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The Influence of Moisture Content on the Flexural Properties of Douglas Fir Dimension Lumber

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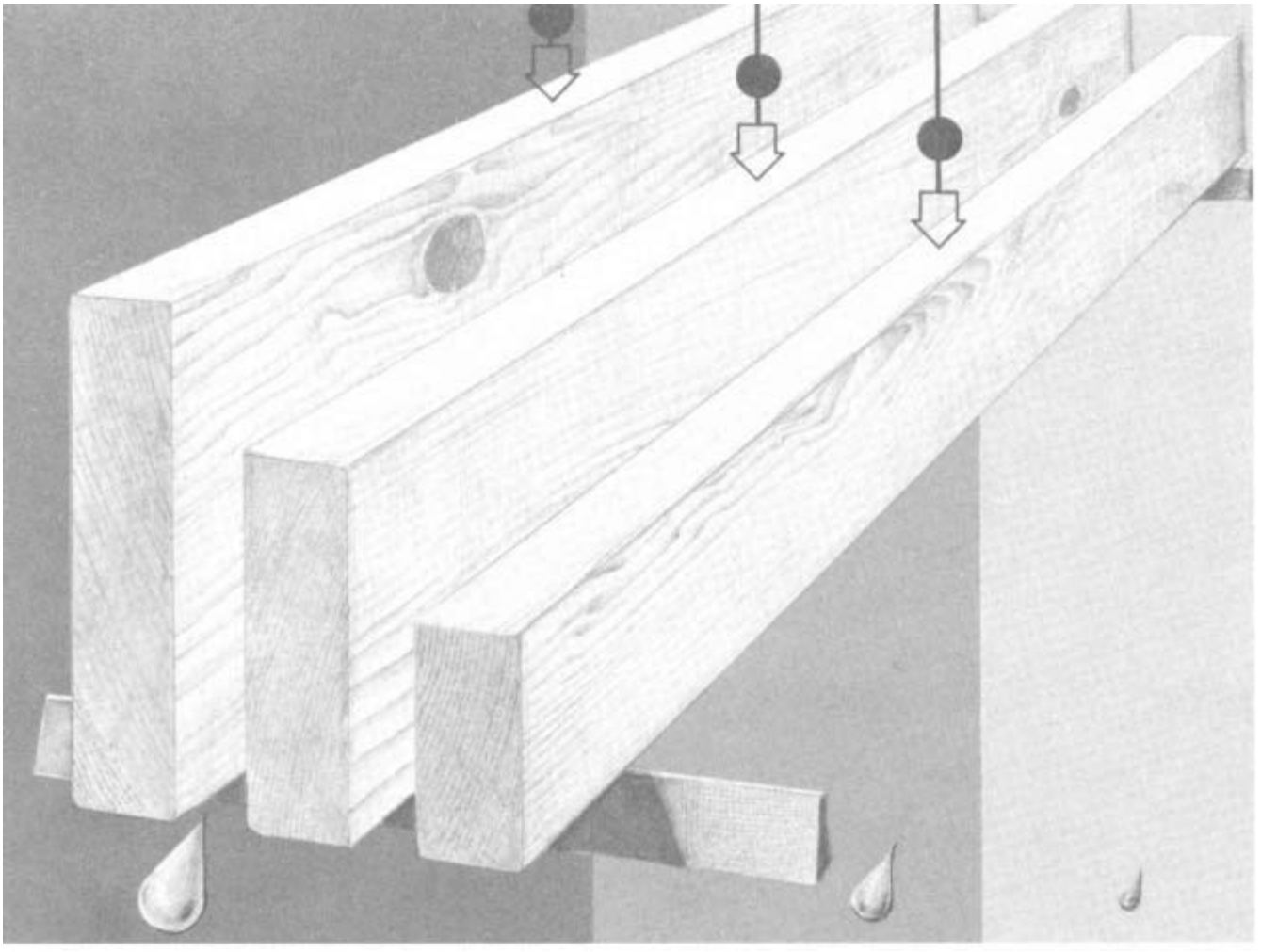

Abstract

Lumber of three grades (Select Structural, No. 2, No. 3) and three sizes (2 x 4, 2 x 6, 2 x 8) was tested on edge in third-point bending at moisture content levels of green, 20 percent, 15 percent, and 10 percent. Results indicate that current ASTM D 245-81 adjustments are valid for modulus of elasticity but not for modulus of rupture.

Keywords: Mechanical properties, bending, moisture content, Douglas Fir, modulus of rupture, modulus of elasticity, stiffness, moment capacity, distributional form.

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The forms Douglas Fir and Southern Pine are from the list "Commercial Names for Lumber," p. 343, in Checklist of United States Trees, Agric. Handb. No. 541, 1979.

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Research Highlights

This paper presents the experimental results of a program to evaluate the effect of moisture content on the flexural properties of Douglas Fir dimension lumber. These studies were initiated because of discrepancies between research evidence and currently accepted design standards. The results can be used to develop procedures for adjusting the data currently being generated in the lumber properties research programs of Canada and the United States.

Lumber of three grades (Select Structural, No. 2, and No. 3) and three sizes (2 x 4, 2 x 6, and 2 x 8) was sampled from a sawmill in Vancouver, British Columbia. For each grade-size combination, the sample was divided into four identical populations based on green stiffness. Three of the groups were then equilibrated to moisture contents of 10, 15, and 20 percent prior to testing. All samples were tested on edge in third-point bending.

The results of this study show that moisture content does influence the strength of lumber throughout the range of strength from weak to strong. The magnitude of the change for a given property was influenced by the grade, width, and moisture content level. From the results of this study, we conclude that:

1. Improvements in modulus of rupture (MOR) and modulus of elasticity (MOE) with drying are significant for Select Structural lumber at virtually all levels of the cumulative frequency distribution. The magnitude of the increase for mean MOE is approximately the same as the 14 percent given in ASTM D 245-81 for lumber with a maximum moisture content of 19 percent. In ASTM D 245, lumber with a maximum moisture content of 19 percent is assumed to have an average moisture content of 15 percent. For fifth percentile MOR the increase is slightly less than the 25 percent given in ASTM D 245.

2. The effect of moisture content on MOE is dependent on lumber width and quality. However, on a percentage scale (dry-green ratio), the magnitude of the difference is probably not of practical importance.

3. Increases in lumber strength with drying are generally less for No. 2 and No. 3 grade lumber than for Select Structural. The increase in fifth percentile MOR may be substantially less than is assumed in D 245-81 (the actual increase ranges from 2.5 to 27 pct for lumber dried to a moisture content of 15 pct).

4. Drying from 15 to 10 percent equilibrium moisture content increased MOE and flexural stiffness for all grades and sizes and increased the fifth percentile MOR of Select Structural lumber. Drying from 15 to 10 percent can sometimes cause substantial reductions in fifth percentile MOR for No. 2 and No. 3 grade lumber.

5. At all moisture content levels MOE can be assumed to be normally distributed, but MOR cannot. For Select Structural lumber the MOR distributions were normal to left skewed (long tail to left), and with No. 2 and No. 3 grades they were normal to right skewed. Left-skewed distributions make the log-normal distribution undesirable for probabilistic studies of lumber properties.

Subsequent publications will present analytical models for adjusting the flexural properties of lumber for changes in moisture content. Future reports will also address the applicability of this data to other species and to other stress modes. Until this series is complete, it is recommended that the results of this study not be incorporated into engineering design codes.

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The Influence of Moisture Content on the Flexural Properties of Douglas Fir Dimension Lumber

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Introduction

In Canada and the United States, lumber properties research programs are in progress (Galligan, Green, Gromala, and Haskell 1980; Green 1983; Madsen 1978) to characterize the mechanical properties of existing grades of dimension lumber. So that the characterizations will relate to the lumber as it is produced, these "in-grade" testing programs are conducted on full-size specimens. For economic reasons, the majority of the flexural testing in the United States program has been conducted using portable equipment without equilibrating the lumber. As would be expected, moisture content of the test material may vary from piece to piece. To interpret how this material will perform at various end-use conditions, and to correctly interpret causes of within- and between-mill variations in properties, it will be necessary to adjust flexural properties for differences in moisture content.

The objective of this study was to investigate the effect of moisture content on the flexural properties of Douglas Fir dimension lumber. This paper details the experimental procedure and summarizes some of the experimental results. Subsequent publications will present analytical models for adjusting the flexural properties of lumber for changes in moisture content. Future reports will also address the applicability of these data to other species and to other failure modes. Until this series of reports is complete, the results of this study should not be incorporated into engineering design codes.

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Background

Current procedures for deriving allowable design properties for lumber are based on test results obtained for small, clear specimens (American Society for Testing and Materials (ASTM) 1983a, 1983c). Properties obtained from these clear specimens are adjusted by a number of factors which convert the results to design values applicable to dimension lumber. Of the many things that affect the flexural properties of clear wood, one of the most important is moisture content. For example, the average modulus of rupture (MOR) of clear, coast-type Douglas-fir would be expected to increase 62 percent in drying from the green condition to an equilibrium moisture content of 12 percent (ASTM 1983c). For at least 70 years, however, it has been recognized that potential increases in the MOR of lumber may be partially or totally offset by the weakening effect of drying degrade (Cline and Heim 1912). For this reason, moisture content design factors for lumber have historically been based on results obtained from tests of full-size commercial lumber.[3] For Douglas Fir dimension lumber, the expected increase in MOR in drying from the green condition to a maximum moisture content of 15 percent is 35 percent[4] (ASTM 1983a).

The current design factors for adjusting the flexural properties of lumber for drying are assumed to be independent of lumber quality (grade, strength ratio, etc.). This assumption is a relatively recent change in design philosophy that was apparently initiated in order to simplify the grading procedure. Prior to 1969, moisture content design factors for lumber 4 inches or less in thickness were calculated as a function of the green strength ratio by what has been termed the “25 percent rule.” This rule may be written as

$$SR_{dry} = SR_{green} + 1/2(SR_{green} - 50) \qquad (1)$$

where

SR = strength ratio, percent.

Thus the maximum increase in MOR was 25 percent for lumber having a strength ratio of 100 percent and dried to an average moisture content of 15 percent. Lumber having a green strength ratio of 50 percent or less was assigned a moisture content design factor of 1.0.

Recent studies in the United States (Gerhards 1968, 1970) and Canada (Madsen 1975; Madsen, Janzen, and Zwaagstra 1980) support the historical assumption that changes in flexural properties with drying are dependent on lumber quality. In fact, the results of these recent studies could be interpreted as indicating that no increase in fifth percentile MOR. the basis for deriving allowable design stress, is justifiable for current grades of dimension lumber.

Despite its historical significance, the applicability of the 25 percent rule to current grades of lumber is doubtful. Not only have the grade descriptions changed significantly in the last 60 years, but the rule only applies to mean properties. The more recent studies of Gerhards and Madsen were conducted on either a limited number of grades, or involved a limited number of widths. Because of these limitations, we felt that insufficient information existed on which to base moisture content strength adjustment procedures for lumber.

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[3]The historical information presented in this section is primarily based on evidence presented in Green (1980)

[4]Lumber with a maximum moisture content of 15 pct is assumed to have an average moisture content of 12 pct (ASTM 1983a).

Experimental Design and Lumber Selection

Approximately 4,700 pieces of green Douglas Fir dimension lumber were obtained from a Vancouver, BC, area sawmill. Lumber of three sizes (2 x 4, 2 x 6, 2 x 8) and three grades (Select Sturctural, No. 2, and No. 3) were selected on the basis of strength-reducing growth characteristics. That is, pieces which normally would be assigned to the No. 2 and No. 3 grades because of wane, splits, shake, and other appearance factors were not selected for the test samples, nor were pieces selected which contained decay. The sampling procedure was also intended to obtain material with strength-reducing characteristics located so that, in testing, these defects would be located where the bending moment was at least 60 percent of the maximum bending moment.

The experimental design, figure 1, was intended to produce groups of approximately 100 specimens for conditioning to equilibrium at moisture contents of 10, 15, and 20 percent in addition to the green group. Four matched distributions of strength and stiffness were desired for each grade-size combination so that moisture content level would be the only factor altering the properties of the experimental groups. Modulus of elasticity (MOE) was used as a sorting criterion for assigning the green lumber to the four moisture content groups. For each grade-size combination the edgewise MOE was first determined by applying loads symmetrically at the one-third points of the span. The span-to-depth ratio was 17:1. A systematic approach was used to ensure a random selection of the tension edge. Boards were oriented so that the grade mark was always in the same position with respect to the testing machine. The approximately 400 pieces were then ranked according to MOE, from lowest to highest. The four specimens with the lowest MOE values were randomly assigned to one of the four moisture levels. Subsequently, the next four pieces were then randomly assigned and the process repeated until all 400-plus pieces were assigned to moisture content levels. Because of the correlation between bending strength and stiffness, we felt that matching of the groups with respect to their distributions of green MOE's would improve the power of the comparison over that obtained in a purely random grouping process.

Drying and Conditioning

After assignment to moisture content groups, all lumber was given an antistain dip treatment in a solution of sodium tetrachlorophenate diluted to a concentration of 1.2 percent. The lumber to be tested green was kept wet by sprinkling until tested. The lumber to be dried to 20, 15, or 10 percent moisture content was end sealed using a standard polyvinylacetate (PVA) end sealer to minimize end checking.

Kiln-drying, using mild schedules, was used to bring the lumber to moisture contents approximately 2 to 3 percent higher than target moisture content levels. The lumber was then stacked and stickered to permit gradual conditioning to target moisture content levels.

