for the tip sections, while the southern pine piles averaged 40 rings for the butt sections and 21 rings for the tip sections. Typical cross sections used in obtaining these ring counts are shown in figure 7.

Typical failures of pile compression specimens are shown in figures 8 and 9. In general, the tip sections failed by crushing of the fibers around and between knots. The butt sections either failed by crushing of the fibers around a knot, when a knot was present, or on a 45° shear plane. Some of the butt specimens failed by crushing of the fibers near the steel banding on the small end of the specimen.

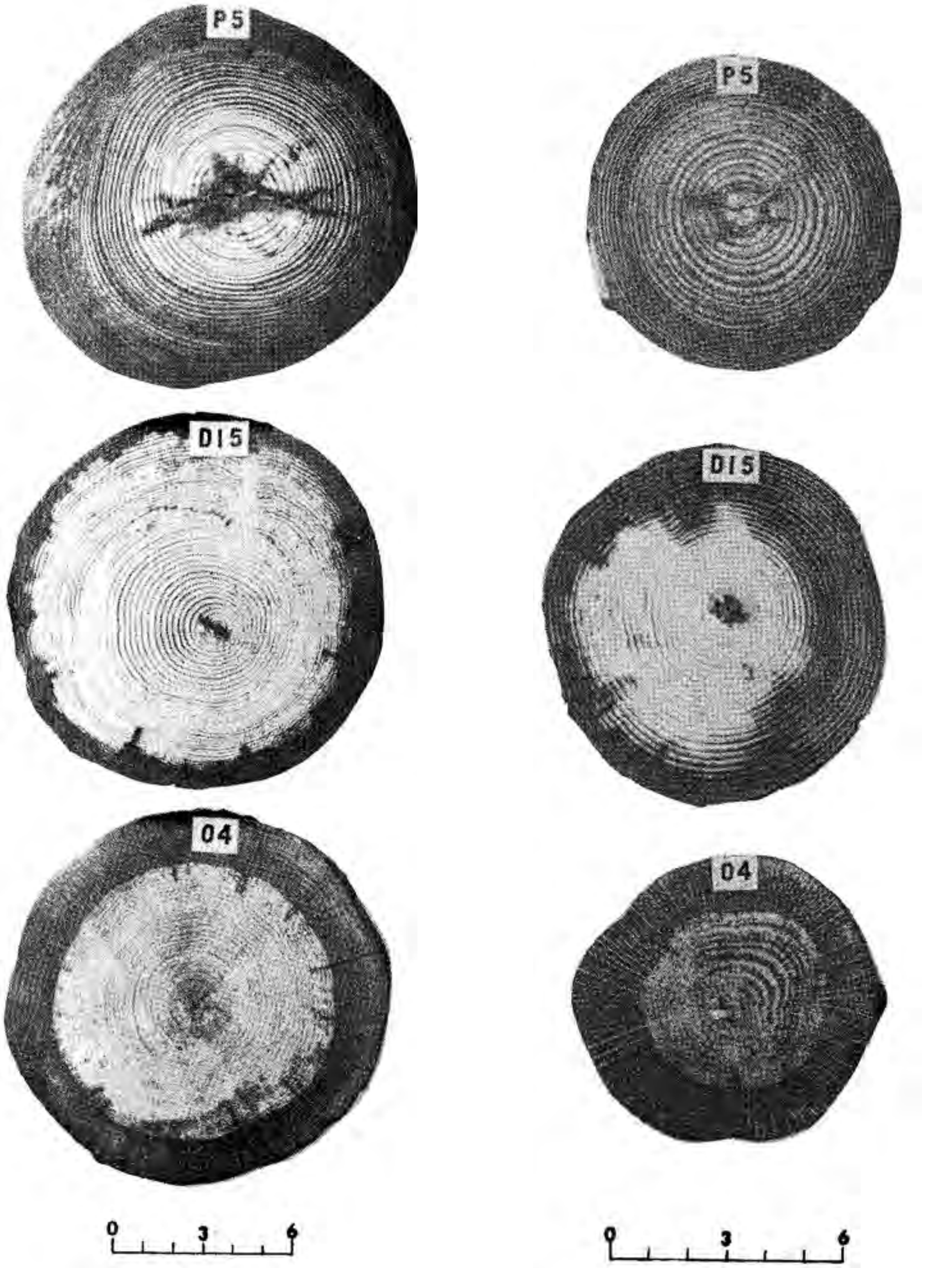


Figure 7.--Typical cross sections from butt end (left) and tip end (right) of test piles. The top row (P5) is southern pine, center row (D15) is Douglas-fir, and bottom row (04) is red oak.

M 130 967

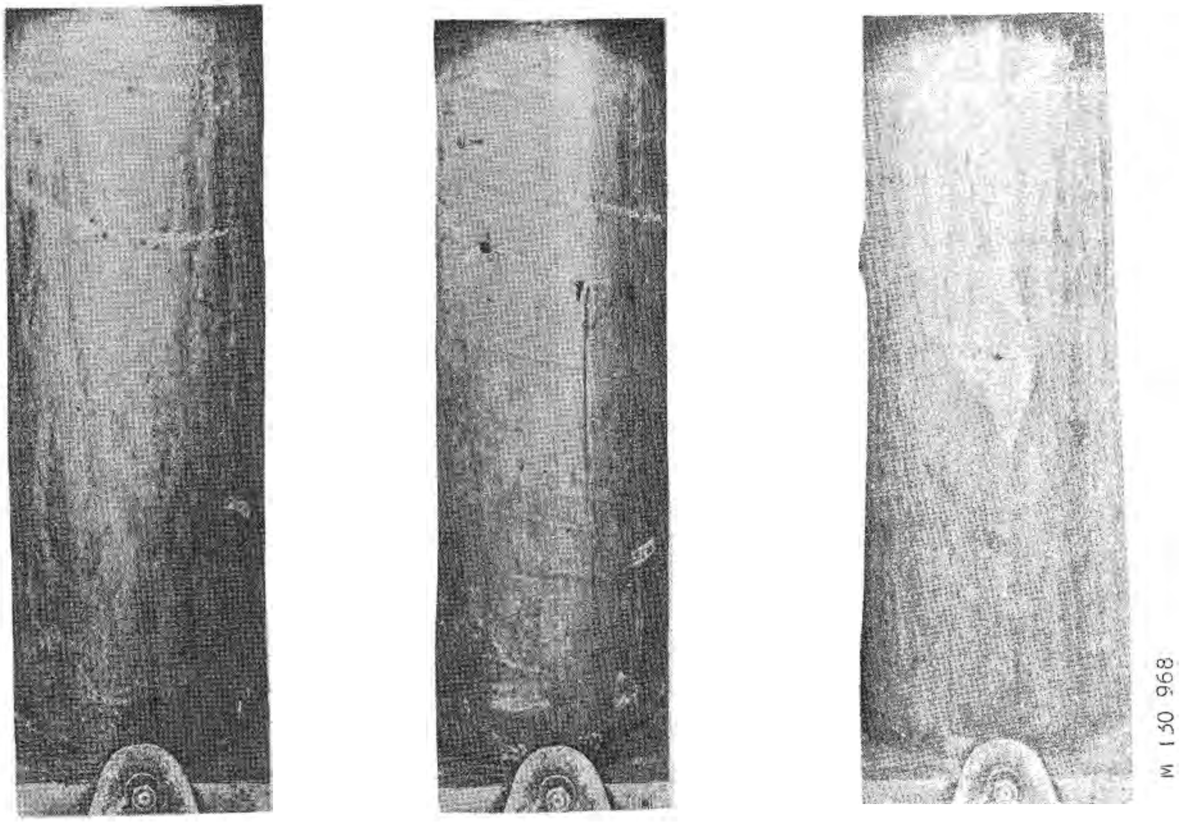
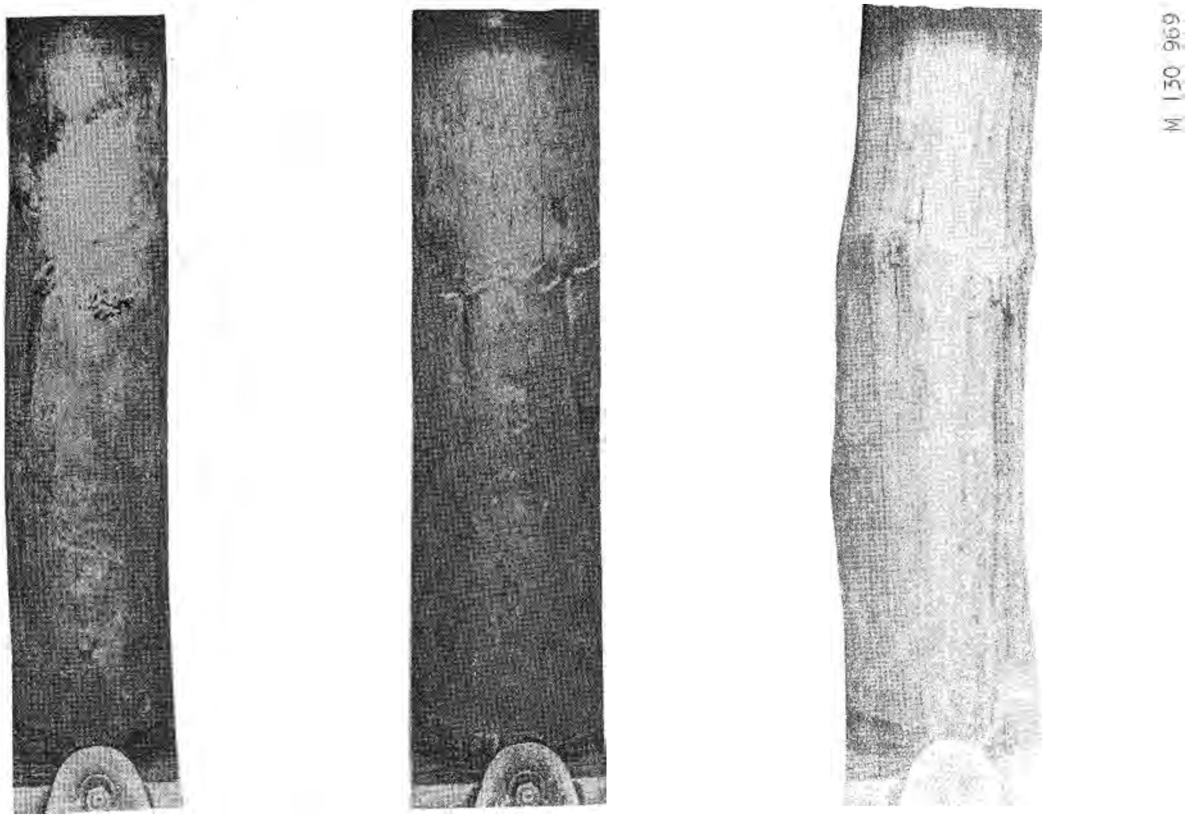


Figure 8.--Typical compression failures in butt sections of test piles: (left) southern pine, specimen P6; (center) Douglas-fir, specimen D8; and (right) red oak, specimen 011.

