West Coast Lumber Inspection Bureau

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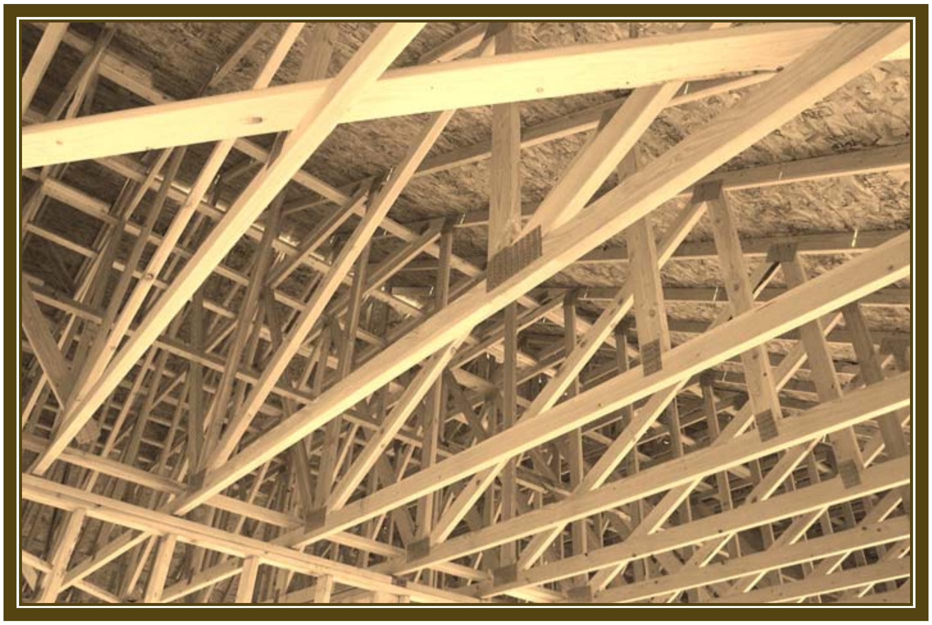

Tension/Bending Ratios of Machine Stress-Rated Lumber

Technical Report No. 2

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The *Quality* Stamp

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ABSTRACT

The ratio of the design tensile strength (F_t) to the design bending strength (F_b) for design values of machine stress grades is based either on actual tests during qualification of a grade or on traditional F_t/F_b ratios. The ratios used in lieu of testing were established in 1969, before tension testing became prevalent. In 1991, the West Coast Lumber Inspection Bureau (WCLIB) began accumulation of test data to examine the appropriateness of traditional F_t/F_b ratios.

At the time of this tabulation, completed in 1998, the WCLIB test data contained 5 commercial species groups, 5 dimension lumber widths, and 3 levels of limiting visual characteristics. Lot mean Modulus of Elasticity values ranged from 1.45 10^6 psi to 2.88 10^6 psi. Modulus of Rupture 5 percent point estimates ranged from 2,541 psi to 7,811 psi; the corresponding tensile strengths from 1,764 psi to 5,271 psi. The 45 data sets contained over 3,200 test specimens in both tension and bending. Parametric and non-parametric estimates of the 5 percent point estimate were examined; a Weibull distribution fit to the lower order statistics of each set was selected for analysis.

This study suggests that 1), the traditional assigned F_t/F_b ratios may not adequately represent a grade qualified by test of only one strength property and, 2), the use of the ASTM D1990 default tension/bending ratio of 0.45 would be appropriate if only bending tests were conducted and tensile values assigned by default. Conversely, the D1990 default value of 1.2 could be used for machine grades if only the tensile values was determined by test and the bending value assigned by default.

INTRODUCTION

Machine Stress-Rated (MSR) Lumber has been commercially produced for over 30 years. MSR lumber first appeared in West Coast Lumber Inspection Bureau (WCLIB) grading rules in 1962.(13) The grade designation of MSR Lumber has always referred to the 5 percent point estimate (PE) edge bending stress value, adjusted to an allowable design value, F_b, and the mean edge modulus of elasticity (MOE).(2) An example of this is an MSR grade with an assigned F_b of 2,400 psi and an MOE of 2.0 x 10^6 psi. It is grade stamped as "2400f-2.0E." While the relationship between the F_b and MOE in MSR grades has changed very little over the years, the ratio of assigned tensile stress (F_t) to F_b has been changed several times. It is the purpose of this report to examine the 5 percent PE tensile/bending (t/b) ratios from recent MSR testing conducted by the WCLIB to see if the test results coincide with the currently published F_t/F_b ratios.

