STRENGTH AND STIFFNESS OF PRESERVATIVE-TREATED MARINE PILES[1]

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ABSTRACT

An assessment was made of the effect of preservative treatments on bending strength and stiffness of full-sized marine piles and small specimens derived from them and on the compression strength of pile sections. Preservative-treated Southern pine and Douglas-fir piles were generally lower in strength than untreated piles. Dual treatments of ACA plus creosote and CCA plus creosote reduced strength more than single treatments with these preservatives. Stiffness and strength in compression were not affected by preservative treatment. Statistical associations between MOE and MOR values of small specimens and full-sized piles in bending were extremely small.

Keywords: Marine piling, preservative treatment, strength, stiffness, bending, compression, Southern pine, Douglas-fir.

INTRODUCTION

In salt and brackish waters of United States shores, wood that is neither protected by naturally contained chemicals nor by preservative treatment may be destroyed by marine borers in a few years or even a few months. Because no timber species grown in North America is immune to marine borers, deep pressure impregnation with suitable preservative solutions is necessary for permanent wood structures in seawater. In past decades, the best practical protection was obtained through full-cell treatments with coal-tar creosote or leach-resistant water-borne preservatives containing copper and chromium or arsenic. Dual treatment is now suggested, especially where severe borer hazard exists, because even thorough creosote impregnation cannot always stop attack by borer species such as *Limnoria, Martesia,* and *Sphaeroma.*

At the suggestion of the U.S. Navy, we have undertaken to learn whether any of the pressure impregnation processes reduce the strength of piles. Southern pine and Douglas-fir, selected for study, possess among other desirable characteristics high bending strength in relation to weight, which suits them particularly for use in heavy structures. The dual treatment and retention recommended by

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American Wood Preservers' Association (AWPA) standards C3 and C18 for these species are:

First treatment: ammoniacal copper arsenite (ACA) or chromated copper arsenate (CCA), 1.0 lb/ft^3 (16.0 kg/m^3).
Second treatment: creosote, 20.0 lb/ft^2 (320.4 kg/m^3).

For round timber piles exposed to severe marine borer hazard, this is considered the best possible protection.

Decades ago, it was concluded that standard preservative treatments with creosote and petroleum oils apparently did not reduce Douglas-fir materially below green strength (Alexander 1936; McGowan 1960; Wilson, 1923, 1946). On the other hand, Boulton-drying in oil heated to 190 F (88 C) or more did reduce strength (Graham 1980). Best (1981) recently reviewed pertinent literature on the strength of wood piles and two unpublished reports to the American Wood Preservers Institute, one by W. S. Thompson on Southern pine (1968, Results on strength tests on piling sections, Mississippi State University) and the other by J. Peterson on Douglas-fir (1968, Strength of Douglas-fir, Oregon State University). The information does not elucidate the effect of preservative treatments on strength; however, it suggests that basic strengths of clear wood from ASTM standard D-2555 (ASTM 1980) may be used for estimating the strengths of piles.

In this paper, we report our assessment of the effect of preservative treatment on bending strength and stiffness of full-size marine piles and of small specimens derived from them, and on the compression strength of pile sections. A statistical test was designed to find a possible correlation between the properties of the piles and those of small specimens.

MATERIALS

The test material consisted of seventy-five piles, eight groups of Southern pine and seven groups of Douglas-fir (Table 1). Their selection and treatment were arranged by the Civil Engineering Laboratory of the U.S. Navy and companies performing pressure impregnation for wood preservation. The piles had been stored several months on land on the southern California coast.

The untreated piles were initially 30 ft (9.14 m) long, the treated piles 25 ft (7.62 m) long. One 4-ft (1.22-m) butt section was cut from each pile before pressure treatment and another from each treated and control pile for compression tests. A 13-inch (330 mm) section was cut adjacent to each compression specimen for machining into small specimens for tests in bending.

PROCEDURE

Tests of full-size piles

Before testing, circumferences were measured at the tip, middle, and butt of each pile. Moisture contents of untreated or creosote-treated piles were obtained with a resistance-type meter near a loading head at a depth of 0.5, 1.0, 1.5, 2.0, and 2.5 inches (12.7, 25.4, 50.8, 63.5 mm).