Figure 9.--Typical compression failures in tip sections of test piles: (left) southern pine, specimen P13; (center) Douglas-fir. specimen D10; and (right) red oak, specimen 02.



Compressive Strength of Small Clear Specimens

Small clear specimens, 1 by 1 inch in cross section, were evaluated under static and impact loading. These loadings were made on specimens taken from opposite sides of the pith (see fig. 1). The specimens were matched so they contained the same annual rings.

In table 10, the results for the small clear specimens are resented and compared with the results obtained on the full-size pile sections. All specimens were tested at a moisture content above the fiber saturation point. Specific gravity values were not obtained for the small clear specimens.

The static compressive strengths for the pile sections were 2 to 15 percent less than for the small clear specimens. The larger differences were for the tip sections. This was expected, since the largest concentration of knots was in the tips. A comparison of the values for the tip and butt sections of each species shows the effect of specific gravity. The butt specimens had higher compressive strength than the tip specimens for Douglas-fir and southern pine, while the tip specimens had the higher compressive strength for the red oak. This was in the same relation as the specific gravities of butt and tip pile sections.

The moduli of elasticity (E values) in compression of the pile tip sections and their small clear specimens were nearly the same. The pile butt sections, however, had considerably higher **E** values than their small clear specimens. Part of the reason for the lower E's of the small clear specimens may be due to the way they were selected from the cross section (fig. 1). It has been found that the stiffer and stronger material in a tree is toward the outside, and this outside portion represents a large percentage of the cross section of a pile. The small clear specimens tested in this study contain a larger percentage of the weaker inner part of the cross section than is contained in the pile, since only two small clear specimens could be obtained from a 7-inch-diameter pile.

Maximum impact strengths for 1- by 1-inch specimens were calculated from load versus time plots. A typical plot is shown in figure 10. Measurement of the load on the end of the specimen opposite the applied force resulted in the recording of some internal wave action on the plots; thus, the highest peak was not interpreted

Table 10.--Comparison of properties of small clear compression parallel to grain specimens with those obtained on pile tips and butts[1]

Species	Static compressive strength[2]			Impact compressive strength[2]		Modulus of elasticity[2]		
	Pile	Small clear specimens	Ratio (col. 2/col. 3)	Small clear specimens	Ratio (col. 5/col. 3)[3]	Pile	Small clear specimens	Ratio (col. 7/col. 8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	P.s.i.	P.s.i.		P.s.i.		1,000 p.s.i.	1,000 p.s.i.	
Red oak								
Tip	3,460	4,010	0.85	10,670	2.73	1,610	1,650	0.98
Butt	3,620	3,720	.97	9,680	2.63	2,120	1,640	1.29
Douglas-fir								
Tip	2,960	3,240	.91	6,320	1.86	1,710	1,800	.95
Butt	3,590	3,650	.98	8,920	2.48	2,200	1,940	1.13
Southern pine:								
Tip	1,820	2,020	.90	6,500	3.24	1,100	1,020	1.08
Butt	2,950	3,050	.97	7,380	2.44	1,810	1,250	1.45

[1] All specimens were evaluated at a moisture content above the fiber saturation point.

[2] Values shown are group averages.

[3] Values shown are the average ratios of individual matched specimens (refer to fig. 1) and are not necessarily the ratio of group averages. There were fewer specimens for impact loading than for static loading.

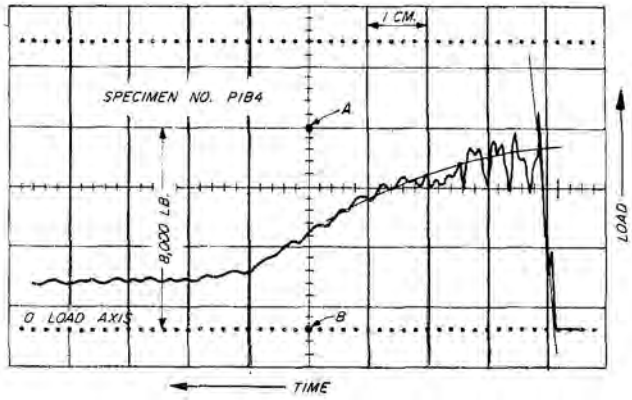


Figure 10.--Typical load-time curve for 1- by 1-inch impact-compression specimens. The sweep time was 0.5 millisecond per centimeter and the calibrated vertical distance between points A and B is equal to 8,000 pounds.

M 130 964

as the maximum applied load. The maximumload was found by drawing smooth curves through the loading and unloading portions, and the intersection of these curves was assumed to be the maximum load. The value of this load was determined by comparison with the calibrated distance shown on the plot.

In comparing the relative strengths of small clear specimens under impact and static loading, the pile material was found to have approximately 2.5 times greater crushing strengthunder impact loading. Actual values ranged from 1.86 to 3.24 times the strength values obtained under static loading. The rate of loading for the impact test was such that the maximum load was reached in approximately 0.25 millisecond. The increase in strength was in general agreement with previous data on the effect of rate of loading and appeared to be independent of species.

Bending Strength

The results of the bending tests on the center 40-foot length of each pile are presented in tables 11 through 13. For all tests, the moisture content of the piles was above the fiber saturation point.

An equation for the bending modulus of elasticity was derived that involved the summation of the two deflections at the load points. The equation is:

$$E = \frac{L^3 R_T}{\pi(\Delta_1 + \Delta_2) D_T^4} \left[\frac{16}{(3 + A)^3} + \frac{(2,756.27 + 4,317.87A + 2,346.67A^2)}{(1 + 3A)^3 (3 + A)^3} + \frac{27.73}{(1 + 3A)^3 A} \right]$$

where E is bending modulus of elasticity,
L is span (in this study, L = 432 inches),
R_T is reaction at the tip end. of the pile,
Δ_1 is deflection at the load point nearest tip,
Δ_2 is deflection at the load point nearest butt,
D_T is diameter of the pile at the tip reaction, and
A is $\frac{D_B}{D_T}$, where D_B is the diameter of the pile at the butt reaction.

This formula is valid only for quarter-point loading and when the loads are proportioned so that the load nearest the butt end is 1.71 times the load nearest the tip end of the pile. A complete derivation of this formula is given in Appendix I.

Modulus of rupture was calculated at each load point. These points were selected because the actual point of failure is difficult to determine in a bending test; also, because the highest stress in the pile should be at one of these points, depending on whether the pile has greater or less taper than the average of all the piles. The formulas for modulus, of rupture are:

At the load point nearest the tip,

$$M\ of\ R_1 = \frac{\left(M_{W_1} + M_1\right) 2,048}{\pi(D_B + 3D_T)^3}$$

where

$$M_{w_1} = 9.075W \left[\frac{7 + A}{4(1 + A)}\right]^2 \left[\frac{A^2 + 14A + 81}{A^2 + 10A + 37}\right]$$

and

$$M_1 = \frac{R_T L}{4}$$

$M \text{ of } R_1$ is modulus of rupture at load point nearest tip,
M_{w_1} is moment at the load point nearest the tip due to weight of the pile,
M_1 is moment at the load point nearest the tip due to imposed loading,
D_B is diameter at the butt reaction,
D_T is diameter at the tip reaction,
W is total weight of the pile,
A is $\frac{D_B}{D_T}$,
R_T is reaction at the tip end of the pile, and
L is span (in this study, L = 432 inches),

At the load point nearest the butt end,

$$M \text{ of } R_2 = \frac{\left(M_{w_2} + M_2\right)2{,}048}{\pi(3D_B + D_T)^3}$$

where

$$M_{w_2} = 2.269W \left[\frac{7A + 1}{1 + A}\right]^2 \left[1 - \frac{67A^2 + 26A + 3}{148A^2 + 40A + 4}\right]$$

and

$$M_2 = R_T \left(\frac{244.2}{L - 244.2}\right) \frac{L}{4}$$

$M \text{ of } R_2$ is modulus of rupture at load point nearest butt,
M_{w_2} is moment at load point nearest butt due to weight of pile, and
M_2 is moment at load point nearest butt due to imposed loading.

Table 11.--Results of bending tests of 40-foot sections of southern pine piles

Specimen No.	Weight	Tip diameter	Butt diameter	Specific gravity[1]	Modulus of rupture	Modulus of elasticity
	Pounds	Inches	Inches		P.s.i.	1,000 p.s.i.
P 1	1,133	7.84	11.34	0.55	4,140	1,280
P 2	1,479	8.36	12.07	.50	4,640	1,140
P 3	1,709	8.49	12.77	.48	3,480	1,350
P 4	1,619	8.45	12.33	.53	5,030	1,340
P 5	1,769	8.40	12.50	.52	4,940	1,490
P 6	1,528	8.34	12.36	.49	4,830	1,430
P 7	1,772	9.02	13.50	.52	4,400	1,220
P 8	1,513	8.92	12.25	.52	4,650	1,300
P 9	1,545	8.73	12.50	.42	3,540	1,320
P 10	1,625	8.75	12.31	.51	3,840	1,280
P 11	1,653	8.35	12.65	.46	4,460	1,380
P 12	1,738	8.99	12.74	.47	4,800	1,350
P 13	1,674	8.60	12.76	.48	4,790	1,290
P 14	1,670	9.00	12.23	.59	6,080	1,600
P 15	1,479	8.10	11.91	.52	5,010	1,350
Average	1,594	8.56	12.41	.50	4,580	1,340

[1] Specific gravity was obtained by averaging the values obtained for the compression specimens.