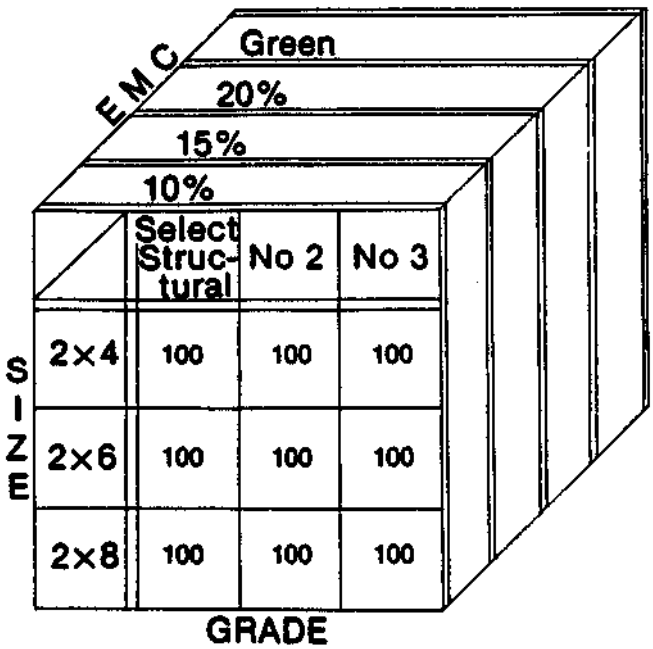

Figure 7.—Experimental design of the moisture content bending properties study. EMC = equilibrium moisture content. (ML84 5317)

The lumber to be dried to 10 percent was stored in the engineering laboratory at Forintek's Western Laboratory where experience had shown lumber to reach an equilibrium moisture content of from 9.5 to 11 percent depending on the time of the year. For the 15 to 20 percent target moisture content groups, outdoor storage and/or conditioning in humidity-controlled chambers was required.

Testing Procedures

When the lumber in a group was judged to be at the desired moisture content (based on moisture meter readings and sample board weights), each piece was tested to failure in one-third point bending as previously described. A testing machine cross-head displacement rate of 0.01 inch per second was used for all specimens. Compared with the rates prescribed in ASTM D 198 (ASTM 1983f), the rates used in this study averaged:

3 times faster for 2 x 4s

2 times faster for 2 x 6s

1.5 times faster for 2 x 8's

These rates induced failures in the weakest specimens in each of the treatment groups in from 0.5 to 1.5 minutes.

For each specimen, MOR and MOE (uncorrected for shear) were calculated as specified in ASTM D 198 (ASTM 1983f). After test, a failure description was coded for each piece. A block cut from close to the fracture zone of each specimen was used for final determination of moisture content and specific gravity (ASTM 1983d, 1983e).[5] A record was also kept of the time required to reach maximum load, the grade of the specimen, and the green MOE.

[5]For volume determination, the specific gravity blocks were not sealed as described in method B of ASTM D 2395. Instead, the submerged weight was determined after a standard period of time had elapsed after immersion.

Results and Discussion

Before discussing the data, we present evidence to show that the matching of the distributions of green MOE was effective. We also show that the moisture conditioning achieved the intended goal of providing matched groups with distinctly different moisture contents.

Verification of Populations

Inspection of the green MOE values for any given grade-size combination indicates that matching of distributions was very effective (table 1). A painnrise comparison of the cumulative frequency distributions of green MOE using the Kolmogorov-Smirnov two-sample test statistic (Conover 1980) showed no significant differences between the treatment groups ($p > 0.75$ for virtually all pairwise comparisons). Likewise, analysis of variance by grade and by size showed no significant differences in mean values of the different moisture content groups. Similarly, no persistent trends in specific gravity with moisture content groups are evident in table 1.

Although slightly different than the target values, the mean moisture contents indicate the effectiveness of the moisture conditioning (table 2). Also it is apparent from the minimum and maximum moisture contents that there was little overlap between different treatment levels.

Moisture Effects on Mean Modulus of Rupture and Modulus of Elasticity

Mean MOR and MOE increase with drying (figs. 2 and 3). Within a moisture content group, properties decrease with decreasing grade, as expected. The standard deviations generally remain constant or decrease slightly with decreasing lumber quality (grade) and increase consistently with decreasing moisture content for both MOR and MOE. Standard deviations and coefficients of variation are shown in table 3.

Analyses of variance were made using all MOR and MOE data to gain a general overview of the mean effects of the experimental variable (table 4). As expected, moisture content, grade, and size, all had significant influence on both MOE and MOR (p □0.0001). In addition, the interaction of grade and size was significant for MOE and MOR. The interactions of moisture content and grade and of moisture content and size were significant for MOR but not for MOE. This indicates a differential influence of moisture content on the two flexural properties.

Table 1 .—Effectiveness of distribution matching

Nominal Size	Grade	Moisture content group	Sample size	Green modulus of elasticity				Mean specific gravity[1]
				Mean	Standard deviation	Minimum	Maximum	
In.		*Pct*		*10^6 lb/in.^{2}*				
2 x 4	Select Structural	10	106	1.39	0.315	0.73	2.20	0.519
		15	105	1.39	.292	.80	2.07	.520
		20	106	1.38	.302	.75	2.09	.517
		Green	106	1.37	.309	.78	2.05	.507
	No. 2	10	107	1.14	.249	.56	1.73	.486
		15	108	1.14	.250	.58	1.76	.483
		20	105	1.14	.253	.51	1.79	.483
		Green	107	1.12	.251	.47	1.75	.483
	No. 3	10	105	.95	.227	.47	1.48	.477
		15	105	.97	.230	.49	1.64	.483
		20	105	.95	.228	.43	1.54	.469
		Green	105	.94	.234	.50	1.65	.487
2x6	Select Structural	10	102	1.59	.285	.89	2.20	.547
		15	97	1.57	.286	.89	2.22	.543
		20	101	1.60	.293	.84	2.40	.542
		Green	103	1.59	.294	.84	2.22	.543
	No. 2	10	103	1.15	.242	.57	1.86	.491
		15	102	1.15	.248	.63	2.00	.489
		20	101	1.14	.241	.60	1.74	.482
		Green	103	1.15	.241	.60	1.82	.482
	No. 3	10	101	1.00	.230	.53	1.73	.490
		15	100	1.00	.224	.51	1.66	.479
		20	94	1.00	.222	.54	1.55	.482
		Green	100	.99	.222	.53	1.60	.478
2 x 8	Select Structural	10	106	1.45	.248	.81	1.98	.504
		15	106	1.44	.257	.80	2.10	.508
		20	102	1.46	.241	.82	2.02	.517
		Green	106	1.45	.252	.83	2.10	.509
	No. 2	10	107	1.13	.227	.68	1.78	.490
		15	107	1.14	.230	.64	1.70	.487
		20	108	1.14	.225	.68	1.74	.481
		Green	107	1.13	.222	.64	1.68	.476
	No. 3	10	106	.98	.225	.55	1.62	.464
		15	100	.98	.228	.55	1.59	.474
		20	106	.97	.226	.48	1.73	.467
		Green	107	.98	.225	.54	1.72	.467

'Specific gravity based on ovendry weight and volume.

Table 2.—Effectiveness of conditioning process

Nominal size	Grade	Moisture content group	Moisture content			
			Mean	Standard deviation	Minimum	Maximum
In.			*Pct*			
2x4	Select Structural	10	10.2	0.4	9.0	11.4
		15	15.8	.9	13.2	17.8
		20	20.4	.9	17.9	22.2
		Green	67.0	37.4	34.9	191.5
	No. 2	10	10.2	.4	8.7	11.5
		15	15.6	1.1	12.1	17.7
		20	19.4	1.0	17.4	22.2
		Green	69.9	30.3	33.2	176.2
	No. 3	10	10.2	.2	9.4	11.0
		15	15.9	.8	13.9	17.7
		20	21.7	1.2	19.4	24.9
		Green	80.1	36.3	34.3	186.9
2x6	Select Structural	10	11.0	.5	9.6	12.1
		15	14.3	.6	13.2	16.2
		20	18.6	.7	17.1	20.5
		Green	66.0	32.1	29.0	184.2
	No. 2	10	10.8	.5	9.2	12.1
		15	14.6	1.2	12.6	17.3
		20	19.0	1.4	17.0	23.5
		Green	76.1	36.1	33.3	181.9
	No. 3	10	10.7	.6	8.4	12.2
		15	14.4	1.2	11.9	17.4
		20	19.1	1.1	17.1	22.2
		Green	76.2	37.8	31.6	178.3
2x8	Select Structural	10	10.2	.3	9.4	11.0
		15	14.9	.7	13.4	16.7
		20	18.7	.7	17.1	20.3
		Green	56.4	26.5	24.8	152.4
	No. 2	10	10.2	.4	9.0	10.9
		15	14.5	.6	12.8	15.9
		20	18.6	1.0	16.3	21.0
		Green	62.4	27.1	30.6	162.8
	No. 3	10	10.3	.4	9.4	11.4
		15	14.5	.9	12.4	16.4
		20	17.8	1.0	15.2	20.2
		Green	69.0	36.3	27.4	204.5

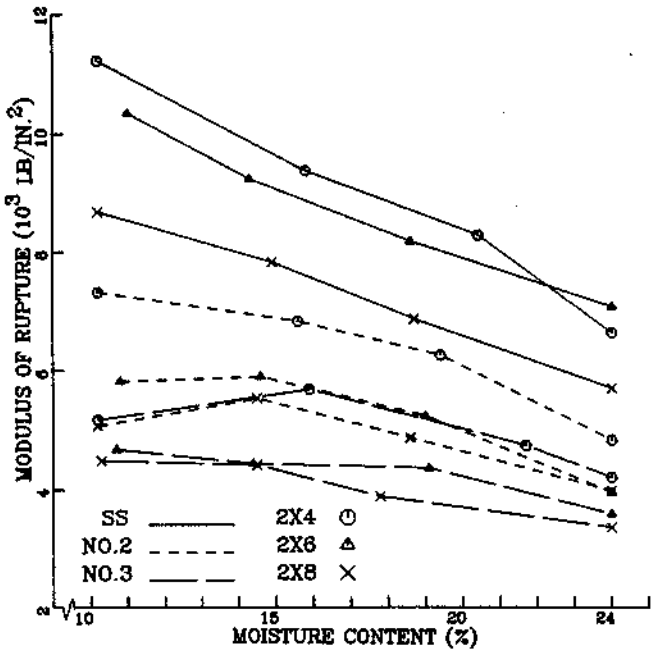

Figure 2.—Effect of moisture content on mean modulus of rupture. (ML85 5139)

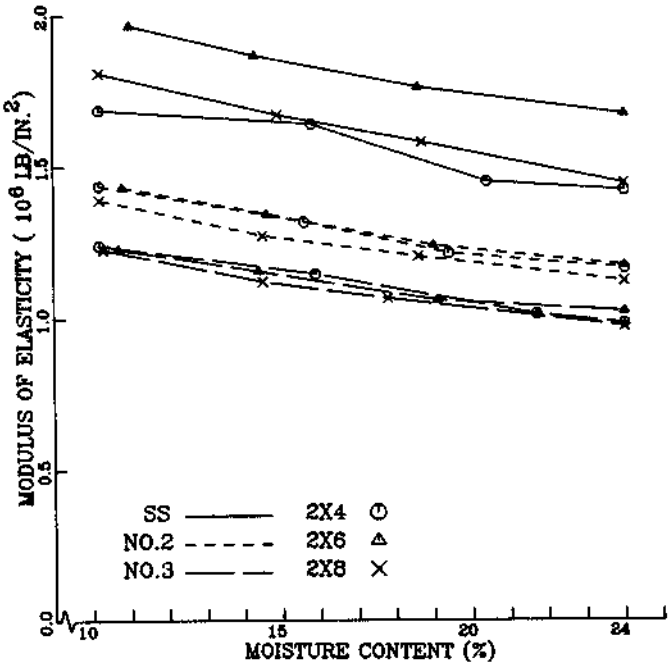

Figure 3.—Effect of moisture content on mean modulus of elasticity. (ML85 5137)

The dry-green ratios for mean MOR and MOE (table 5) measure a percentage change from the green value and indicate a substantial improvement in properties with drying. For MOE, trends in the dry-green ratio with either grade or size are not apparent. Despite the statistical significance of grade and size for MOE, on the percentage scale of dry-green ratios the maximum difference is less than 8 percent and probably not of practical importance. For lumber dried to an average moisture content of 15 percent, the dry-green ratios for MOE are close to the value of 1.14 assumed by ASTM D 245 (ASTM 1983a). With mean MOR, consistent trends with size and grade are also not apparent, except that for a given width the dry-green ratio of No. 3 grade is usually lower than that of the other two grades. The dry-green ratios of mean MOR for lumber dried to an average moisture content of 15 percent are generally larger than the expected value of 1.25 given in ASTM D 245 (ASTM 1983a).

It is generally assumed that lumber strength increases with decreasing moisture content. For mean MOR, this assumption appears to be true only for Select Structural lumber. For No. 2 and No. 3 grade lumber the mean MOR increases with decreasing moisture content only for final moisture contents equal to or above 15 percent (table 5). Drying from 15 to 10 percent sometimes causes reductions in the mean MOR of No. 2 and No. 3 grade lumber. The existence of an optimum drying level has also been observed with certain mechanical properties of clear wood (Gerhards 1982) but generally at much lower moisture content levels than observed in this study.

A comparison of dry-green ratios for MOE indicates increases at all drying levels. In all cases mean MOE increased when the lumber dried from 15 percent moisture content to 10 percent. For some grade-size combinations, however, the increase was not large.

