PROPERTIES AND GRADING OF SOUTHERN PINE TIMBERS

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ABSTRACT

Bending and compression parallel-to-the-grain tests were conducted on approximately 200 dry southern pine 140- by 140-mm (6- by 6-in.) timbers, 3 m (10 ft.) long, sampled from two mills in the South. Dynamic modulus of elasticity (MOE) was also obtained using pulse echo stress wave techniques. The results suggest that currently assigned allowable bending strength, compressive strength, and MOE values are appropriate for Select Structural and No. 2 visual grades. The relationship between bending strength and compressive strength parallel to the grain was found to be similar to that for standard 38-mm- (nominal 2- in.-) thick dimension lumber. A significant relationship was found between pulse echo MOE and static bending properties and between specific gravity and static bending properties. We conclude that there are no technical barriers to the development of a mechanical grading system for structural timbers. Such a system would provide more precise assignment of allowable properties and thus allow better utilization ofthe forest resource. However, new grading and quality control procedures would have to be developed and approved before mechanical grading of timbers could be conducted under the American Lumber Standard system.

Timbers are defined as lumber 114 mm (5 in.) or more in the least dimension (ASTM D 9 (2)). Structural timbers are used in many ways, from transportation structures such as railroad bridges to timber-frame structures for farm or commercial settings. In 1994, timbers represented 3.1 percent of the estimated 1.1 million m^3 (15.01 billion board feet) of southern pine lumber production (figures supplied by Southern Forest Products Association (SFPA) and include production of 4 by dimension lumber).

The grading of structural timbers is based on visual assessment of growth characteristics and defects, with properties derived from tests of small, clear specimens (ASTM D 245 (2)). Unlike the data on dimension lumber graded by visual means, little data are available for assessing current property assignments for structural timbers. Also, mechanical grading procedures commonly used with 38-mm (2-in.) dimension lumber are not available for timbers. The lack of mechanical grading alternatives makes more precise property assignments impossible. Thus, designers of timber structures cannot optimize their structural designs to meet individual needs.

The objectives of this study were to assess current property assignments for visually graded southern pine 140- by 140-mm (6- by 6-in.) timbers and to establish a technical basis for the mechanical grading of southern pine timbers.

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BACKGROUND

VISUAL GRADING OF TIMBERS

There are some significant differences between the application of visual grading techniques to structural dimension lumber 89 mm (4 in.) and less in thickness and the application to timbers. Grading rules for dimension lumber are standardized across grading agencies. Thus, for example, the knot sizes for No. 2 lumber are the same regardless of species. This was not always true. Prior to the early 1960s, neither grade names nor grade descriptions were standardized across all species. Grade descriptions for timbers are still not standardized. Thus, for example, required knot sizes for No. 2 southern pine timbers (18) are not the same as those for Douglas-fir timbers (21). Another difference is that dimension lumber is graded for all intended uses, For all species except southern pine, timbers are graded as either beams and stringers or post and timbers. A beam and stringer is a member 114 mm (5 in.) or more in thickness with a width more than 51 mm (2 in.) greater than the thickness. Beams and stringers are primarily used to resist bending stress, and the grade description for the middle third of the length of the beam is more stringent than that for the outer two-thirds. Posts and timbers are members 5 by 5 and larger, where the width is not more than

TABLE 1. — SI equivalents for nominal dry dimensions.

Nominal	Standard
(in.)	(mm)
4 by 4	89 by 89
4 by 7	89 by 165
5 by 5	114 by 114
5 by 6	114 by 140
5 by 8	114 by 184
6 by 6	140 by 140
6 by 7	140 by 165
6 by 12	140 by 286
7 by 9	165 by 210
8 by 16	184 by 387
8 by 18	184 by 438
12 by 12	286 by 286

TABLE 2. — Summary of sample sizes for bending and compression parallel-to-grain data on structural timbers in Bulletin 108.[a]

		Bending		Compression	
Species group	Moisture content	Nominal sizes	Sample size	Nominal sizes	Sample size
Southern pine	Green	5 by 8 to 12 by 12	202	5 by 8 to 8 by 18	137
	Dry	5 by 8 to 8 by 16	65	4 by 4 to 6 by 6	116
Douglas Fir-Larch	Green	5 by 8 to 8 by 16	351	5 by 6 to 6 by 6	792
	Dry	5 by 8 to 8 by 16	185	6 by 6	372
Western hemlock	Green	8 by 16	39	6 by 6	182
	Dry	8 by 16	44	6 by 6	102
Tamarack	Green	6 by 12	15	6 by 7	4
	Dry	6 by 12	5	4 by 7 to 6 by 7	6
Red pine	Green	6 by 12	15	6 by 7	5
	Dry	6 by 12	5	4 by 7 to 6 by 7	6
Redwood	Green	7 by 9 to 8 by 16	42	6 by 6	34
	Dry	7 by 9 to 8 by 16	18	6 by 6	18

[a] Refer to Table 1 for SI equivalents.