Full-size piles were tested in bending in random sequence on a universal testing machine, 600,000-lb (272-t) capacity, as per ASTM D-198, except for the loading arrangement shown in Fig. 1 that conformed to ASTM D-1036. Curved piles were
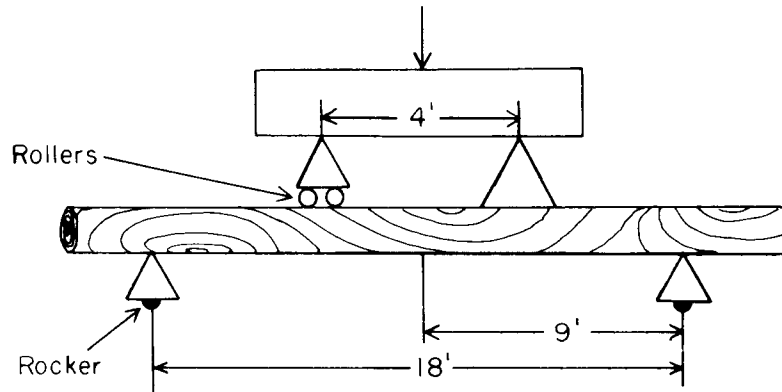
FIG. 1.   Diagram of the testing apparatus showing the loading arrangement.

rotated during loading until there was no horizontal curve. The loading rate was 0.53 inches (13.5 mm) per minute until failure; then the head speed was increased until 10 inches (254 mm) of deflection occurred.

Data were recorded in two ways: by a strip chart attached to the universal testing machine, accompanied by observers' written data sheets, and by magnetic tape and digital recorder, accompanied by microphone observations. Maximum breaking loads, abnormalities such as severe slope of grain or overabundance of knots, and type of failure (compression, tension, and shear) were recorded on the data sheets and on magnetic tape by speaking into a microphone.

After these tests, 3-inch (76.2 mm) cross sections were cut from each pile near the point of failure for preservative analyses. From these cross sections, moisture content specimens were also taken. Moisture content of salt-treated and untreated specimens was determined by the oven-dry method. The Karl Fischer method was used for specimens dual-treated with creosote and salt (Resch and Ecklund 1963).

Salt-treated wood was weighed, oven-dried at 221 F (105 C), and reweighed before the water content was calculated. Preservative retention data were used to adjust oven-dry weight so that moisture content was expressed as weight of water divided by weight of oven-dry, preservative-free wood.

Two samples were taken from each dual-treated section containing salt and creosote. After weighing, the samples were immediately placed in measured amounts of anhydrous methanol in a tightly covered bottle and soaked for about 1 week before titration according to the Karl Fischer method. Again, moisture content was expressed for oven-dry, preservative-free wood by subtracting the amount of preservative from the preservative retention value.

Preservative retention was analyzed on plugs drilled from portions of the piles retained for that purpose (Table 1). The preservative analyses followed the American Wood Preservers Association standards A2, A7, and A9, except that plugs were split lengthwise. Preservative content was expressed in pounds per cubic foot of wood. Values for specific gravity were originally based on green volume and oven-dry weight of wood containing preservative, then adjusted to the basis of oven-dry, preservative-free weight of wood.

TABLE 1. *Preservative retention of Southern pine and Douglas-fir marine piles within 1-inch depth.*

