MACHINE STRESS RATING (MSR) OF GREEN DOUGLAS-FIR

D. V. Snodgrass[1]

Engineering Consultant
Route 2, Box 208-A, Vashon Island, WA 98070

and

F. E. Woeste

Associate Professor
Agricultural Engineering Department, Virginia Tech, Blacksburg, VA 24061

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ABSTRACT

A large sample was selected from a production run of unseasoned 2 × 4 Douglas-fir, which had been graded and grade stamped as Standard and Better in accordance with WWPA grading rules. From the large samples, 250 pieces were selected by visual quality rules for machine stress rating and subsequently graded by a qualified lumber grader. The 250 pieces were numbered and rank ordered by MOE and separated into two treatment groups based on the MOE ranking. The even number pieces were placed in an environment of 70 F and 50% relative humidity and allowed to dry.

Both sample groups were tested by a ⅓ point bending load to evaluate the MOE and MOR of the specimens. The average MOEs of air-seasoned and unseasoned samples were equal from a design standpoint. The MOR data were fitted by probability distributions. The exact relationship between the lower percentile values of the air-seasoned and unseasoned MOR was not clear because of a crossing-over of the probability density curves. It was clear from the MOR data analyses that seasoning causes inherently strong material in bending to become yet stronger.

To more accurately assess the impact of drying on lumber bending strength, a reliability type analysis was recommended.

Keywords: Grading, MOE, MOR, bending strength.

INTRODUCTION

Machine stress-rated (MSR) lumber has been produced and sold since 1963. During this time, producers have limited the application of the machine grading system to seasoned (kiln-dried) lumber. The reasons for this production practice are probably economic since there have been no grading rules or regulatory restrictions to prevent the application of machine grading to unseasoned lumber.

If lumber is to be machine graded in an unseasoned state, questions are raised with respect to the mechanical properties of lumber after it has dried in use. The questions addressed in this study are: (1) Is the lumber more or less stiff after it has dried? (2) Does the lumber have more or less strength in bending after it has dried? If these relationships are established, producers and grading agencies will have guidelines necessary to calibrate grading machines and to set up in-plant quality control procedures.

This study is limited to the investigation of the stiffness and bending strength

[1] Former Quality Control Manager, Simpson Timber Co., Shelton, WA.

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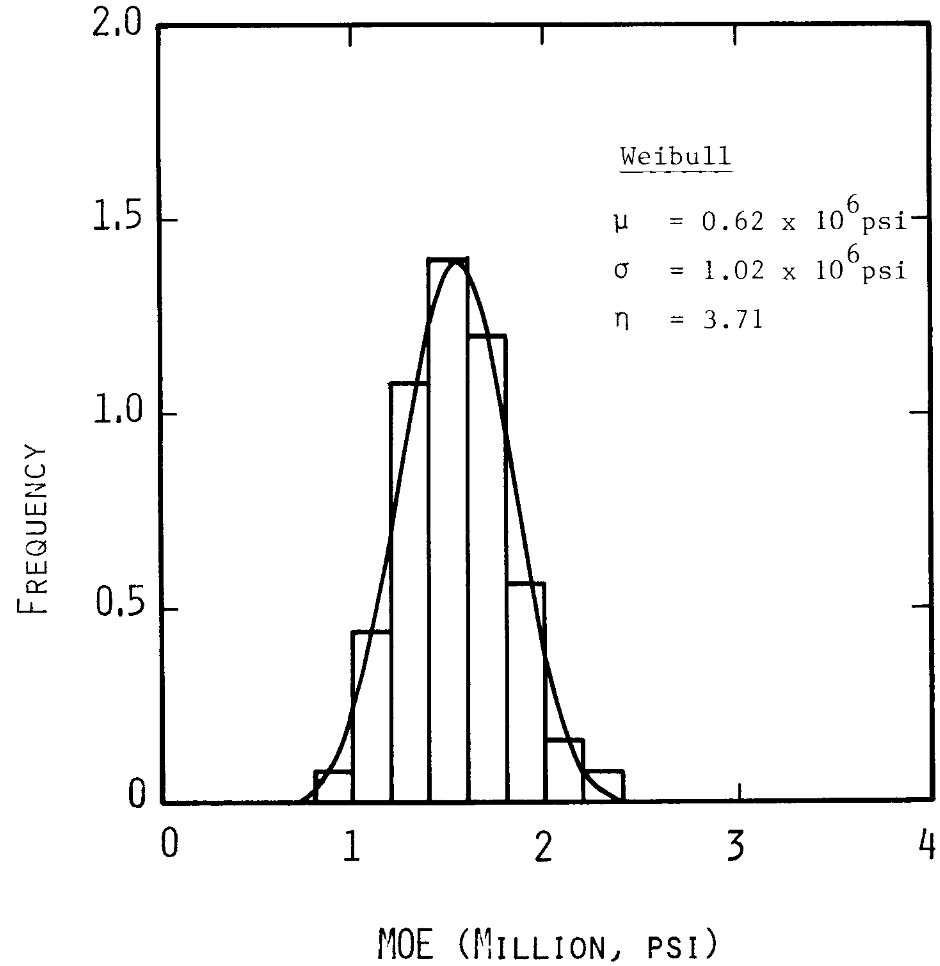