Table 12.--Results of bending tests of 40-foot sections of Douglas-fir piles

Specimen No.	Weight	Tip diameter	Butt diameter	Specific gravity[1]	Modulus of rupture	Modulus of elasticity
	Pounds	Inches	Inches		P.s.i.	1,000 p.s.i.
D 1	1,164	9.04	11.78	0.50	6,230	1,950
D 2	1,215	9.06	12.18	.40	5,320	1,360
D 3	975	9.57	11.63	.44	6,080	1,720
D 4	1,252	10.05	11.95	.48	7,330	1,990
D 5	1,157	9.55	12.25	.50	5,720	1,590
D 6	1,343	10.10	12.22	.50	7,550	2,120
D 7	1,162	9.10	12.32	.45	6,000	1,400
D 8	1,132	8.86	12.00	.58	5,180	1,540
D 9	1,064	8.37	11.52	.56	7,140	1,900
D 10	1,160	9.62	12.18	.47	6,710	1,670
D 11	871	8.58	11.35	.44	6,270	1,660
D 12	1,195	9.60	11.95	.52	7,750	2,050
D 13	1,116	8.61	12.11	.48	5,310	1,490
D 14	1,181	9.21	12.21	.54	7,020	1,720
D 15	1,305	9.25	12.40	.46	5,300	1,430
Average	1,153	9.24	12.00	.49	6,330	1,710

---

[1] Specific gravity was obtained by averaging the values obtained for the compression specimens.

Table 13.--Results of bending tests of 40-foot sections of red oak piles

Specimen No.	Weight	Tip diameter	Butt diameter	Specific gravity[1]	Modulus of rupture	Modulus of elasticity
	Pounds	Inches	Inches		P.s.i.	1,000 p.s.i.
O 1	2,294	10.00	13.85	0.68	8,850	1,550
O 2	1,972	10.36	13.47	.67	6,560	1,100
O 3	1,842	9.83	12.86	.63	7,460	1,280
O 4	1,471	8.38	12.05	.62	7,910	1,430
O 5	1,503	8.68	12.17	.63	[2] 8,190	1,310
O 6	1,996	10.72	13.27	.64	[2] 7,530	1,230
O 7	2,970	12.08	15.94	.63	7,520	1,300
O 8	1,455	8.63	11.50	.67	7,400	1,350
O 9	1,509	8.20	12.00	.63	8,450	1,480
O 10	2,293	10.70	14.25	.66	7,410	1,360
O 11	1,643	9.30	12.08	.66	[2] 7,350	1,050
O 12	1,882	9.81	13.06	.65	7,360	1,290
O 13	2,180	10.70	14.15	.68	8,780	1,530
O 14	1,858	9.26	12.97	.64	8,570	1,630
O 15	2,051	10.18	13.33	.62	8,070	1,460
Average	1,928	9.79	13.13	.65	7,830	1,360

---

[1] Specific gravity was obtained by averaging the values obtained for the compression specimens.

[2] Loading was stopped on these specimens before reaching maximum load due to excessive deflection. However, the load was within 10 percent of maximum.

Other symbol definitions are the same as those used in the previous formulas. These formulas take into account both the stress due to the weight of the pile and the effect of a 2-foot overhang at each end. The formula for M_2 is only valid when the imposed loads are proportioned as in this study. A complete derivation of these formulas is given in Appendix II.

Of the two values of modulus of rupture calculated for each pile, the one toward the tip end was always the critical value. Practically all failures occurred near this load point, because of the lower specific gravity or the large concentration of knots toward the tip end. These factors are probably responsible for the apparently low values of modulus of rupture for southern pine and Douglas-fir. Their values (4,580 p.s.i. for southern pine and 6,330 p.s.i. for Douglas-fir) were approximately 25 percent less than the values obtained in the ASTM pole study (13), where the poles had failures toward the butt end. The modulus of rupture of 7,830 pounds per square inch for the oak piles appears reasonable for this species. Its higher specific gravity toward the tip end assisted in counteracting the effect of knots. The apparent effect of steam conditioning on the strength of southern pine was evident again, as it was in the compression evaluations. An increase of 25 percent in modulus of rupture, which may be the percentage loss due to steaming of these piles, would make southern pine compare quite well with Douglas-fir.

The average values of modulus of elasticity (E) for the piles were 1,340,000, 1,710,000, and 1,360,000 p.s.i. for southern pine, Douglas-fir, and red oak, respectively. The E values for the southern pine and Douglas-fir piles were lower than those obtained in the ASTM pole study (13). This is possibly due to using the deflections under both loads to obtain an average value for each pile. The modulus of elasticity at the butt load should compare quite well with that obtained in the pole study, but the inclusion of the lower value under the tip load made the values for the piles lower.

Typical failures of the bending specimens are shown in figure 11. Failures generally started with compression wrinkles near knots, and followed by splintering tension failures. Most failures occurred at the tip load point.

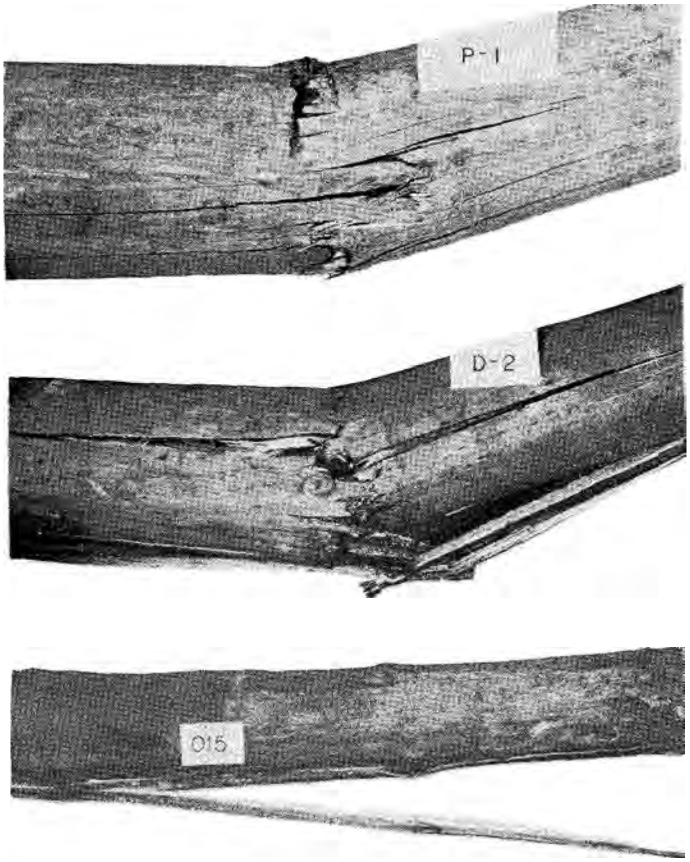


Figure 11.--Typical failures of piles in bending: (top) southern pine, specimen P1; (center) Douglas-fir, specimen D2; and (bottom) red oak, specimen 015.

M 130 970

Bending Strength of Small Clear Specimens

The results of bending tests on 1- by 1-inch small clear specimens taken from each pile and a comparison with the results obtained for the piles are presented in table 14. Two small clear specimens were evaluated for each pile, one from the tension side and one from the compression side. The modulus of rupture values for the piles were 10 to 18 percent less than for the small clear specimens. The ratios of small

Table 14.--Comparison of bending properties of piles with small clear specimens

Species	Modulus of rupture			Modulus of elasticity		
	Pile	Small clear specimens	Ratio	Pile	Small clear specimens	Ratio
	P.s.i.	P.s.i.		1,000 p.s.i.	1,000 p.s.i.	
Red oak	7,830	9,520	0.82	1,360	1,430	0.95
Douglas-fir	6,330	7,180	.88	1,710	1,500	1.14
Southern pine	4,580	5,090	.90	1,340	1,040	1.29

clear specimens and pile static strengths, shown in tables 10 and 14, indicate a greater effect of knots on bending strength than on compressive strength. This was expected from information previously obtained on structural timbers.

The ratios of modulus of elasticity values of small clear specimens to pile values showed the same trend in bending as found in static compression. The generally lower E values for the small clear specimens are probably due to their lower specific gravity compared to that of the piles. These specimens were taken from near the tip of the piles and far enough away from the surface to avoid the more dense surface-treated portions.

PART 2:

EFFECT OF KILN-DRYING ON STRENGTH OF SOUTHERN PINE PILES

The strength values for southern pine obtained in Part 1 were considerably below those expected for the species. These low values were attributed to the steam-conditioning the piles received prior to preservative-treatment.

An alternative method of conditioning southern pine piles prior to preservative-treatment involves kiln-drying to a moisture content of 35 to 40 percent. Less loss in strength from kiln-drying as compared to steam-conditioning was indicated by the ASTM pole research program. However, no data were available on full-size piles to indicate the possible effects of kiln-drying and preservative-treatment on compressive strength.

Objective and Scope

The objective of this study was to determine the compression parallel to grain strength on sections of full-size southern pine piles in three conditions--green, kiln-dried to 30 to 40 percent moisture content, and kiln-dried and preservative-treated. Thirty sections were evaluated in each condition after restoring them to a moisture content above fiber saturation point. These sections, a total of 90, were obtained from 15 piles.

Specimen Material

Southern pine piles were selected from timber produced between Hattiesburg and Lumberton, Miss., in Lamar and Forest Counties. The species in these stands were reported to be slash and second-growth longleaf.

Fifteen 30-foot-long piles with tip diameters of 7 to 8 inches were used. Five-foot-long test sections were cut from the piles, as shown in figure 12. Five piles were cut according to each of schedules A, B, and C. This resulted in 30 specimens for each of the three test conditions.

When the piles were cut into sections, 1-inch-long disks were cut from between each section and from each end of the pile, as shown in figure 12. These disks were used for determination of specific gravity, ring count, and percent summerwood.

An attempt was made to obtain piles which were fairly free of knots. The maximum size knots had a diameter of 2-1/2 inches. The maximum sum of knots within any 1 foot of length was 6 inches. Twenty-nine of the 90 test specimens had no knots.