From 1962 until 1993, commercial machine grading in North America used MOE as the mechanically measured variable; “MSR” denoted both the process of mechanical grading and the graded lumber product. In 1993, density measurement was introduced as a predicting variable with the introduction of the XLG grading machine.(7) One result of this introduction was a new series of grades termed “MEL”. Now both “MSR” and “MEL” refer to grades defined by performance criteria rather than the traditional description of a particular mechanical process.(2) This study of t/b ratios relates to mechanical grading using MOE as the measured variable; in this report, the terms MSR, machine stress grading, or mechanical grading refer only to the historical tradition and process of MOE-related grading.

This report summarizes WCLIB observations over the period of 1981 to 1998, with specific MSR t/b data accumulated from 1991 to 1997. The tabular results and some preliminary conclusions of this study were presented in a Technical Forum at the 1998 Annual Meeting of the Forest Products Society in Merida, Yucatan, Mexico.

BACKGROUND

MSR lumber was originally developed as a way to identify the higher strength lumber grades from relatively lower strength lumber species. The idea was to segregate material based on individual piece stiffness rather than traditional visual characteristics. As the grading model was refined, visual restrictions were added to stiffness as MSR grading criteria. These visual restrictions were primarily on permitted edge characteristics; latter, visual restrictions were added by most agencies for portions of the piece not mechanically tested. (7)

In the early days of MSR, primary emphasis was placed on the assigned edgewise bending strength (MOR) and modulus of elasticity (MOE). The assigned tensile design value (F_t) was linked as a ratio to the F_b, calculated from the MOR; however, this ratio changed over time as more information accumulated on full-size lumber performance. Initially the ratio was 1; it was changed to 0.8 in the mid-1960's. (9) Since 1969, a sliding scale has been in use (F_t/F_b = 0.8 for the highest grades and decreases to 0.5 for the1/3 edge knot grades). Table 1 lists the default ratios in use since approximately 1963.

With the development of tensile testing machines and the continued growth of the metal plate truss industry, research on the tensile properties of full-size lumber increased in the 1970's. In the 1980's, WCLIB began collecting matching tensile test data when conducting the bending tests

required for MSR qualification. In 1992, both tensile and bending became a requirement of qualification.(14) As a consequence of these changes, both tensile and bending strength data began to accumulate for MSR grades qualified by WCLIB. It was observed that ratios of the 5 percent PE tensile (t) and bending (b) strength values from qualification tests were not in agreement with the traditional F_t/F_b ratios. Attention then was focused on these ratios in subsequent tests, in some cases by increasing the number of failed specimens to provide better information for t/b ratio estimates.

Table 1. Historical Assigned F_t/F_b Ratios

Grade	EK	Early 1960's	Mid- 1960's	1969 to Present
2400f - 2.0E	1/6	1	0.8	0.8
2100f - 1.8E	1/6	1	0.8	0.75
1500f - 1.4E	1/4	1	0.8	0.6
1200f - 1.2E	1/3	1	0.8	0.5

During the period that knowledge of MSR tension values was increasing, the North American In-grade test program of visual grades was completed. Tension/bending ratios from compiled test data formed the basis of the F_t/F_b ratios of untested visual grades. This process was standardized in ASTM D1990 which specifies a factor of 0.45 be multiplied by the near-minimum MOR to estimate a near minimum tensile value in lieu of testing in tension. If estimating MOR from tensile strength, a factor of 1.2 is specified. (3)

The F_t/F_b assignment procedure adopted for the visual grades by ASTM D1990 may be a suitable default position for properties not verified by test; however, experience has shown those defaults are too conservative for MSR grades when the ratio is verified with qualification tests of both properties. Consequently, there was interest in analyzing MSR tension/bending performance to determine if the current default ratios established in 1969 prior to extensive tension testing remained appropriate.

Other Studies

In reporting on property relationships developed from the In-grade analysis of visual grades, Green and Kretschmann reviewed the assignment of allowable tensile property values for MSR, analyzed visually graded "In-grade" data, and noted possible anomalies in current practice. (11)

An extensive survey of lumber from MSR mills in Canada was conducted by the Canadian Wood Council in the late 1980's (6). Samples of 30 specimens per grade per mill were collected from 18 mills. Equal samples were obtained for tension and bending tests. Although the report on this survey does not list the resulting t/b ratios directly, interpolation from data presented in Figures 4.20 and 4.21 of that report indicates a range of t/b ratios very similar to those determined in this WCLIB study.

METHODS

Sampling Procedures

The data that comprises the basis for this report came from tests at 6 lumber mills. Tests at these mills usually were conducted to qualify an MSR grade at that mill. The WCLIB procedures require a candidate sample to pass criteria for full-size tests of MOE on edge, MOR on edge, and tensile strength. While the MOE has both mean and near minimum requirements, the two strength properties are described by near minimum values only. To meet this latter requirement, qualification tests are routinely designed to break only the lower tail of the strength distribution. Traditionally, when a predetermined grade has been identified for qualification, the proof load level may be set slightly higher than that calculated from the allowable design value. While suitable for qualification, this procedure may not supply sufficient near minimum strength data for study of a t/b ratio. Consequently, to collect data for this analysis, some studies were modified with increased sample sizes and proof load levels to ensure that both the non-parametric 5 percent point estimate (NPE) and the 5 percent tolerance limit (75% confidence) could be estimated with more than the minimum number of broken specimens.