FIG. 1. The MOE of unseasoned 2 × 4 Douglas-fir is fitted well by the 3-parameter Weibull distribution. The MOE was calculated based on a 1.5 in. × 3.5 in. cross section.

of 2 × 4 Douglas-fir from one mill in Shelton, Washington. The sample was selected such that the data are related to the relative stiffness and bending strength of the unseasoned and seasoned materials rather than to levels of stiffness and bending strength of any particular grade of 2 × 4 Douglas-fir.

RELATED LITERATURE

A detailed discussion of the influence of moisture content on the strength and stiffness of lumber is given by Green (1980). He reviews research results and moisture corrections from 1912 to 1980. It suffices to say at this point that strength ratio was known in 1930 to be a factor that interacted with moisture content and strength. According to Green (1980), the 1930 revision of ASTM D-245 gave the following equation:

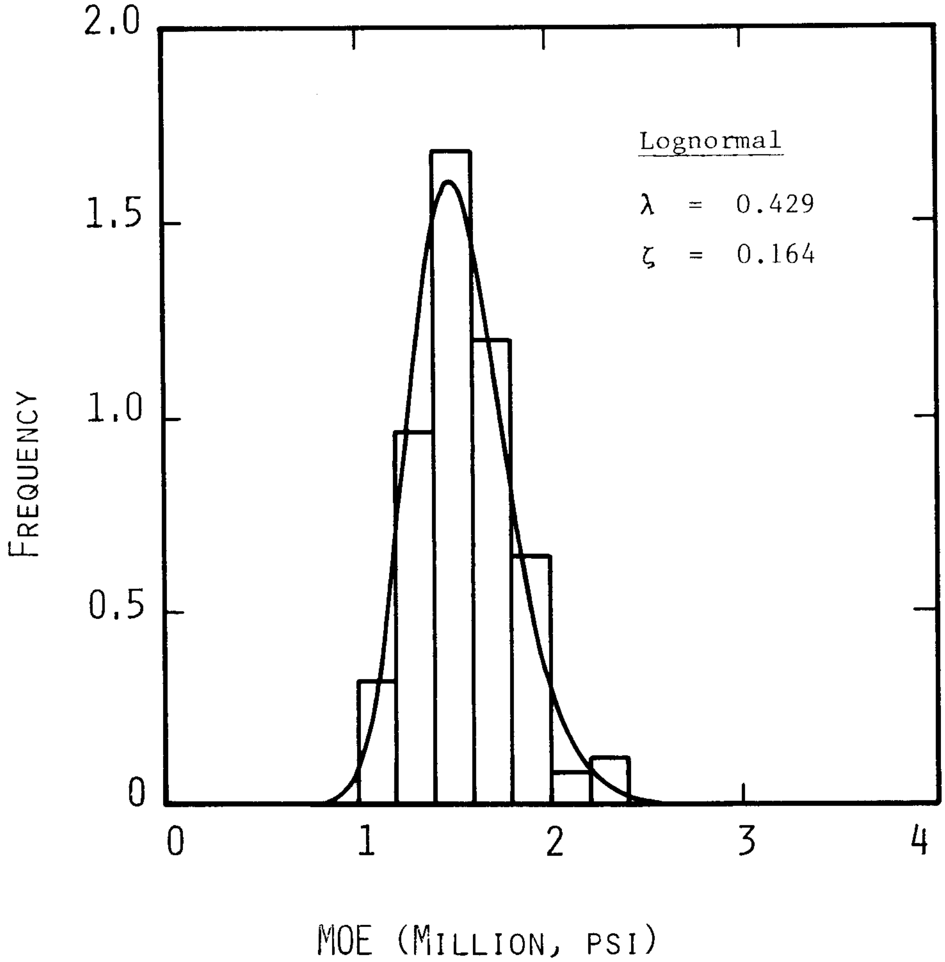

FIG. 2. The MOE of air-seasoned 2 × 4 Douglas-fir is fitted well by lognormal distribution. The MOE was calculated based on a 1.5 in. × 3.5 in. cross section.

$$\text{SR dry} = \text{SR green} + \tfrac{1}{2}(\text{SR green} - 50)$$

where SR denotes strength ratio. However, ASTM D245-81 reports an allowable increase in bending of 35%, independent of strength ratio or grade. Similar values are given for tension, compression, and modulus of elasticity, MOE.

