BENDING STRENGTH OF WATER-SOAKED GLUED LAMINATED BEAMS

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ABSTRACT

The effects of water soaking on the bending strength and stiffness of laminated timber were determined by deriving wet-dry ratios for these properties. Values for these ratios, when compared to currently recommended wet use factors, confirm the value now used for modulus of rupture. For modulus of elasticity, the reduction due to water soaking was found to be less than that now recommended.

Results will be useful to organizations preparing design standards for heavy timbers subject to potentially high moisture contents.

BENDING STRENGTH OF WATER-SOAKED GLUED LAMINATED BEAMS[1]

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INTRODUCTION

In recent years, glued laminated (glulam) timbers have been used increasingly in high moisture environments, due in part to growing confidence in the efficacy of structural waterproof adhesives and preservative treatments for wood. Because glulam timbers are most often manufactured for use under dry conditions, most reported testing has taken account only of timbers under dry use. Little information is currently available on strength changes due to soaking dry beams.

This study considers the effects of high moisture content on the strength and stiffness of glulam beams. Wet-dry ratios derived from the test data are then compared to current design recommendations. A total of 60 glulam beams were tested, 30 of Douglas-fir and 30 of southern pine. Half of the beams in each species group were tested near 12 percent moisture content and the remaining were water-soaked prior to testing.

The history of design stresses for glulam timbers since 1954 is well documented. In USDA Technical Bulletin 1069, published in that year, Freas and Seibo (6) recommend “basic stresses” for various properties under both dry and wet conditions. They did not specifically define “dry” and “wet” conditions, but the presently accepted definitions limit dry use to “less than 16 percent [moisture content] as in most covered structures” (2).

Freas and Seibo did not base their dry-wet stress adjustments on actual tests of wet beams. instead, they modified dry-beam stress values in terms of American Society for Testing and Materials (ASTM) Standard D 245 (3). This standard is used as a guide in establishing allowable properties for visually graded lumber. The 1949 version, referenced by Freas and Seibo, recommended a 25 percent increase in modulus of rupture (MOR) for seasoning effects. The ratio of dry to wet MOR values tabulated by Freas and Seibo reflects this ASTM recommendation. For modulus of elasticity (MOE) the ratio of dry to wet values tabulated in their report assumes one-half the seasoning effect suggested for MOR (12.5 pct). inverting these seasoning increases then provides wet use factors for MOR (1/1.25 = 0.80) and MOE (1/1.125 = 0.89).

These ratios formed the basis for all glulam industry specifications until 1971. Then the American institute of Timber Construction, while retaining the 0.80 factor for bending stress, revised the 0.89 factor for modulus of elasticity to 0.833 (1), a reciprocal of the ASTM D 245-69 (4) correction for drying from green

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[1] This research was conducted in cooperation with the American Institute of Timber Construction.

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

to 15 percent moisture content or below. These factors were published as part of AITC Specification 117 (1). Later versions of this specification recommend the 0.833 factor for wet-use MOE.

Questions which have arisen regarding the accuracy of these factors include the following: (1) Are seasoning factors, derived for small, clear specimens, directly applicable to full-size lumber? (2) Is the strength of rewetted wood the same as that of wood in the green condition?

The present study should contribute to determining the accuracy and applicability of the currently recommended factors in terms of full-scale beams and actual design situations.

RESEARCH MATERIALS

The beam combinations used for this study were also part of another study where the beam design, material selection, and beam manufacture are more completely described (7). Douglas-fir beams were designated as group E, southern pine beams as group F.

For each group, the one outer compression and two outer tension laminations of the 12-inch-deep beams were selected for stiffness as well as visual characteristics. The remaining six inner laminations of the nine-lamination beams were visually graded only. Each outer tension lamination was oriented such that a near maximum strength reducing characteristic permitted in the tension lamination grade was located within 2 feet of midlength. Also, 30 to 40 percent of the beams intentionally had finger joints in this highly stressed midlength region of the outer tension lamination.

There was a slight difference in manufacturing the finger joints for the two species. Finger joints in the southern pine were cut perpendicular to the wide face and were made using a phenol-resorcinol adhesive. Finger joints in the Douglas-fir were cut parallel to the wide face and were joined using a melamine-urea adhesive.