Most samples were collected as serial, “on-grade” samples from large production lots. Sample sets as small as 53 were accepted; however, often samples over 100 were taken to comprise a better sample of production and provide more data. There were a total of 45 data sets.

Several of the data sets were developed from exploratory studies to establish the performance level of a potential MSR lumber selection. In this case, specific visual and mechanical grade criteria were established prior to sampling. The same general sampling criteria were used for these studies because the inferences for t/b analysis required the same data.

Some of the sample sizes and proof loading procedures were designed to estimate the 10th percentile of the distribution, rather than the 5th. This broke more lumber; however, more information about the distribution tail was then available. To ensure that the 10th percentile was found (or the 5th in other cases), the Warren-Glick (12) method of testing was sometimes employed.

Specimens

This report is a compilation of individual studies at production lumber mills; consequently, a variety of species, grades, and sizes are included. The species groups in the study were Douglas fir, Douglas fir-North, Hem-Fir, Alaskan Yellow Cedar, Spruce-Pine-Fir, and Spruce-Pine-Fir (South). All lumber was nominal 2 inch dimension, 2x3, 2x4, 2x6, 2x8 and 2x10. Douglas fir included both S-Dry and S-Grn samples.

MSR grades being evaluated at the mills ranged from 1350f-1.3E to 2400f-2.2E; consequently, visual quality levels (linked to F_b levels) also ranged from 1/3rd to 1/6th edge characteristics. The grade levels in the more exploratory studies also fell within this general range. Sample lot mean MOE values ranged from 1.45 10^6 psi. to 2.88 10^6 psi.

Testing

WCLIB qualification procedures specify both tension and edge-bending testing procedures. The tension testing machine uses fixed, urethane grips with a gage length of approximately 8 ft. Tension test specimens were oriented to center the maximum visual defect when possible. Testing procedures followed ASTM D4761.(5)

MOE and MOR values were both measured in an edgewise orientation (load on the narrow face) following ASTM D4761. Visually apparent critical defects were centered in the test span when possible; however, the selection of the tension edge was random. A span/depth ratio of 21 was used. Table 2 summarizes the sample size tested.

Table 2. Sample Size

Total Data Sets: 45 (45 - t; 45 - b)

Total Pieces: 7004 (3240 - b; 3764 - t)

Pieces proof-loaded per data set (N):
35 to 157; average of 72 (b) & 83 (t).

Pieces broken per data set (n): 3 to 17;
average of approx. 9 (b) & 10 (t).

Analysis

There is no standardized methodology for determining the tension/bending ratio in the near-minimum region of a strength distribution. A critical assumption is that both the bending sample and the tension sample are equally representative of the underlying population. Consequently, the subsequent analysis addressed two methods of determining the t/b ratio--that is, t_i/b_i:

1) non-parametric methods where the relative order statistics are assumed equally valid for determining t_i and $b_{i.}$, and
2) point estimates of t_i and $b_{i.}$ determined from distributions fit to the tail data.

It is important to consider more than one order statistic because the test specimens are only a <u>sample</u> of the underlying population for which an inference is drawn. The population fifth percentile is not likely to correspond exactly with the sample 5 percent PE. The t_5 and b_5 values are valid estimates of the true 5th percentile; however, in any matched data set, t_5 and b_5 may actually be at different points in the confidence interval around the true 5th percentile of their respective true, but unknown, distributions.

RESULTS

The first effort was to develop ratios (t_i/b_i) based on non-parametric estimates (order statistics). Quickly it became apparent that some instability existed in the 1st, and perhaps 2nd, order statistic ratios. Fig. 1 uses 3 data sets representing 1/3, 1/4 and 1/6 EK to illustrate both the "instability" and that the t/b ratio appears to stabilize above the lowest order statistics. Is this because either t_1 or b_1 is an outlier? Or, is it because the samples do not represent equally well the t_1, t_2, t_3... and b_1, b_2, b_3 of the underlying population for which a well-behaved ratio is assumed? As a consequence, and after many trials with combinations of non-parametric-based ratios, the use~~d~~ of non-parametric t_i and b_i values was abandoned in favor of parametric estimates.