The preceding discussion, which illustrates the uncertainty over the past years of the true moisture effect on lumber, led the authors to an in-plant lumber experiment to verify or calibrate the machine stress rating procedure for green 2 × 4 Douglas-fir. Furthermore, the plant study was motivated by the fact that there may be a moisture, strength, machine stress grading interaction not common to the interactions between moisture, strength, and the visual grading system. The authors were unaware of any research studies that investigated the effect of mois-

TABLE 1. *MOE statistics are given for the unseasoned and air-seasoned 2 × 4 Douglas-fir lumber. From a practical standpoint the average MOEs are equal.*

Treatment	Sample size	Average MOE	Coefficient of variation	Distribution parameters[1] μ, σ, η, or λ, ζ
Unseasoned	125	1.540	0.180	0.62, 1.02, 3.71
Air seasoned	125	1.556	0.165	0.429, 0.164

[1] The fits were significant by the Chi-square goodness-of-fit test. Both fits were significant at the 50% level.

ture on the strength and stiffness of machine stress rated, MSR, 2 × 4 Douglas-fir.

It should be noted at this point that there was no detected size-moisture interaction with strength, MOR, or stiffness for southern pine (Wilson 1981). However, Wilson's conclusion was based on a three-way analysis of variance, which deals only with the means of the properties. This research result leaves the possibility that (1) there may be a size-moisture content interaction with strength or stiffness for Douglas-fir, and (2) there is in fact a size-moisture interaction with strength or stiffness for the lower percentiles of each characteristic. The lower percentiles of both strength and stiffness have the greatest impact on structural safety.

DESCRIPTION, SELECTION, AND PREPARATION OF SAMPLE

The sample tested was selected from a production run of unseasoned 2 × 4 Douglas-fir that was surfaced to American Lumber Standards PS 20-70 (US Dep. Comm. 1970) sizes for green lumber, 1$^9/_{16}$ in. × 3$^9/_{16}$ in. This lumber had been graded and grade-stamped as Standard and Better in accord with WWPA grading rules (1981).

All pieces that met the sample criteria were accepted for test in the order that they came from the production line. The criteria for sample selection were: (1) each piece was to have one or more knots at the edges of the wide face located in the center ⅓ of a 73½ in. span, and (2) knot size was specified to be between ⅝ in. and ⅞ in. in diameter or such that it would occupy at least one-sixth of the cross section and not more than one-fourth of the cross section. This sampling required over 1,000 pieces to be inspected to find the 250 pieces that met the criteria for selection. All samples were selected by the same technician. However, when the samples were inspected by a qualified lumber grader, it was discovered that 71 of the 250 contained edge knots judged to be larger than ⅞ in. These pieces are identified in the data as "less than VQL-2."

Each piece was numbered for identification and marked for placement in the testing machine. Random orientation of knots for placement on the tension (or compression) edge during the bending test was accomplished by maintaining the position of the grade stamp on each piece in a constant relationship to placement of the piece in the testing machine.

TESTING

The testing was completed in the WWPA portable testing machine that was developed for the wood industry "In-Grade" testing program (Galligan et al.