Table 3.—Modulus of rupture and modulus of elasticity of Douglas Fir at various moisture contents

Nominal size	Grade	Moisture content group	Sample size	Modulus of elasticity[1]				Modulus of rupture[1]			
				Mean	Standard deviation	Coefficient of variation	Fifth percentile[2]	Mean	Standard deviation	Coefficient of variation	Fifth percentile[2]
		Pct		*---- 10^6 lb/in.^{2} ---*		*Pct*	*10^6 lb/in.^{2}*	*---- 10^3 lb/in.^{2} ----*		*Pct*	*10^3 lb/in.^{2}*
2 x 4	Select Structural	10	106	1.688	0.387	22.9	1.076	11.230	2.887	25.7	6.049
		15	105	1.644	.364	22.1	1.062	9.384	2.284	24.3	5.344
		20	106	1.455	.319	21.9	.942	8.290	1.656	20.0	5.740
		Green	106	1.424	.315	22.1	.938	6.643	1.382	20.8	4.526
	No. 2	10	107	1.436	.329	22.9	.906	7.313	2.908	39.8	2.730
		15	108	1.320	.311	23.6	.803	6.832	2.273	33.3	2.819
		20	105	1.219	.276	22.7	.761	6.262	2.304	36.8	2.131
		Green	107	1.168	.261	22.3	.735	4.840	1.534	31.7	2.337
	No. 3	10	105	1.240	.318	25.7	.796	5.175	2.417	46.7	2.165
		15	105	1.148	.295	25.7	.751	5.688	2.249	39.5	1.827
		20	105	1.016	.252	24.8	.641	4.749	1.742	36.7	2.032
		Green	105	.986	.250	25.3	.646	4.214	1.500	35.6	1.711
2 x 6	Select Structural	10	102	1.968	.399	20.3	1.288	10.352	2.547	24.6	5.490
		15	97	1.871	.362	19.4	1.242	9.245	2.357	25.5	5.408
		20	101	1.768	.356	20.1	1.153	8.184	1.701	20.8	4.860
		Green	103	1.678	.331	19.7	1.096	7.078	1.590	22.5	4.258
	No. 2	10	103	1.431	.352	24.6	.869	5.817	2.511	43.2	2.012
		15	102	1.345	.306	22.7	.911	5.898	2.439	41.4	2.183
		20	101	1.244	.283	22.7	.833	5.242	1.900	36.2	2.449
		Green	103	1.177	.260	22.1	.767	3.957	1.479	37.4	1.720
	No. 3	10	101	1.228	.315	25.6	.757	4.679	2.251	48.1	1.517
		15	100	1.156	.279	24.1	.731	4.440	1.830	41.2	1.786
		20	94	1.062	.262	24.7	.683	4.366	1.765	40.4	1.594
		Green	100	1.025	.237	23.1	.640	3.590	1.345	37.5	1.543
2 x 8	Select Structural	10	106	1.811	0.338	18.6	1.236	8.679	2.325	26.8	4.645
		15	106	1.674	.333	19.9	1.136	7.827	2.023	25.8	4.217
		20	102	1.586	.279	17.6	1.134	6.874	1.565	22.8	3.962
		Green	106	1.448	.252	17.4	1.010	5.710	1.212	21.2	3.472
	No. 2	10	107	1.389	.299	21.5	.932	5.074	2.309	45.5	1.857
		15	107	1.274	.277	21.7	.828	5.538	2.412	43.5	1.955
		20	108	1.208	.265	21.9	.816	4.875	1.692	34.7	1.965
		Green	107	1.125	.222	19.8	.774	3.986	1.313	33.0	1.880
	No. 3	10	106	1.227	.306	25.0	.764	4.490	2.173	48.4	1.735
		15	100	1.122	.279	24.8	.750	4.417	2.180	49.3	1.471
		20	106	1.068	.257	24.1	.646	3.886	1.616	41.6	1.365
		Green	107	.976	.225	23.1	.616	3.359	1.286	38.3	1.435

[1]Original data contained three significant digits. Additional digits retained to permit further computations with minimum round off error.

[2]Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table 4.—Partial analysis of variance table for modulus of rupture and modulus of elasticity

Effect	Degrees of freedom	H_0: No effect[1] on modulus of rupture		H_0: No effect[1] on modulus of elasticity	
		F-statistic	p > F	F-statistic	p > F
Size	2	137.4	0.0001	41.4	0.0001
Grade	2	1208.9	.0001	1125.9	.0001
Moisture content	3	207.1	.0001	142.6	.0001
Grade x size	4	13.2	.0001	24.8	.0001
Moisture content x size	6	3.2	.0035	1.1	.3583
Moisture content x grade	6	25.1	.0001	1.06	.3867
Moisture content x size x grade	12	1.7	.0624	.31	.9878

[1]Null hypothesis is that there is no effect of the factor or interaction on modulus of rupture or modulus of elasticity. p is the probability of rejecting this hypothesis when it is true.

Table 5.—Ratio of dry to green properties for mean modulus of rupture and modulus of elasticity

Nominal size	Grade	10 percent moisture content group	15 percent moisture content group	20 percent moisture content group
In.				
		MODULUS OF RUPTURE		
2 x 4	Select Structural	1.691	1.413	1.248
	No. 2	1.511	1.412	1.294
	No. 3	1.228	1.350	1.127
2 x 6	Select Structural	1.463	1.306	1.156
	No. 2	1.470	1.491	1.325
	No. 3	1.303	1.237	1.216
2 x 8	Select Structural	1.520	1.371	1.204
	No. 2	1.273	1.389	1.223
	No. 3	1.337	1.315	1.157
		MODULUS OF ELASTICITY		
2 x 4	Select Structural	1.185	1.154	1.022
	No. 2	1.229	1.130	1.044
	No. 3	1.258	1.164	1.030
2 x 6	Select Structural	1.173	1.115	1.054
	No. 2	1.216	1.143	1.057
	No. 3	1.198	1.128	1.036
2 x 8	Select Structural	1.251	1.156	1.095
	No. 2	1.235	1.132	1.074
	No. 3	1.257	1.150	1.094

Moisture Effects on Fifth Percentile Modulus of Rupture and Modulus of Elasticity

As was true with mean properties, fifth percentile strengths generally improve with drying (fig. 4). In general, the dry-green ratios[6] for fifth percentile MOR are much less than those for mean MOR (table 6). Except, perhaps, for Select Structural, it is doubtful that expected ASTM D 245 (ASTM 1983a) increases[7] are achieved for most of the material. For all widths, however, the increase in MOR with decreasing moisture content was larger for Select Structural than for No. 3. As noted for mean MOR, fifth percentile MOR may be reduced in drying from 15 to 10 percent.

The effect of moisture content on fifth percentile MOE is very similar to that for mean MOE (fig. 5) and dry-green ratios (table 6). Unlike MOR, there is little variation in the MOE moisture content relationship with percentile level.

Moisture Effects on Moment Capacity and Stiffness

Lumber design procedures could be simplified if parameters were found which were not sensitive to changes in moisture content. Two potential parameters are moment capacity and flexural stiffness.

Moment capacity, RS, is the product of MOR and section modulus. Bending stress, R, may be calculated from:

$$R = \frac{M}{S} \qquad (2)$$

where

R = modulus of rupture
M = bending moment
S = section modulus.

For a given beam type, span, and load configuration, moment capacity is an indication of a beam's ability to resist bending movement. As lumber dries it shrinks, and moment of inertia and section modulus decrease. These decreases might offset any increases in MOR and MOE.

[6]It should be cautioned that dry-green ratios of fifth percentiles are much less stable than dry-green ratios of mean values This is because the nonparametric estimates of fifth percentiles (ASTM 1983b) used are extreme order statistics for those sample sizes and are more subject to variation than estimates of the mean Thus, the natural variation of these estimates can cause relatively large changes in the dry-green ratios

[7]Twenty-five pct for lumber dried to an average moisture content of 15 pct and 35 pct for lumber dried to a moisture content of 12 pct

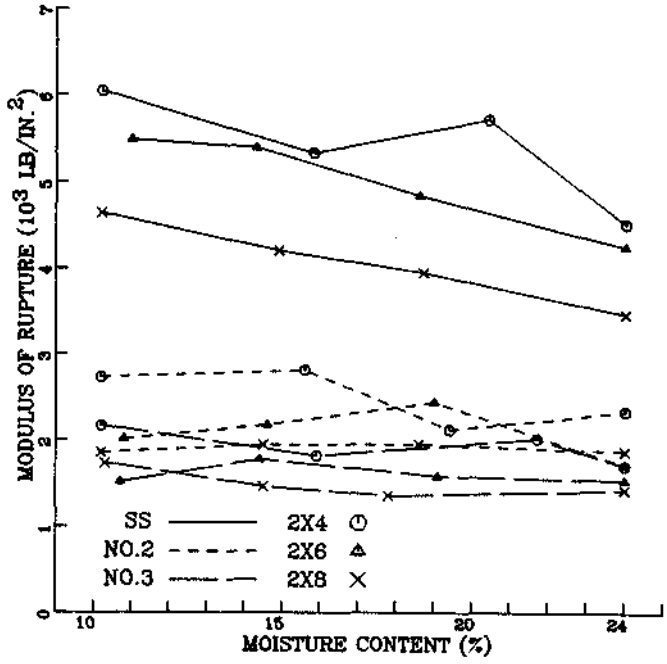

Figure 4.—Effect of moisture content on fifth percentile modulus of rupture. (ML85 5138)

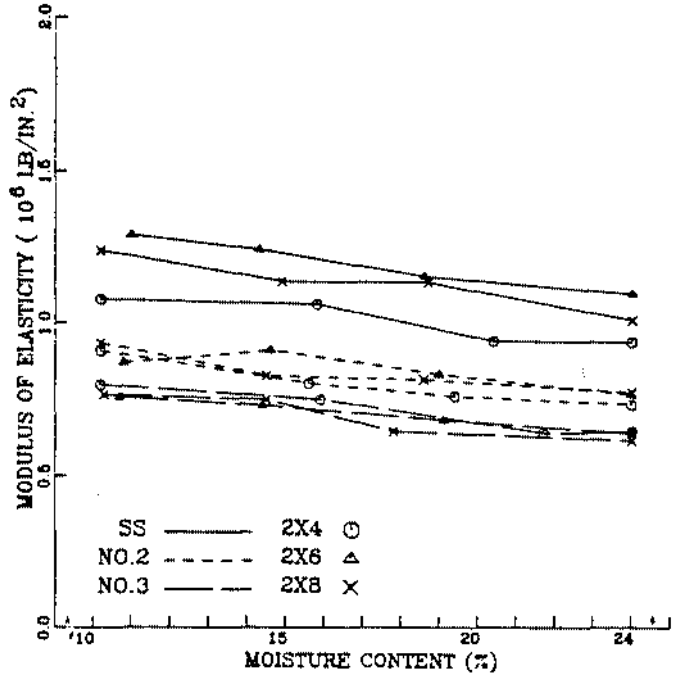

Figure 5.—Effect of moisture content on fifth percentile modulus of elasticity. (ML85 5136)

Flexural stiffness, EI, is the product of the MOE and the moment of inertia. The deflection, □, of a simply supported beam may be calculated from:

$$\square = \frac{KPL^3}{EI} \qquad (3)$$

where

K = a constant that depends upon the load and support conditions
P = load
L = the span
E = modulus of elasticity
I = moment of inertia.

For one beam-type, span, and load configuration, flexural stiffness is really an indication of the ability of a beam to resist deflection.

Descriptive statistics for the moment capacities and flexural stiffness obtained in this study are given in table 7. Weibull distributions fit to these data are summarized in appendix A.

As expected, both the mean and fifth percentile dry-green ratios for moment capacity (table 8) are less than those for MOR (tables 5 and 6). For many grade-size combinations, however, moment capacity is still quite sensitive to a change in moisture content and thus offers little advantage over MOR as a design parameter.

With flexural stiffness, the increase in MOE with drying may be totally offset by the reduction in section modulus (table 8). This insensitivity of flexural stiffness to changes in moisture content is consistent with other results reported in the literature (Johnson 1965; Madsen, Janzen, and Zwaagstra 1980; Wood and Soltis 1964).

Moisture Effects on Property Distributions

The effect of moisture content on lumber properties can also be discussed in terms of the general effect on property distributions. Here it is more convenient to discuss changes in the distribution of MOR (or MOE) rather than changes in particular percentiles. To enhance our understanding of the moisture content effect and to provide basic information needed for future analytical studies, the distributional form of the data is analyzed and described.

Modulus of Rupture

Inspection by size and grade of the experimental cumulative frequency distributions of the four moisture content groups indicates that MOR is generally increased by drying (appendix B, fig. B1). The effect of drying is more dramatic for Select Structural lumber than for either No. 2 or No. 3 grades. Improvement in MOR wth drying is also larger at the high end of the distributions than at the low.

Table 6.—Ratio of dry to green values of the fifth percentile nonparametric point estimate of modulus of rupture and modulus of elasticity

Nominal size	Grade	10 percent moisture content group	15 percent moisture content group	20 percent moisture content group
In.				
	MODULUS OF RUPTURE			
2 x 4	Select Structural	1.337	1.181	1.268
	No. 2	1.168	1.206	.912
	No. 3	1.265	1.068	1.188
2 x 6	Select Structural	1.289	1.270	1.141
	No. 2	1.170	1.269	1.424
	No. 3	.938	1.157	1.033
2 x 8	Select Structural	1.338	1.215	1.141
	No. 2	,988	1.040	1.045
	No. 3	1.209	1.025	.951
	MODULUS OF ELASTICITY			
2 x 4	Select Structural	1.147	1.132	1.004
	No. 2	1.233	1.093	1.035
	No. 3	1.232	1.163	.992
2 x 6	Select Structural	1.176	1.133	1.052
	No. 2	1.133	1.188	1.086
	No. 3	1.183	1.142	1.067
2 x 8	Select Structural	1.224	1.125	1.123
	No. 2	1.204	1.070	1.054
	No. 3	1.240	1.218	1.049

With Select Structural lumber, the individual cumulative frequency distributions for a given size are distinct over most of the distribution. If there is any overlap of the distributions for adjacent moisture content levels, it usually occurs at, or below, the fifth percentile. For No. 2 and No. 3 grade material few generalizations about the occurrence of overlap are possible. It does appear, however, that all overlaps between the dry and the green cumulative density function occurs in the lower half of the distributions.

Modulus of Elasticity

Examination of the experimental cumulative density functions for MOE (fig. B2) indicates that drying improves MOE for all grade-size combinations. However, no consistent trends with grade and size are apparent. Further, the improvements do not appear to be very dependent upon position in the distribution. Unlike the tendency of the MOR experimental cumulative density functions to overlap in the lower half of the distribution for No. 2 and No. 3 grades, no particular patterns in the occurrence of overlaps is apparent for MOE.