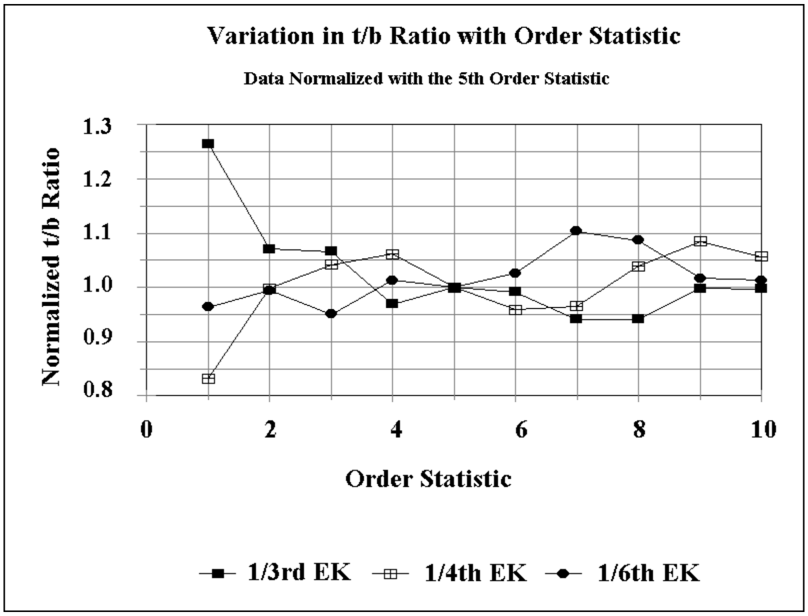

Figure 1. t/b ratios generated by the ratio of corresponding order statistics from two matched t and b data sets. Data is normalized using the 5th order statistic as the divisor.

Parametric estimates were based on fitting a Normal distribution and 2 and 3-parameter Log Normal and Weibull distributions to the lower order statistics of each data set. The linear regression method of distribution fitting described in paragraph X4.7 of ASTM standard D5055 was employed. (4) Quality of distribution fit was judged by the standard error. As would be expected, there was a variation in "fit quality" among the data sets; the 3-parameter Weibull was chosen as best overall distribution for the subsequent analysis.

Table 3 lists the data set descriptors (width, EK, mean MOE, and species group) and the test results - the 5 percent point estimates of t and b and the resulting t/b ratios. All data sets of size NB or NT (bending or tension) were tested, breaking sufficient specimens, n (b,t), to obtain an estimate of the 5 percent point estimate (PE). The 5 percent point estimates were obtained through tail fitting a Weibull distribution and are labeled b5 PE and t5 PE for bending strength and tensile strength, respectively. Only data sets with 3 or more broken specimens were included in the analysis. As noted, the average pieces broken per set and used in the analysis were 9 (b) and 10 (t). [Note, more than 3 data points are desirable for estimating distribution parameters. In this study the goal was only to optimize the estimation of lower order statistics with limited available data.]

In most data sets, all of the broken specimens were used in the analysis - the number is shown in Table 3; however, several data sets that were collected in the earliest days of the study (marked with an asterisk in the “broken n(b,t)”column) had much greater numbers of broken specimens in either tension or bending, as the techniques to be used in creating lower tail data were being explored. In these sets, the number of specimens selected for the analysis was restricted to the lower number in either property in order to keep the analytical process consistent. Consequently, in these sets, equal numbers of tension and bending specimens were chosen; the number chosen for the analysis was used in the calculation of the “average” number broken.

At the end of Table 3 is a summary listing the average, maximum and minimum values and the total numbers of specimens tested. The range of the t/b ratios in the table is 0.50 to 1.01. None fall below 0.5, the value that is currently assigned to grades with lower MOR values. Although some of the data sets have relatively high MOR values, only a few t/b ratios exceed the 0.8 value currently assigned to grades at high MOR levels.

No strong trends of t/b ratio with lumber width, species, EK, lot mean MOE or MOR were noted. The mean and range of the t/b ratios can be viewed by these grouping variables in Tables 4 to 8. The variability within the groupings of Tables 4-8 suggests that generalizations about t/b ratios based on these criteria are not sufficient for design property assignment.