The beams were fabricated in commercial laminating plants. After finger jointing, laminations were surfaced to 1-3/8-inch thickness, spread with phenol-resorcinol adhesive, and assembled into nine-lamination beams. After manufacture, the beams were surfaced to 3-118-inch width and trimmed to a 20-foot length. Except for lumber grades of the outer lamination, the beam manufacturer followed PS 56-73 (9).

RESEARCH METHODS

Conditioning

From each species group of 30 beams, half were randomly selected to be tested in the dry condition. These beams were stored for a period of from 1 to 2 months prior to testing. Test results have also been reported in (7).

Beams to be tested wet remained in covered storage for an additional 5 months. They were then measured, weighed, and stickered in an outdoor, uncovered tank at FPL and immersed in water. After 6 weeks, three southern pine beams (F-06, -09, and -19) were removed and tested. At that time, increment cores taken from near the ends of the Douglas-fir beams indicated little penetration Of water. Therefore, all remaining beams were soaked an additional 2-1/2 months.

At the end of the 4-month immersion period, all beams were removed from the tank, set on edge under a sprinkler, and tested over a 4-day period.

Test Equipment

Beam tests were performed following established standards given in ASTM D 198 (5). A mechanical testing machine was used to apply a two-point load on a span of 19 feet. Deflection was measured using a transducer attached to a yoke, permitting the detection of motion of the midspan centroidal axis relative to the centroidal axis above the test supports. Transducer and test machine electrical outputs were recorded by an x-y recorder.

Procedure

Beam weight and dimensions were recorded just prior to testing. Next, the beam was mounted on the test supports and the load heads were spaced 2 feet either side of midspan. Load was applied at a continuous rate of 0.9 inch per minute until the machine load dropped to 50 percent of the maximum. Notes were taken of the loads at which either audible or physical signs of distress were first noticed. Estimates of the order of failure propagation were also noted.

Following dry beam failures, moisture content of each lamination was determined in undamaged wood as close as possible to the failure, using a resistance-type moisture meter. Moisture contents of individual laminations were averaged to estimate beam moisture content.

For the wet beams, moisture contents were approximated by assuming a moisture content of 10 or 11 percent prior to soaking and measuring the increase in beam weight during soaking; also, one representative beam from each species group was analyzed in more detail to sample moisture distribution: 1/4-inch-thick concentric shells sawn from a 2-inch-long cross section taken from near the failure (Fig. 1) were ovendried and weighed.