51 mm (2 in.) greater than the thickness. (See **Table 1** for SI equivalents of nominal dimensions.)

Because posts and timbers are graded primarily to resist axial compressive stresses, the grade requirements are the same regardless of position along the length of the member. Southern pine timbers are graded without regard to anticipated use, as is dimension lumber. For all species, including southern pine, allowable properties for timbers are estimated from clear-wood data and adjusted according to procedures in ASTM D 245. There are few data for judging the suitability of these property assignments.

MECHANICAL GRADING OF DIMENSION LUMBER

Several procedures are available for machine grading of lumber. The traditional procedure of machine stress rating (MSR) relies upon the relationship between strength and stiffness to establish grade boundaries. Sorting efficiency for lumber grades is further controlled by visual restrictions on allowable edge knot sizes (6). Qualifying lumber for an MSR grade is an iterative procedure in which deflection limits are set for individual grades and the resulting output is tested for conformance to claimed properties. Traditionally, modulus of elasticity (MOE) and modulus of rupture (MOR) values have been used to establish the grade cut-off settings on an MSR machine. Other property values are determined either as a function of MOR (ultimate tensile and compressive stress) or by the clear-wood procedure (shear strength parallel to grain and compression strength perpendicular to grain).

The strength–MOR relationships used to calculate ultimate tensile stress (UTS) and ultimate compressive stress (UCS) from MOR were determined from tests of softwood species (7). For UCS, the relationship is as follows:

$$\text{If MOR} \geq 19.55 \text{ MPa},\quad \text{UCS/MOR} = 14.208(1/\text{MOR}) + 0.338$$

$$(\text{If MOR} \geq 2.835 \times 10^3 \text{ psi},\quad \text{UCS/MOR} = 2.061(1/\text{MOR}) + 0.338) \qquad [1]$$

or

$$\text{If MOR} < 19.55 \text{ MPa } (< 2.835 \times 10^3 \text{ psi}),\quad \text{UCS/MOR} = 1.06$$

The traditional relationship between UTS and MOR for MSR lumber is a discontinuous function (7). Other relationships may be used with appropriate quality control.

BULLETIN 108 DATA

The most comprehensive data set available for U.S. timbers is that given in Bulletin 108 (4). In total, 2,760 tests were conducted on softwood timbers in sizes ranging from 5 by 6 to 12 by 12 **(Table 2).** The bending tests were conducted in edgewise bending using third-point loading. The beams were tested at a constant span of 4.6 m (15 ft.), resulting in a span-to-depth ratio ranging from 14:1 to 22:1. Compression tests were conducted using 610-mm- (2-ft.-) long pieces cut from the ends of bending members.

Although an impressive data set, the data are of limited usefulness. For example, the southern pine data were separated into green and dry groupings, but the dry data had an average moisture content (MC) of 19 percent with a range from 12 to 28 percent. Because the percentage at which properties cease to become affected by MC is only about 23 percent, little difference was expected, or found, between green and dry properties. Also, no standardized grading system existed at the time these pieces were tested. Insufficient knot data are given in the publication to allow sorting into current grades. The data that were recorded suggests that much of the timber would have been graded as Select Structural by current rules.

A width effect model of the following form was fit to the southern pine data:

$$R_2 = R_1(W_1/W_2)^{1/N} \qquad [2]$$

where:

W_1 and W_2 = initial and final specimen widths corresponding to initial and final MOR values of R_1 and R_2

$1/N$ = shape parameter for the width-property relationship.

The shape factor for the Bulletin 108 data on southern pine was found to be approximately $N = 9$ for beams of approximately equal thickness. This is the same as that given in ASTM D 245. For 38-mm- (2-in.-) thick dimension lumber tested at a constant span-to-depth ratio, the power factor is $N = 2.8$ (10). A factor of $N = 9$ indicates much less effect of specimen width on MOR than does a factor of 2.8. However, the extremely high quality of the specimens, coupled with the difficulty of sorting out much data of varying widths for a given thickness, make this observation of questionable utility.