Kiln Drying

The American Creosote Works, 1305 Dublin, New Orleans, La., kiln-dried 60 pile sections

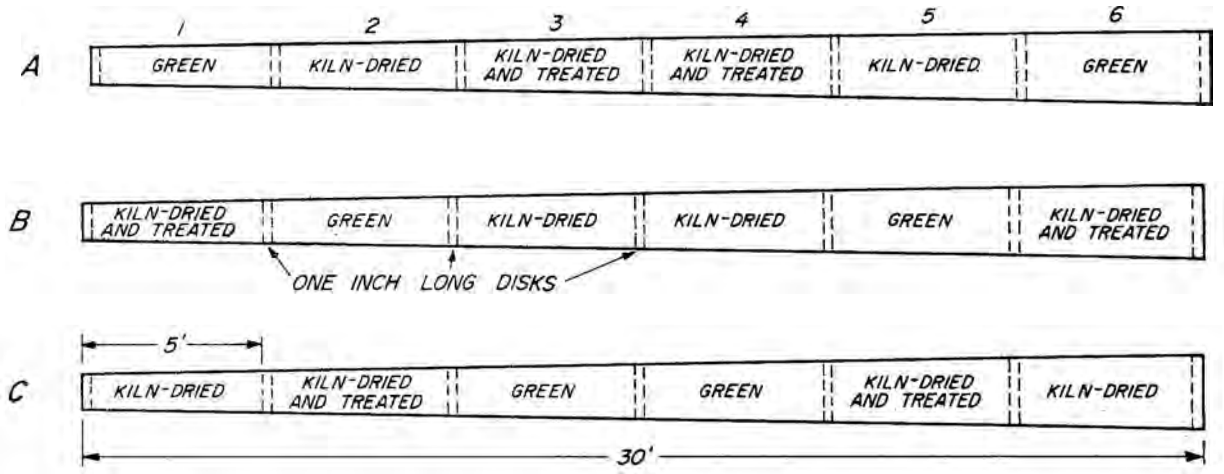


Figure 12.--Cutting schedules for obtaining sections and disks from piles. M 135 610

(fig. 12) and furnished the drying data. Before being dried, the ends of these pile sections were sealed with phenol-resorcinol end coating. The drying temperatures and limes are given in table 15. They are typical of what is being used by the industry. The moisture gradient was determined within each pile section after drying, This was done by taking four increment cores around the circumference and obtaining the moisture content of the cores for each 1 inch of depth from the outside toward the pith. The four cores were averaged to obtain the average moisture content for each inch of depth; data are presented in table 16.

Table 15.--Temperatures and times used for kiln drying of pile sections.

Dry-bulb temperature	Wet-bulb temperature	Time
°F.	°F.	Hours
134	120	24
144	120	47
153	120	47
165	120	46

[1] Data furnished by American Creosote Works, New Orleans, La.

Table 16.--Moisture gradients within pile sections after kiln drying[1]

Pile section No.[2]	Moisture content by 1-inch increments from surface toward pith			
	1st inch	2d inch	3d inch	4th inch
	Percent	Percent	Percent	Percent
A2K	32	43	40	....
A3T	19	31	35	....
A4T	25	37	35	....
A5K	18	26	27	32
B1T	14	20	24	....
B3K	27	39	40	....
B4K	25	38	36	....
B6T	13	20	22	25
C1K	16	25	27	
C2T	16	23	26	....
C5T	15	20	28	38
C6K	17	22	24	29
D2K	17	22	26	....
D3T	14	22	28	....
D4T	18	19	28	....
D5K	12	21	26	....
E1T	13	17	23	....
E3K	10	16	22	....
E4K	12	20	25	....
E6T	21	27	30	....
F1K	17	27	33	....
F2T	21	33	50	....
F5T	18	28	28	31
F6K	16	27	28	28
G2K	13	24	30	....
G3T	14	21	24	25
G4T	16	23	25	....
G5K	10	17	22	....
H1T	20	28	38	....
H3K	13	21	32	....
H4K	13	22	25	....
H6T	13	22	26	....
I1K	32	38	35	....
I2T	18	28	30	....
I5T	14	20	27	....
I6K	19	24	29	....
J2K	18	25	28	....
J3T	12	19	22	....
J4T	17	21	27	....
J5K	28	32	24	22
K1T	18	23	24	....
K3K	14	21	27	....
K4K	16	24	26	....
K6T	38	40	41	....
L1K	27	33	43	....
L2T	15	20	24	....
L5T	13	22	26	....
L6K	14	22	25	29
M2K	25	33	31	....
M3T	33	43	39	....
M4T	15	22	24	....
M5K	18	29	32	....
N1T	11	15	19	....
N3K	15	21	25	....
N4K	15	22	24	24
N6T	14	23	25	27
O1K	22	28	34	....
O2T	22	32	39	....
O5T	16	24	25	28

Table 16.--Moisture gradients within pile sections after kiln drying[1]

Pile section No.[2]	Moisture content by 1-inch increments from surface toward pith: 1st inch	2d inch	3d inch	4th inch
	Percent	Percent	Percent	Percent
06K	18	28	29	29
Average	18	26	29	....

---

[1] Data furnished by American Creosote Works, New Orleans, La.

[2] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "K" and "T" are for kiln-dried and treated, respectively.

Preservative-Treatment

The Southern Wood Preserving Co., Atlanta, Ga., treated 30 of the kiln-dried pile sections (fig. 12) with creosote and furnished the treating data. The phenol-resorcinol end coating was left on the pile sections during treating. The conditioning and treating schedule for the pile sections is given in table 17. Two hours of presteaming at 245° F. were used to soften the outer fibers and allow penetration of the creosote. The pile sections treated extremely fast in spite of an attempt to hold the pressure buildup to a slow rate. The gross injection of creosote was reached by the time the pressure reached 200 p.s.i.

The net retention of each pile section was determined by weighing before and after treatment, table 18. The distribution of creosote and water in the pile sections was determined from assay borings. The average values for the 30 pile sections are given in table 19.

Table 17.--Conditioning and treating schedule for creosote-treated southern pine pile sections[1]

Item	Value
Presteaming	
Time (hr.)	2
Temperature (°F.)	245
Pressure (p.s.i.)	13
Treatment	
Initial air pressure (p.s.i.)	40
Temperature of creosote (°F.)	200
Treating pressure (p.s.i.)	200
Time to reach maximum pressure (min.)	30
Pressure time[2] (min.)	0
Time to reduce maximum pressure to zero (min.)	10
Final vacuum	
Pressure (in.)	22.5 to 26.0
Time (min.)	50
Gross injection of creosote (lb./cu. ft.)	17.42
Net retention of creosote (lb./cu. ft.)	12.65

---

[1] Data furnished by Southern Wood Preserving Co., Atlanta, Ga.

[2] The gross injection of creosote was reached at the time the pressure reached 200 p.s.i.

Table 18.--Net retention of creosote of each pine section as determined by weighing the sections before and after treatment[1]

Pile section No.[2]	Weight before treating	Weight gained during treating	Volume of pile section	Net retention of creosote
	Pounds	Pounds	Cu. ft.	Lb./cu. ft.
A3T	95.00	30.00	2.26	13.27
A4T	109.00	32.50	2.53	12.85
B1T	73.50	30.00	1.78	16.85
B6T	154.25	49.75	3.63	13.71
C2T	93.50	32.50	2.49	13.05
C5T	140.00	30.75	3.19	9.64
D3T	90.50	26.25	2.00	13.13
D4T	104.75	27.50	2.26	12.17
E1T	75.00	28.50	1.79	15.92
E6T	125.00	35.00	2.60	13.46
F2T	113.50	29.00	2.35	12.34
F5T	158.00	35.50	3.32	10.69
G3T	92.50	28.25	2.26	12.50
G4T	102.00	27.00	2.36	11.44
H1T	70.25	19.25	1.69	11.39
H6T	128.50	29.00	2.47	11.74
I2T	69.50	23.50	1.79	13.13
I5T	95.50	24.25	2.26	10.73
J3T	85.50	27.25	2.02	13.48
J4T	97.50	28.50	2.23	12.78
K1T	52.75	28.25	1.58	17.88
K6T	107.00	43.50	2.74	15.88
L2T	83.75	31.75	1.80	16.71
L5T	105.50	37.00	2.24	16.52
M3T	81.00	33.25	2.02	16.46
M4T	91.75	36.00	2.26	15.93
N1T	75.00	27.75	2.00	13.38
N6T	142.00	41.00	3.16	12.97
O2T	72.25	26.50	1.69	15.68
O5T	117.00	34.50	2.61	13.22
Average	100.04	31.12	2.31	13.63

---

[1] Data furnished by Southern Wood Preserving Co., Atlanta, Ga.

[2] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "T" is for treated.

Table 19.--Distribution of creosote and moisture content in pile sections after treating as obtained from assay borings[1]

Sampled section zone	Retention	Moisture content	Specific gravity
	Lb./cu. ft.	Percent	
Outer 1/2 inch	19.38	20	0.54
1/2 to 2 inches	9.74	22	.55
2 to 3 inches	[2]3.70	25	.50
Weighted average	9.58	23	.53

[1] Data furnished by Southern Wood Preserving Co., Atlanta, Ga.

[2] Several borings didn't have 3 inches of sapwood. Based on inches of treated wood, the retention would be 4.44 lb. per cu. ft.

Test Methods and Specimen Preparation

Upon arrival of the pile sections at the U.S. Forest Products Laboratory, they were submerged in water for approximately 30 days in an attempt to restore them to a moisture content above the fiber-saturation point. All pile sections were tested in this soaked condition.

A 3-foot-long specimen was cut from each 5-foot-long pile section. This specimen was evaluated in compression parallel to grain using the same test method used in Part 1.

Two small clear compression parallel to grain specimens were cut from the portion of the pile section remaining after obtaining the 3-foot-long specimen. The small clear specimens were obtained from opposite sides of the pith. When possible, specimens were 2 by 2 by 8 inches in size, but some specimens were proportionately reduced in size due to an insufficient amount of clear material.

The volume of the disk cut from between the pile sections was obtained by immersion. The specific gravity was based on the ovendry weight and green volume. Rings per inch from the outside to the pith were counted for each disk. Percent summerwood values were obtained on the disks from the tip and butt ends of each pile.

Discussion of Results

The results of the compressive parallel to the grain strength tests of 3-foot pile sections, all tested in the soaked condition, are presented in table 20 for the green specimens, table 21 for the kiln-dried specimens, and table 22 for the kiln-dried and treated specimens. The pile sections had average crushing strengths as follows:

Condition	P.s.i.
Green	3,880
Kiln-dried	3,430
Kiln- dried and treated	3,940

These results indicate a greater strength for the piles after treatment. Since creosote is chemically inert with wood and would not cause a physical bulking action, there is no reason to believe the addition of creosote resulted in a strength increase. One hypothesis that might explain the increase in strength is that the moisture contents of the wood fibers in the treated specimens were not above the fiber-saturation point, even though there was enough water present in the specimens to indicate a high moisture content. This amount of water could be present in the cell cavities without penetrating the cell walls which are coated with the petroleum carrier for the creosote. However, there is no way to verify this explanation from the data. A reduction in moisture content of about 2 percent below the fiber-saturation point could account for the increase in strength of the treated sections over that of the kiln-dried sections.