Table 7.—Flexural stiffness and moment capacity for Douglas Fir at various moisture contents

Nominal Size	Grade	Moisture content group	Sample size	Modulus capacity[1]				Flexural stiffness[1]			
				Mean	Standard deviation	Coefficient of variation	Fifth percentile[2]	Mean	Standard deviation	Coefficient of variation	Fifth percentile[2]
In.		*Pct*		*- - - - - 10^3 lb•in. - - - - -*		*Pct*	*10^3 lb•in.*	*- - - 10^6 lb•in.^{2}- - - -*		*Pct*	*10^6 lb•in^2*
2 x 4	Select Structural	10	106	33.693	8.151	24.2	18.735	8.694	1.720	19.8	5.917
		15	105	29.044	6.872	23.7	16.716	8.823	1.756	19.9	5.911
		20	106	26.714	5.279	19.8	18.523	8.247	1.733	21.0	5.474
		Green	106	22.290	4.556	20.4	15.348	8.544	1.874	21.9	5.660
	No. 2	10	107	22.069	8.664	39.3	8.542	7.448	1.580	21.2	4.945
		15	108	21.245	6.922	32.6	8.828	7.141	1.571	22.0	4.481
		20	105	20.007	7.316	36.6	6.835	6.845	1.493	21.8	4.437
		Green	107	16.282	5.185	31.8	7.893	7.025	1.571	22.4	4.454
	No. 3	10	105	15.736	7.260	46.1	6.642	6.476	1.536	23.7	4.220
		15	105	17.949	7.144	39.8	5.647	6.313	1.580	25.0	4.150
		20	105	15.453	5.628	36.4	6.591	5.839	1.414	24.2	3.659
		Green	105	14.129	5.019	35.5	5.898	5.911	1.486	25.1	3.872
2 x 6	Select Structural	10	102	76.535	18.382	24.0	40.983	39.271	7.053	18.0	26.390
		15	97	70.019	17.610	25.1	40.828	38.587	6.801	17.6	26.281
		20	101	64.365	13.469	20.9	38.270	38.359	7.396	19.3	25.229
		Green	103	58.510	13.199	22.6	34.985	39.089	7.725	19.8	25.246
	No. 2	10	103	43.634	18.514	42.4	15.169	29.125	6.621	22.7	18.318
		15	102	45.322	18.466	40.7	16.992	28.385	6.048	21.3	19.553
		20	101	41.726	15.077	36.1	19.655	27.443	6.130	22.3	18.386
		Green	103	33.073	12.380	37.4	14.195	27.892	6.162	22.2	17.953
	No. 3	10	101	34.902	16.718	47.9	11.282	24.754	5.813	23.5	15.770
		15	100	34.231	14.093	41.2	13.867	24.409	5.595	22.9	15.674
		20	94	34.878	13.997	40.1	12.698	23.545	5.619	23.9	15.213
		Green	100	29.782	11.247	37.8	12.851	23.918	5.552	23.2	14.848
2 x 8	Select Structural	10	106	108.553	30.458	26.3	61.969	87.309	14.502	16.6	61.385
		15	106	115.818	27.674	25.5	58.566	85.040	15.376	18.1	60.480
		20	102	98.057	22.338	22.8	55.478	83.761	13.869	16.6	60.478
		Green	106	85.600	18.184	21.3	52.117	81.903	14.241	17.4	58.014
	No. 2	10	107	68.239	30.878	45.2	25.271	67.766	13.428	19.8	46.637
		15	107	76.639	32.857	42.9	27.337	64.644	12.995	20.1	43.152
		20	108	69.138	23.902	34.6	27.911	63.420	13.350	21.0	43.821
		Green	107	59.366	19.483	32.8	27.977	63.067	15.523	19.9	43.349
	No. 3	10	106	60.217	28.664	47.6	22.980	59.660	13.804	23.1	38.372
		15	100	61.335	30.058	49.0	20.762	57.180	13.659	23.9	39.046
		20	106	54.740	22.492	41.1	19.561	55.597	12.839	23.1	34.570
		Green	107	49.858	19.129	38.4	21.255	54.452	12.613	23.2	34.488

[1]Original data contained three significant digits. Additional digits retained to permit computations with minimum round off error.

[2]Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table 8.—Ratio of dry to green properties for moment capacity and flexural stiffness

Nominal size	Grade	Flexural stiffness						Moment capacity					
		10 percent		15 percent		20 percent		10 percent		15 percent		20 percent	
		Mean	NPE[1]	Mean	NPE[1]	Mean	NPE[1]	Mean	NPE[1]	Mean	NPE[1]	Mean	NPE[1]
In.													
2x4	Select Structural	1.02	0.92	1.03	0.94	0.97	0.92	1.51	1.22	1.30	1.09	1.20	1.21
	No.2	1.06	1.01	1.02	1.00	.97	.95	1.36	1.08	1.30	1.12	1.23	.87
	No.3	1.10	1.03	1.07	1.06	.99	.95	1.11	1.13	1.27	.96	1.09	1.12
2x6	Select Structural	1.00	.91	.99	.88	.98	.96	1.31	1.17	1.20	1.17	1.10	1.09
	No.2	1.05	1.07	1.02	.98	.99	.99	1.32	1.07	1.37	1.20	1.26	1.38
	No.3	1.03	1.05	1.02	1.01	.98	1.01	1.17	0.87	1.15	1.08	1.17	.99
2x8	Select Structural	1.07	1.02	1.04	1.08	1.02	.97	1.27	1.19	1.35	1.12	1.15	1.06
	No.2	1.07	1.08	1.02	1.04	1.01	1.07	1.15	.90	1.29	.98	1.16	1.00
	No.3	1.10	1.09	1.05	1.08	1.02	1.02	1.21	1.08	1.23	0.98	1.10	.92

[1]NPE = Nonparametric estimate of the fifth percentile (ASTM 1983b).

Moment Capacity and Stiffness

The effect of moisture content on moment capacity appears quite similar to that for MOR (fig. 83). Although it was previously shown that moment capacity is less sensitive to changes in moisture content than is MOR, moment capacity is still obviously affected by changes in moisture content. Although flexural stiffness generally increases with drying, the degree of improvement appears to be quite small at all levels of the experimental cumulative density function (fig.84).

Comparison of Data Sets

It is often desirable to combine various subsets of data to more clearly delineate general trends in treatment effects or to achieve certain production or marketing goals. Combining sets of very dissimilar data, however, may obscure general trends or mask minor, but important, discrepancies. Decisions about proposed groupings (here, grades sizes or moisture content) should be based on both statistical and practical comparisons of dissimilarity and upon equality of general trends within the individual subsets. Information on which to base practical decisions as well as some statistical comparison has already been presented. This section presents additional statistical comparisons of the moisture content-property data.

Comparison of Groups

Three tests were used to test the hypothesis that there were no differences between grade-size moisture content groups. First a Kolmogorov-Smirnov two-sample test statistic (Conover 1980) was used to test the equality of pairs of distributions. Then a comparison of mean values of the moisture content groups was conducted within each grade-size combination using an analysis of variance for each variable and then conducting a multiple comparison of the group means, using a series of modified two-sample t-tests (Miller 1981). Finally a modified median (chi-square) test with continuity correction (Conover 1980) was used to compare fifth percentiles. With the sample sizes used in this study, the modified median test lacks power (will tend to indicate equality for dissimilar data groups) when applied to fifth percentiles. This is because of a scarcity of observations in the tail regions.

Test results for MOR and MOE are presented in tables 9 and 10 for flexural stiffness and moment capacity. If none of the groups could be considered equal ($p < 0.2$ for each comparison), then the entry is “none equal.” Otherwise, the groups are listed. The ordering has no importance in the case of distributions. For means and fifth percentiles, the groups are ordered from high to low with respect to the indicated property. If two groups share a common underline, they cannot be considered different, p 20.2. If groups do not share a common underline, they are significantly different, $p < 0.2$.

Table 9.—Tests of equality of experimental parameters for modulus of elasticity and modulus of rupture. Groups for which equality cannot be rejected at p = 0.2[1,2]

Basis of comparison			Modulus of rupture			Modulus of elasticity	
Nominal size	Grade	Moisture content group	Distribution	Mean	Fifth percentile	Distribution	Mean
In.		*Pct*					
				MOISTURE CONTENT[3]			
2 × 4	Select Structural		none equal	none equal	10 20 15 G[2]	10 15 20 G	10 15 20 G
	No. 2		10 15 20 G	none equal	15 10 G 20	10 15 20 G	none equal
	No. 3		none equal	none equal	10 20 15 G	10 15 20 G	10 15 20 G
2 × 6	Select Structural		none equal	none equal	10 15 20 G	none equal	none equal
	No. 2		10 15 20 G	15 10 20 G	20 15 10 G	10 15 20 G	none equal
	No. 3		10 15 20 G	10 15 20 G	15 20 G 10	10 15 20 G	10 15 20 G
2 × 8	Select Structural		none equal	none equal	10 15 20 G	none equal	none equal
	No. 2		10 15 20 G	15 10 20 G	20 15 G 10	none equal	none equal
	No. 3		10 15 20 G	10 15 20 G	10 15 G 20	10 15 20 G	none equal
				GRADE[4]			
2 × 4		10	none equal	none equal	S 2 3	none equal	none equal
2 × 6			none equal	none equal	S 2 3	none equal	none equal
2 × 8			none equal	none equal	S 2 3	none equal	none equal
2 × 4		15	none equal	none equal	none equal	none equal	none equal
2 × 6			none equal	none equal	S 2 3	none equal	none equal
2 × 8			none equal	none equal	none equal	none equal	none equal
2 × 4		20	none equal	none equal	S 2 3	none equal	none equal
2 × 6			none equal	none equal	none equal	none equal	none equal
2 × 8			none equal	none equal	none equal	none equal	none equal
2 × 4		Green	none equal	none equal	S 2 3	none equal	none equal
2 × 6			none equal	none equal	S 2 3	none equal	none equal
2 × 8			none equal	none equal	none equal	none equal	none equal
				SIZE[5]			
	Select Structural	10	none equal	none equal	4 6 8	none equal	none equal
		15	4 6 8	4 6 8	6 4 8	8 4 6	8 4 6
		20	4 6 8	4 6 8	4 6 8	none equal	none equal
		Green	none equal	none equal	4 6 8	8 4 6	8 4 6
	No. 2	10	none equal	none equal	4 6 8	4 6 8	4 6 8
		15	4 6 8	4 6 8	4 6 8	4 6 8	6 4 8
		20	4 6 8	none equal	6 4 8	none equal	6 4 8
		Green	4 6 8	4 8 6	4 8 6	4 6 8	6 4 8
	No. 3	10	4 6 8	4 6 8	4 8 6	4 6 8	4 8 6
		15	none equal	4 8 6	4 6 8	4 6 8	6 4 8
		20	4 6 8	none equal	4 6 8	4 6 8	8 6 4
		Green	4 6 8	4 6 8	4 6 8	6 4 8	6 4 8

[1]Tests of distributions based on Kolmogorov-Smirnov tests of means based on analysis of variance and modified multiple comparison t-test, tests of fifth percentiles based on chi-square test.

[2]Groups sharing a common underline cannot be considered different, p 20.2. Groups which do not share a common underline, p <0.2. For distributions, order of groups does not represent order of distribution. For means and fifth percentiles, groups are ordered from high to low. None equal = for each combination of two groups, equality was rejected p <0.2.

[3]Moisture content groups: G = green: 10 = 10 pct; 15 = 15 pct; 20 = 20 pct.

[4]Grades: S = Select Structural: 2 = No. 2 3 = No. 3.

[5]Nominal sizes: 4 = 2 x 4; 6 = 2 x 6: 8 = 2 x 8.

Table 10.—Tests of equality of experimental parameters for moment capacity and flexural stiffness. Groups for which equality cannot be rejected at p = 0.2[1]

Basis of comparison		Moment capacity			Flexural stiffness		
Nominal size	Grade	Distribution	Mean	Fifth percentile	Distribution	Mean	Fifth percentile
In.				MOISTURE CONTENT			
2 × 4	Select Structural	none equal[1]	none equal	10 20 15 G[2]	10 20 G 15	15 10 G 20	10 15 G 20
	No. 2	10 15 20 G	10 G 15 20	15 10 G 20	10 15 20 G	10 15 G 20	10 20 G 15
	No. 3	none equal	none equal	10 20 G 15	10 15 G 20	10 15 G 20	10 15 G 20
2 × 6	Select Structural	none equal	none equal	10 15 20 G	10 15 20 G	10 G 15 20	10 15 G 20
	No. 2	10 15 20 G	15 10 20 G	20 15 G 10	10 15 G 20	10 15 G 20	15 20 10 G
	No. 3	10 15 20 G	10 20 15 G	15 G 20 10	10 15 20 G	10 15 G 20	10 15 20 G
2 × 8	Select Structural	none equal	none equal	10 15 20 G	10 15 20 G	10 15 20 G	10 15 20 G
	No. 2	15 10 20 G	15 20 10 G	G 20 15 10	10 15 20 G	10 15 20 G	10 20 G 15
	No. 3	10 15 20 G	15 10 20 G	10 G 15 20	10 15 20 G	10 15 20 G	15 10 20 G

[1]See Table 9 for explanation of symbols.

Modulus of Rupture

Tests of the equality of means and of the equality of distributions indicate that MOR values at the different moisture content levels are distinct for Select Structural (table 9—moisture content). For No. 2 and No. 3 there is a tendency for the MOR values at 10 and 15 percent moisture content to be equal. At the fifth percentile, the chi-square test indicates no difference between MOR values at different moisture content levels for many of the grade-size combinations. Because of the lack of power of the test, practical (tables 5 and 6) rather than statistical judgments should be used in judging equality between moisture levels.

Statistical tests confirm the superiority of Select Structural lumber, even at the fifth percentile (table 9—grade). Inspection of table 3 indicates that the fifth percentile MOR of Select Structural is from 85 to 170 percent higher than that of No. 2. Often, however, the fifth percentiles of No. 2 and No. 3 were judged equal. In general, differences in fifth percentile MOR values in excess of 30 percent were required before the chi-square test indicated significance at the 95 percent level. Again the insensitivity of this test is seen.

MOR is less sensitive to size than to grade (table 9—size and grade). Tests of mean and distributional properties indicate a tendency for the 2 x 6 and 2 x 8 MOR's to be equal for No. 2 and No. 3 lumber. With Select Structural lumber, equality sometimes occurred between 2 x 4's and 2 x 6's.

Modulus of Elasticity

Tests of the equality of means and distributions (table 9) indicate that MOE distributions at the four moisture levels are generally distinct. There is, however, a tendency for the 20 percent and green values to be equal.