UBC DATA ON DOUGLAS-FIR TIMBERS

Madsen and Stinson (13) of the University of British Columbia (UBC) reported results of tests on 1,684 pieces of Douglas-fir lumber ranging from 4 by 6 to 8 by 16. All the lumber was obtained from one mill in Vancouver, B.C. The green lumber was proof-loaded on edge in one-third-point bending using a span-to-depth ratio of 17:1. The rate of loading was fast, so that failure usually occurred in 60 seconds or less. The results do not present a clear trend with respect to the effect of specimen volume on bending strength. For a given thickness, strength was found to generally decrease with increasing width **(Fig. 1).**

The trend between width and strength for timbers is similar to that obtained by Madsen in previous studies on dimension lumber. It is steeper than that found with the Bulletin 108 timber data. For current grades of timber, volume effect relationships found by Madsen and Stinson are probably more realistic than Bulletin 108 trends. For a brittle material, one would also expect that strength would decrease with increasing thickness. However, Madsen and Stinson found that strength tended to increase with increasing thickness, for a given width. To explain this anomalous trend, it was postulated that a knot is less likely to intersect the whole tension zone in a timber than it is in thinner members. Also, if one were to look at only the data for 6 by and 8 by timbers, the data appear more linear than would be expected from the exponential form given in Equation [2].

Allowable bending properties for timbers in the National Design Specification (NDS) (1) are given without regard to beam volume. For Select Structural Douglas Fir-Larch (North) Beams and Stringers, 2.1 F_b is 23.2 MPa (3.36×10^3 psi), and for No. 1 grade it is 18.9 MPa (2.73×10^3 psi) (1). Most strength values for timbers obtained by Madsen and Stinson were higher than these allowable values. The MOE values were also generally higher than the current NDS values of 11.0 GPa (1.60×10^6 psi), for both grades, especially for Select Structural.

MOISTURE CONTENT EFFECTS ON TIMBER PROPERTIES

ASTM D 245 provides factors that can be used to estimate changes in timber properties as a result of seasoning. For MOE, a 2 percent increase is allowed for seasoning from green to 15 percent maximum MC. For UCS parallel to the grain, a 10 percent increase is allowed. No increase in MOR above the green values is allowed for seasoned timbers.

Data on approximately 50 green and dry Sitka spruce and western hemlock 8 by 16 timbers cut in Alaska were reported in USDA Technical Bulletin No. 226 (14) **(Table 3).** Each of the selected trees was 9.8 m (32 ft.) long. Half of each tree was used to obtain a dry specimen, and the other to obtain a green specimen. Use of the butt log for the dry specimen was alternated between trees. By current standards, the timbers were generally of high quality. Approximately 86 percent of western hemlock timbers and 95 percent of Sitka spruce were graded "S2" or higher (minimum estimated strength 75% that of clear wood) by the rules of USDA Circular 295 (15). Thus, most timbers would probably have been graded as Select Structural by current rules for western timbers. The green timbers were tested immediately after shipment to the Forest Products Laboratory. The remaining timbers were air-dried for several years prior to testing. All timbers were tested on edge in one-third-point