The specific gravity values presented in tables 20, 21, and 22 were obtained from the 1-inch disk cut from the piles (see fig. 12). The values for the disk from each end of a pile section were averaged to obtain the specific gravity for the test specimen. Comparison of the average specific gravities for the three conditions indicates that the method of assigning conditions within the full-length piles resulted in good matching of this property. The average values of 0.54 compare quite well with the values of 0.54 and 0.56 for longleaf and slash pine presented in the Wood Handbook (10).

The modulus of elasticity values for the three groups were nearly the same, with average values of 1,630,000, 1,660,000, and 1,660,000 p.s.i.

for the green, kiln-dried, and kiln-dried and treated specimens, respectively, when tested in the soaked condition,

The results of the compression parallel to grain strength tests of the small clear specimens tested in the soaked condition are presented in table 23 for the green specimens, table 24 for the kiln-dried specimens, and table 25 for the

Table 20.--Results of compression-parallel-to-grain tests of green southern pine pile sections[1]

Specimen No.[2]	Specific gravity[3]	Weight	Diameter		Maximum load	Crushing strength	Modulus of elasticity
			Top	Bottom			
		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
A1G	0.53	60	8.35	8.65	98	3,580	1,410
A6G	.56	114	10.80	11.02	194	4,240	1,940
B2G	.50	75	9.10	9.35	110	3,370	1,300
B5G	.55	118	11.10	11.45	196	4,060	1,910
C3G	.50	109	10.20	10.72	149	3,650	1,330
C4G	.50	115	10.90	11.04	170	3,650	1,340
D1G	.57	63	8.35	8.80	104	3,780	1,560
D6G	.63	127	10.57	11.06	205	4,680	1,850
E2G	.53	74	8.85	9.20	101	3,280	1,450
E5G	.57	109	10.40	10.55	190	4,470	1,710
F3G	.57	113	10.56	10.97	159	3,630	1,580
F4G	.57	111	11.00	11.00	184	3,860	1,960
G1G	.54	66	8.65	8.72	117	3,980	1,740
G6G	.58	107	10.65	10.95	197	4,420	2,030
H2G	.55	63	8.70	8.90	113	3,800	1,660
H5G	.60	87	9.79	10.00	169	4,490	2,270
I3G	.52	65	8.74	9.00	118	3,920	1,910
I4G	.54	75	9.39	9.54	139	4,010	1,960
J1G	.50	54	7.78	8.13	90	3,760	1,460
J6G	.60	102	10.40	10.40	187	4,400	2,120
K2G	.44	52	8.12	8.42	82	3,190	1,130
K5G	.51	92	9.95	10.06	143	3,680	1,450
L3G	.56	75	9.15	9.35	138	4,190	2,120
L4G	.56	87	9.63	9.65	160	4,400	2,230
M1G	.48	54	7.70	8.07	64	2,740	1,360
M6G	.57	97	9.96	10.20	152	3,910	1,600
N2G	.50	81	9.40	9.63	126	3,640	1,660
N5G	.54	118	10.94	11.28	192	4,100	1,780
O3G	.51	85	9.55	9.62	128	3,570	1,610
O4G	.52	90	9.65	10.00	140	3,840	1,640
Average	.54	88	9.61	9.86	144	3,880	1,630

---

[1] All specimens were soaked in water for approximately 30 days prior to testing.

[2] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "G" is for green.

[3] Values are the average for disk obtained from each end of pile sections and are based on green volume and ovendry weight.

kiln-dried and treated specimens. As with the 3-foot pile specimens, the kiln-dried specimens had the lowest average crushing strength, 3,650 p.s.i. The green specimens had an average crushing strength of 4,180 p.s.i., and the kiln-dried and treated specimens had an average crushing strength of 4,100 p.s.i. The individual values were obtained by averaging the two small

Table 21.--Results of compression-parallel-to-grain tests of kiln-dried southern pine pile sections[1]

Specimen No.[2]	Specific gravity[3]	Weight	Diameter		Maximum load	Crushing strength	Modulus of elasticity
			Top	Bottom			
		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
A2K	0.54	63	8.74	9.15	105	3,500	1,580
A5K	.55	91	10.47	10.64	158	3,670	1,720
B3K	.52	75	9.70	10.06	110	2,960	1,560
B4K	.53	90	10.40	10.80	138	3,250	1,610
C1K	.50	64	9.15	9.45	99	3,010	1,470
C6K	.53	108	11.58	11.92	184	3,490	1,450
D2K	.56	66	8.82	9.00	106	3,460	1,580
D5K	.60	90	10.05	10.25	156	3,940	1,910
E3K	.54	73	9.47	9.70	122	3,450	1,480
E4K	.56	80	9.85	10.10	138	3,640	1,680
F1K	.54	77	9.65	9.67	122	3,320	1,620
F6K	.61	126	12.00	12.04	214	3,790	2,260
G2K	.54	66	9.06	9.17	121	3,760	1,690
G5K	.56	88	10.35	10.55	170	4,030	1,960
H3K	.56	70	9.02	9.36	110	3,440	1,930
H4K	.58	78	9.48	9.65	140	3,970	1,890
I1K	.51	50	7.98	8.15	73	2,920	1,470
I6K	.56	83	9.95	10.27	146	3,760	1,880
J2K	.52	58	8.43	8.80	88	3,140	1,460
J5K	.58	84	10.02	10.32	155	3,930	1,840
K3K	.48	59	8.73	9.04	83	2,780	1,230
K4K	.49	70	9.40	9.67	102	2,940	1,260
L1K	.55	62	8.72	8.92	111	3,710	1,930
L6K	.58	90	10.27	10.40	160	3,850	2,180
M2K	.50	55	8.35	8.78	80	2,940	1,370
M5K	.54	74	9.70	9.95	122	3,320	1,530
N3K	.51	77	9.83	10.20	124	3,270	1,700
N4K	.52	90	10.34	10.65	140	3,350	1,660
O1K	.49	51	8.15	8.35	74	2,840	1,210
O6K	.57	97	10.70	10.86	162	3,610	1,650
Average	.54	77	9.61	9.84	127	3,430	1,660

---

[1] All specimens were soaked in water for approximately 30 days prior to testing.

[2] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "K" is for kiln-dried.

[3] Values are the average for disk obtained from each end of pile sections, and are based on green volume and ovendry weight.

clear specimens tested for each pile section. The reason for the higher values for the treated specimens over those of the kiln-dried specimens is probably the same as for thefull-size sections.

Again, comparison of the average specific gravities for the three conditions showed good matching of this property.

Moisture content determinations were made

Table 22.--Results of compression-parallel-to-grain tests of kiln-dried and treated southern pine pile sections[1]

Specimen No.[2]	Specific gravity[3]	Weight	Diameter		Maximum load	Crushing strength	Modulus of elasticity
			Top	Bottom			
		Pounds	Inches	Inches	Tons	P.s.i.	1,000 p.s.i.
A3T	0.54	76	9.50	9.67	144	4,060	1,530
A4T	.54	84	9.75	10.10	138	3,690	1,620
B1T	.49	65	8.72	8.95	95	3,180	1,200
B6T	.58	122	11.72	12.05	211	3,910	1,900
C2T	.51	77	9.62	10.08	106	2,920	1,280
C5T	.51	107	11.35	11.53	176	3,470	1,410
D3T	.56	76	9.20	9.47	135	4,060	1,730
D4T	.58	82	9.60	9.85	162	4,460	1,720
E1T	.52	66	8.64	8.83	121	4,130	1,440
E6T	.59	100	10.46	10.57	189	4,400	1,800
F2T	.55	91	10.07	10.45	132	3,300	1,370
F5T	.57	119	11.58	11.75	202	3,840	1,770
G3T	.54	74	9.20	9.50	150	4,510	1,900
G4T	.55	80	9.55	9.90	163	4,540	1,960
H1T	.54	54	8.12	8.20	118	4,540	1,740
H6T	.61	92	10.00	10.32	182	4,640	2,050
I2T	.51	58	8.32	8.65	109	4,020	1,600
I5T	.55	74	9.55	9.75	156	4,340	1,890
J3T	.53	71	9.05	9.35	129	4,010	1,630
J4T	.54	79	9.54	9.92	156	4,350	1,690
K1T	.43	51	7.73	7.93	76	3,230	1,190
K6T	.53	96	10.25	10.50	160	3,870	1,680
L2T	.54	74	8.95	9.04	131	4,160	2,160
L5T	.56	94	9.70	10.00	164	4,440	2,280
M3T	.50	70	8.87	9.17	108	3,500	1,400
M4T	.52	78	9.40	9.66	118	3,400	1,510
N1T	.50	62	8.85	9.10	118	3,840	1,510
N6T	.56	116	11.46	11.75	197	3,820	1,710
O2T	.51	59	8.25	8.80	100	3,740	1,460
O5T	.54	97	10.45	10.70	164	3,840	1,760
Average	.54	81	9.58	9.85	144	3,940	1,660

[1] All specimens were soaked in water for approximately 30 days prior to testing.

[2] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "T" is for treated.

[3] Values are the average for disk obtained from each end of pile sections and are based on green volume and ovendry weight.

for all the small clear specimens. The values presented in tables 23, 24, and 25 indicate that all the specimens were sufficiently wet to be considered at or above the fiber-saturation point for southern pine.

The rings per inch and percent summerwood for the outer 2 inches, as measured on the butt of each pile, are given in table 26.