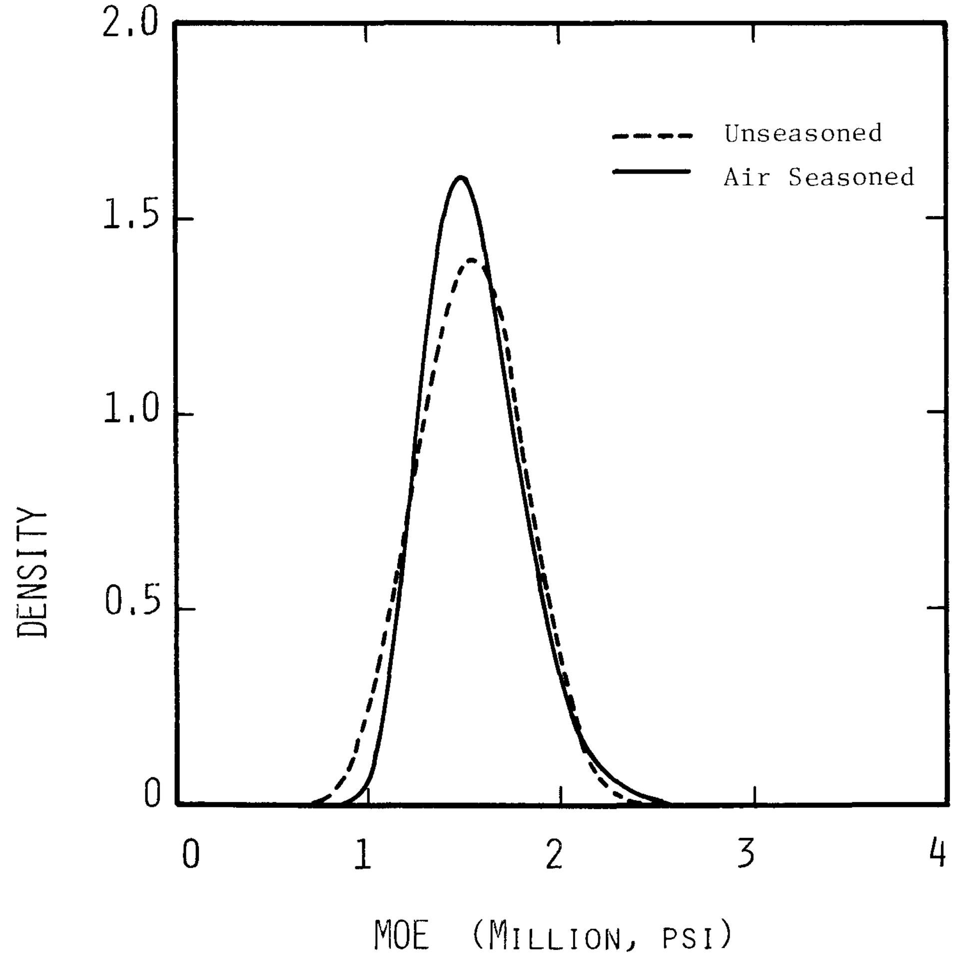

FIG. 3. While the average MOE for each treatment group is approximately equal, the density functions shown suggest the possibility of a slight difference in skewness. The unseasoned lumber has an appearance of negative skew, whereas the air-seasoned lumber has a positive or lognormal type skew.

1980). All of the pieces were first nondestructively tested to determine their MOE value by placing the worst edge defect in the center third of the test span. The ratio of the test span to depth was 21. The pieces were then rank ordered with respect to MOE and so numbered. This MOE ranking procedure was used by Wilson (1981). The pieces with odd-numbered rank order were then tested to failure in bending. The pieces with even-numbered rank order were placed in a controlled environment of 70 F and relative humidity of 50% and allowed to dry to an equilibrium moisture content condition. After drying, the pieces were again measured for MOE and then tested to failure in bending.

Moisture content in both the unseasoned and seasoned state was determined in accord with ASTM D 143 from a 1 in. long piece cut from each sample at time of test (ASTM 1982).

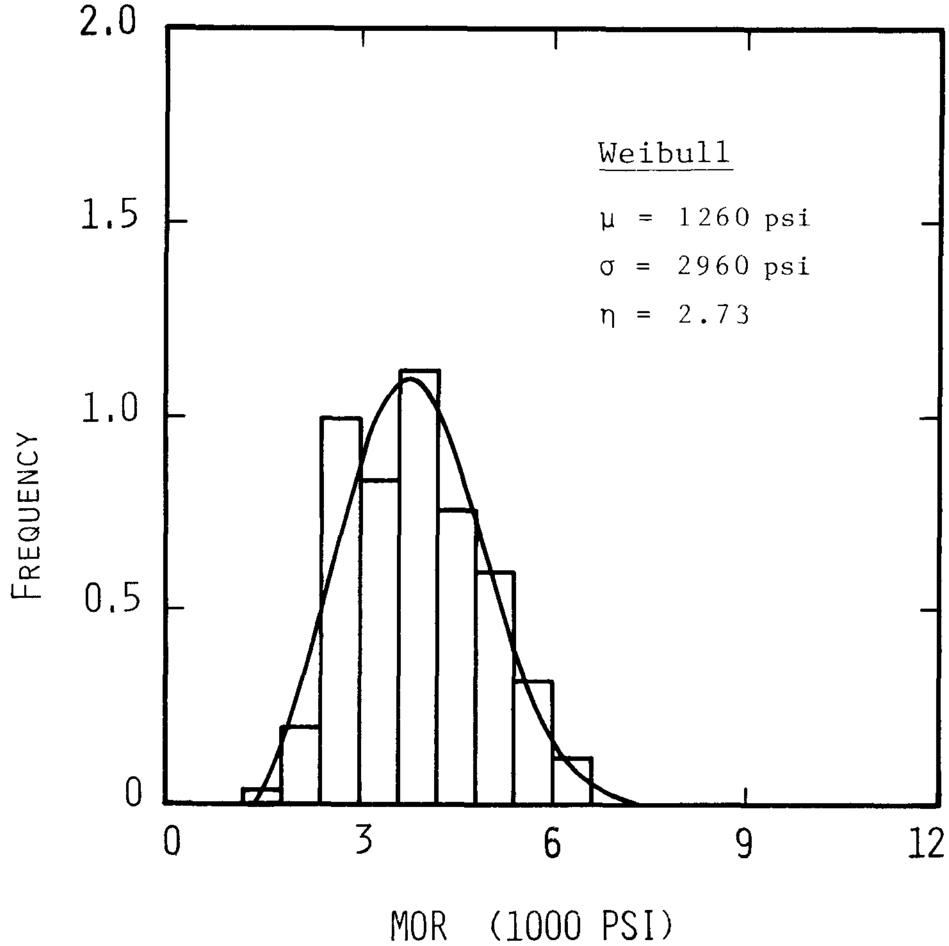

FIG. 4. The MOR of unseasoned 2 × 4 Douglas-fir is fitted by the 3-parameter Weibull distribution. The 125 MOR values were calculated by using a 1.5 in. × 3.5 in. cross section.