AWPA code	Treatment[1] and desired retention	Assay zone	Plugs per pile[2]	Specific gravity[3]	Average retention (lb/ft³)				
					Creo-sote	Total salt	Chrome	Copper	Arsenic
Southern pine									
—	Untreated	—		0.54	0	0	0	0	0
C3	2.5 lb/ft³ ACA	0.–0.5, 0.5–2 in.	3	.54	0	5.18	2.46	0.83	1.89
C3	2.5 lb/ft³ CCA	0.–0.5, 0.5–2 in.	3	.56	0	6.76	0	3.43	3.33
C3	20 lb/ft³ creosote	0–2 in.	3	.54	28.9	0	0	0	0
C18	1 lb/ft³ CCA, air-dry, creosote	0–1 in.	6	.55	31.1	1.38	0.63	0.18	0.57
C18	1 lb/ft³ CCA kiln-dry, creosote	0–1 in.	6	.54	27.6	1.58	0.68	0.23	0.67
C18	1 lb/ft³ ACA, air-dry, creosote	0–1 in.	6	.55	29.5	1.70	0	0.81	0.89
C18	1 lb/ft³ ACA, kiln-dry, creosote	0–1 in.	6	.53	29.8	2.04	0	1.05	0.99
Douglas-fir									
—	Untreated	—		0.47	0	0	0	0	0
C3	2.5 lb/ft³ ACA	0–1 in.	3	.44	0	4.67	0	2.37	2.30
C3	20 lb/ft³ creosote	0–2 in.	3	.44	21.6	0	0	0	0
C18	1 lb/ft³ CCA, air-dry, creosote	0–1 in.	6	.46	16.1	0.56	0.27	0.07	0.22
C18	1 lb/ft³ CCA, kiln-dry, creosote	0–1 in.	6	.44	18.7	0.79	0.36	0.12	0.31
C18	1 lb/ft³ ACA, air-dry, creosote	0–1 in.	6	.46	30.5	1.05	0	0.51	0.54
C18	1 lb/ft³ ACA, kiln-dry, creosote	0–1 in.	6	.46	30.6	1.12	0	0.53	0.59

[1] Five piles per treatment.
[2] Plugs ½ inch in diameter, based on the following calculation: (0.5 in.)²(π)/4 × 1 × 3 = 0.60 in.³ (9.83 cm³).
[3] Based on green volume and preservative-free oven-dry weight.

Tests on compression sections

Compression tests on 4-ft pile sections were made after bringing them to or above fiber saturation point. For this purpose, the sections were cut to 45 inches (1.14 m) truly perpendicular to the axis of compression and then submerged in water in a retort under 90 psig (439 kg/m²). Water impregnation treatment of pine required 1 day and of Douglas-fir 1 week.

Moisture content of creosoted specimens was recorded with five readings of a resistance-type meter in the middle of the piece at ½-inch (12.7-mm) increments to a depth of 2½ inches (63.5 mm). Moisture content of dual-treated piles was assumed to be similar to that of creosoted piles and moisture content of salt-treated piles similar to that of untreated specimens.

After measurement of length and circumference at butt and tip, the sections were loaded to failure at the rate of 200 kips (90.7 t) per minute.

Tests on small specimens

For bending tests, sixteen small specimens were manufactured from each 13-inch (330-mm) section of the untreated and treated piles to 1- × 1- × 13-inch (25.4- × 25.4- × 300-mm) dimension, in accordance with a systematic statistical design suggested by the U.S. Navy (Fig. 2). Because of the systematic sampling, these specimens were either clear or contained various growth characteristics. Additional small clear specimens of the same dimension were obtained from the same treated and untreated piles to make up a subsample for inclusion in the statistical analysis.
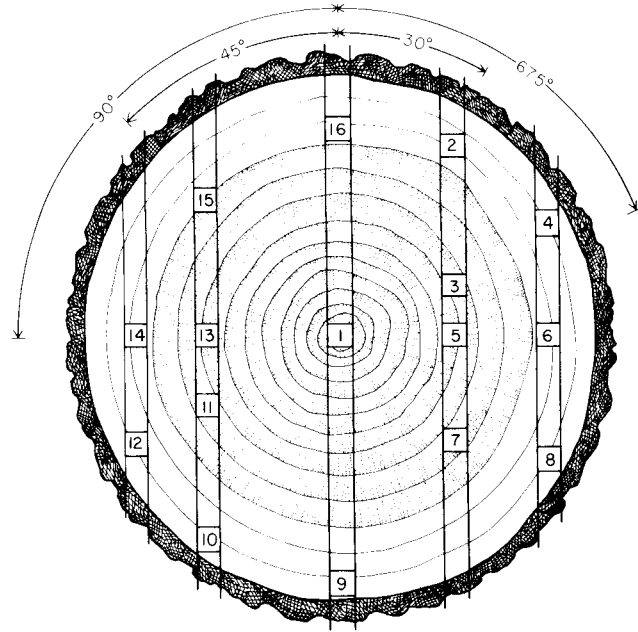
FIG. 2.   A cross section showing the scheme for obtaining small specimens of full-size piles for tests in bending (suggested by the Civil Engineering Laboratory of the U.S. Navy).