Table 23.--Results of small clear compression-parallel-to-grain specimens cut from green southern pine pile sections

Specimen No.[1]	Moisture content	Specific gravity[2]	Crushing strength[3]	Ratio of pile to minor
	Percent		P.s.i.	
A1G	72	0.50	4,100	0.87
A6G	42	.60	4,330	.98
B2G	98	.47	3,650	.92
B5G	91	.52	4,050	1.00
C3G	86	.47	3,750	.97
C4G	96	.49	3,920	.93
D1G	53	.57	4,510	.84
D6G	75	.60	4,350	1.08
E2G	59	.55	4,250	.77
E5G	66	.59	4,740	.94
F3G	77	.56	4,070	.89
F4G	61	.55	3,950	.98
G1G	81	.55	4,330	.92
G6G	54	.58	4,750	.93
H2G	39	.58	4,440	.86
H5G	53	.57	4,530	.99
I3G	57	.55	4,210	.93
I4G	61	.57	4,300	.93
J1G	77	.49	3,720	1.01
J6G	64	.60	4,510	.98
K2G	42	.47	3,620	.88
K5G	91	.53	3,980	.92
L3G	46	.61	4,530	.92
L4G	56	.57	4,560	.96
M1G	60	.55	3,670	.75
M6G	47	.61	4,450	.88
N2G	78	.51	3,860	.94
N5G	67	.57	4,280	.96
O3G	76	.54	3,920	.91
O4G	63	.57	4,040	.95
Average	66	.55	4,180	.93

---

[1] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "G" is for green.

[2] Specific gravity is based on green volume and ovendry weight.

[3] Values are the average of two specimens.

Statistical Analysis

The crushing strength data for the pile sections and for the small clear specimens were analyzed using the analysis of variance technique. With this technique, it was possible to account for the variation in the data due to (1) the three treatments (green, kiln-dried, and kiln-dried and

Table 24.--Results of small clear compression-parallel-to-grain specimens cut from kiln-dried southern pine pile sections

Specimen No.[1]	Moisture content	Specific gravity[2]	Crushing strength[3]	Ratio of pile to minor
	Percent		P.s.i.	
A2K	41	0.51	3,740	0.94
A5K	42	.56	3,970	.92
B3K	44	.53	3,070	.96
B4K	33	.53	3,260	1.00
C1K	38	.50	3,240	.93
C6K	49	.53	3,890	.90
D2K	36	.56	4,020	.86
D5K	36	.61	4,100	.96
E3K	42	.55	3,750	.92
E4K	39	.59	3,720	.98
F1K	40	.55	3,270	1.02
F6K	34	.65	4,130	.92
G2K	38	.50	3,480	1.08
G5K	35	.55	4,090	.99
H3K	43	.56	3,360	1.02
H4K	38	.57	4,160	.95
I1K	43	.52	3,630	.80
I6K	39	.59	3,880	.97
J2K	39	.56	3,480	.90
J5K	35	.58	4,030	.98
K3K	43	.50	3,360	.83
K4K	37	.54	3,060	.96
L1K	36	.55	3,890	.95
L6K	34	.61	4,220	.91
M2K	40	.49	3,130	.94
M5K	34	.58	3,590	.92
N3K	33	.55	3,270	1.00
N4K	41	.56	3,730	.90
O1K	43	.52	2,990	.95
O6K	35	.59	3,880	.93
Average	39	.54	3,650	.94

[1] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "K" is for kiln dried.

[2] Specific gravity is based on green volume and ovendry weight.

[3] Values are the average of two specimens.

treated), (2) differences between piles, (3) differences along the length of the pile, and (4) error.

The following model was used to describe the different parameters contributing to a strength value.

$$E(y) = \mu + \beta_i + \tau_j + \theta_j P_r$$

Table 25.--Results of small clear compression-parallel-to-grain specimens cut from kiln-dried and treated southern Dine pile sections

Specimen No.[1]	Moisture content[2]	Specific gravity[2]	Crushing strength[3]	Ratio of pile to minor
	Percent		P.s.i.	
A3T	31	0.50	3,630	1.12
A4T	30	.53	4,060	.91
B1T	32	.48	3,540	.90
B6T	33	.59	4,080	.96
C2T	28	.52	3,610	.81
C5T	31	.52	3,650	.95
D3T	26	.57	4,880	.83
D4T	25	.59	5,180	.86
E1T	28	.53	3,890	1.06
E6T	32	.60	4,600	.96
F2T	30	.56	3,560	.93
F5T	30	.56	4,270	.90
G3T	27	.54	4,350	1.04
G4T	29	.56	4,620	.98
H1T	25	.52	4,180	1.09
H6T	29	.53	4,030	1.15
I2T	29	.53	4,140	.97
I5T	24	.57	4,530	.96
J3T	26	.54	4,230	.95
J4T	28	.53	4,110	1.06
K1T	30	.45	3,590	.90
K6T	29	.56	4,310	.90
L2T	37	.57	4,320	.96
L5T	32	.59	4,560	.97
M3T	36	.51	3,660	.96
M4T	33	.52	3,780	.90
N1T	26	.52	4,060	.95
N6T	31	.57	4,310	.89
O2T	31	.52	3,380	1.11
O5T	34	.51	4,010	.96
Average	30	.54	4,100	.96

[1] First letter is the pile designation; the number is the position in the pile, starting with 1 at the tip end; and the "T" is for treated.

[2] Moisture content and specific gravity were obtained by extraction. Specific gravity based on green volume and ovendry weight.

[3] Values are the average of two specimens.

where $\underline{E(y)}$ is the expected strength value,
$\underline{\mu}$ is the mean of all strength values,
$\underline{\beta_i}$ is the effect due to differences between piles (i = 1, 2, 3, ..., 15),
$\underline{\tau_j}$ is effect due to the treatment (j = 1, 2, 3),
$\underline{\theta_j}$ is effect due to position along a pile associated with a particular treatment (j =1, 2, 3),
$\underline{P_r}$ is constant multiplier of $\underline{\theta}$; depending upon the position alongthepile.

The values of $\underline{P_r}$ for the six positions along the pile were -5, -3, -1, +1, +3, and +5, starting with the tip and proceeding to the butt end, The model assumes that the strength varies lineally along the length of the pile. This assumption appeared to be reasonable from a plot of average crushing strength at each position versus position.

The results of the analysis of variance are presented in table 27 for the pile sections and in table 28 for the small clear specimens. Since the calculated "F" ratios are greater than the critical "F" ratios, the effects due to differences between piles, differences between treatments, and position along the pile are significant. From the small value of residual mean squares as com-

Table 26.--Rings per inch and percent summerwood measured on the ends of the piles

Pile letter	Rings per inch in outer 2 inches		Percent summerwood in outer 2 inches	
	Butt	Tip	Butt	Tip
			Percent	Percent
A	13	14	44	40
B	8	10	52	44
C	9	8	47	42
D	10	10	48	40
E	7	8	51	46
F	14	12	41	46
G	12	13	47	46
H	9	9	50	42
I	11	11	48	45
J	6	8	57	36
K	7	8	45	26
L	12	12	56	42
M	7	6	42	48
N	7	8	48	45
O	7	9	48	38
Average	9	10	48	42

Table 27.--Results of analysis of variance for southern pine pile sections

Source of variation	Degrees of freedom	Sum of squares	Expected mean square	Calculated "F" ratio	Critical[1] "F" ratio
Mean	1	12,659,250	12,659,250	----	----
Differences between piles	14	82,542	5,896	14.927	1.86
Differences between treatments	2	45,486	22,743	57.577	3.14
Position along the pile	3	44,864	14,955	37.861	2.75
Residual or error	70	27,664	395	----	----
Total	90	12,859,806	----	----	----

[1] These values are for a 95 percent level of significance.

Table 28.--Results of analysis of variance for small clear specimens taken from southern pine pile sections.

Source of variation	Degrees of freedom	Sum of squares	Expected mean square	Calculated "F" ratio	Critical[1] "F" ratio
Mean	1	14,230,899	14,230,899	----	----
Differences between piles	14	63,897	4,564	7.842	1.86
Differences between treatments	2	49,882	24,942	42.856	3.14
Position along the pile	3	29,417	9,806	16.849	2.75
Residual or error	70	40,723	582	----	----
Total	90	14,414,818	----	----	----

[1] These values are for a 95 percent level of significance.

pared to the other mean squares, it would appear that most of the variation in the data has been accounted for.

The residual mean square can be used to establish 95 percent confidence intervals for the treatment (green, kiln-dried, and kiln-dried and treated) averages. These are presented in table 29. The confidence intervals for the green and kiln-dried specimens do not overlap, and therefore the loss in strength due to kiln-drying is real and significant. The confidence intervals for the green and kiln-dried and treated specimens do overlap, and therefore their strengths are not different.

Table 29.--Confidence intervals for average crushing strengths of green, kiln-dried, and kiln-dried and treated southern pine specimens

Condition	Sample average	95 percent confidence interval
	P.s.i.	P.s.i.
PILE SECTIONS		
Green	3,880	3,810 to 3,950
Kiln-dried	3,430	3,360 to 3,500
Kiln-dried and treated	3,940	3,870 to 4,010
SMALL CLEAR SPECIMENS		
Green	4,180	4,090 to 4,270
Kiln-dried	3,650	3,560 to 3,740
Kiln-dried and treated	4,100	4,010 to 4,190

Summary of Findings

1. In Part 1, the average compressive strengths of specimens taken from the butt and tip ends of the piles were:

	Tip (p.s.i.)	Butt (p.s.i.)
Red oak	3,460	3,620
Douglas-fir	2,960	3,590
Southern pine	1,820	2,950

2. Tests of 1- by 1-inch small clear specimens under impact loading showed average crushing strengths of 1.86 to 3.24 times that of statically loaded specimens.

3. The average values of modulus of rupture were 7,830, 6,330, and 4,580 p.s.i. for red oak, Douglas-fir, and southern pine, respectively.

4. The average bending modulus of elasticity values were 1,360,000, 1,710,000, and 1,340,000 p.s.i. for red oak, Douglas-fir, and southernpine, respectively.

5. The southern pine piles evaluated in Part 1 appeared to have strengths lower than expected. The lower strength values were possibly due to the steam-conditioning to which they were subjected for 15 hours at 245° F.

6. Kiln-drying of southern pine piles at the conditions used in Part 2 caused a reduction in crushing strength of about 12 percent over that of green piles when both were evaluated with moisture contents above the fiber-saturation point.