Moment Capacity and Stiffness

As previously noted, the effect of moisture content on moment capacity and flexural stiffness is similar to that for MOR and MOE, respectively, except that moment capacity and flexural stiffness are less sensitive to drying (table 10). Grade and size comparisons are not shown in table 10. Grade effects are identical to those shown in table 9 and, as expected, all size effects are significant.

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Appendix A
Distributional Form of the Flexural Data

Normal Distribution

Whether or not the data could have come from a normal population was tested using the Kolmogorov-Smirnov (KS) goodness-of-fit test (Conover 1980) using the SAS computer package (Systems Analysis System Institute 1979) and the probability plot correlation coefficient (PPC) test (Filliben 1975). The KS test is perhaps better known, but the PPC test has more power against a range of distribution alternatives. In addition, the PPC test is probably more sensitive to data points in the tails of the distribution. Skewness (lack of symmetry) and kurtosis (degree of flatness) were also examined. Because the sample sizes used in this study are less than required to assure that the coefficients of skewness and kurtosis are normally distributed, critical values for these coefficients were obtained from table A6 of Snedecor and Cochran (1967).

For 26 of the 36 data sets the PPC tests did not reject normality for MOR (table A1). The number was slightly higher (28 of 36) for the KS test. From the opposite perspective, normality was rejected 28 percent of the time by the PPC test. Data for the drier distributions (10 and 15 pct) were much more likely to have significant PPC coefficients indicating a lack of normality, than were the wetter groups. Almost half (15 of 36) of the groups exhibited significant skewness and one-quarter (9 of 36) significant kurtosis. Of those groups with significant skewness, all the Select Structural groups were left skewed[1] and all the No. 2 and No. 3 grade distributions were right skewed. Those distributions with significant kurtosis tended to be flatter than would be expected for a normal distribution.

With MOE, normality was rejected six times by the PPC test and only twice by the KS test. The number of MOE distributions with significant skewness (14 of 36) was surprising. Previous experience had indicated that skewness is usually less common with MOE than with MOR.

Results of normality tests for EI and RS are not presented because they are virtually identical to those for MOE and MOR, respectively.

Weibull Distribution

Tables A2 through A5 present the estimated parameters for the three-parameter Weibull distribution fit to the data using a maximum likelihood estimation procedure.[2] Tables A6 through A9 present the estimates for the two-parameter Weibull distribution. The Weibull distribution was selected because of its flexibility in fitting both right-skewed[3] (shape parameters less than about 3.6) and left-skewed (shape parameters greater than about 3.6) distributions.

The "goodness-of-fit" of the Weibull distribution to the MOR and MOE data was evaluated visually using cumulative distribution functions and histograms, as well as by calculating critical values of the Anderson-Darling A^2 test (Anderson and Darling 1954) and KS tests. The A^2 test has been shown to have good power against a number of distributional alternatives (Littell, McClave, and Offen 1979).

In almost all cases the three-parameter Weibull distribution fit the data quite well (table A10). In only 3 of 36 cases was significant lack of fit indicated for MOR using the A^2 test. Lack of fit was not a problem for MOE. In no instances did the KS test indicate a lack of fit for either MOE or MOR. This confirms observations in the literature about the insensitivity of this test as an indication of goodness-of-fit for distributions other than the normal (Filliben 1975; Shapiro, Wilk, and Chen 1968). As expected, the two-parameter Weibull distribution did not fit the data quite as well as did the three-parameter distribution (table A11).

A visual comparison of the experimental and theoretical cumulative distribution functions indicated a good fit. in those instances where the Weibull distribution did not appear to fit, the data appeared to be bimodal, and it is doubtful that any other standard distribution would have fit better. Differences between the Weibull and nonparametric point estimates for MOR and MOE are given in tables A10 and A11 for comparison.

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[1]A left-skewed distribution has a relatively long 'tail" toward decreasing MOR values.

[2]Warren, W. G. Program for maximum likelihood estimation of Weibull parameters. Personal communication to Forest Products Laboratory, Madison, WI.

[3]A right-skewed distribution has a relatively long 'tail" toward increasing values of the property.

Table A1.—Assessment of normality for modulus of rupture and modulus of elasticity

Nominal size	Grade	Moisture content group	Modulus of rupture					Modulus of elasticity		
			KS[1]	PPC[2]	Skewness[3]	Kurtosis[4]	KS[1]	PPC[2]	Skewness[3]	Kurtosis[4]
In.		*Pct*								
2 × 4	Select Structural	10	--[5]	--	--	--	--	--	--	--
		15	--	--	--	--	--	--	--	--
		20	--	--	--	--	--	--	--	--
		Green	--	--	--	--	--	--	--	--
2 × 6		10	--	--	--	--	--	--	--	--
		15	--	--	--	--	--	--	--	--
		20	**[6]	--	*	--	--	--	--	--
		Green	--	--	--	--	--	--	--	--
2 × 8		10	*[7]	--	--	*	--	--	--	--
		15	**	--	*	--	--	--	--	--
		20	--	*	**	--	--	--	--	--
		Green	--	--	--	--	--	--	--	--
2 × 4	No. 2	10	--	--	--	--	--	--	--	--
		15	--	--	--	--	--	--	--	--
		20	--	--	--	**	--	--	--	--
		Green	--	--	--	--	--	--	--	--
2 × 6		10	--	*	**	--	--	*	**	--
		15	--	--	--	--	*	*	**	--
		20	--	*	**	--	--	*	**	*
		Green	--	--	**	--	--	--	--	--
2 × 8		10	--	*	*	--	--	--	--	--
		15	*	*	--	**	--	--	--	--
		20	--	--	--	*	--	--	*	--
		Green	--	--	--	**	--	--	--	--
2 × 4	No. 3	10	**	**	**	--	--	--	*	--
		15	--	--	*	--	--	--	*	--
		20	--	--	*	--	--	--	--	--
		Green	--	--	--	--	--	*	**	--
2 × 6		10	*	*	*	--	--	*	**	--
		15	--	**	**	**	--	--	*	*
		20	--	--	--	*	--	--	*	--
		Green	--	--	--	--	--	--	--	--
2 × 8		10	*	**	**	--	--	*	**	*
		15	*	**	*	**	--	--	*	--
		20	--	--	--	--	*	--	*	--
		Green	--	--	*	*	--	--	**	--

[1]KS Kolmogorov-Smirnov goodness-of-fit test (Snedecor and Cochran 1967, Systems Analysis System Institute 1979).

[2]Probability plot correlation test (Filliben 1975).

[3]Lack of symmetry.

[4]Degree of flatness.

[5]-- indicates there is no reason to reject normality with p >0.05.

6* indicates there is reason to reject normality with 0.01 <p □ 0.05.

[7]**indicates there is reason to reject normality with p □ 0.01.

Table A2.—Three-parameter Weibull distribution for the modulus of rupture of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 5 percent point[1]			5 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		Pct				10^3 lb/in.^{2}				
2 x 4	Select Structural	10	3.652	10.367	1.886	6.483	5.655	7.311	5.788	4.820
		15	4.816	10.255	.000	5.535	4.824	6.246	4.938	3.896
		20	4.635	7.376	1.542	5.428	4.903	5.594	4.988	4.105
		Green	2.969	4.174	2.920	4.455	4.131	4.779	4.183	3.667
	No. 2	10	2.469	7.519	.644	2.902	2.339	3.466	2.430	2.121
		15	2.896	6.706	.856	3.261	2.722	3.799	2.808	2.493
		20	3.076	7.018	.000	2.672	2.115	3.230	2.205	1.859
		Green	3.263	5.061	.301	2.337	1.950	2.725	2.013	1.420
	No. 3	10	1.878	4.861	.869	1.868	1.572	2.164	1.620	1.859
		15	2.446	5.814	.526	2.252	1.820	2.685	1.889	1.549
		20	2.420	4.473	.777	2.088	1.764	2.412	1.817	1.318
		Green	2.635	4.135	.537	1.876	1.566	2.187	1.616	1.141
2x6	Select Structural	10	4.749	11.321	.000	6.057	5.238	6.876	5.370	4.821
		15	3.038	7.243	2.778	5.502	4.901	6.103	5.998	4.326
		20	5.783	8.853	.000	5.297	4.727	5.867	4.818	4.150
		Green	3.438	5.458	2.172	4.473	4.040	4.905	4.110	3.680
	No. 2	10	1.989	5.398	1.025	2.238	1.866	2.610	1.926	1.627
		15	2.254	5.834	.727	2.289	1.849	2.729	1.919	1.444
		20	2.132	4.330	1.407	2.482	2.191	2.773	2.238	2.113
		Green	2.486	3.821	.570	1.727	1.430	2.024	1.477	1.222
	No. 3	10	1.611	4.040	1.048	1.687	1.448	1.925	1.487	1.273
		15	2.121	4.196	.715	1.749	1.463	2.036	1.509	1.077
		20	2.672	4.827	.081	1.669	1.245	2.093	1.313	1.016
		Green	2.057	2.967	.960	1.660	1.438	1.882	1.474	1.274
2 x 8	Select Structural	10	4.353	9.550	.000	4.827	4.060	5.594	4.184	3.955
		15	4.559	8.580	.000	4.473	3.893	5.053	3.986	3.223
		20	5.349	7.469	.000	4.287	3.821	4.753	3.896	2.486
		Green	3.974	4.767	1.385	3.643	3.292	3.993	3.348	2.921
	No. 2	10	1.841	4.631	.955	1.878	1.578	2.177	1.626	1.328
		15	1.902	4.984	1.112	2.157	1.815	2.499	1.870	1.597
		20	3.209	5.368	.077	2.205	1.731	2.678	1.807	1.729
		Green	2.552	3.456	.922	2.001	1.722	2.280	1.766	1.596
	No. 3	10	1.808	4.230	.733	1.551	1.300	1.803	1.340	1.205
		15	1.704	4.085	.768	1.483	1.232	1.734	1.273	1.036
		20	2.077	3.603	.692	1.554	1.284	1.825	1.327	1.164
		Green	2.234	3.036	.671	1.474	1.252	1.697	1.288	1.073

[1]Nonparametric estimate of the fifth percentile (ASTM 1983[13]).

Table A3.—Three-parameter Weibull distribution for the modulus of elasticity of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 50 percent point[1]			50 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*					*10^6 lb/in.^{2}*			
2 x 4	Select Structural	10	2.243	0.920	0.873	1.654	1.572	1.736	1.585	1.559
		15	2.369	.903	.845	1.618	1.538	1.698	1.551	1.549
		20	2.807	.915	.641	1.444	1.376	1.512	1.387	1.399
		Green	2.500	.822	.695	1.405	1.337	1.472	1.348	1.358
	No. 2	10	2.871	.971	.571	1.425	1.356	1.494	1.368	1.352
		15	2.686	.865	.551	1.306	1.240	1.372	1.251	1.229
		20	3.037	.864	.447	1.213	1.154	1.271	1.163	1.159
		Green	3.463	.909	.350	1.168	1.113	1.222	1.122	1.094
	No. 3	10	2.257	.760	.566	1.213	1.146	1.280	1.156	1.106
		15	2.470	.765	.469	1.129	1.068	1.191	1.078	1.047
		20	2.843	.735	.362	1.008	.955	1.061	.964	.942
		Green	2.027	.543	.505	.959	.907	1.010	.915	.887
2 x 6	Select Structural	10	3.348	1.328	.778	1.968	1.881	2.055	1.895	1.873
		15	3.371	1.227	.769	1.869	1.789	1.949	1.802	1.808
		20	3.451	1.228	.664	1.768	1.691	1.845	1.703	1.674
		Green	4.373	1.387	.416	1.691	1.620	1.762	1.632	1.596
	No. 2	10	2.319	.871	.659	1.402	1.328	1.477	1.340	1.280
		15	2.131	.699	.725	1.314	1.249	1.379	1.260	1.242
		20	2.350	.709	.615	1.221	1.161	1.281	1.171	1.147
		Green	2.597	.711	.545	1.162	1.107	1.218	1.116	1.095
	No. 3	10	2.038	0.690	0.616	1.193	1.125	1.260	1.136	1.113
		15	2.463	.729	.508	1.137	1.076	1.197	1.086	1.072
		20	2.124	.595	.534	1.035	.976	1.094	.986	.995
		Green	2.565	.631	.465	1.012	.960	1.063	.969	.943
2 x 8	Select Structural	10	3.282	1.108	.819	1.809	1.737	1.882	1.749	1.708
		15	2.832	.979	.802	1.661	1.591	1.731	1.603	1.578
		20	3.238	.921	.760	1.583	1.523	1.643	1.533	1.505
		Green	3.525	.887	.650	1.449	1.396	1.502	1.405	1.400
	No. 2	10	2.484	.777	.699	1.370	1.307	1.433	1.317	1.317
		15	2.548	.738	.620	1.258	1.200	1.317	1.210	1.187
		20	1.920	.550	.720	1.174	1.119	1.230	1.128	1.122
		Green	2.769	.634	.561	1.116	1.069	1.163	1.077	1.085
	No. 3	10	2.274	.745	.565	1.200	1.136	1.264	1.146	1.139
		15	2.267	.671	.527	1.098	1.039	1.158	1.048	1.009
		20	2.588	.701	.445	1.053	.999	1.107	1.008	1.989
		Green	2.300	.553	.485	.957	.910	1.004	.917	.913

[1]Nonparametric estimate of the 50th percentile (ASTM 1983b).