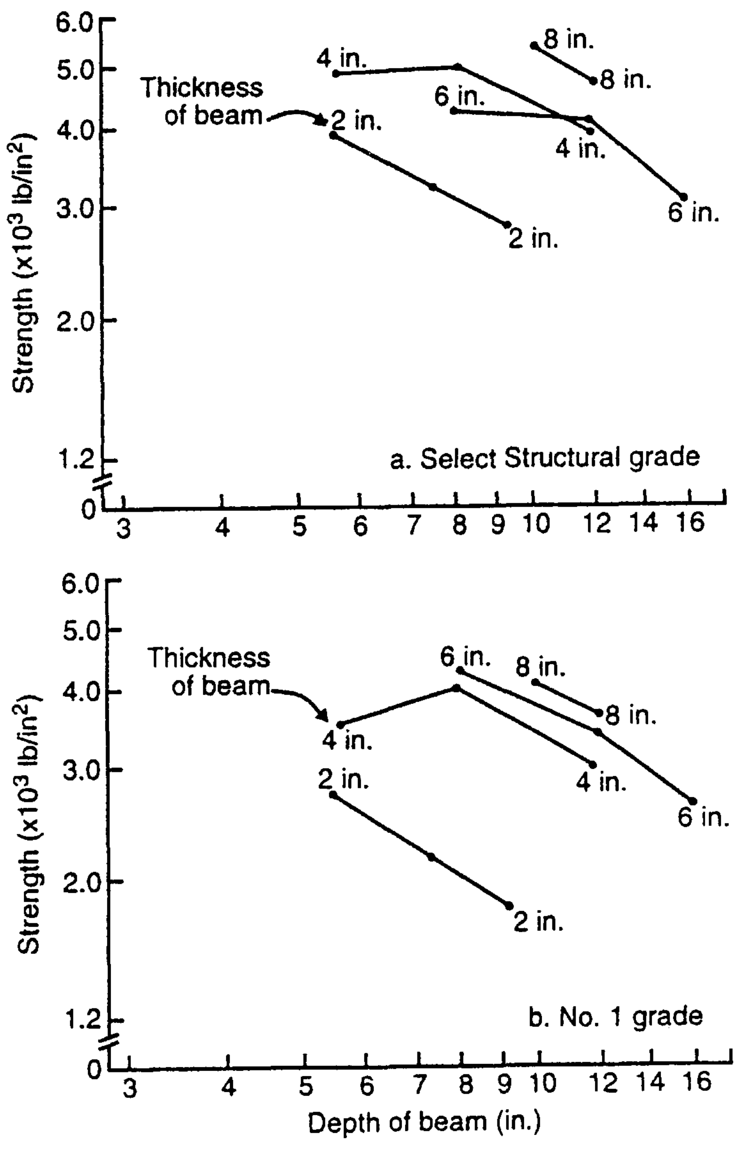

Figure 1. — Effect of beam depth on 5th percentile MOR of Douglas-fir timbers. Adapted from (13). 1 inch = 25.4 mm, 1 psi = 6.89 kPa.

bending using a span-to-depth ratio of approximately 11:1. The MOE of both species increased approximately 12 percent in drying to about 17 percent MC. Fifth-percentile MOR increased 8 to 10 percent, while the average value increase was closer to 20 percent.

An earlier study (5) on ten 9.8-m- (32-ft.-) long Douglas-fir 8 by 16 timbers was similar to Markwardt's study (14), except that the tree end to be tested dry was not alternated from tree to tree. The results were similar to those of Markwardt **(Table 3).** About the same time, Betts (3) presented data on loblolly pine timbers seasoned slowly undercover for 21 months. This process was used to avoid excessive checking. Mean MOR increased about 20 percent and mean MOE increased about 16 percent **(Table 3).**

Littleford (12) presented a limited amount of data from tests of approximately 27 green and air-dried Douglas-fir timbers. All the timbers were 6 by 12 in cross section and were tested on edge in one-third-point bending using a span-to-depth ratio of approximately 15:1. The mean MOE of these timbers increased 9 percent upon drying, and the mean MOR increased 23 percent **(Table 3).**

This information suggests that the current ASTM adjustments in timber properties involve conservative judgments of the effect of MC on flexural properties. Thus, those conducting research on the properties of timbers should not assume that their results will be independent of MC. The property increases might also be achieved for timbers that are used inside a covered structure, but they may not be achieved for members directly exposed to weathering. As with dimension lumber, MC appears to have less effect on MOR at the 5th percentile level than at the mean, and thus the increase depends on lumber quality.

Materials and methods

Timber sample

Approximately two-hundred 140- by 140-mm by 3-m (6- by 6-in. by 10-ft.) untreated southern pine timbers were obtained from mills in Mississippi and Alabama, 100 pieces per mill **(Table 4).** The timbers were graded by a quality supervisor of the Southern Pine Inspection Bureau (SPIB) for characteristics that directly affect properties, such as knots and slope of grain. Half the timbers were Select Structural and half No. 2. The estimated "strength ratio" (theoretical strength of member with defect divided by strength of member without a defect present) was approximately 0.73 for Select Structural and 0.40 for No. 2 grade. The timbers were dry when purchased and were stored for several months prior to testing. Measurements of the overall dimensions and weight to the nearest pound (0.45 kg) were taken for each timber.

Sorting procedure

Research has shown that pulse-echo longitudinal stress wave techniques hold promise for determining MOE of timbers (11, 17). To obtain the stress wave measurement of MOE (PE MOE), a double-threaded screw was placed in the end of the timber and an accelerometer attached. Pulse energy was introduced to the specimens through a hammer impact on the opposite end. Echo waves were recorded to obtain a time between peaks on an oscilloscope. The PE MOE was calculated using the speed of the sound wave, c, and density ρ of each timber using the following equation (16):

$$\text{PE MOE} = c^2\rho \qquad [3]$$

The 100 timbers of each grade were ranked on PE MOE and successive pairs of timbers randomly assigned to one of two groups. One group was assigned for testing in bending and the other for testing in compression parallel to grain.