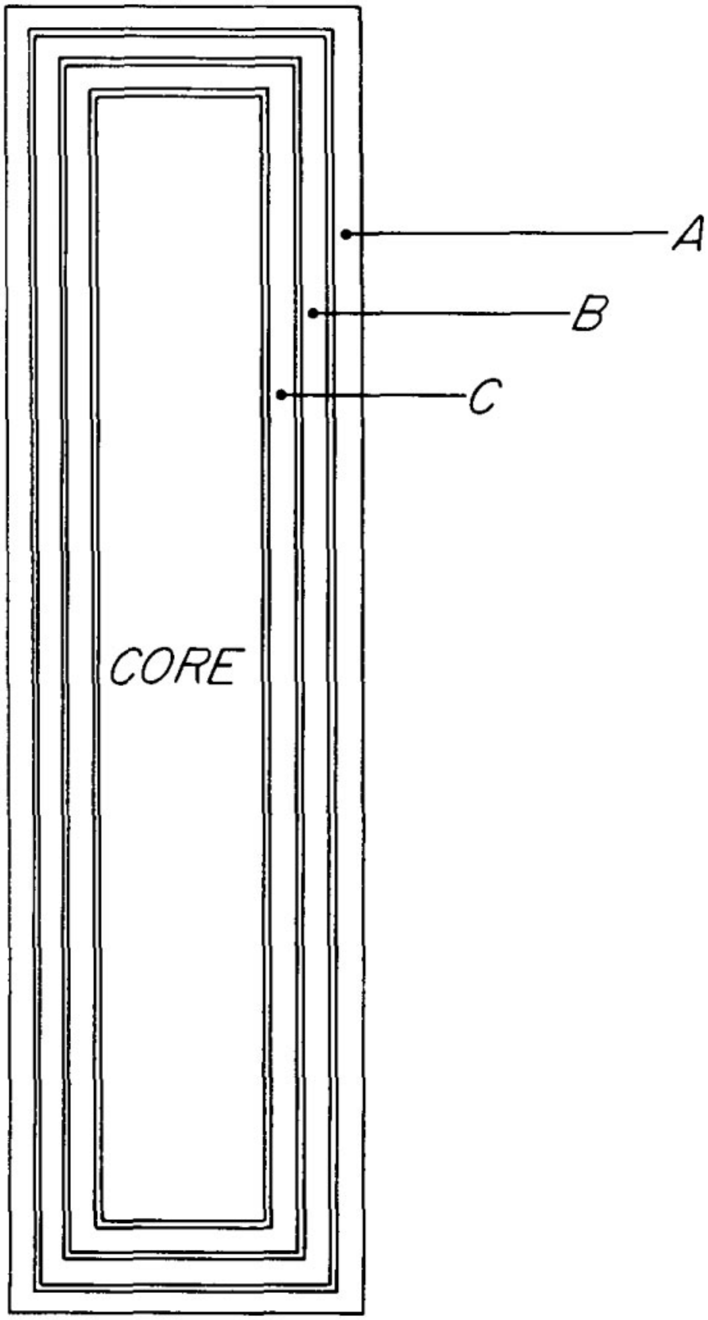

Figure 1.–Concentric shells (A, B, and C) 114-inch thick cut from a sample of each species to determine moisture distribution after water soaking.

(M 145 638)

RESULTS

Physical Properties

Physical properties of the beams are given in Table 1. Properties of the lumber used for beam manufacture are described in (7).

Dimensions measured after soaking, expressed as a percent of the dry dimension, showed a greater change in the width than in the depth. The Douglas-fir width change was 4.2 percent compared to 6.0 percent for the southern pine. Depth of both species increased 3.0 percent. These changes resulted in an 11 percent increase in section modulus (S) for the Douglas-fir and a 13 percent increase in S for the southern pine. Moment of inertia (**I**) increased 14 percent for Douglas-fir and 16 percent for southern pine. The weight increase was also greater for the southern pine, about 45 percent versus 30 percent for Douglas-fir.

Mechanical Properties

Average bending properties for the dry and wet beams are given in Table 2; predicted wet beam properties, based on the dry properties and recommended wet use factors, are also included. Two different MOR and MOE values are given for the tests under wet conditions. One was calculated based on dry dimensions prior to soaking and the other based on the actual dimensions following soaking.

The wet beam strength properties of greatest interest to the designer are those calculated using dry dimensions. Values for load carrying capacity and stiffness of wet beams may be obtained using these dry dimensions for MOR’ and MOE’ without knowledge of the wet dimensions. Discussion of results will be limited to the value for the wet test conditons calculated using dimensions measured prior to soaking. Values thus calculated will be referred to as MOR' and MOE’; their derivation is given in appendix 1.

Load-deflection curves displayed a characteristic difference between the wet and the dry beams. (Fig. 2). The dry beam curves were nearly linear (elastic) all the way to failure. However, the wet beam curves departed from linearity (plastic deflection) beginning at a stress just above 2,000 pounds per square inch in most cases.

Table 1.– Average physical properties of dry and wet glulam beams

Beam group	Dimensions		Section modulus, S	Moment of inertia **I**	Weight	Moisture content	Specific gravity 1/
	Width	Depth					
	In.	In.	In.^{3}	In.^{4}	lb	Pct	
			DOUGLAS-FIR				
Dry beams	3.08	12.39	78.8	488.2	190.8	10	0.52
Wet beams							
before soaking	3.08	12.40	78.9	489.4	190.3	—	.52
alter soaking	3.21	12.78	87.9	558.4	246.8	43	—
			SOUTHERN PINE				
Dry beams	3.14	12.35	79.8	492.9	186.6	11	.50
Wet beams							
before soaking	3.11	12.37	79.3	490.6	189.8	—	.51
after soaking	3.30	12.76	89.5	571.3	277.0	62	—

1/ Based on volume at dry conditions and calculated ovendry weight.

Table 2 —Average bending strength and stillness properties of dry and wet glulam beams[1]

Test condition	Modulus of rupture			Modulus of elasticity		
	Average		Coefficient of variation	Average		Coefficient of variation
	Dry dimension	Wet dimension		Dry dimension	Wet dimension	
	Lb/in.	Lb/in.	Pct	Million lb/in.	Million lb/in.	Pct
			DOUGLAS-FIR			
Dry	6,170	—	16	2.05	—	6
K x dry [2]	4,940	—	—	1.71	—	—
Wet	5,220	4,710	15	1.80	1.57	[3] 3-4
			SOUTHERN PINE			
Dry	6,590	—	17	1.69	—	4
K x dry [2]	5,270	—	—	1.41	—	—
Wet	5,320	4,720	8	1.54	1.32	[3] 7-8

[1] Values given are an average of 15 beam tests

[2] Recommended wet use factor: K = 0.80 lor modulus of rupture and 0.833 for modulus of elasticity (1).