Table A4.—Three-parameter Weibull distribution for the flexural stiffness of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 50 percent point[1]			50 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				10^6 lb · in.^{2}				
2 x 4	Select Structural	10	2.696	4.785	4.440	8.617	8.250	8.983	8.309	8.289
		15	2.902	5.163	4.225	8.775	8.392	9.159	8.454	8.447
		20	2.847	5.033	3.767	8.192	7.821	8.563	7.880	7.876
		Green	2.564	4.997	4.108	8.440	8.039	8.840	8.103	8.097
	No. 2	10	3.089	4.995	2.980	7.416	7.086	7.747	7.139	6.977
		15	3.013	4.805	2.851	7.106	6.773	7.438	6.827	6.717
		20	3.113	4.761	2.583	6.815	6.500	7.131	6.550	6.598
		Green	3.372	5.350	2.218	7.017	6.688	7.346	6.741	6.621
	No. 3	10	2.554	4.075	2.862	6.392	6.065	6.719	6.118	5.966
		15	2.547	4.213	2.575	6.223	5.893	6.554	5.947	5.789
		20	2.917	4.230	2.069	5.799	5.501	6.097	5.549	5.455
		Green	2.076	3.300	2.988	5.754	5.446	6.062	5.496	5.329
2 x 6	Select Structural	10	4.402	29.553	12.370	39.562	38.035	41.089	38.280	37.810
		15	4.161	27.556	13.547	38.779	37.291	40.267	37.531	37.122
		20	3.605	26.431	14.538	38.414	36.816	40.011	37.073	37.143
		Green	4.295	31.819	10.152	39.368	37.718	41.018	37.983	37.344
	No. 2	10	2.407	16.914	14.115	28.639	27.230	30.049	27.465	26.492
		15	2.254	14.608	15.429	27.844	26.558	29.129	26.765	26.291
		20	2.376	15.490	13.705	26.981	25.677	28.285	25.887	25.353
		Green	2.563	16.618	13.039	27.443	26.133	28.753	26.344	25.999
	No. 3	10	2.261	13.989	12.353	24.249	22.994	25.504	23.196	22.873
		15	2.609	15.370	10.734	24.090	22.874	25.306	23.070	23.024
		20	2.200	13.143	11.901	23.027	22.768	24.286	21.971	22.415
		Green	2.541	14.708	10.866	23.598	22.390	24.806	22.585	22.217
2 x 8	Select Structural	10	3.689	52.692	39.782	87.491	84.417	90.564	84.911	83.786
		15	3.110	49.221	40.957	84.707	81.472	87.941	81.992	81.720
		20	3.503	48.593	40.022	83.788	80.805	86.771	82.285	80.810
		Green	3.622	51.156	35.792	82.024	79.025	85.024	79.507	78.929
	No. 2	10	2.594	36.298	35.524	67.040	64.211	69.868	64.666	64.908
		15	2.663	35.861	32.772	64.023	61.276	66.769	61.717	60.680
		20	2.036	29.176	37.563	61.933	59.130	64.736	59.581	59.118
		Green	2.771	35.690	31.312	62.579	59.934	65.225	60.359	59.792
	No. 3	10	2.456	35.970	27.714	58.697	55.787	61.607	56.255	55.845
		15	2.337	33.830	27.197	56.117	53.179	59.054	53.652	52.096
		20	2.746	36.848	22.774	55.018	52.305	57.731	52.742	51.345
		Green	2.316	31.095	26.874	53.418	50.776	56.060	51.201	50.364

[1]Nonparametric estimate of the 50th percentile (ASTM 1983b).

Table A5.—Three-parameter Weibull distribution for the moment capacity of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 5 percent point[1]			5 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				10^3 lb • in.				
2 x 4	Select Structural	10	3.996	31.559	5.108	20.115	17.627	22.602	18.027	15.253
		15	4.995	31.684	0.000	17.483	15.340	19.625	15.685	13.001
		20	5.001	25.064	3.688	17.528	15.784	19.271	16.065	13.074
		Green	2.948	13.688	10.082	15.081	14.025	16.136	14.195	13.155
	No. 2	10	2.517	22.755	1.877	8.868	7.142	10.594	7.419	6.174
		15	3.102	21.570	1.971	10.250	8.482	12.017	8.767	8.207
		20	3.095	22.417	0.000	8.586	6.791	10.382	7.080	6.246
		Green	3.161	16.693	1.328	7.851	6.583	9.120	6.787	4.824
	No. 3	10	1.904	14.806	2.620	5.730	4.816	6.644	4.963	5.447
		15	2.412	18.252	1.746	7.072	5.722	8.422	5.939	4.903
		20	2.436	14.529	2.552	6.884	5.782	7.907	5.953	4.322
		Green	2.659	13.920	1.749	6.305	5.257	7.353	5.425	3.947
2 x 6	Select Structural	10	4.901	83.569	0.000	45.587	39.698	51.476	40.645	36.410
		15	3.048	54.203	21.617	42.072	37.555	46.589	38.281	34.298
		20	5.720	69.665	0.000	41.447	36.824	46.070	37.567	32.928
		Green	3.358	44.503	18.545	36.920	33.419	40.420	33.982	30.136
	No. 2	10	2.053	40.937	7.315	16.946	14.063	19.829	14.527	11.756
		15	2.284	44.700	5.697	17.873	14.488	21.258	15.032	11.356
		20	2.118	34.171	11.463	19.872	17.579	22.165	17.947	16.778
		Green	2.473	31.871	4.824	14.413	11.956	16.871	12.351	10.337
	No. 3	10	1.611	30.056	7.844	12.640	10.859	14.421	11.146	9.587
		15	2.116	32.277	5.572	13.504	11.304	15.704	11.658	8.332
		20	2.734	39.005	.223	13.385	9.933	16.838	10.488	8.218
		Green	2.028	24.514	8.046	13.712	11.917	15.507	12.206	10.392
2 x 8	Select Structural	10	4.448	127.267	.000	65.267	55.612	74.922	57.164	54.343
		15	4.648	118.884	.000	62.744	54.799	70.688	56.077	45.305
		20	5.347	106.562	.000	61.143	54.473	67.813	55.545	35.136
		Green	3.957	71.420	20.798	54.517	46.309	59.725	50.147	44.963
	No. 2	10	1.833	61.697	13.354	25.558	21.589	29.527	22.227	18.601
		15	1.953	69.376	15.076	30.234	25.310	35.157	26.101	22.192
		20	3.227	76.110	1.099	31.418	24.676	38.159	25.760	24.969
		Green	2.597	52.016	13.228	29.804	25.559	34.048	26.241	23.617
	No. 3	10	1.833	56.606	9.957	21.155	17.735	24.574	18.285	16.649
		15	1.707	56.469	10.895	20.809	17.330	24.288	17.889	14.895
		20	2.120	50.980	9.554	22.114	18.251	25.977	18.872	16.547
		Green	2.247	45.385	9.679	21.778	18.440	25.116	18.977	15.897

[1]Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table A6.—Two-parameter Weibull distribution for the modulus of rupture of Douglas Fir lumber at various moisture contents

Nominal sire	Grade	Moisture content group	Estimated Weibull parameters			Weibull 5 percent point[1]			5 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				*10^3 lb/in.^{2}*				
2 x 4	Select Structural	10	4.464	12.339	0.0	6.344	5.581	7.107	5.704	4.820
		15	4.816	10.255	0.0	5.535	4.903	6.167	5.005	3.896
		20	5.747	8.961	0.0	5.345	4.852	5.837	4.931	4.105
		Green	5.458	7.220	0.0	4.190	3.783	4.597	3.849	3.667
	No. 2	10	2.802	8.256	0.0	2.860	2.312	3.408	2.400	2.121
		15	3.398	7.635	0.0	3.186	2.685	3.686	2.765	2.493
		20	3.076	7.018	0.0	2.672	2.186	3.159	2.265	1.859
		Green	3.526	5.386	0.0	2.320	1.970	2.669	2.026	1.420
	No. 3	10	2.510	5.966	0.0	1.827	1.441	2.214	1.503	1.859
		15	2.798	6.422	0.0	2.221	1.799	2.643	1.867	1.549
		20	3.053	5.359	0.0	2.026	1.679	2.372	1.734	1.318
		Green	3.139	4.737	0.0	1.839	1.527	2.150	1.577	1.141
2x6	Select Structural	10	4.749	11.321	0.0	6.057	5.348	6.766	5.462	4.821
		15	4.488	10.172	0.0	5.248	4.597	5.899	4.702	4.326
		20	5.783	8.853	0.0	5.297	4.783	5.810	4.866	4.150
		Green	5.074	7.721	0.0	4.299	3.844	4.755	3.918	3.680
	No. 2	10	2.621	6.630	0.0	2.134	1.700	2.569	1.770	1.627
		15	2.702	6.679	0.0	2.225	1.777	2.673	1.849	1.444
		20	3.151	5.946	0.0	2.317	1.927	2.707	1.989	2.113
		Green	3.033	4.458	0.0	1.674	1.370	1.978	1.419	1.222
	No. 3	10	2.387	5.366	0.0	1.546	1.188	1.904	1.245	1.273
		15	2.727	5.065	0.0	1.704	1.381	2.027	1.433	1.077
		20	2.739	4.917	0.0	1.663	1.308	2.017	1.365	1.016
		Green	3.055	4.058	0.0	1.535	1.257	1.813	1.301	1.274
2x8	Select Structural	10	4.353	9.550	0.0	4.827	4.215	5.439	4.314	3.955
		15	4.559	8.580	0.0	4.473	3.937	5.009	4.023	3.223
		20	5.349	7.469	0.0	4.287	3.837	4.737	3.909	2.486
		Green	5.325	6.202	0.0	3.550	3.201	3.900	3.257	2.921
	No. 2	10	2.505	5.795	0.0	1.771	1.390	2.152	1.451	1.328
		15	2.611	6.300	0.0	2.020	1.598	2.442	1.666	1.597
		20	3.270	5.451	0.0	2.198	1.830	2.565	1.889	1.729
		Green	3.486	4.459	0.0	1.902	1.606	2.198	1.653	1.596
	No. 3	10	2.414	5.179	0.0	1.513	1.182	1.844	1.235	1.205
		15	2.319	5.064	0.0	1.407	1.065	1.748	1.120	1.036
		20	2.709	4.406	0.0	1.472	1.178	1.766	1.226	1.164
		Green	2.981	3.797	0.0	1.402	1.148	1.656	1.189	1.073

[1]Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table A7.—Two-parameter Weibull distribution for the modulus of elasticity of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 50 percent point[1]			50 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				10^6 lb/in.^{2}				
2 x 4	Select Structural	10	4.889	1.849	0.0	1.716	1.637	1.795	1.649	1.559
		15	5.140	1.795	0.0	1.672	1.598	1.746	1.610	1.549
		20	5.209	1.587	0.0	1.479	1.415	1.543	1.425	1.399
		Green	5.106	1.555	0.0	1.447	1.383	1.511	1.394	1.358
	No. 2	10	4.931	1.572	0.0	1.459	1.393	1.526	1.403	1.352
		15	4.803	1.448	0.0	1.341	1.279	1.404	1.289	1.229
		20	4.935	1.334	0.0	1.238	1.181	1.295	1.191	1.159
		Green	5.067	1.274	0.0	1.185	1.113	1.238	1.141	1.094
	No. 3	10	4.413	1.369	0.0	1.260	1.195	1.325	1.206	1.106
		15	4.375	1.269	0.0	1.167	1.106	1.228	1.116	1.047
		20	4.594	1.118	0.0	1.032	.981	1.083	0.990	0.942
		Green	4.376	1.091	0.0	1.003	.951	1.055	0.960	0.887
2 x 6	Select Structural	10	5.676	2.134	0.0	2.000	1.919	2.081	1.932	1.873
		15	5.835	2.023	0.0	1.900	1.824	1.977	1.836	1.808
		20	5.632	1.916	0.0	1.795	1.722	1.868	1.734	1.674
		Green	5.882	1.814	0.0	1.704	1.638	1.770	1.649	1.596
	No. 2	10	4.452	1.579	0.0	1.455	1.380	1.530	1.392	1.280
		15	4.767	1.477	0.0	1.368	1.301	1.434	1.312	1.242
		20	4.742	1.366	0.0	1.264	1.202	1.326	1.212	1.147
		Green	4.974	1.288	0.0	1.196	1.141	1.252	1.150	1.095
	No. 3	10	4.315	1.359	0.0	1.249	1.181	1.316	1.192	1.113
		15	4.532	1.273	0.0	1.174	1.114	1.234	1.124	1.072
		20	4.525	1.170	0.0	1.079	1.022	1.136	1.031	.995
		Green	4.894	1.122	0.0	1.041	.922	1.091	1.000	.943
2 x 8	Select Structural	10	6.125	1.954	0.0	1.841	1.773	1.908	1.784	1.708
		15	5.542	1.817	0.0	1.701	1.631	1.770	1.643	1.578
		20	6.303	1.708	0.0	1.611	1.552	1.670	1.562	1.505
		Green	6.481	1.556	0.0	1.471	1.420	1.522	1.428	1.400
	No. 2	10	5.177	1.515	0.0	1.412	1.350	1.473	1.360	1.317
		15	5.128	1.391	0.0	1.295	1.239	1.352	1.248	1.187
		20	5.062	1.321	0.0	1.229	1.175	1.284	1.183	1.122
		Green	5.693	1.220	0.0	1.143	1.098	1.189	1.106	1.085
	No. 3	10	4.370	1.356	0.0	1.246	1.182	1.311	1.192	1.139
		15	4.477	1.238	0.0	1.141	1.081	1.200	1.091	1.009
		20	4.602	1.175	0.0	1.085	1.032	1.138	1.040	0.989
		Green	4.726	1.072	0.0	.992	.944	1.039	.952	.913

[1]Nonparametric estimate of the 50th percentile (ASTM 1983b).