TABLE 3. — Effect of MC on flexural properties of timbers.

Species	Condition	Sample size	Moisture content Mean	Low	High	Mean MOE		MOR Mean		MOR 5th percentile	
			(%)			(× 10³ MPa)	(×10⁶ psi)	(MPa)	(× 10³ psi)	(MPa)	(× 10³ psi)
Sitka spruce[a]	Green	20	34.4	29	53	8.569	1.243	29.823	4.326	23.99	3.48
	Dry	20	17.3	14	23	9.660	1.401	36.614	5.311	25.99	3.77
	Dry/Green	--	--	--	--	1.127	1.127	1.228	1.228	1.08	1.08
Western hemlock[a]	Green	28	41.6	31	59	9.362	1.358	33.636	4.879	25.78	3.74
	Dry	29	17.5	16	19	10.486	1.521	39.620	5.747	28.47	4.13
	Dry/Green	--	--	--	--	1.120	1.120	1.178	1.178	1.10	1.10
Douglas-fir[b]	Green	10	31.0	26	36	9.907	1.437	37.503	5.440	--	--
	Dry	10	16.4	15	17	11.175	1.621	46.466	6.740	--	--
	Dry/Green	--	--	--	--	1.128	1.128	1.239	1.239	--	--
Douglas-fir[c]	Green	26	35.1	--	--	11.203	1.625	42.240	6.127	33.73[e]	4.89
	Dry	28	17.4	--	--	12.182	1.767	51.996	7.542	39.61[e]	5.75
	Dry/Green	--	--	--	--	1.087	1.087	1.231	1.231	1.17	1.17
Southern pine[d]	Green	12	50.9	36	79	10.000	1.450	38.744	5.620	--	--
	Dry	12	19.7	22	18	11.637	1.688	46.335	6.721	--	--
	Dry/Green	--	--	--	--	1.164	1.164	1.196	1.196	--	--

[a] 8 by 16 timbers (14).
[b] 8 by 16 timbers (5).
[c] 6 by 12 timbers (12).
[d] 8 by 16 timbers (3).
[e] Calculated using an assumed normal distribution.

TABLE 4. — Properties of dry southern pine 6 by 6 timbers.

Property	Grade[a]	Sample size	MC	SG[b]	Value at property level: Mean		COV[c]	5th percentile	
					($\times 10^3$MPa)	($\times 10^6$ psi)	(%)	($\times 10^3$MPa)	($\times 10^6$ psi)
MOE									
Static	SS	47	14	0.48	9.879	1.433	28.6	5.791	0.840
	No. 2	52	14	0.46	8.921	1.294	32.9	4.612	0.669
Stress wave	SS	47	14	0.48	9.086	1.318	27.6	5.377	0.780
	No. 2	52	14	0.46	8.452	1.226	23.4	5.005	0.726
MOE C[d]					($\times 10^3$MPa)	($\times 10^6$ psi)	(%)	($\times 10^3$MPa)	($\times 10^6$ psi)
Static	SS	50	12	0.48	10.825	1.570	29.0	5.902	0.856
	No. 2	52	12	0.45	9.556	1.386	28.2	5.095	0.739
Stress wave	SS	50	12	0.48	9.846	1.428	27.6	5.247	0.761
	No. 2	51	12	0.45	8.881	1.288	25.7	5.171	0.750
MOR					(MPa)	($\times 10^3$ psi)	(%)	(MPa)	($\times 10^3$ psi)
	SS	47	14	0.48	36.125	5.240	23.9	22.536	3.269
	No. 2	52	14	0.46	26.259	3.809	37.4	13.919	2.019
UCS					(MPa)	($\times 10^3$ psi)	(%)	($\times 10^3$MPa)	($\times 10^6$ psi)
	SS	50	12	0.48	25.701	3.728	23.3	17.883	2.594
	No. 2	52	12	0.45	22.716	3.295	24.7	15.718	2.280

[a] SS is Select Structural.
[b] Specific gravity based on ovendry weight and volume.
[c] Coefficient of variation (percent).
[d] MOE C = modulus of elasticity measured in compression parallel to the grain.