All specimens were allowed to equilibrate about 3 weeks in a standard climate room at 70 F (21 C) and 70% relative humidity. The 12% moisture content was verified by oven-drying several control samples. After reaching equilibrium, the bending specimens were machined to ½- × ½- × 13-inch (12.7- × 12.7- × 300-mm) dimension and stored again in the standard climate room until testing.

The bending tests were conducted, in response to the U.S. Navy's request and because of the large number of specimens, as rapidly as the Instron testing machine allowed, that is, with a head speed of 1.97 inches (50 mm) per minute. The testing span was 11 inches (279 mm). Samples were oriented pith side up. Both load and deflection were recorded on tape from LVDT's and also on a mechanically driven chart.

The width, depth, and condition of each specimen were recorded before each test.

The specific gravity of each pile was represented by values determined on the small control specimens. Only clear peripheral specimens (Fig. 2, numbers 2, 4, 6, 8, 9, 10, 12, 14, 15, 16) were chosen from each group of sixteen pieces because they were at the depth where preservative retention was known for all piles. The dimensions and weight of the samples on which specific gravity was determined were recorded. The percent of moisture, 12%, was subtracted from these weights. Values for specific gravity were then calculated from green volume.

Statistical analyses

First, statistical tests were designed to show differences in strength and stiffness between (1) untreated and treated full-size piles, (2) full-size piles receiving

different preservative treatments, and (3) full-size piles of Douglas-fir and Southern yellow pine.

Statistical tests (1) and (3) were a one-way analysis of variance (95% confidence level). Statistical test (2) was a one-way analysis of variance with the Newman-Keuls method, separated bending and compression properties for each species into statistically distinguishable groups. An estimate of the confidence interval of the mean for each treatment was obtained to find overlapping intervals. If the absolute value of the difference between means exceeded the statistically significant difference, the true effects of the two treatments are not claimed to be equal.

Second, to discover whether properties of full-size piles (the dependent variables) might be predicted from data obtained from small specimens (the independent variables) tested in accordance with the sampling scheme suggested by the U.S. Navy, we determined strength and stiffness values not only of these specimens, but also of clear small samples. The predictability was tested with a straight line regression-correlation analysis. As before, we examined whether significant differences existed between small specimens from untreated and treated piles, from piles receiving different treatments, and from piles of different wood species.

Statistical analyses on full-size piles were made with values obtained from tests at specific moisture contents. All correlation analyses between full-size piles and small specimens were repeated twice, once with strength and stiffness values adjusted theoretically to a uniform 12% moisture content and once with values adjusted to moisture content at the fiber saturation point. Theoretical adjustment was made along the line representing change in MOE and MOR with change in moisture content. The line was calculated with the formula and species values from the *Wood Handbook*, Section 4 (U.S. Forest Products Laboratory 1974).

RESULTS

Values for specific gravity and preservative retention of full-size piles (Table 1) were those normally expected in a sample of this material.

Untreated versus treated piles.—Average values for strength and stiffness of piles tested in bending and compression are given in Table 2. In bending, untreated piles showed the highest average values both in stiffness and in strength. Differences in modulus of elasticity (MOE) between untreated and treated Southern pine piles could be observed but could not be proven statistically significant.

Effects of different treatments.—Apparently, Southern pine piles were weakened in bending by dual treatment; however, salt-only or creosote-only did not cause a statistically significant reduction. Stiffness and compression values derived from Southern pine piles did not vary significantly from treatment to treatment.