[3] Coefficient of variation values were slightly different when calculated using wet versus dry dimensions due to variations in dimensional change.

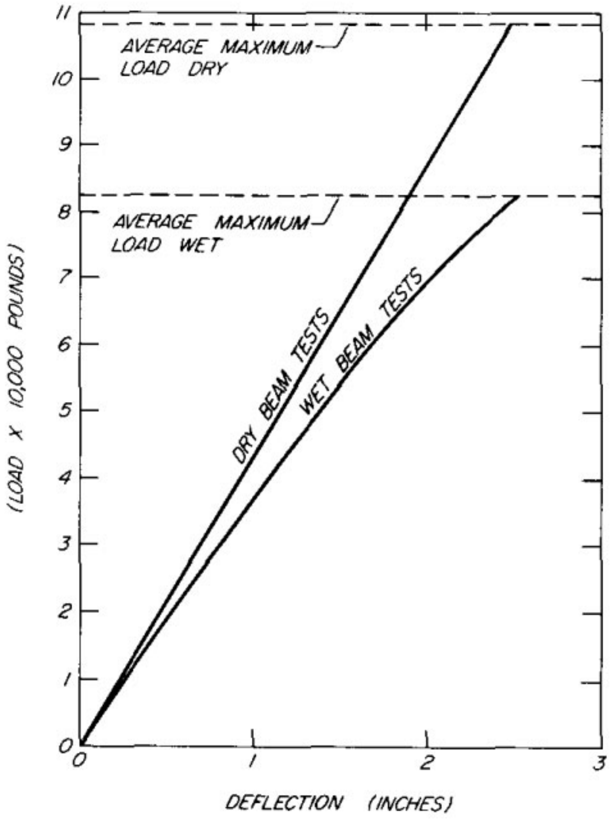

Figure 2.—Comparison of the average load-deflection curves for Douglas-fir wet and dry beams. (M 145 637)

Beam Failures

Dry beam failures all appeared to Initiate in the outer tension laminations. Most wet beam failures also began in the outer tension zone, but some appeared in the compression zone and as shear failures along the neutral axis. Beam failure data are summarized in Table 3.

Table 3. — Sources of failure in wet and dry beams expressed as a percentage of the beam group

Source of failure	Douglas-fir		Southern pine	
	Dry	Wet		Wet
	Pct	Pct	Pct	Pct
Knots and related grain deviation	50	20	40	20
Finger joints	10	40	40	60
Compression wrinkling	0	13	0	20
Shear failure	0	27	0	0
Combinations of knots. finger joints, or sloping grain	40	0	20	0

ANALYSIS OF RESULTS

Degree of Saturation

After 4 months of soaking, the southern pine beams appeared to be nearly completely saturated, but the Douglas-fir beams showed complete saturation only to a depth of about 1/4 inch from the surface. However, Wilson (11) showed that changes in mechanical properties are minimal above an average moisture content which he called the "intersection point" (Mp) Based on weight increases due to water sorption, all beams removed from the water tank had average moisture contents above this Mp value.

One beam was selected from each species group to sample the actual moisture distribution. After testing, 2-inch-long sections were cut from near the failure areas in each beam. Depths to which the sections appeared saturated (Fig. 3) suggest a much steeper moisture gradient in the Douglas-fir beams.

These visual examinations were quite subjective; therefore, concentric shells were cut from a beam section of each species (Fig. 1) to obtain moisture contents by ovendrying (Table 4). Results indicate that all of the southern pine and all but the inner core of the Douglas-fir had moisture contents exceeding Mp (12). This inner core represented 39 percent of the cross-sectional area and a lesser percentage of the moment of inertia.