In addition to the testing of the selected specimens, the MOE values of some of the full length boards were measured by centering the boards in the testing machine. This was done to facilitate a comparison between the "random" MOE measurement and the MOE measurement made with edge knots placed in the center third of the test span.

ANALYSIS AND RESULTS

Modulus of elasticity, MOE

The MOE was calculated for each treatment group, unseasoned and air seasoned, using the standard cross section of 1.5 in. × 3.5 in. This procedure was used since engineering analysis of 2-in. dimension lumber in service utilizes the standard dry size for computations regardless of the seasoning condition at the time of manufacture. Therefore, by using a constant cross section, the modulus of rupture, MOR, analysis is comparable to a moment capacity analysis.

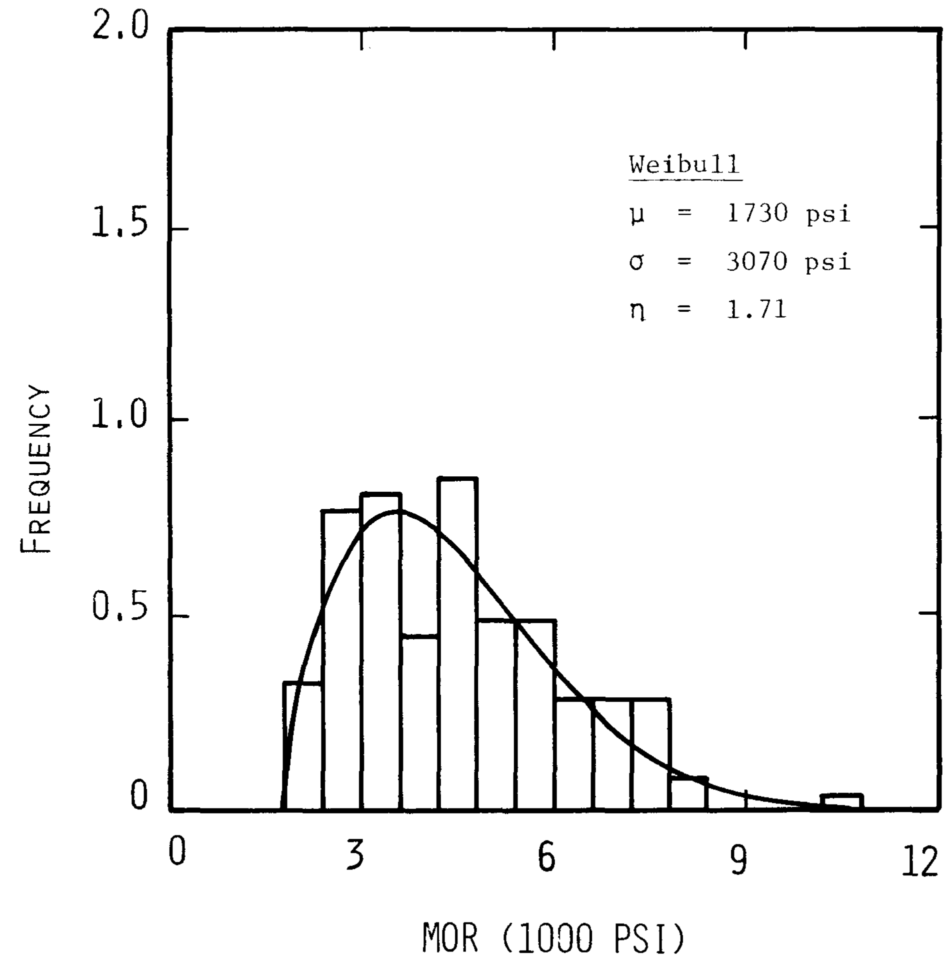

FIG. 5. The MOR of air-seasoned 2 × 4 Douglas-fir is fitted by the 3-parameter Weibull distribution. The 123 MOR values were calculated by using a 1.5 in. × 3.5 in. cross section.

Each set of MOE data was fitted by the lognormal and 3-parameter Weibull distribution. The two fits were evaluated by the Chi-square goodness-of-fit test and a visual inspection of the fitted density function and histogram. For the unseasoned data (Fig. 1), the 3-parameter Weibull provided the best fit, and for the air seasoned data (Fig. 2) the lognormal distribution provided the best fit.

The means, coefficients of variation, and distribution parameters of the two data sets are given in Table 1. The most important statistic of this table, from a designer's standpoint, is the average MOE, since the average is used in all calculations involving MOE. The average MOE of the unseasoned and air-seasoned lumber differ by approximately 1%. Thus from a design standpoint these averages may be considered equal.

From a structural reliability point of view, the distribution of MOE is of interest. The air-seasoned and unseasoned MOE distribution fits are compared in Fig. 3.