Table 3. Summary of Data Set Tests and Resulting Tension/Bending Ratios

Referenc	Width	EK	Set Mean	Set	Set	Broken	Sample	Sample	Ratio	Species
Code	(2x..)	Nom Size	MOE	b5 PE	t5 PE	n (b,t)	NB	NT	t/b	Group
--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
93-46	3	4	1.77	5968	3009	5,3	54	53	0.50	SPF
93-47	3	6	1.94	6707	3727	12,10	91	78	0.56	SPF
93-45	10	6	2.59	6457	3992	3,11	53	101	0.62	DF
93-32	3	6	2.53	7240	4595	9,9	58	55	0.64	DF
93-33	3	4	2.03	5431	2871	13,13	60	55	0.53	DF
97-32	4	4	1.98	4253	2832	9,10	101	105	0.67	DF
97-32	4	3	1.6	3286	1978	8,10	102	104	0.60	DF
94-06	8	6	2.04	5609	4065	8,15	53	125	0.73	DF
94-07	4	6	1.98	5757	5040	13,12	53	103	0.88	DF
95-30	4	6	1.82	5347	4286	7,6	54	53	0.80	SPFS
95-30	6	6	1.92	4679	3896	12,9	54	53	0.83	SPFS
95-30	4	4	1.61	4199	3191	8,10	54	53	0.76	SPFS
95-29	4	6	2.31	5920	4887	8,12	54	54	0.83	DF-GRN
95-29	6	6	2.07	5260	3993	14,10	54	53	0.76	DF-GRN
95-27	6	6	1.91	5136	3919	11,8	54	53	0.76	DF
95-27	6	4	1.69	3983	2453	9,8	53	53	0.62	DF
95-23	6	4	1.66	3893	2297	5,7	53	53	0.59	HF
95-23	6	6	1.99	5035	3876	10,5	53	53	0.77	HF
95-22	4	6	1.9	5256	4210	12,13	54	53	0.80	HF
95-28	4	4	1.63	3707	2854	12,9	54	53	0.77	DF
95-28	4	6	1.99	4319	4351	8,9	54	53	1.01	DF
95-28	4	6	2.32	5964	3891	8,9	54	53	0.65	DF
94-50	8	6	2.45	5470	3870	4,6	53	102	0.71	DF
94-04	4	6	2.25	6285	3939	13,17	53	125	0.63	DF
93-03	6	6	2.5	5884	4491	4,12	53	103	0.76	DF
93-34	3	4	1.52	4075	2783	11,11	55	53	0.68	DF
93-28	3	4	1.49	4621	2567	12,4	55	55	0.56	SPF
93-29	3	6	2	7811	4557	7,7	54	55	0.58	SPF
93-12	4	6	2.27	6279	4626	3,9	54	102	0.74	DF
93-07	8	6	2.63	5586	4475	4,11	53	102	0.80	DF
91-03	3	6	2.03	5880	3717	9*	113	109	0.63	DF
91-1C	6	6	2.34	5271	3801	12*	56	104	0.72	DF
91-06	3	6	2.34	6720	4410	14*	133	130	0.66	DF
91-12	10	6	2.88	5418	4410	7*	122	124	0.81	DF
92-06	3	3	1.45	2541	1827	10*	102	105	0.72	DF
92-10	6	4	1.73	3675	2436	10*	149	157	0.66	DF
92-13A	6	6	2.59	6300	4263	10*	35	36	0.68	DF
92-13C	6	6	2.16	5712	3570	10*	81	80	0.63	DF
91-13	6	3	1.47	2982	1764	10*	100	101	0.59	HF
91-16	6	4	1.63	3717	2604	10*	130	130	0.70	HF
92-04A	6	6	1.89	4935	3885	10*	89	88	0.79	HF
91-09	3	4	1.7	4746	3108	10*	130	130	0.66	HF
91-10	3	6	1.96	7308	5271	10*	133	130	0.72	HF
92-04B	6	4	1.69	4494	2814	10*	60	71	0.63	HF
94-03	6	6	2.21	5172	3675	6,17	53	103	0.71	DF
No of						Total =	3240	3764		
45		Ave =	2.01	5206	3624	Ave =	72	84	0.70	
		Max =	2.88	7811	5271	Max =	149	157	1.01	
		Min =	1.45	2541	1764	Min =	35	36	0.50	

EK: Edge Knot grade restriction, 3 (1/3), 4 (1/4), and 6 (1/6)
MOE: Modulus of Elasticity in edgewise bending
b5 PE: Weibull-derived lower 5 % point estimate of bending strength
t5 PE: Weibull-derived lower 5% point estimate of bending strength
b,t: Number of broken specimens in bending (b) and tension (t) used in the analysis. * signifies equal b,t; see text.
NB, NT: Total number of specimens in the data sets in bending (NB) and tension (NT)
t/b: Ratio of t5 PE to b5 PE

Table 4. Mean and Range of t/b by EK Categories

EK	Mean t/b	t/b Range	Sets
1/6	0.73	0.56 - 1.01	29
1/4	0.64	0.50 - 0.77	13
1/3	0.64	0.59 - 0.72	3

Table 5. Mean and Range of t/b by MOR Levels

MOR, psi*	Mean t/b	t/b Range	Sets
>5800	0.66	0.50 - 0.72	14
4000-5800	0.74	0.53 - 1.01	23
<4000	0.66	0.59 - 0.77	8