The extent that additional core saturation of the Douglas-fir may have further affected bending properties can be estimated. Based

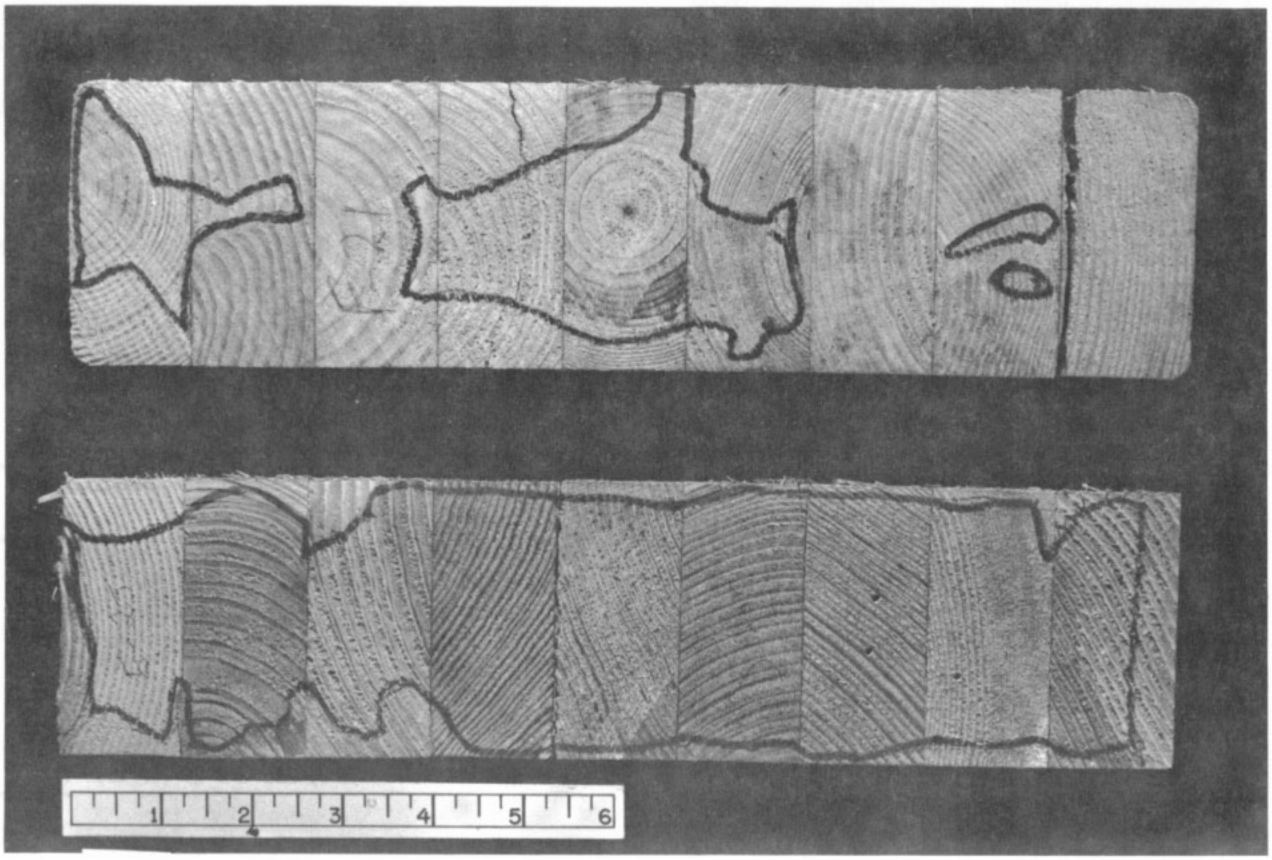

Figure 3.—Beam cross sections cut from two of the soaked beams to compare moisture distribution. The top section is from a southern pine beam and the other is Douglas-fir. The region outside of the outlined area appeared to be saturated while that inside appeared to contain less water. (M 143 950)

Table 4. —Moisture content of wet beam sections shown in Figure 1

Shell identification [1]	Area [2]	Moment of inertia [2]	Moisture content	
			Douglas-fir	Southern pine
	Pct	Pct	Pct	Pct
A	21	28	80	90
B	21	25	29	60
C	19	19	24	48
Core	39	28	20	46

[1] Identified in figure 1.

[2] Wet samples were 1/4-inch thick. and half of the 1/16-inch-thick saw kerf was attributed to the sections they separated.

on the average moisture content of the inner core and its portion of the total moment of inertia, it is estimated that at least 90 percent of the expected changes had occurred. Given the likely moisture gradient within the core, practically all of the change in bending properties due to moisture content probably had occurred.