Douglas-fir was weakened most in bending by the dual treatment CCA, creosote; and the strength was significantly reduced from that of the dual, salt-only, and creosote-only treatments. Douglas-fir piles treated with CCA and creosote failed in shear during the bending tests because of burst checks present before testing. Burst checks are internal separations perpendicular to the growth rings that sometimes develop during pressure treatment. Thus these piles yielded the

TABLE 2. *Stiffness and strength of full-size marine piles in bending and compression.*[1]

		Bending tests	
	Avg. MC (%)	Avg. stiffness (MOE × 10⁶ psi)	Avg. strength (MOR psi)
Southern pine[2]			
Untreated	17	1.94	8,008
Creosote	22	1.61	5,950
ACA	47	1.54	5,534
CCA	20	1.75	5,410
ACA, air-dry, creosote	32	1.56	4,874
ACA, kiln-dry, creosote	18	1.58	4,576
CCA, air-dry, creosote	10	1.38	4,568
CCA, kiln-dry, creosote	33	1.50	3,766
Douglas-fir[2]			
Untreated	15	1.92	8,394
Creosote	15	1.58	6,862
ACA, kiln-dry, creosote	23	1.64	6,346
ACA, air-dry, creosote	14	1.44	5,876
ACA	22	1.42	5,620
CCA, air-dry, creosote	16	1.33	4,210
CCA, kiln-dry, creosote	15	1.01	3,478

		Compression tests	
		Avg. stiffness (×10⁶ psi)	Avg. compression strength (psi)
Southern pine[2]			
CCA		0.82	3,770
CCA, kiln-dry, creosote		0.97	3,492
Creosote		0.88	3,494
CCA, air-dry, creosote	Fiber saturation	0.92	3,356
Untreated		0.76	3,270
ACA		0.78	3,186
ACA, air-dry, creosote		0.90	3,168
ACA, kiln-dry, creosote		0.92	3,144
Douglas-fir[2]			
Untreated		0.67	3,346
Creosote		0.79	3,200
ACA, air-dry, creosote		0.74	2,306
CCA, air-dry, creosote		0.74	2,786
ACA, kiln-dry, creosote		0.72	2,622
ACA		0.62	2,462
CCA, kiln-dry, creosote		0.55	1,880

[1] Items within individual brackets do not differ significantly from one another; however, items contained in different brackets differ from each other at the 95% probability level.
[2] Five piles per treatment.

lowest values most consistently. Without burst checks, higher values would have been expected. Douglas-fir piles showed significant differences in stiffness among treatments.

The compressive strength was significantly reduced for the group of piles treat-

TABLE 3. *Linear association between stiffness and strength in bending of small specimens and of full-size piles.*[1]

Averaged small specimens	Numbers of		Property	Coefficient of determination R^2
	Piles	Specimens		
All treated	75	1,040	MOE	0.33
			MOR	0.16
All untreated	10	160	MOE	0.41
			MOR	0.22
All treated Southern pine	35	560	MOE	0.35
			MOR	0.46
All treated Douglas-fir	30	480	MOE	0.30
			MOR	0.23

[1] Unadjusted for moisture content.

ed with CCA, kiln-dried, and then treated with creosote. Again, the reason for reduction was most likely the burst checks. However, MOE in compression was not reduced significantly.

Differences between species.—Average values for the two wood species for MOE and MOR in bending with each preservative treatment did not differ significantly except between Southern pine and dual-treated (CCA, kiln-dry, creosote) Douglas-fir containing burst checks. In compression, Southern pine piles showed slightly higher values than Douglas-fir piles. That difference could be secured statistically with only three treatments: ACA; CCA, air-dry, creosote; and CCA, kiln-dry, and creosote.

Prediction from small specimens.—A prediction of pile properties from values derived from small specimens was attempted by means of correlation and regression analyses. When treated small specimens were used for predicting full-scale MOE and MOR, the regression lines accounted for only a relatively small amount of the variation (Table 3), even though they proved to be statistically significant. Correlation coefficients were somewhat higher when the association was tested between values of small untreated specimens and of untreated full-sized piles.

Subsampling of small clear specimens did not improve the predictability of regression equations but rather reduced it in most cases.

Comparing stiffness and bending strength of small specimens with that of full-sized piles by species did not improve prediction equations sufficiently to be useful. Nor did the method of the Wood Handbook (U.S. Forest Products Laboratory 1974) for adjusting strength and stiffness to a 12% MC level improve predictability. The correlation coefficients obtained were lower in all cases than those with unadjusted strength and stiffness values.