Table A8.—Two-parameter Weibull distribution for the flexural stiffness of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 50 percent point[1]			50 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				10^6 lb • in.^{2}				
2 x 4	Select Structural	10	5.680	9.424	0.0	8.835	8.485	9.186	8.541	8.289
		15	5.755	9.559	0.0	8.969	8.616	9.321	8.673	8.447
		20	5.426	8.968	0.0	8.383	8.034	8.731	8.090	7.876
		Green	5.139	9.326	0.0	8.684	8.303	9.065	8.364	8.097
	No. 2	10	5.287	8.110	0.0	7.567	7.246	7.888	7.297	6.977
		15	5.173	7.787	0.0	7.254	6.941	7.567	6.991	6.717
		20	5.134	7.466	0.0	6.951	6.645	7.258	6.694	6.598
		Green	5.052	7.667	0.0	7.131	6.815	7.447	6.865	6.621
	No. 3	10	4.804	7.106	0.0	6.584	6.273	6.896	6.323	5.966
		15	4.494	6.963	0.0	6.418	6.093	6.743	6.145	5.789
		20	4.689	6.414	0.0	5.932	5.645	6.219	5.691	5.455
		Green	4.425	6.530	0.0	6.011	5.702	6.320	5.752	5.329
2 x 6	Select Structural	10	6.504	42.209	0.0	39.896	38.492	41.301	38.717	37.810
		15	6.488	41.450	0.0	39.174	37.756	40.591	37.984	37.122
		20	5.899	41.466	0.0	38.949	37.430	40.467	37.674	37.143
		Green	5.874	42.248	0.0	39.692	38.154	41.231	38.401	37.344
	No. 2	10	4.814	31.943	0.0	29.602	28.192	31.011	28.419	26.492
		15	5.004	31.040	0.0	28.848	27.519	30.176	27.733	26.291
		20	4.855	30.087	0.0	27.899	26.567	29.231	26.781	25.353
		Green	4.979	30.421	0.0	28.262	26.960	29.564	27.169	25.999
	No. 3	10	4.706	27.200	0.0	25.162	23.924	26.400	24.123	22.873
		15	4.788	26.758	0.0	24.786	23.585	25.987	23.778	23.024
		20	4.682	25.877	0.0	23.929	22.704	25.153	22.901	22.415
		Green	4.857	26.212	0.0	24.307	23.144	25.470	23.331	22.217
2 x 8	Select Structural	10	6.866	93.520	0.0	88.659	85.756	91.562	86.223	83.786
		15	6.061	91.716	0.0	86.334	83.129	89.539	83.645	81.720
		20	6.784	89.756	0.0	85.036	82.162	87.909	82.624	80.810
		Green	6.522	87.977	0.0	83.169	80.303	86.036	80.764	78.929
	No. 2	10	5.612	73.519	0.0	68.871	66.115	71.627	66.558	64.908
		15	5.563	70.167	0.0	65.693	63.045	68.341	63.471	60.680
		20	5.292	69.137	0.0	64.511	61.779	67.242	62.218	59.118
		Green	5.666	68.379	0.0	64.096	61.558	66.633	61.966	59.792
	No. 3	10	2.444	69.329	0.0	60.619	57.725	63.513	58.190	55.845
		15	4.646	62.915	0.0	58.142	55.226	61.059	55.695	52.096
		20	4.808	60.948	0.0	56.475	53.823	59.126	54.250	51.345
		Green	4.735	59.796	0.0	55.341	52.714	57.969	53.136	50.364

[1]Nonparametric estimate of the 50th percentile (ASTM 1983b).

Table A9.—Two-parameter Weibull distribution for the moment capacity of Douglas Fir lumber at various moisture contents

Nominal size	Grade	Moisture content group	Estimated Weibull parameters			Weibull 5 percent point[1]			5 percent[1] tolerance limit, 95 percent confidence	
			Shape	Scale	Location	Estimate	95 percent lower confidence limit	95 percent upper confidence limit	Weibull	Nonparametric
In.		*Pct*				10^3 lb • in.				
2 x 4	Select Structural	10	4.768	36.862	0.0	19.773	17.542	22.004	17.900	15.253
		15	4.995	31.684	0.0	17.483	15.550	19.415	15.861	13.001
		20	5.841	28.844	0.0	17.347	15.769	18.925	16.022	13.074
		Green	5.540	24.201	0.0	14.157	12.806	15.508	13.024	13.155
	No. 2	10	2.838	24.890	0.0	8.739	7.085	10.393	7.351	6.174
		15	3.478	23.689	0.0	10.085	8.528	11.641	8.778	8.207
		20	3.095	22.417	0.0	8.586	7.037	10.136	7.286	6.246
		Green	3.505	18.132	0.0	7.770	6.599	8.942	6.787	4.824
	No. 3	10	2.530	18.104	0.0	5.595	4.417	6.773	4.606	5.447
		15	2.781	20.277	0.0	6.968	5.640	8.296	5.854	4.903
		20	3.074	17.424	0.0	6.630	5.501	7.758	5.683	4.322
		Green	3.151	15.874	0.0	6.184	5.135	7.233	5.304	3.947
2 x 6	Select Structural	10	4.901	83.569	0.0	45.587	40.396	50.779	41.230	36.410
		15	4.555	76.970	0.0	40.099	35.191	45.007	35.980	34.298
		20	5.720	69.665	0.0	41.447	37.385	45.510	38.038	32.928
		Green	5.034	63.858	0.0	35.399	31.634	39.164	32.239	30.136
	No. 2	10	2.657	49.647	0.0	16.230	12.972	19.488	13.496	11.756
		15	2.743	51.291	0.0	17.372	13.934	20.810	14.487	11.356
		20	3.161	47.317	0.0	18.490	15.384	21.595	15.884	16.778
		Green	3.028	37.274	0.0	13.975	11.440	16.510	11.848	10.337
	No. 3	10	2.394	40.000	0.0	11.569	8.889	14.250	9.319	9.587
		15	2.727	39.054	0.0	13.143	10.668	15.617	11.066	8.332
		20	2.757	39.254	0.0	13.368	10.534	16.202	10.989	8.218
		Green	3.033	33.693	0.0	12.654	10.350	14.957	10.721	10.392
2 x 8	Select Structural	10	4.448	127.267	0.0	65.267	57.176	73.358	58.476	54.343
		15	4.648	118.884	0.0	62.744	55.349	70.138	56.538	45.305
		20	5.347	106.562	0.0	61.143	54.711	67.574	55.745	35.136
		Green	5.307	92.981	0.0	53.129	47.906	58.352	48.746	44.963
	No. 2	10	2.524	77.933	0.0	24.028	18.888	29.168	19.714	18.601
		15	2.649	87.053	0.0	28.365	22.504	34.225	23.446	22.192
		20	3.288	77.288	0.0	31.321	26.109	36.533	26.947	24.969
		Green	3.499	66.377	0.0	28.405	23.999	32.811	24.707	23.617
	No. 3	10	2.444	69.329	0.0	20.564	16.100	25.027	16.818	16.649
		15	2.333	70.279	0.0	19.674	14.924	24.424	15.688	14.895
		20	2.743	62.016	0.0	20.999	16.864	25.134	17.529	16.547
		Green	2.973	56.358	0.0	20.754	18.538	22.970	19.455	18.621

[1]Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table A10.—Evaluation of the fit of a three-parameter Weibull distribution to the modulus of rupture and modulus of elasticity data

Nominal size	Grade	Moisture content group	Indicators of fit for modulus of rupture			Indicators of fit for modulus of elasticity		
			Lack of fit[1] test	Percent difference in estimate[2]		Lack of fit[1] test	Percent difference in estimate[2]	
				Median	Fifth[3] percentile		Median	Fifth[3] percentile
In.		*Pct*						
2 x 4	Select Structural	10	--	−3.1	7.2	--	−1.6	3.9
	No. 2		--	−1.0	6.3	--	−.6	1.1
	No. 3		--	8.2	−13.7	--	2.4	−3.3
2 x 6	Select Structural		--	−2.6	10.3	--	−.2	2.9
	No. 2		--	−4.0	11.2	--	.1	3.7
	No. 3		--	1.2	11.2	--	.2	2.6
2 x 8	Select Structural		*	1.4	3.9	--	−.7	2.5
	No. 2		--	−.7	1.4	--	.4	.2
	No. 3		--	6.6	−10.6	--	.5	.4
2 x 4	Select Structural	15	--	−.8	3.6	--	−2.4	4.6
	No. 2		--	−3.9	15.7	--	1.2	4.3
	No. 3		--	0.0	23.3	--	2.1	−6.9
2 x 6	Select Structural		--	.3	1.8	--	1.1	2.8
	No. 2		--	−5.1	4.9	--	2.1	−1.4
	No. 3		--	1.2	−2.1	--	−1.4	−.6
2 x 8	Select Structural		--	−2.2	6.1	--	−.9	.8
	No. 2		*	−1.4	10.4	--	−.1	2.7
	No. 3		--	−.2	.8	--	.5	−5.6
2 x 4	Select Structural	20	--	−0.7	−5.4	--	−0.1	1.8
	No. 2		*	−1.4	25.4	--	1.1	1.4
	No. 3		--	−3.8	2.8	--	.3	−3.2
2 x 6	Select Structural		--	−1.8	9.0	--	−.5	2.6
	No. 2		--	.8	1.4	--	2.1	2.1
	No. 3		--	−1.2	4.7	--	−2.1	−.3
2 x 8	Select Structural		--	−1.7	8.2	--	0.0	−.5
	No. 2		--	−2.5	12.2	--	−2.7	2.6
	No. 3		--	−6.1	13.9	--	.9	3.3
2 x 4	Select Structural	Green	--	2.1	.9	--	4.8	.8
	No. 2		--	.1	0.0	--	1.9	.1
	No. 3		--	.6	9.7	--	.2	−2.4
2 x 6	Select Structural		--	−.8	.5	--	−.5	2.4
	No. 2		--	−4.5	−3.3	--	1.3	.6
	No. 3		--	−5.9	7.6	--	−.4	3.6
2 x 8	Select Structural		--	.5	18.7	--	−1.1	1.7
	No. 2		--	−4.1	6.4	--	−.1	.5
	No. 3		--	−.7	2.7	--	.6	3.4

[1]*indicates significant lack of fit at the □ = 0.05 level using the Anderson-Darling test (Anderson and Darling 1954).

[2] Percent difference = 100 (Weibull estimate-nonparametric estimate) ÷ nonparametric estimate.

[3] Nonparametric estimate of the fifth percentile (ASTM 1983b).

Table AII.—Evaluation of the fit of a two-parameter Weibull distribution to the modulus of rupture and modulus of elasticity data

Nominal size	Grade	Moisture content group	Indicators of fit for modulus of rupture			Indicators of fit for modulus of elasticity		
			Lack of fit[1] test	Percent difference in estimate[2]		Lack of fit[1] test	Percent difference in estimate[2]	
				Median	Fifth[3] percentile		Median	Fifth[3] percentile
In.		*Pct*						
2 × 4	Select Structural	10	—	−2.2	4.9	—	2.1	−6.4
	No. 2		—	.6	4.8	*	1.7	−5.0
	No. 3		*	14.6	−15.6	*	6.4	−12.2
2 × 6	Select Structural		—	−2.6	10.3	—	1.4	−1.9
	No. 2		—	.4	6.1	*	3.9	−6.7
	No. 3		*	9.2	1.9	*	5.0	−9.8
2 × 8	Select Structural		*	2.0	3.9	—	1.0	−2.7
	No. 2		—	4.7	−4.6	*	3.5	−8.4
	No. 3		*	2.7	−12.8	*	4.4	−10.1
2 × 4	Select Structural	15	—	−.8	3.6	—	−.6	−5.2
	No. 2		—	−2.7	13.0	—	4.0	−2.9
	No. 3		—	1.8	21.6	*	5.6	−14.2
2 × 6	Select Structural		—	1.6	−3.0	—	.5	−2.1
	No. 2		—	−2.7	1.9	*	6.3	−13.1
	No. 3		—	5.6	−4.6	*	1.9	−9.6
2 × 8	Select Structural		—	−2.2	6.1	*	1.4	−6.4
	No. 2		*	3.4	3.3	*	2.8	−5.8
	No. 3		*	2.0	−4.4	*	4.5	−14.9
2 × 4	Select Structural	20	—	−0.2	−6.9	—	2.4	−4.8
	No. 2		*	−1.4	25.4	—	3.2	−3.9
	No. 3		—	−1.1	−.3	—	2.7	−8.6
2 × 6	Select Structural		—	−1.8	9.0	—	1.0	−1.9
	No. 2		*	5.6	−5.4	*	5.6	−12.4
	No. 3		—	−.9	4.3	—	2.1	−11.1
2 × 8	Select Structural		—	−1.7	8.2	*	1.8	−6.0
	No. 2		—	−2.3	11.9	*	1.8	−9.9
	No. 3		—	6.2	7.8	*	3.9	−4.6
2 × 4	Select Structural	Green	—	.2	−7.4	—	3.4	−7.4
	No. 2		—	.7	−.7	—	3.4	−3.5
	No. 3		—	2.5	7.5	*	4.9	−14.4
2 × 6	Select Structural		—	.6	1.0	—	.2	−.1
	No. 2		—	−.8	−2.7	*	4.3	−7.6
	No. 3		—	−1.6	−.5	—	2.5	−4.4
2 × 8	Select Structural		—	−.3	2.2	—	1.0	−2.6
	No. 2		—	−1.7	1.2	—	2.2	−6.5
	No. 3		—	13.3	−2.3	*	4.3	−7.1

[1]*indicates significant lack of fit at the □ = 0.05 level using the Anderson-Darling test (Anderson and Darling 1954).

[2] Percent difference = 100 (Weibull estimate-nonparametric estimate) ÷ nonparametric estimate.

[3] Nonparametric estimate of the fifth percentile (ASTM 1983b).