* 5 percent PE MOR

Table 6. Mean and Range of t/b by Width Categories

Nominal Width	Mean t/b	t/b Range	Sets
3	0.62	0.50 - 0.72	11
4	0.76	0.60 - 1.01	12
6	0.70	0.59 - 0.83	17
8	0.74	0.71 - 0.80	3
10	0.72	0.62 - 0.81	2

Table 7. Mean and Range of t/b by MOE Categories

MOE,psi 10^6*	Mean t/b	t/b Range	Sets
>2.3	0.72	0.62-0.83	11
>2.0; <2.3	0.66	0.53-0.76	9
>1.7; <2.0	0.74	0.50-1.01	14
<1.7	0.66	0.56-0.77	11

* Sample lot mean MOE

Table 8. Mean and Range of t/b by Species Categories

Species Group	Mean t/b	t/b Range	Sets
DFir-dry*	0.70	0.53-1.01	27
DFir-grn	0.79	0.76-0.83	2
HemFir	0.69	0.59-0.79	9
SPF	0.55	0.50-0.58	4
SPF-S	0.80	0.76-0.83	3

* DFir and DFirN

Because the machine grading model is acknowledged as involving several variables, linear multiple regression analyzes were conducted using combinations of the grouping variables of Tables 4-8. Using EK, lot mean MOE, nominal width and the 5 percent PE MOR (b5PE) as independent variables resulted in one of the highest R^2, 0.62. The MOE and nominal width were grouped together as shown in ref. (10) where a width exponent of 0.29 is shown to express the width effect on strength. The expression for the estimated tension/bending ratio (t/b') is:

$$t/b' = 0.526 + 0.109EK - .0001b5PE + 0.103MOE/(Width)^{0.29}$$

where t/b' = the estimated t/b ratio
EK = the limiting edge characteristic category (3,4,or 6)

b5PE = the 5 percent PE MOR, psi
Width = the actual width, inches
MOE = lot mean MOE, 10^6 psi.

This must be recognized as an over-simplified analysis because the predicting variables are not totally independent. Further, an R^2 of 0.62, while explaining 62% of the variability in t/b (even if the assumptions of independence were met) is not sufficiently precise to set t/b ratios. A visual depiction of this relationship is included with a discussion in Appendix A.

As noted, ASTM D1990 has single default assignments of tension and bending design values based on data obtained in many tests of visual grades.(3) This WCLIB study suggests similar "minimum"-type values for default:

WCLIB Rank	t/b ratio	b/t ratio
Lowest	0.504	0.99
Next Lowest	0.529	1.14
ASTM D1990 Default	0.45*	1.20**

* Maximum t/b ratio when tension design values are to be assigned with a default ratio, based on bending strength tests.
**Maximum b/t ratio when bending design values are to be assigned with a default ratio, based on tensile strength tests.

The regression could be used to scale the default according to the estimated t/b ratio (t/b') determined in qualification if, for example, MOR is the only strength property evaluated. This has the advantage of using more of the data obtained in the qualification test and, as a consequence, higher default values if justified by the data:

t/b'	Default Ratio
0.6	0.45
0.7	0.56
0.8	0.67

where: t/b' = the estimated t/b ratio based on EK, b5PE, and MOE/(width)$^{0.29}$.
Default Ratio = examples of possible default ratios that could be obtained through use of the regression approach, based on qualification data. See Appendix A for further discussion.

While not all commercial species, geographical regions and/or grades could be included in the WCLIB study, as noted, these results generally agree with those reported by Barrett and Lau for Canadian lumber (6).

CONCLUSIONS

1. If t/b ratios are to be determined by use of the lowest order statistics of bending and tensile strength, results will be erratic and not necessarily well representative of trends in the underlying distribution predicted through the use of more data.

2. A Weibull distribution fit to the lower tails of tension and bending strength distributions provided the best available 5 percent point estimates for the t/b ratio. Using this methodology, all available strength data in the vicinity of the 5 percent point was used to make the estimate. Although the number of specimens included in the estimate varied, the average was 9 in bending and 10 in tension.

3. The t/b values currently assigned above 0.7 are not supported as a default representation by this study. Verification by test of both tension and bending 5 percent PE values could validate higher ratios, however.

4. Lower strength level grades with 1/3rd edge characteristic limitations may be understated in tension through the use of the current default ratio of 0.5 if only bending strength is verified by test.

5. Variability of data set t/b ratios was high across all grouping categories: Mean lot MOE, 5 percent PE MOR, limiting edge characteristics, nominal width and species. The conclusion is that evaluation of both tensile and bending strength at the time of qualification is desirable. This not only establishes the basis for both assigned properties but also provides insights for subsequent production quality control.