Modulus of Rupture

The reduction in load-carrying capacity of the beams due to water soaking was 15 percent for the Douglas-fir and 19 percent for the southern pine. To determine if the reduction was different than expected, the actual strength of dry beams, the predicted strength after water soaking (K x dry, Table 2). and the actual strength after soaking (MOR’) were compared using an analysis of variance. Since the strength properties of the two species were similar, the analysis was conducted on the total sample as well as the individual species groups. While the reduction due to soaking was significant at the 0.05 level, the difference between the predicted and actual wet strength was not significant. Thus, the current recommendation to treat wet strength as 80 percent of dry strength cannot be rejected.

Two methods (appendix II) served to establish a confidence interval on the wet-dry ratio for MOR. The results of these analyses were nearly identical. The 95 percent confidence interval for the water soaking effect was between a 10 and 25 percent reduction in strength. Although the best estimate for the wet use factor was 0.83, the 0.80 factor now used is well within the 95 percent confidence interval, and these results do not support changing it.

Modulus of Elasticity

The decrease in MOE due to water soaking was 12 percent for Douglas-fir and 9 percent for southern pine. An analysis of variance indicated that the MOE for both species was significantly higher at the 0.05 level than the predicted value based on the 0.833 factor. Thus, the recommended reduction may be greater than necessary for efficient design.

Analyses conducted to determine a 95 percent confidence interval for the mean water soaking effect on MOE (appendix II) show a reduction interval of about 5 to 15 percent. The currently recommended wet-use factor, 0.833, falls outside this 95 percent confidence interval. Based on the data, the best estimate for this factor would be 0.89, the factor recommended and used before 1971.

As shown in Figure 2, the water-soaked beams exhibited a more "plastic" deflection at high loads. Before revising the wet-use factor for MOE in material standards, the effect of cyclic wetting and drying of members should be considered. There is evidence that such cycling increases deflection beyond that in a constant wet condition (8). Either this must be considered in design or a conservative value of MOE might be recommended for all wet-use conditions to predict deflections.

CONCLUSIONS

Average bending strength of water-soaked glulam beams was slightly, but not significantly, higher than predicted based on dry beam tests and the adjustment factor presently recommended. The recommended wet-use factor of 0.80 is within the 95 percent confidence interval for the mean effect, and no change appears warranted.

The average bending stiffness of the water-soaked glulam beams was significantly higher than predicted based on dry beam tests and the recommended adjustment factor. The best estimate of the wet-use MOE factor is 0.89 with a 95 percent confidence interval extending from 0.85 to 0.95–the present recommended factor is 0.833. However, due to the possibility of increased deflection under cyclic wet and dry conditions, caution is recommended before changing to a higher wet-use factor for MOE.

APPENDIX I

STRENGTH AND STIFFNESS OF TEST BEAMS AT DRY AND WET CONDITIONS

Bending Strength

The bending strength or load carrying capacity of a beam is a function of both the modulus of rupture (MOR) and the section modulus (S).

$$P = (MOR)(S)$$

where

P = some measure of the bending strength.

Upon water soaking, MOR will decrease but S will increase due to swelling.

Let

$$(MOR_w) = a_1(MOR_d)$$

and

$$S_w = a_2 S_d$$

where the subscripts w and d refer to wet and dry conditions, respectively, and a_1 and a_2 are adjustment factors. Then

$$P_w = (MOR_w)S_w = (a_1)(MOR_d)(a_2)(S_d)$$

and

$$P_w = K_a(MOR_d)(S_d)$$

where

$K_a = a_1a_2$, which is a single adjustment factor to account for changes in both modulus of rupture and section modulus upon soaking.

in the following expression,

$$(MOR') = K_a(MOR_d) = (MOR_w)\left(\frac{S_w}{S_d}\right)$$

the bending strength under wet conditions, $(MOR_w)(S_w)$, is expressed in terms of the dry section modulus. S_d, and a new term, MOR'. The modulus of rupture value MOR', when used with dry dimensions, will predict wet beam bending strength and was used in this report as a measure of the modulus of rupture. Thus,

$$P_w = (MOR')(S_d)$$

Bending Stiffness

Bending stiffness, which is the product Of the modulus of elasticity (MOE) and moment of inertia (I), is also a property which varies with moisture content:

$$D = (MOE)(I)$$

where $\underline{D}$ is some measure of bending stiffness. Upon soaking, MOE will decrease but **I** will increase due to swelling.