Preservative treatment did not significantly reduce strength and stiffness measured on small specimens, with the exception of MOR for Southern pine (Table 4). The variation among strength and stiffness values of small specimens was great enough to obscure most of the difference attributable to species.

CONCLUSIONS

Preservative-treated Southern pine and Douglas-fir piles analyzed in this study averaged between 18 and 59% lower in strength than untreated piles. Southern

TABLE 4. *Stiffness and strength of small specimens in bending at 12% moisture content.*[1]

Species and treatment	Average stiffness (MOE × 10⁶ psi)	Species and treatment	Average strength (MOR psi)

| | | Clear specimens only[2] | |

Southern pine

Untreated	2.50	Untreated	17,984
ACA, air-dry, creosote	2.16	ACA	17,176
Creosote	2.07	CCA	16,828
ACA	2.02	ACA, air-dry, creosote	16,518
CCA, kiln-dry, creosote	2.01	CCA, air-dry, creosote	15,338
ACA, kiln-dry, creosote	1.96	Creosote	15,211
CCA, air-dry, creosote	1.92	ACA, kiln-dry, creosote	15,057
CCA	1.81	CCA, kiln-dry, creosote	15,025

Douglas-fir

Untreated	2.18	Untreated	15,748
CCA, air-dry, creosote	2.11	CCA, kiln-dry, creosote	15,444
CCA, kiln-dry, creosote	2.07	CCA, air-dry, creosote	15,438
Creosote	2.03	Creosote	15,296
ACA, air-dry, creosote	1.99	ACA	14,753
ACA	1.93	ACA, air-dry, creosote	13,419
ACA, kiln-dry, creosote	1.76	ACA, air-dry, creosote	12,945

| | | Systematically obtained specimens[2] | |

Southern pine

Untreated	1.90	Untreated	15,535
ACA, air-dry, creosote	1.89	CCA	14,361
CCA, kiln-dry, creosote	1.82	ACA	14,356
CCA, air-dry, creosote	1.72	ACA, air-dry, creosote	14,217
Creosote	1.70	CCA, air-dry, creosote	13,597
ACA	1.69	CCA, kiln-dry, creosote	13,297
CCA	1.62	Creosote	12,512

Douglas-fir

Untreated	2.06	Untreated	14,670
CCA, air-dry, creosote	1.85	CCA, air-dry, creosote	12,982
Creosote	1.69	Creosote	12,941
ACA, air-dry, creosote	1.65	ACA	11,751
ACA	1.54	ACA, air-dry, creosote	11,434
CCA, kiln-dry, creosote	1.53	ACA, kiln-dry, creosote	10,724
ACA, kiln-dry, creosote	1.52	CCA, kiln-dry, creosote	10,159

[1] Items within individual brackets do not differ significantly from one another; however, items contained in different brackets differ from each other at the 95% probability level.
[2] Five piles per treatment, 16 specimens per pile = 80 specimens per treatment.

pine had 21% lower strength values with the four dual treatments (ACA, air-dry, creosote; ACA, kiln-dry, creosote; CCA, air-dry, creosote; CCA, kiln-dry, creosote) than with the single treatments (creosote; ACA; CCA). The dual treatments (CCA, air-dry, creosote; CCA, kiln-dry, creosote) reduced strength of Douglas-fir piles a statistically significant 38% more than single treatments.

Treatments reduced MOE only in Douglas-fir piles. Reductions for Southern pine piles were not statistically significant. Stiffness and strength in compression were not affected in either species by preservative treatment. The only deviation was due to the unexpected presence of burst checks in CCA-creosote dual treated Douglas-fir piles.

Differences in strength and stiffness between Southern pine and Douglas-fir piles were largely insignificant statistically. Bending tests on small samples derived from full-size piles were not useful in predicting the strength and stiffness of these piles.

Tests on small (1- × 1- × 13-inch) specimens containing various growth characteristics, obtained with a newly suggested systematic sampling procedure, do not appear useful for discerning differences in strength and stiffness due to preservative treatment or species; but neither did a test on a limited sample of small clear specimens.

Values obtained in this study may assist in selecting treated marine piles for their proper use. The full-scale tests were made on material that realistically represents piles that would be used. The treatment influences were sufficiently evident to support engineering judgments on adjustment of design stresses.

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