6. All of the observations concerning stability and variability of t/b estimates relate to variability in the estimates of the 5 percent PE's. The variability of these estimates in the data sets suggests re-evaluation of qualification test procedures to require samples larger than the usual 53 in order to better represent the underlying distributions. The number of broken specimens should be 5 or more. Lastly, use of the non-parametric PE for qualification should be re-examined. If the sample size is sufficiently large so that 5 or more pieces are broken, the non-parametric methodology may be sufficient; however, this study demonstrates the instability of lower order statistics and resulting estimates from small samples. Even if larger samples are employed, the distribution fitting procedure used in this study will make use of more data and likely provide a better estimate of the 5 percent PE.

None of these recommendations will be costly, as the number of specimens broken is small and the technology of parametric estimation is now automated. Larger samples require longer testing time; however, the amount suggested is a small trade-off for the increased confidence in the data.

7. Default ratios used to assign allowable tension or bending values (design values assigned without test verification) should be consistent with similar ratios in ASTM D1990 unless other information is used to justify a different default ratio. If tests are conducted only in bending (the tension value to be assigned using a default ratio), the maximum t/b ratio should be 0.45. If tests are conducted only in tension and the bending value is assigned by default procedures, the b/t ratio should be no larger than 1.20.

If an agency develops sufficient data to justify a model-based default system, such as described in Appendix A, a test-based default may be a better choice than the ASTM D1990 values.

8. Both the data-based and model-based default t/b ratios presented herein are potential considerations for ASTM D6570. (2)

References:

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APPENDIX A

RELATING MSR GRADING QUALIFICATION TO TENSION/BENDING RATIO

Predicting t/b with MSR Criteria

The accuracy with which a t/b ratio could be predicted with the data from the 45 data sets of this study using the known EK, Width, lot mean MOE, and lot 5 percent PE MOR was examined by a scatter plot and regressions. These simulated a grade qualification where bending strength is determined and design tensile strength is to be assigned by default. It should be remembered that the assigned F_b and F_t (the design values) are chosen with judgement as well as test data. An example is a test result that achieved a qualification level of 2,449 psi (after adjustment by 2.1). The producing mill likely will choose 2400f as the allowable design level because that is a current marketing category. The relationships discussed herein relate to test data adjusted by 2.1, but not further modified for design. A t/b ratio established by test only sets limits on subsequent market-related choices for F_b and F_t.

In this example, the relationship used is as reported in the text:

$$t/b' = 0.526 + 0.109EK - .0001b5PE + 0.103MOE/(W)^{0.29}$$

where t/b' = the estimated t/b ratio
EK = the limiting edge characteristic category (3,4,6)
b5PE = the 5 percent PE MOR, psi
W = the actual width, inches
MOE = lot mean MOE, 10^6 psi.

The size effect is accommodated in the expression with mean lot MOE as in reference (10). The resulting $R^2 = 0.62$. Keep in mind that this effort really results in estimating the tensile value (t) since b is an input. The literature suggests an R^2 in the this range would be expected if the effort was to estimate strength from MOE and EK parameters.(7) In this study, however, the classic relationships did not yield R^2 values in the range of 0.6 for estimates of t unless all of the above parameters were present in some form.

The variability in t/b results should not be surprising. With two strength variables, both related to nondestructive predictors with R^2 values in the range of 0.6, the resultant ratio must reflect the variability in the properties themselves.

Table A1 is a tabulation of some of the regression results from this study. It is important to remember that an overriding caveat to these analyzes is that independence is assumed for all the "independent" variables of the regression. Clearly, b5PE is not independent of either EK or MOE, nor is MOE independent of EK. It is also clear that the lack of balance (stratification) in some of the variables - width is a good example with only 3 - 2x8 and 2 - 2x10 data sets - must be considered in using the results. Nevertheless, this simplified analysis seemed appropriate for a quick look at the 45 data sets which represented a large and varied number of specimens.

Table A1. Regression Results with the 45 Data Sets

	Model	R^2
t/b' =	$0.526 + 0.109\ EK - 0.0001\ b5PE + 0.103\ MOE/(W)^{0.29}$	0.62
	$0.611 + 0.678\ EK - 0.201\ MOE/(W)^{0.29}$	0.31
	$0.545 + 0.547\ EK - 0.073\ MOE$	0.21
	$0.688 - 2.8e\text{-}05\ b5PE + 0.117\ MOE/(W)^{0.29}$	0.03

The relationship in the first regression is shown in Figure A1. The figure displays the familiar machine grading dispersion that suggests a transform may be of value. Logarithmic transforms succeeded in only modest increases, however; resulting R^2 values were 0.64. No further evaluations were made.