STATIC TESTING

Bending tests were conducted according to ASTM D 198 procedures (2). The beams were loaded on edge with loads applied at the one-third point of the span. The span-to-depth ratio was 17:1. A constant rate of cross-head movement of about 5 mm (0.2 in.) per minute assured failure in about 20 minutes. After testing, a 25.4-mm- (1-in.-) thick section was removed from each timber for determination of MC and specific gravity (ASTM D 4442 and D 2395, method A (2)).

Specimens to be tested in compression parallel to grain were cut to a length of 2.8 m (9 ft., 3 in.) and the ends squared. Compression tests were conducted on these full-length timbers according to ASTM D 198. The timbers were tested as short columns using a restraining cage that provided five supports at 728-mm (28-in.) intervals on each side along the length. A loading rate of approximately 2.5 mm (0.1 in.) per minute in cross-head speed yielded an average time to failure of about 13 minutes. Modulus of elasticity in compression parallel to the grain (MOE C) was determined using deflections measured with two linear variable differential transformers (LVDTs) on either side of the member. The MOE C values reported are the average of the two readings over the 1.8-m (6-ft.) gage length. As with the bending specimens, MC and specific gravity specimens were collected for each timber after testing.

RESULTS AND DISCUSSION

VISUALLY GRADED LUMBER

Properties of the visually graded timbers tested in this study are shown in **Table 4.** The average specific gravity of the specimens was less than the value of 0.55 reported in the NDS (1). The MC of the bending specimens was about 15 percent and that of the compression specimens about 12 percent. This difference was probably a result of gradual drying of the room in which the timbers were stored as winter approached. In all cases, the properties of Select Structural timbers were significantly higher than those of No. 2 timbers (at the 0.05 level of significance) and MOE C was higher than MOE.

Comparison of properties obtained in this study with those published for southern pine requires that the values be adjusted to an equivalent basis. The allowable MOE values given in the NDS are for a span-to-depth ratio of 21:1 and a uniformly distributed load. For southern pine, the NDS values are given for wet (green) service conditions. We increased the allowable MOE value 2 percent to adjust to an average MC of 15 percent (ASTM D 245). Our timbers were tested in one-third-point bending and a span-to-depth ratio of 17:1. The adjustment in MOE for loading was a correction of only 1.003 (ASTM D 2915). This slight correction was ignored in the results. The average MOE of our data is close to that given in the NDS **(Table 5)** and within a 75 percent confidence interval on the median value.

To compare bending strength values, we multiplied the allowable bending strength given in the NDS by the general adjustment factor of 2.1 (ASTM D 245). The nonparametric 5th percentile of the timbers was above the NDS value for both grades **(Table 5).**

The NDS value for the allowable UCS parallel to grain was multiplied by 1.9 to compare it to the experimental UCS data. The NDS value was increased 10 percent for seasoning. The compressive strengths determined in our study were well above those given in the NDS, especially for No. 2 grade **(Table 5).** That the clear wood procedure of ASTM D 245 underestimates compressive strength parallel to grain is consistent with findings for 38-mm- (2-in.-) thick dimension lumber (19,20).

PROPERTY RELATIONSHIPS

Property relationships are a basis for setting allowable properties for both visually and mechanically graded lumber. The strength–stiffness relationship for the timbers in our study is given in **Table 6.** Although slightly lower than expected, the coefficient of determination is still significant and useful. The lower value may be a result of the limited data. The correlation between properties and specific gravity, also shown in **Table 6,** was approximately the expected value.

Figure 2 shows the relationship between compressive and bending strength for the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of MOR. The relationship for timbers appears to follow the general trend found for 38-mm (2-in.) dimension lumber (7-9). The slight degree of instability, as evidenced by the higher ratio of the 90th and 95th percentile points, was probably a result of the limited number of specimens. However, we conclude that the general UCS/MOR relationship used to assign properties to mechanically graded lumber could be applied to mechanically graded southern pine timbers. Further, it would appear that the conservative relationship given in ASTM D 1990 (2) for assigning compressive properties to visually graded dimension lumber could be applied to visually graded timbers that are not tested in compression.

POTENTIAL FOR MECHANICAL GRADING

One objective of our study was to evaluate the technical basis for establishing a mechanical grading system for structural timbers. The first step would be to establish a 95 percent lower confi-

TABLE 5. — Experimental and allowable properties for dry southern pine 6 by 6 timbers.