7. Kiln-drying of southern pine piles did not affect the compressive modulus of elasticity.

LITERATURE CITED

1. Alexander, J.B.
   1953. Wood piles--specifications and mechanics, Forest Prod. J. 3(2): 62-64.
2. American Insurance Association.
   1967. National building code. New York, N.Y.; Chicago, Ill.; and San Francisco, Calif.
3. American Society for Testing and Materials.
   1964. Standard specifications for round timber piles. ASTM Specif. D 25-58, Amer. Soc. Testing Mater., Philadelphia, Pa.
4. ____________
   1967. Static tests of timbers in structural size, ASTM Standard D 198-67, Amer. Soc. Testing Mater., Philadelphia, Pa.
5. American Wood-Preservers' Association.
   1964. Preservative treatment of piles by pressure processes. AWPASpecif. C3-64.
6. American Wood Preservers Institute.
   1961. Pressure treated timber foundation piles for permanent structures. Amer. Wood Preserv. Inst., Chicago, Ill.
7. Chellis, RD.
   1961. Pile foundations. McGraw-Hill Book Co., Inc., New York.
8. International Conference of Building Officials.
   1964. Uniform building code. Pasadena, Calif.
9. Southern Building Code Congress.
   1965. Southern standard building code, Birmingham, Ala.
10. U.S. Forest Products Laboratory.
    1955. Wood Handbook. U.S. Dep. Agr., Agr. Handb. No. 72.
11. Wilkinson, T.L.
    1964. Effect of confining pressure on the compression-parallel-to-the-grain strength of small clear wood specimens. U.S. Forest Serv. Res. Note FPL-057. Forest Prod. Lab., Madison, Wis.
12. Wilson, T.RC.
    1930. The selection of marine piling. The Constructor.
13. Wood, L.W., Erickson, E.C.O., and Dohr, A.W.
    1960. Strength and related properties of wood poles, Final Rep. ASTM Wood Pole Res. Program. Amer. Soc. Testing Mater., Philadelphia, Pa.

APPENDIX I

DERIVATION OF A FORMULA FOR BENDING MODULUS OF ELASTICITY FOR A ROUND, TAPERED PILE SUBJECTED TO QUARTER-POINT LOADING

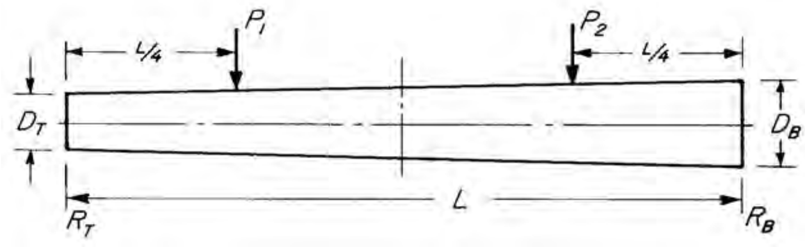


Figure 13.--Round tapered pile subjected to unequal quarter-point loading. M 135 608

For this study, it was desired to have an expression for modulus of elasticity, E, involving the deflections under P_1 and P_2

The general expression for deflection, Δ, by the method of work is

$$\Delta = \int_0^L \frac{Mm}{EI} dx \tag{1-1}$$

where M is the bending moment due to the imposed loading
m is the bending moment due to a unit load at the point of desired deflection
E is the modulus of elasticity
I is the moment of inertia
L is the span

From equation (1-1) the deflection under P_1 is

$$\Delta_1 = \int_0^L \frac{Mm_1}{EI} dx \tag{1-2}$$

and the deflection under P_2 is

$$\Delta_2 = \int_0^L \frac{Mm_2}{EI} dx \tag{1-3}$$

Taking the summation of equations (1-2) and (1-3),

$$\Delta_1 + \Delta_2 = \int_0^L \frac{M}{EI} (m_1 + m_2) dx \tag{1-4}$$

an expression involving the deflections under the loads, and E is obtained.

In order to evaluate the integral in equation (1-4), I must be put in terms of the variable of integration, x.

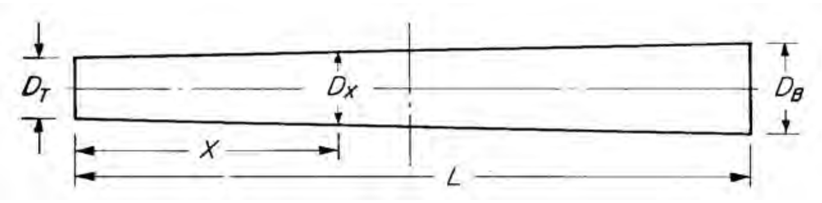


Figure 14.--Diagram for relating diameters of round tapered pile. M 135 609

The moment of inertia of a circular cross section at any position, x, in the span is:

$$I_x = \frac{\pi D_x^4}{64} \tag{1-5}$$

Since diameter, D_x, is the quantity that changes with x, a relation between some known diameter and x is desired. From proportions, the following ratios can be obtained:

$$\frac{D_x - D_T}{x} = \frac{D_B - D_T}{L} \tag{1-6}$$

Solving for D_x:

$$D_x = \frac{x}{L}(D_B - D_T) + D_T \tag{1-7}$$

Substituting equation (1-7) into (1-5) and rearranging:

$$I_x = \frac{\pi D_T^4}{64}\left[\frac{x}{L}\left(\frac{D_B - D_T}{D_T}\right) + 1\right]^4 \tag{1-8}$$

The first part of equation (1-8) is the moment of inertia, I_T, at the tip reaction. Let:

$$\beta = \frac{D_B - D_T}{LD_T} \tag{1-9}$$

and rewrite equation (1-8) as:

$$I_x = I_T(1 + \beta x)^4 \tag{1-10}$$

With an expression for I_x, all that remain in order to evaluate the integral in equation (1-4) are expressions for M, m_1, and m_2 in terms of x.

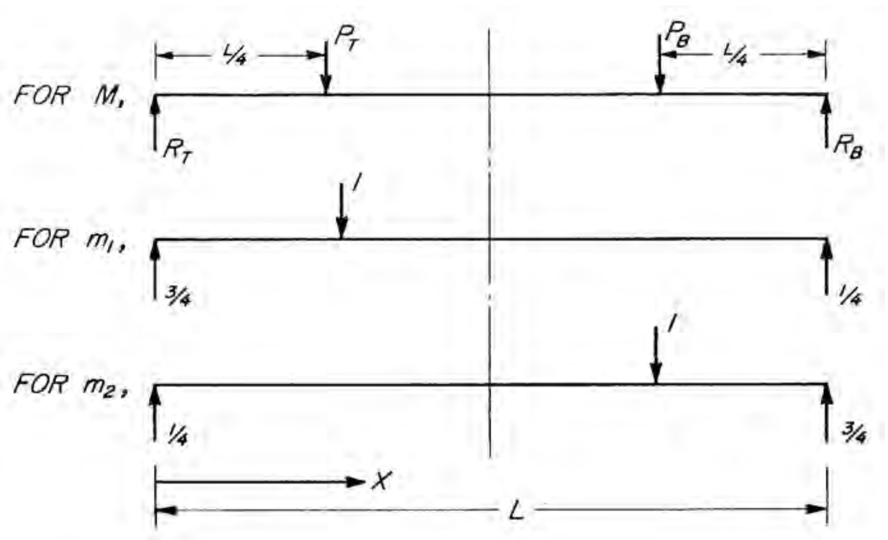


Figure 15.--Schematic loading diagrams for determining moments in terms of x. M 135 607

From figure 15, for $x = 0$ to $x = \frac{L}{4}$:

$$M = R_T x \tag{1-11}$$

$$m_1 = \frac{3}{4} x \tag{1-12}$$

and

$$m_2 = \frac{1}{4} x \tag{1-13}$$

for $x = \frac{L}{4}$ to $x = \frac{3L}{4}$:

$$M = R_T x - P_1 (x - \frac{L}{4}) \tag{1–14}$$

$$m_1 = \frac{3}{4} x - 1(x - \frac{L}{4}) \tag{1–15}$$

and

$$m_2 = \frac{1}{4} x \tag{1–16}$$

and for $x = \frac{3L}{4}$ to $x = L$:

$$M = R_T x - P_1 (x - \frac{L}{4}) - P_2 (x - \frac{3L}{4}) \tag{1-17}$$

$$m_1 = \frac{3}{4} x - 1(x - \frac{L}{4}) \tag{1–18}$$

and

$$m_2 = \frac{1}{4} x - 1(x - \frac{3L}{4}) \tag{1–19}$$

Substituting the expressions for $\underline{M}$, $\underline{m_1}$, $\underline{m_2}$, and $\underline{I_x}$ into equation (1-4), we get

$$\Delta_1 + \Delta_2 = \int_0^{\frac{L}{4}} \frac{R_T x(\frac{3x}{4} + \frac{x}{4})dx}{EI_T(1 + \beta x)^4} + \int_{\frac{L}{4}}^{\frac{3L}{4}} \frac{\left[(R_T - P_1)x + \frac{P_1 L}{4}\right]\left[(\frac{L}{4} - \frac{x}{4}) + \frac{x}{4}\right]dx}{EI_T(1 + \beta x)^4}$$

$$+ \int_{\frac{3L}{4}}^{L} \frac{\left[(R_T - P_1 - P_2)x + (P_1 + 3P_2)\frac{L}{4}\right]\left[(\frac{L}{4} - \frac{x}{4}) + (\frac{3L}{4} - \frac{3x}{4})\right]dx}{EI_T(1 + \beta x)^4} \tag{1-20}$$

Evaluation of the integrals and substituting in

$$R_T = \frac{3P_1 + P_2}{4} \tag{1-21}$$

results in:

$$\Delta_1 + \Delta_2 = \frac{(3P_1 + P_2)L^3}{768EI_T(1 + \frac{\beta L}{4})^3} + \frac{P_2 L^3(48 + 40\beta L + 9\beta^2 L^2)}{3{,}072EI_T(1 + \frac{3\beta L}{4})^3 (1 + \frac{\beta L}{4})^3}$$

$$+ \frac{P_1 L^3(48 + 56\beta L + 17\beta^2 L^2)}{3{,}072EI_T(1 + \frac{3\beta L}{4})^3 (1 + \frac{\beta L}{4})^3} + \frac{P_1 L^3(1 + 2\beta L + \beta^2 L^2)}{768EI_T(1 + \beta L)^3 (1 + \frac{3\beta L}{4})^3}$$

$$+ \frac{P_2 L^3(1 + 2\beta L + \beta^2 L^2)}{256EI_T(1 + \beta L)^3 (1 + \frac{3\beta L}{4})} \tag{1-22}$$

This is now a general expression involving $\underline{E}$ and the deflections under the loads for a round, tapered beam with quarter-point loading. To make equation (1-22) more useful, it should be put in terms of the quantities measured in this study.