Let

$$MOE_w = b_1 MOE_d$$

$$I_w = b_2 I_d$$

where subscripts $\underline{w}$ and $\underline{d}$ refer to wet and dry conditions, respectively, and $\underline{b_1}$ and $\underline{b_2}$ are moisture content adjustments for MOE and **I.** If

$$D_w = (MOE_w)(I_w) = b_1 b_2 (MOE_d)(I_d)$$

then

$$D_w = K_b (MOE_d)(I_d)$$

where the single constant K_b adjusts for the changes in both MOE and **I.**

Following from this,

$$(MOE') = k_b (MOE_d) = (MOE_w)\left(\frac{I_w}{I_d}\right)$$

The new value derived, MOE′, is a modulus of elasticity calculated as the product of K_b and the dry beam MOE. Using this value, the wet beam stiffness may be approximated without knowing the true wet beam moment of inertia.

Thus,

$$D_w = (MOE')(I_d)$$

Table I-1.—Data for individual beam tests

Beam	Douglas fir						Southern pine					
	Dimensions		Moisture	Specific	Modulus of	Modulus of	Dimensions		Moisture	Specific	Modulus of	Modulus of
No.	Width	Depth	content	gravity	rupture [1]	elasticity [1]	Width	Depth	content	gravity	rupture [1]	elasticity [1]
	In.	In.	Pct		Lb/in.²	Million Lb/in.²	In.	In.	Pct		Lb/in.²	Million Lb/in.²
						DRY CONDITIONS						
1	3.07	12.38	11	0.49	5,120	1.91	3.11	12.33	11	0.53	8,380	1.73
2	3.09	12.40	12	.51	5,300	2.02	3.13	12.34	10	.51	7,060	1.72
3	3.08	12.40	8	.52	6,760	1.98	3.15	12.37	10	.50	7,280	1.70
4	3.07	12.40	10	.52	6,110	2.02	3.11	12.40	10	.49	6,530	1.65
5	3.07	12.40	10	.51	7,250	2.04	3.11	12.38	12	.51	7,040	1.80
6	3.09	12.40	11	.50	6,420	1.97	3.11	12.32	11	.48	5,620	1.60
7	3.08	12.39	10	.53	5,500	2.26	3.14	12.32	10	.49	6,500	1.69
8	3.06	12.40	10	.51	6,990	2.22	3.14	12.31	10	.51	7,310	1.67
9	3.07	12.41	11	.54	5,820	2.21	3.15	12.35	12	.50	5,900	1.70
10	3.08	12.42	10	.52	5,680	1.98	3.14	12.36	11	.49	5,420	1.62
11	3.08	12.39	10	.54	5,220	1.96	3.17	12.37	12	.51	4,800	1.75
12	3.08	12.39	10	.55	5,690	2.07	3.17	12.37	13	.48	4,780	1.67
13	3.08	12.40	12	.56	5,150	1.97	3.18	12.35	11	.49	6,890	1.55
14	3.08	12.40	10	.50	6,800	1.86	3.14	12.36	11	.50	8,710	1.77
15	3.09	12.32	12	.53	8,740	2.21	3.13	12.33	11	.50	6,660	1.74
						WET CONDITIONS						
1	3.23	12.79	42	.53	4,590	1.83	3.29	12.83	62	.51	5,290	1.51
2	3.18	12.82	48	.53	5,360	1.83	3.20	12.83	64	.52	5,340	1.52
3	3.21	12.79	42	.51	4,970	1.75	3.19	12.66	[2] 50	.51	5,250	1.61
4	3.20	12.79	41	.53	5,150	1.82	3.53	12.68	[2] 47	.53	5,930	1.76
5	3.22	12.74	38	.53	6,820	1.88	3.27	12.78	69	.51	5,140	1.43
6	3.21	12.78	41	.51	4,600	1.79	3.30	12.77	60	.52	5,180	1.71
7	3.19	12.78	42	.52	5,940	1.72	3.26	12.71	62	.50	5,710	1.29
8	3.21	12.74	44	.52	6,300	1.88	3.29	12.74	74	.49	5,830	1.58
9	3.18	12.78	50	.51	4,080	1.74	3.26	12.78	71	.51	5,270	1.50
10	3.23	12.82	44	.50	4,970	1.87	3.55	12.70	[2] 51	.51	5,010	1.56
11	3.21	12.80	43	.53	4,590	1.81	3.29	12.77	61	.53	5,690	1.50
12	3.19	12.77	45	.52	4,560	1.66	3.29	12.82	67	.52	5,420	1.67
13	3.23	12.81	44	.53	4,760	1.85	3.29	12.78	69	.51	5,630	1.44
14	3.21	12.70	42	.54	5,590	1.76	3.28	12.74	53	.50	4,260	1.48
15	3.18	12.75	44	.53	6,010	1.74	3.25	12.79	64	.52	4,860	1.50

[1] Modulus of rupture and modulus of elasticity based on dry dimensions.