TABLE 2. *The MOR of unseasoned and air-seasoned 2 × 4 Douglas-fir was fitted by the 3-parameter Weibull distribution. Parameters and goodness-of-fit results are given.*

Treatment	Sample size	Weibull parameters			Chi-square test stat.	5% critical value[1]
		μ (psi)	σ (psi)	η		
Unseasoned	125	1,260	2,960	2.73	5.48	5.99 (2)
Air seasoned	123	1,730	3,070	1.71	1.10	5.99 (2)

[1] Numbers in parentheses denote the appropriate degrees of freedom for the Chi-square tests.

The crossing over of the two curves makes them difficult to compare in a simple fashion, especially when one realizes that the averages are nearly identical.

One observation is that the unseasoned lumber may have a slight negative skew. The air-seasoned MOE, which is fitted by the lognormal distribution, has a positive skew. In any event, the perceived differences are very small, and they could be the result of random sampling and subsequent probability distribution estimation. For the purpose of this research, the MOE of air-seasoned and unseasoned 2 × 4 Douglas-fir sampled is the same when used in service at the standard size. Therefore, if unseasoned lumber is treated as being identical to seasoned lumber in a quality control program for MOE, the result for air-seasoned lumber in service will be satisfactory.

Modulus of rupture, MOR

Of equal or greater importance than MOE quality control is the quality control of bending strength. The air-seasoned data set of 123 specimens and the unseasoned data set of 125 specimens were fitted by the lognormal and 3-parameter Weibull distributions. In both cases, the 3-parameter Weibull provided the best fit. The histograms of MOR and 3-parameter Weibull fits are shown in Figs. 4 and 5.

The unseasoned 2 × 4 Douglas-fir MOR data are nearly symmetrical about their average. On the other hand, the 2 × 4 seasoned data are highly skewed to the right or have a positive skew. A summary of the distribution fits is given in Table 2. The estimated parameters are summarized, and the goodness-of-fit tests are reported.

In Fig. 6 the unseasoned and air-seasoned density curves are overlaid for comparison purposes. A crossing over of the lower tail is evidenced. The relationships between the lower percentile values are not clear. However, it is clear from viewing the upper tails of the distribution fits that seasoning causes inherently strong material in bending to become yet stronger. This phenomenon has been documented by Madsen (1975) and Wilson (1981) as a result of large testing programs. From the standpoint of a manufacturer who supplies material for designers, quality control on the fifth percentile is the major concern.

By examining Fig. 7, one can study the relationship between air-seasoned bending strength and unseasoned bending strength at all percentile levels of unseasoned bending strength. From the first percentile to the sixth percentile of the unseasoned strength, the air-seasoned strength is greater than the unseasoned strength. From the seventh to the twelfth percentile of the unseasoned bending strength, the reverse is true. In this range, seasoning reduces bending strength. From the thir-