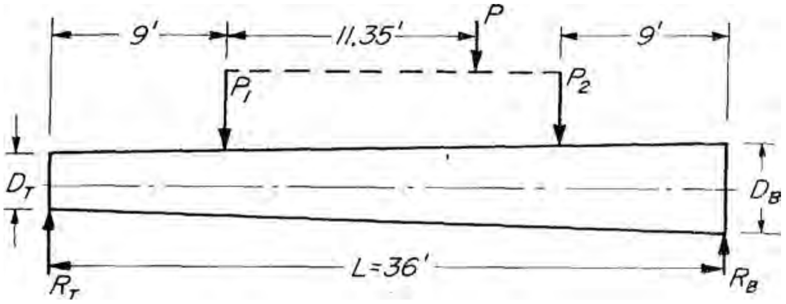


Figure 16.--Loading diagram for bending strength evaluation of test pile, showing principal dimensions used in determining modulus of elasticity. M 135 606

The values obtained from the test are tip reaction, R_T tip diameter, D_T and butt diameter, D_B. From the dimensions of the bending test setup:

$$P_1 = 0.85\ R_T \tag{1-23}$$

and

$$P_2 = 1.45\ R_T \tag{1-24}$$

Substituting equations (1–23) and (1–24) into equation (1–22) and solving for 2 results in

$$E = \frac{L^3 R_T}{I_T(\Delta_1 + \Delta_2)} \left[\frac{1}{256(1 + \frac{\beta L}{4})^3} + \frac{(110.4 + 105.6\beta L + 27.5\beta^2 L^2)}{3{,}072(1 + \frac{3\beta L}{4})^3 \quad (1 + \frac{\beta L}{4})^3} + \frac{(5.2 + 10.4\beta L + 5.2\beta^2 L^2)}{768(1 + \beta L)^3 \quad (1 + \frac{3\beta L}{4})^3} \right] \tag{1-25}$$

Putting b and I_T in terms of the measured diameters:

$$I_T = \frac{\pi D_T^4}{64} \tag{1-26}$$

and

$$\beta L = \frac{D_B - D_T}{D_T}$$

or letting

$$\frac{D_B}{D_T} = A$$

then

$$\beta L = A - 1 \tag{1-27}$$

Substituting equations (1–26) and (1–27) into equation (1–25):

$$E = \frac{L^3 R_T}{\pi(\Delta_1 + \Delta_2) D_T^4} \left[\frac{16}{(3 + A)^3} + \frac{(2{,}756.27 + 4{,}317.87A + 2{,}346.67A^2)}{(1 + 3A)^3 \quad (3 + A)^3} + \frac{27.73}{(1 + 3A)^3 A} \right] \tag{1-28}$$

which is the expression for E given in the text of this report.

APPENDIX II

DERIVATION OF FORMULAS FOR MODULUS OF RUPTURE OF A ROUND, TAPERED PILE SUBJECTED TO QUARTER-POINT LOADING

For this study, it was desired to have expressions for modulus of rupture at each of the load points. These expressions should include the effect of the weight of the pile as well as the imposed loading.

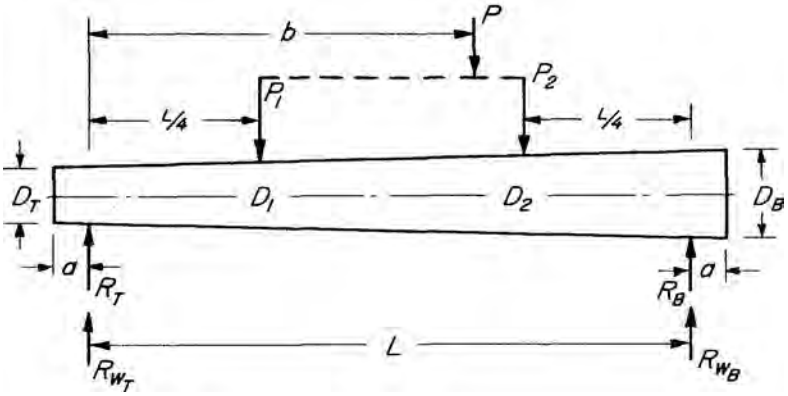


Figure 17.--Schematic loading diagram of round tapered pile subjected to unequal quarter-point loading and dead weight of pile. M 135 605

First, the moment at P_1 due to the weight of the pile shall be found. The total weight of the pile is

$$W = R_{W_T} + R_{W_B} \tag{2-1}$$

and the total volume of the pile:

$$V = (L + 2a)\frac{\pi}{4}\left(\frac{D_T + D_B}{2}\right)^2 \tag{2-2}$$

Therefore

$$\frac{W}{V} = \frac{\left(R_{W_T} + R_{W_B}\right)16}{(L + 2a)(D_T + D_B)^2} \tag{2-3}$$

The volume of the pile from the tip to P_1 is:

$$V_1 = \frac{\pi}{4}\left(\frac{D_T + D_1}{2}\right)^2\left(\frac{L}{4} + a\right) \tag{2-4}$$

Substituting equations (2-4) and (2-1) into equation (2-3):

$$W_1 = \frac{W}{4}\left(\frac{D_T + D_1}{D_T + D_B}\right)^2\left(\frac{L + 4a}{L + 2a}\right) \tag{2-5}$$

which is the weight of the pile from the tip to P_1.

The point at which W_1 acts as a concentrated load is

$$y_1 = \left(\frac{L}{4} + a\right) \frac{\left(D_1^2 + 2D_1D_T + 3D_T^2\right)}{4\left(D_1^2 + D_1D_T + D_T^2\right)} \tag{2-6}$$

from the load point at P_1.

The moment at P_1 due to W_1 is

$$M_{w_1} = \frac{W}{4}\left(\frac{D_T + D_1}{D_T + D_B}\right)^2 \left(\frac{L + 4a}{L + 2a}\right)\left(\frac{L + 4a}{4}\right) \frac{\left(D_1^2 + 2D_1D_T + 3D_T^2\right)}{4\left(D_1^2 + D_1D_T + D_T^2\right)} \tag{2-7}$$

The moment at P_2 due to the weight of the pile is found in the same way as M_{w_1}. This moment is

$$M_{w_2} = \frac{W}{4}\left(\frac{D_B + D_2}{D_T + D_B}\right)^2 \left(\frac{L + 4a}{L + 2a}\right)\left(\frac{L + 4a}{4}\right)\left[1 - \frac{\left(D_B^2 + 2D_BD_2 + 3D_2^2\right)}{4\left(D_B^2 + D_BD_2 + D_2^2\right)}\right] \tag{2-8}$$

The moment at P_1 due to the imposed loading is

$$M_1 = R_T \frac{L}{4} \tag{2-9}$$

and the moment at P_2 due to the imposed loading is

$$M_2 = \frac{R_B L}{4} = R_T\left(\frac{b}{L - b}\right)\frac{L}{4} \tag{2-10}$$

The preceding equations are expressions for the moments at each of the load points. The stress at each point can be found by adding the moments and dividing by the section modulus for each point. Before doing this, the equations for moment should be put in terms of the quantities measured in this study. These are W, R_T, D_T, and D_B.

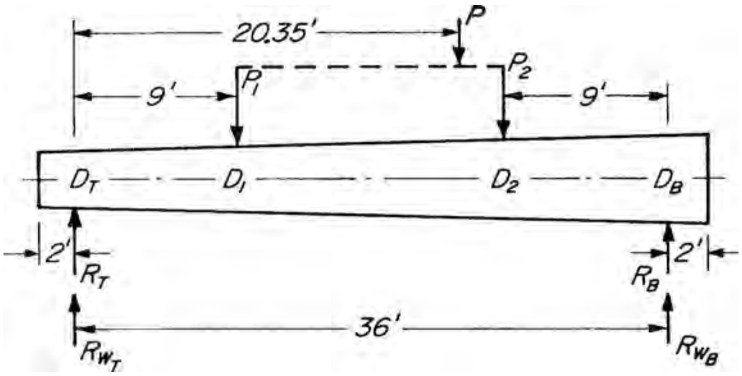


Figure 18.--Loading diagram for bending strength evaluations of test pile, showing principal dimensions used in obtaining modulus of rupture. M 135 604

Assuming that D_T and D_B are at the reactions instead of at the end of the pile, the

$$D_1 = \frac{D_B + 3D_T}{4} \tag{2-11}$$

and

$$D_2 = \frac{3D_B + D_T}{4} \tag{2-12}$$

Substituting in L = 36', a = 2', and equations (2-11) and (2-12) into the equations for moment:

$$M_{w_1} = 9.075W \left[\frac{7 + A}{4(1 + A)}\right]^2 \left[\frac{A^2 + 14A + 81}{A^2 + 10A + 37}\right] \tag{2-13}$$

where

$$A = \frac{D_B}{D_T} \tag{2-14}$$

Continuing,

$$M_{w_2} = 2.269W \left[\frac{7A + 1}{1 + A}\right]^2 \left[1 - \frac{67A^2 + 26A + 3}{148A^2 + 40A + 4}\right] \tag{2-15}$$

$$M_1 = R_T \frac{L}{4} \tag{2-16}$$

and

$$M_2 = R_T \left(\frac{244.2}{L - 244.2}\right) \frac{L}{4} \tag{2-17}$$

The expressions for modulus of rupture are

$$M \text{ or } R_1 = \frac{M_{w_1} + M_1}{S_1} \tag{2-18}$$

at P_1 and

$$M \text{ of } R_2 = \frac{M_{w_2} + M_2}{S_2} \tag{2-19}$$

at P_2.

The section moduli are

$$S_1 = \frac{\pi D_1^3}{32} = \frac{\pi}{32}\left(\frac{D_B + 3D_T}{4}\right)^3 \tag{2-20}$$

and

$$S_2 = \frac{\pi D_2^3}{32} = \frac{\pi}{32}\left(\frac{3D_B + D_T}{4}\right)^3 \tag{2-21}$$

Substituting equations (2-20) and (2-21) into the equations for modulus of rupture:

$$\text{M of R}_1 = \frac{\left(M_{w_1} + M_1\right)2{,}048}{(D_B + 3D_T)^3\pi} \qquad (2\text{-}22)$$

and

$$\text{M of R}_2 = \frac{\left(M_{w_2} + M_2\right)2{,}048}{(3D_B + D_T)^3\pi} \qquad (2\text{-}23)$$

which are the expressions for modulus of rupture given in the text of this report.

ABOUT THE FOREST SERVICE. . . .

As our Nation grows, people expect and need more from their forests--more wood; more water, fish and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- * Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- * Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- * Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.