Property	Grade	Point estimate	0.75 CI[a] Lower		0.75 CI[a] Upper		Equivalent allowable[b]	
			($\times 10^3$ MPa)	($\times 10^6$ psi)	($\times 10^3$ MPa)	($\times 10^6$ psi)	($\times 10^3$ MPa)	($\times 10^6$ psi)
Mean MOE								
	SS	1.43	9.24	1.34	10.69	1.55	10.53	1.53
	No. 2	1.29	7.79	1.13	9.03	1.31	8.41	1.22
5th percentile MOR			(MPa)	($\times 10^3$ psi)	(MPa)	($\times 10^3$ psi)	(MPa)	($\times 10^3$ psi)
	SS	3.27	21.37	3.10	24.13	3.50	21.72	3.15
	No. 2	2.02	13.31	1.93	15.86	2.30	12.27	1.78
5th percentile UCS			(MPa)	($\times 10^3$ psi)	(MPa)	($\times 10^3$ psi)	(MPa)	($\times 10^3$ psi)
	SS	2.59	17.44	2.53	18.68	2.71	13.72	1.99
	No. 2	2.28	13.58	1.97	16.82	2.44	7.58	1.10

[a] Confidence interval.
[b] Allowable values from SPIB(18). MOE values were multiplied by 1.02 to correct for MC; UCS values were multiplied by 1.10 to correct for MC and 1.9 to correct for general adjustment factor of ASTM D 245; MOR values were multiplied by 2.1 to correct for general adjustment factor of ASTM D 245.

TABLE 6. — Property relationship for southern pine timbers.[a]

Property relationship Y	Property relationship X	Sample size	English units A	English units B	SI units A	SI units B	r^2	RMSE English	RMSE SI
MOE	PE MOE	99	-0.0251	1.091	-0.173	1.091	0.71	0.227	1.565
MOR	PE MOE	102	1.195	2.594	8.238	2.594	0.30	1.195	8.238
UCS	PE MOE	99	1.262	1.661	8.700	1.661	0.50	0.612	4.219
MOR	MOE	99	1.626	2.105	11.210	2.105	0.34	1.238	8.536
UCS	MOE	102	1.299	1.496	8.955	1.496	0.55	0.580	4.000
MOE	SG	99	-0.0493	3.024	-0.340	3.024	0.19	0.371	2.557
MOR	SG	99	-3.056	1.610	-21.068	1.610	0.40	1.179	8.127
UCS	SG	102	-0.891	9.544	-6.143	9.544	0.42	0.659	4.543
PE MOE	SG	99	0.0425	2.632	0.293	2.632	0.24	0.276	1.903
MOE	Micro/ft.	99	-0.0294	3.592	-0.009	3.592	0.51	0.297	2.048
MOE C	PE MOE	102	-0.0154	1.100	-0.106	1.100	0.88	0.153	1.055
MOE C	SG	102	-0.395	4.061	-2.723	4.061	0.30	0.36	2.481

[a] Units of measurement: MOE, PE MOE, MOE C = $\times 10^6$ psi (English) and 10^3 MPa (SI); MOR, UCS = $\times 10^3$ psi and MPa; Micro/ft. = µs/ft. and µs/m. r^2= coefficient of determination; RMSE = root mean square error; MOE C = MOE measured in compression parallel to the grain; PE MOE = MOE determined by pulse echo stress wave techniques.

dence limit on the MOE–MOR regression **(Fig. 3).** This could be used to set grade boundaries for proposed mechanical grades. Non-strength-reducing characteristics, such as wane or warp, would likely be set equivalent to those of No. 2 timbers. The next step would be to sort out a group of timbers (e.g., 60 per grade) that meet the MOE and visual requirements and test them to verify the proposed properties. Allowable knot restrictions could be set by comparing knot sizes of timbers that failed to make the proposed grade and those that survived the minimum load requirement. Such a two-step process is already in progress for oak timbers (8, 11).

We did not conduct tensile tests on southern pine timbers. However, property relationships between MOR and MOE, and between UCS and MOR, seem to follow the trends expected for dimension lumber. Thus, we see no reason to doubt the ratio between tensile and bending strength of 0.55 given in ASTM D 245.

Our results indicate that there are no technical barriers to establishing a mechanical grading system for timbers. Such a system would allow more precise property assignment than currently possible with visual grading. Further, a mechanical grading system would allow users to optimize structural design to meet their individual needs by specifying grades having properties not currently possible with visual grading. Acceptance of this procedure by the American Lumber Standards system would require approval of grading and quality control procedures. Evaluation of this system for mechanical grading of recycled timbers, and for grading timbers in place in wood structures, would be logical extensions of this research.