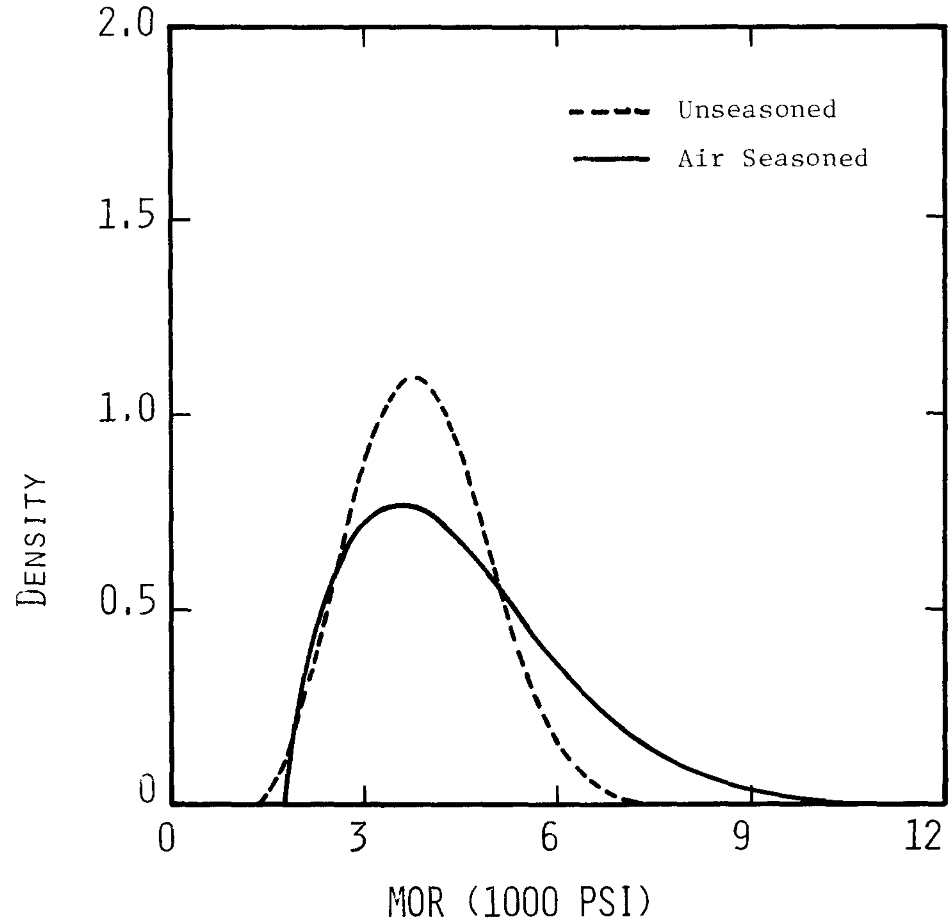

FIG. 6. The MOR density functions graphically illustrate how seasoning influences the bending strength of 2 × 4 Douglas-fir. In the lower strength range the effect of seasoning is not clear. In the upper strength range; however, seasoning has a large impact on bending strength.

teenth to the ninety-ninth percentile, the air-seasoned bending strength is greater than the unseasoned strength. The meaning of these results is indeed confusing.

However, from a manufacturing and design standpoint, the strength value of the fifth percentile is the primary, if not the only, concern. The ratio of seasoned to unseasoned bending strength at the fifth percentile was 1.006 for this sample of 2 × 4 Douglas-fir. This result is welcome for quality control concerns. In MSR production, proof loads are applied at the fifth percentile value as specified for each grade. Assuming that the material being manufactured is on grade, a proof load at the fifth percentile of the unseasoned material will serve the same quality control function as proof loading seasoned material. Higher quality lumber may demonstrate a different behavior in the fifth percentile region.

In terms of structural reliability, the two treatments should not provide the same level of structural safety. The degree of variation in safety is difficult to

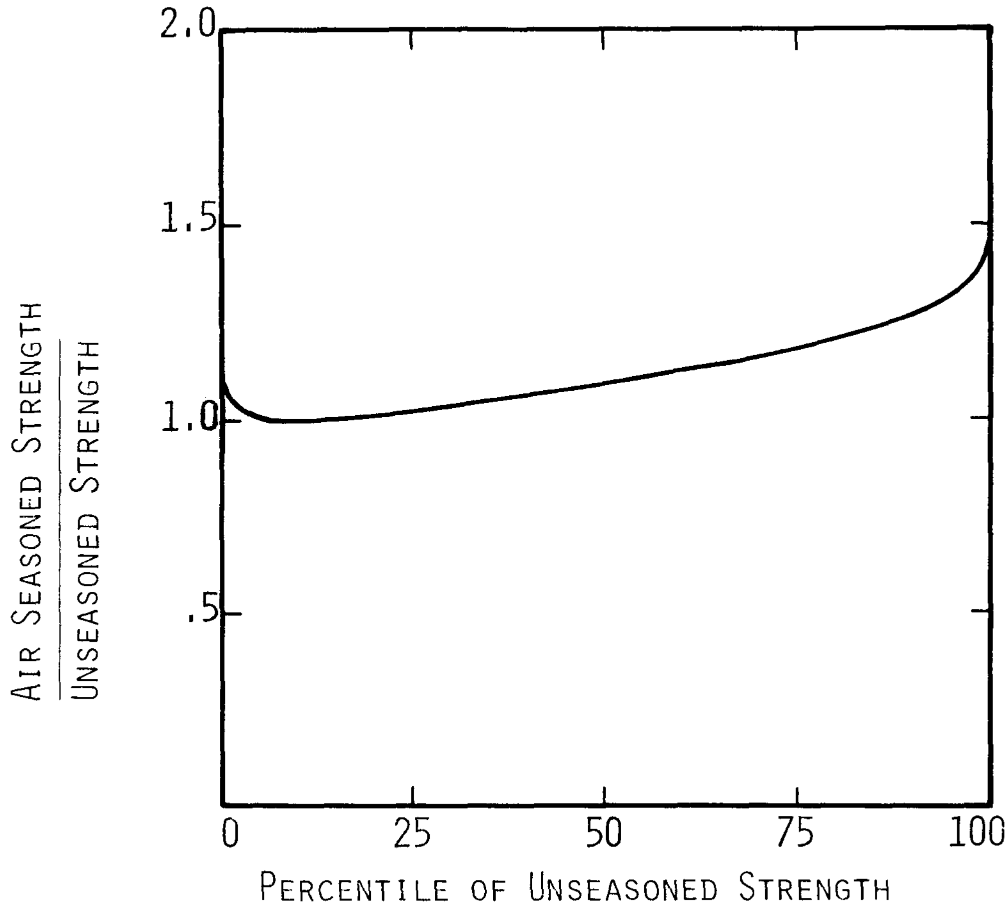

Fig. 7. The abscissa is the percentile of the unseasoned bending strength of the 2 × 4 Douglas-fir. At each percentile value, the ratio of air-seasoned to unseasoned strength was calculated and it is plotted as the ordinate.

assess without a formal reliability analysis. Ninety-nine percent air-seasoned material is 43% stronger than the 99% unseasoned material. However, the possibility of a structure experiencing a load at that level of stress is virtually impossible; hence added strength due to seasoning at the high percentile has little or no impact on safety. In the lower ranges from the first to the fiftieth percentiles, there exists a possibility of loads, but the increase in strength due to seasoning is less than 10% percent. The above discussion demonstrates the need for the reliability analysis of lumber data to obtain conversion factors such as the factor to convert green lumber strength to dry lumber strength.