Appendix B
Supplementary Figures

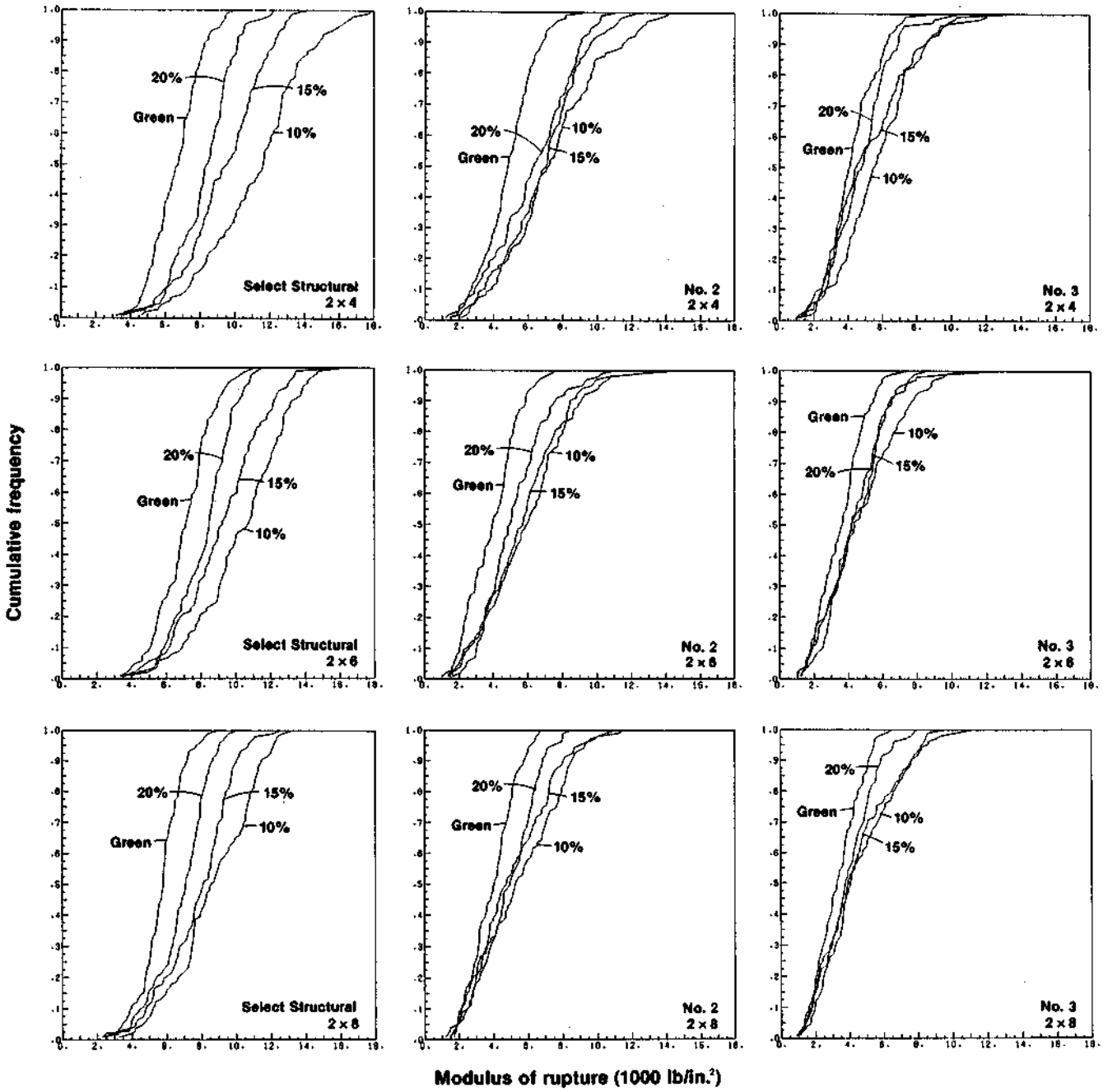

Figure B1. —Cumulative frequency distributions for modulus of rupture at four moisture content levels. (ML85 5140)

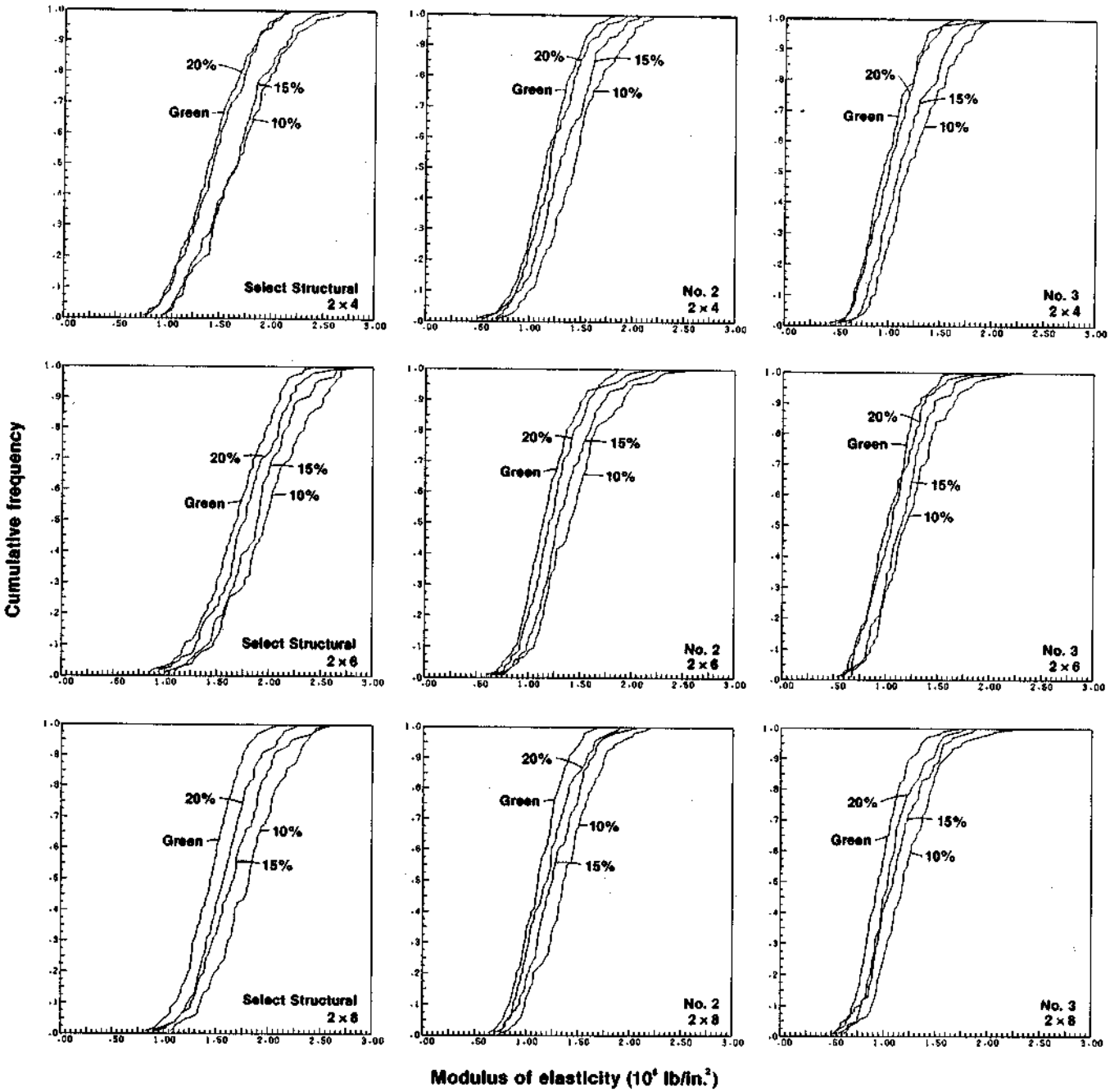

Figure B2.—Cumulative frequency distribution for modulus of elasticity at four moisture content levels. (ML85 5141)

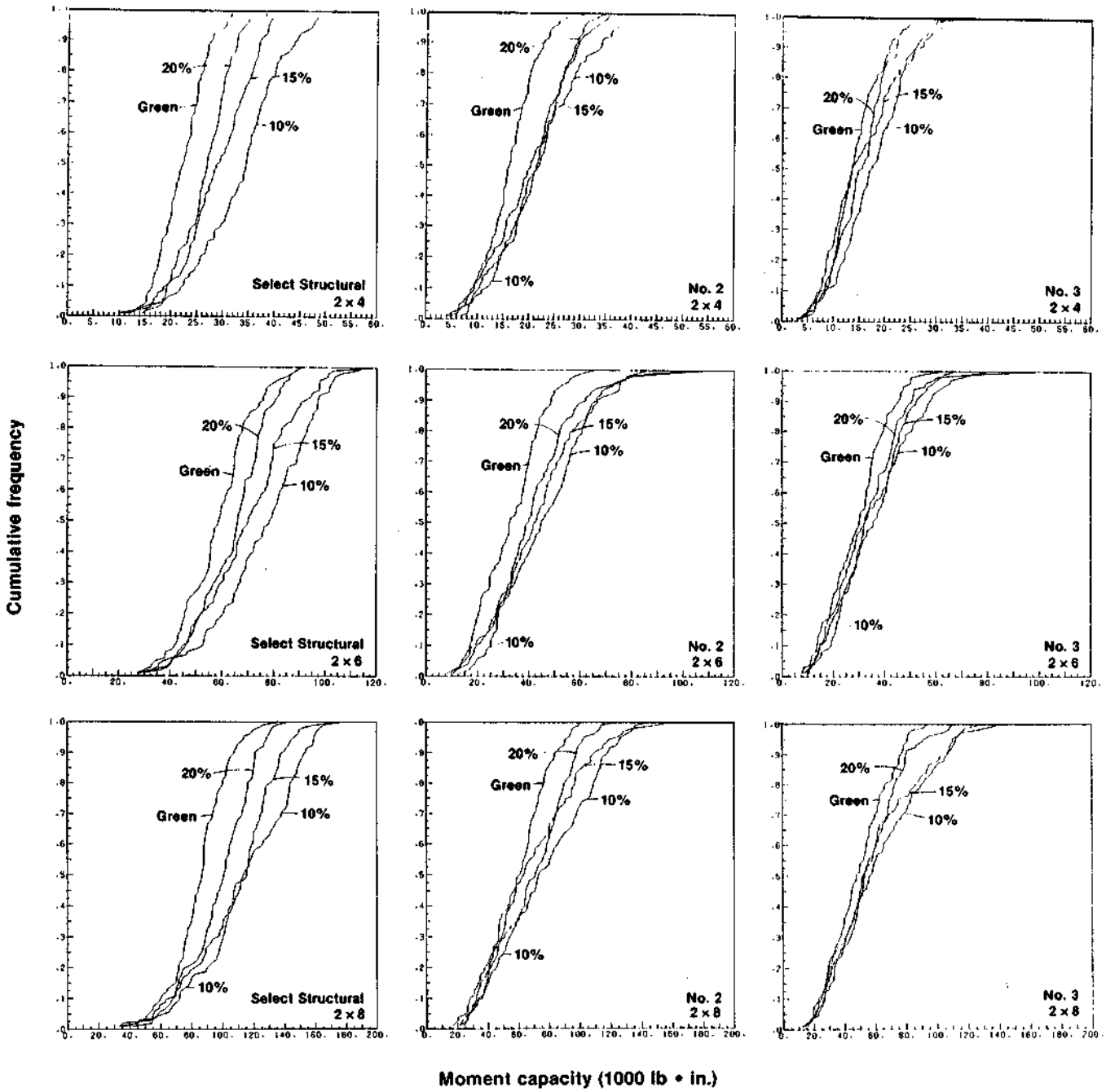

Figure B3.—Cumulative frequency distributions for moment capacity, RS, at four moisture content levels. (ML85 5142)

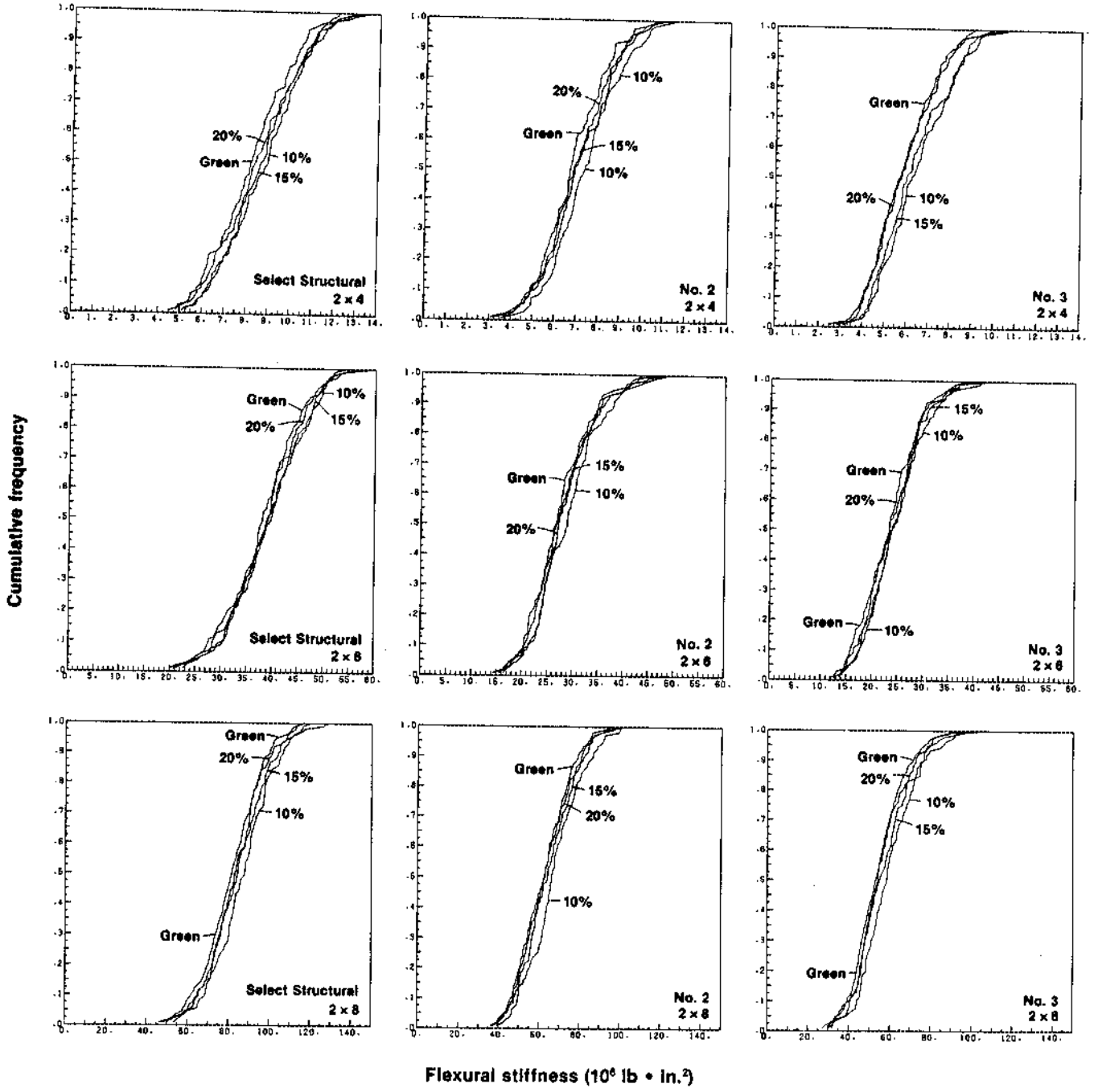

Figure B4.—Cumulative frequency distribution for flexural stiffness at four moisture content levels. (ML85 5143)

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