Figure A1 displays the 95% content interval for individual data sets. This leads to another conclusion that might be reached with the above analysis - that there is potential with MSR for using the lower bound on the distribution to establish default t/b ratio limits, rather than using the ASTM D1990 approach of a single default value of 0.45. Using Figure A1 as the basis for an example, the following default values could be assigned based on predicted t/b ratios (t/b') calculated from data taken during qualification in bending only. If the 45 data sets were accepted as representing the practice of the qualifying mill, it would expected that 97.5% of t/b ratios would fall above the default value predicted from t/b' (Table A2).

Table A2. Predicted Tension/Bending Mean and Lower 2.5% Ratios

Predicted Ratio t/b'	Default t/b Baseline
0.8	0.67
0.7	0.56
0.6	0.45

Further Reflections on MSR Qualification

Under the American Lumber Standard system, each species, grade and size combination of lumber is required to be qualified, by test - a step also referred to as "certification".(1) This requirement assesses the performance of the proposed product, providing the data upon which a supervisory agency can base approval for a grading operation and a specific product. In addition, however, if proper preparations and measurements accompany the qualification test, significant estimates of potential overall yield as well as relative performance and yield compared to “competing” grades, both visual and MSR, can be obtained by the producing mill.(8) This information also provides the background for further studies during production when yield and grade options come under question [see Appendix C of ref (8)].

The importance of the variables demonstrated in the text and this Appendix suggests a further objective of qualification - - the building of data bases by producers that have “a family of grades and sizes” and by supervisory agencies that can produce a compendium of producer’s data in order to conduct and refine t/b ratio evaluation and allowable property assignment.

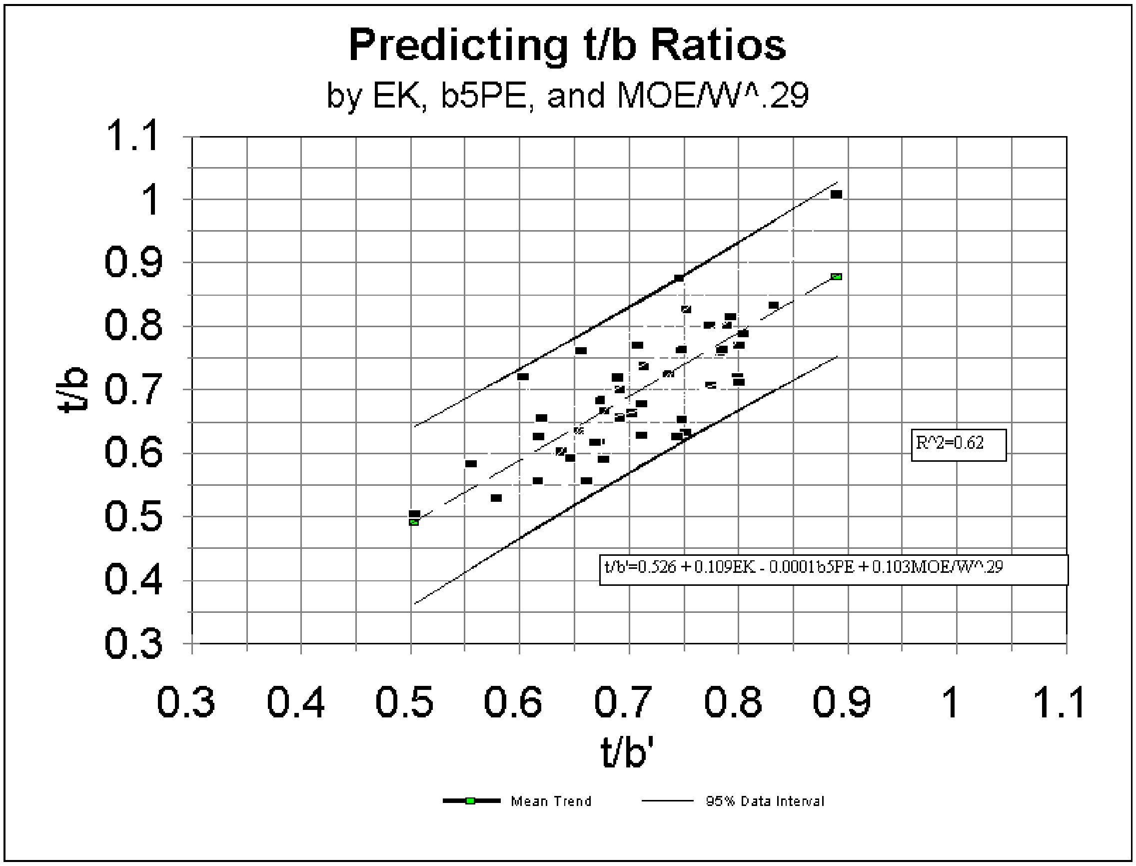

Figure A1. Using edge knot categories, bending strength, modulus of elasticity and width as input variables to predict tension/bending (t/b) ratios.