DISCUSSION

A question that is relevant to the quality control of MSR lumber is: "Shall edge MOE be measured at random or should it be measured with the worst edge defect placed in the center third of the test span?" One hundred nineteen pieces were tested for comparison of the two options offered in MSR Quality Control procedures. Random measurement is assumed to be accomplished by measuring MOE at the center of the board. These test data indicate that MOE measured at the center of the board is somewhat higher than that measured with the worst edge defect placed in the center third of the span. The average MOE measured at random was 1.570×10^6 as opposed to 1.523×10^6 or 3% higher. The coefficient of variation was also greater (0.21 vs. 0.19) for the random measurement of MOE. The higher level of variability was probably caused by the presence of knots acceptable to standard grade in the material being sampled, which are larger than those selected for the center third of the test span. It is felt that these data are valid only to indicate direction of bias when comparing the two methods of test. To establish the magnitude of the bias, it will be necessary to undertake a more definitive study.

The presence of knots in the pieces tested larger than those specified for sample selection raised a question of whether or not these pieces should be discarded from the analysis. Inasmuch as all pieces were selected by the same person and were then assigned to either the unseasoned group or the group to be seasoned with regard only to rank order of MOE value, the chance of any one piece appearing in either group was the same. Therefore, for the purposes of addressing the questions of change in stiffness, EI, due to change in moisture content and relative bending strength in an unseasoned or seasoned condition, comparisons of the entire group tested are more appropriate than restricting data to those pieces having only edge knots as originally specified.

SUMMARY AND CONCLUSIONS

One hundred and twenty-five pieces of unseasoned and air-seasoned 2 × 4 mill run Douglas-fir were tested for MOE and MOR. The material was selected from surfaced green lumber at Shelton, Washington, so that edge knots would be involved in the center third of the loaded span for all pieces. Only pieces having edge knots equal to ¼ in. of the cross section or less were selected. Upon subsequent grading by a licensed grader, it was observed that some pieces had edge knots greater than one-fourth the cross section in size. Since the effect of moisture content on the quality control procedures in MSR production was the only goal of the study, the entire data base with pieces less than the intended visual quality was used. This was a conservative action in that the lowest ratio of air-seasoned strength to unseasoned strength in Fig. 7 was 0.998. This is to say that if we use an MOR quality control measure on unseasoned lumber, it will predict quality control of the seasoned 2 × 4 lumber and not be more than 0.2% against the side of safety. Using the total data set is clearly justified.

The following conclusions were reached from the mill run 2 × 4 Douglas-fir tests.

1) The average MOEs of air-seasoned and unseasoned samples were equal from a design viewpoint.

2) MOE quality control procedures treating the unseasoned lumber as if it had standard dry sizes will provide quality control for the lumber in seasoned service conditions.

3) The distributions of MOR for the air-seasoned and unseasoned lumber are different, with the inherently strong lumber becoming stronger due to seasoning.

4) MOR quality control procedures in MSR production, such as proof loading at the fifth percentile, will detect the same degree of quality in the unseasoned material as it would in the seasoned material.

5) To more accurately assess the impact of drying on lumber bending strength, a reliability type analysis would be useful.

REFERENCES

ASTM. 1982. Standard methods of testing small clear specimens of timber, D 143. ASTM Book of Standards Part 22, American Society of Testing and Materials, Philadelphia, PA.

Galligan, W. L., D. W. Green, D. S. Gromala, and J. H. Haskell. 1980. Evaluation of lumber properties in the United States and their application to structural research. For. Prod. J. 30(10): 45–50.

Green, D. W. 1980. Adjusting the static strength of lumber for changes in moisture content. Proceedings of the workshop How the Environment Affects Lumber Design: Assessments and Recommendations. U.S. Forest Products Laboratory, Madison, WI. 146 pp.

Madsen, B. 1975. Moisture content–strength relationship for lumber subjected to bending. Structural Research Series Report No. 11, University of British Columbia, Vancouver, B.C. 24 pp.

United States Department of Commerce. 1970. American softwood lumber standard. NBS Voluntary Product Standard, PS 20-70. 26 pp.

Wilson, F. J. 1981. The effect of moisture content on the flexural strength and stiffness of southern pine dimension lumber. M.S. thesis submitted to Virginia Polytechnic Institute and State University, Blacksburg, VA. 196 pp.

WWPA. 1981. Standard grading rules for western lumber. Western Wood Products Association, Portland, OR.