[2] Tested after 6 weeks' immersion. all others tested after 4 months' immersion.

Individual Beam Test Results

Physical and strength properties of the 60 glulam beams are given in Table I-1. For the wet conditions, the dry dimensions were used to calculate the strength properties shown. Thus, modulus of rupture values given are MOR and modulus elasticity values given are MOE' as previously described.

APPENDIX II

DETERMINATION OF THE 95 PERCENT CONFIDENCE INTERVAL FOR MEAN WET-USE FACTORS FOR STRENGTH AND STIFFNESS

To compare the measured reduction factors due to water soaking to the recommended, values, 95 percent confidence intervals on the mean factors were determined by two methods.

Method 1. Distribution of a quotient.

A distribution, Z, formed by the quotient of properties wet (Y) and those dry (X), was assumed to be normal. Then

$$\bar{z} = \bar{y} / \bar{x}$$

where

$\bar{z}$ - the mean of population Z

$\bar{x}$ = the mean of population X

$\bar{y}$ = the mean of population Y

and

$$\sigma_z = V_z \bar{z}$$

where

σ_z = the standard deviation of the population Z.

V_z = coefficient of variation of Z and can be approximated by the expression[1/]

$$V_z = \sqrt{V_x^2 + V_y^2}$$

where

$$V_x = \frac{\sigma_x}{\bar{X}}$$

$$v_y = \frac{\sigma_y}{\bar{y}}$$

σ_x = the standard deviation of the population X.

σ_y = the standard deviation of the population Y.

A confidence interval on z provides an indication of the true ratio between wet and dry properties.

$$\text{confidence interval} = \bar{z} + (t)(SE)$$

where

t = a tabulated value depending upon the sample size, n, and significance level selected. The 0.05 level was selected for these two-tailed comparisons, and t = 2.145 and 2.045 for 14 and 29 degrees of freedom, respectively.

SE = standard error of the mean which is

$$\frac{\sigma_z}{\sqrt{n}}$$

Properties of the Z distribution are listed in Table II-1. Table II-2 includes confidence intervals on factors applicable if wet dimensions rather than dry dimensions are available.

Method 2. Computer Simulations.

As a comparative analysis, random numbers were generated from normal distributions of $\bar{x}$ and $\bar{y}$. One thousand random selections of $\bar{y} / \bar{x}$ formed the distribution of $\bar{z}$. A 95 percent confidence interval on $\bar{z}$ was then calculated assuming normality and using the method previously described. The results (Table II-1) were essentially the same as with the first method.

[1/] Approximation suggested by Dr. A. Peyrot, Department of Civil and Environmental Engineering, University of Wisconsin, Madison.

Table II-1.—Summary of confidence interval analysis on wet use factors based on dry dimensions

Parameters	Modulus of rupture			Modulus of elasticily	
	Douglas-fir	Southern pine	Species combined	Douglas-fir	Southern pine
Method 1					
$\bar{z}$	0.846	0.807	0.826	0.876	0.911
σ_z	.185	.155	.170	.061	.078
95 percent confidence limits on $\bar{z}$	.74-.95	.72-.89	.76-.49	.84-.91	.87-.95
Method 2					
Confidence interval by computer simulation	.75-.95	.73-.89	74-.91	.86-.89	.88-.94

Table II-2.—Summary of confidence intervals on wet use factors based on wet dimensions

Parameters	Modulus of rupture			Modulus of elasticity	
	Douglas-fir	Southern pine	Species combined	Douglas-fir	Southern pine
Method 1					
$\bar{z}$	0.763	0.715	0.739	0.766	0.781
σ_z	.169	.137	.153	.051	.062
95 percent confidence limits on $\bar{z}$	.67-.86	.64-.79	.68-.80	.74-.79	.74-.82

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