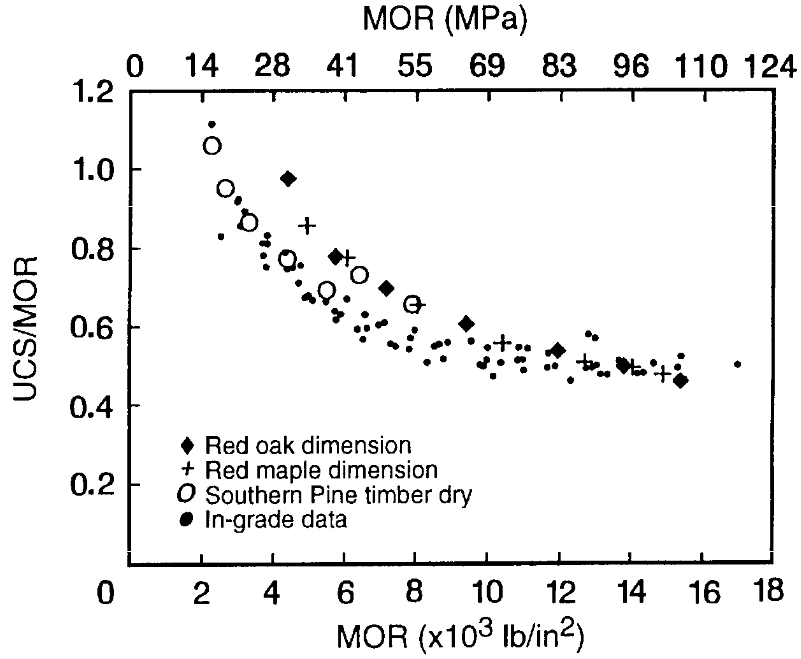

Figure 2. — Relationship of compressive strength to bending strength for dry southern pine 6 by 6 lumber.

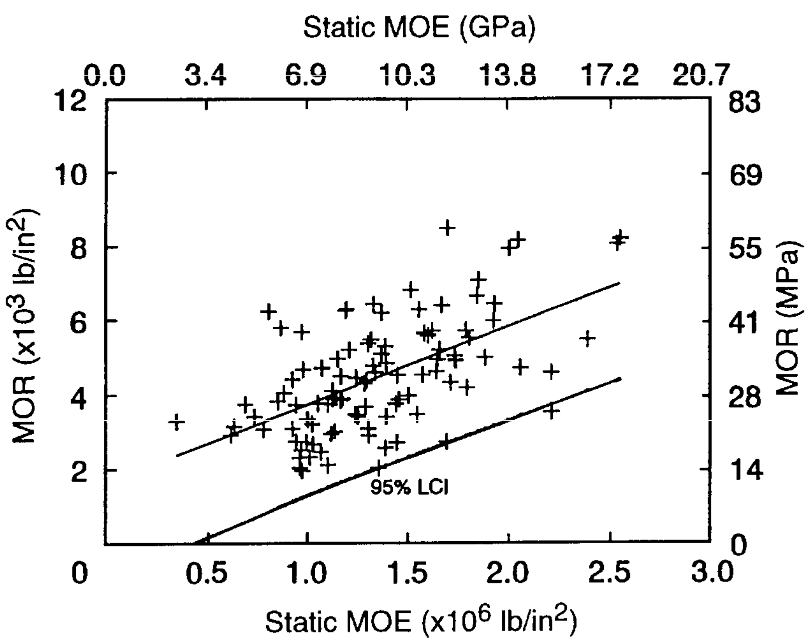

Figure 3. — Relationship of bending strength to MOE for dry southern pine 6 by 6 lumber.

Conclusions

The results of this study on the properties of dry southern pine 6 by 6 timbers led to the following conclusions:

1. Bending strength and MOE data support the currently assigned allowable F_b and E values.

2. Compressive strength parallel-to-grain data suggest that the currently assigned allowable compressive strength parallel to grain, F_c, is conservative.

3. The relationship between ultimate compressive stress parallel to grain and modulus of rupture is essentially the same as that observed for dry 38-mm (2-in.) hardwood or softwood dimension lumber.

4. There are significant relationships between MOR and MOE, as determined by static and pulse-echo stress wave procedures.

5. There is apparently no technical reason to hinder the development of a mechanical grading system for southern pine timbers. Such a system would allow more efficient utilization of structural timbers.

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