TESTING OF LAMINATED TIMBER JOISTS

WESTERN ARCHRIB[1]
1988

D. HIMMELFARB

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#66

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ABSTRACT

One hundred and thirty-two full scale flexural tests were performed on a structural glued-laminated joist product manufactured by WESTERN ARCHRIB from Western Spruce and Lodgepole Pine.

Measurements were taken to allow for the calculation of allowable stresses in flexure, shear, and M.O.E..

Recommendations for design are made.

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1.0 INTRODUCTION

In 1986 WESTERN ARCHRIB in co-operation with the Canadian and Alberta Forestry Services conducted a test program on structural glued-laminated timber (glulam) manufactured from Alberta grown Spruce and Pine lamstock. This test program led to the development of a proprietary grade of glulam which has since been successfully marketed under the trade name "WESTLAM". The use of Spruce and Pine lumber represents a dramatic shift away from traditional manufacture which over the previous 35 years had relied entirely on the use of imported Douglas-Fir lumber.

Glulam has also traditionally been made in 3,5 and 6-3/4 inch widths from nominal 2X4, 2X6 and 2X8 lumber. The resulting beams, although providing high load carrying capacity, are often too heavy to be lifted into place by hand. WESTERN ARCHRIB believes that a light-weight product made by resawing 3 inch wide glulam beams into two 1½ inch thick joists would solve this problem. Laminated joists of this type could be fastened together on site and in place to provide as many plies as required to carry the applied loads. However, resawing of lumber may change its grade and therefore a test program was required to establish the strength and stiffness properties of "WESTLAM-JOISTS" manufactured in this way.

The results of this test program form the basis for this report.

1.1 OBJECTIVE

The objective of this report is to establish the strength and stiffness properties necessary to allow for the engineered use of WESTLAM joists in beams, headers and joist systems.

2.0 MANUFACTURE

Initially 2X4 glulam beams were assembled in accordance with the grade combinations given in Table 1. Once face bonding was complete the 3½ inch wide members were planed to a uniform thickness of 3¼ inches and then resawn into two pieces approximately 1.6 inches wide.

The resawn samples (joists) were numbered and the matching "pairs" identified by an A/B designation.

Refering to Table 1, it can be seen that two symmetrical grade combinations were tested. This results in what is termed an "EX" grade. EX grades can be used in the joist direction without regard to their orientation. It is believed that this feature was necessary in order for this type of product to be successful.

Overall manufacture was in conformance with WESTERN ARCHRIB's <u>WESTLAM MANUFACTURING STANDARD.</u>[1]

One hundred samples were manufactured to provide information on flexural strength and stiffness. These samples were divided into two groups being 12 inches and 15 inches in depth.Thirty two samples were also made to determine shear strength. A summary of manufacturing data is presented in Table 2.

3.0 TEST PROCEDURES

All 132 joist tests were conducted by the Alberta Research Council. The methods of testing, equipment used and test results are presented in Alberta Research Council Report FPLE - 183[2]. . Loading configuration, rate of load application and joist dimensions were in accordance with ASTM D198-84.[3]

4.0 TEST RESULTS

The test results are summarized in Tables 3,4 and 5. The term modulus of rupture (M.O.R.) refers to the level of outer fibre bending stress at failure. In the calculation of M.O.R. allowance has been made for the self-weight of the joist. The value reported for the modulus of elasticity (M.O.E.) represents a "full span" M.O.E. and includes the effect or deformations due to internal shear stresses. Shear stress has been calculated in accordance with basic engineering principles.

5.0 DISCUSSION OF RESULTS

In most cases flexural failure of both the 12 and 15 inch test specimens initiated from the outermost tension lamination (i.e. 94 out of 100). Further, in 90% of these tests, failure was associated with either the location of a knot or an end joint. Of the 100 flexural test joists manufactured, 62% had an end joint located within the middle third of the test span (zone of constant and maximum bending moment).

TABLE 1: GRADE COMBINATIONS USED FOR MANUFACTURE OF TEST JOISTS.

BEAM SPAN (in.)	DESIGNATION	ZONE	MINIMUM M.O.E. (p.s.i.)	VISUAL[1] GRADE
192	one-eighth layup	outer 1/8 compression	1,550,000	B
		remainder of outer ¼ compression	1,400,000	C
		inner ½	no restriction	D
		remainder of outer ¼ tension	1,400,000	C
		outer 1/8 tension	1,550,000	B
240	one-tenth layup	outer 1/10 compression	1,550,000	B
		remainder of outer 2/10 compression	1,600,000	C
		remainder of outer 3/10 compression	1,400,000	C
		inner 4/10	no restriction	D
		remainder of outer 3/10 tension	1,400,000	C
		remainder of outer 2/10 tension	1,600,000	C
		outer 1/10 tension	1,550,000	B
48	one-eight layup	as per 192 inch span joists		

NOTES: 1. In accordance with WESTLAM MANUFACTURING STANDARD(1) grade designation.

TABLE 2: MANUFACTURING DATA

NUMBER OF BEAMS PRODUCED	NUMBER OF LAMINATIONS	NOMINAL CROSS-SECTIONAL DIMENSIONS	LENGTH (IN.)
40	8	1.6" x 12"	192"
60	10	1.6" X 15"	240"
32	8	1.6" x 12"	48"

TABLE 3: 12" JOIST DATA SUMMARY (FLEXURE)

BEAM NUMBER	M.O.R. (psi)	M.O.E. $X10^6$ psi	MOISTURE CONTENT (%)	DENSITY (lbs./cu.ft.)
1A	5227	1.54	11.0	28.4
1B	5597	1.65	10.6	29.0
2A	4500	1.28	11.3	28.8
2B	4539	1.26	11.4	28.5
3A	4732	1.49	10.3	29.0
3B	5174	1.62	10.3	28.7
4A	5946	1.61	10.7	29.0
4B	5920	1.62	10.4	29.3
5A	4975	1.43	10.8	28.6
5B	5518	1.55	10.3	28.8
6A	5258	1.55	11.3	28.9
6B	6308	1.62	11.0	29.1
7A	5476	1.37	11.1	28.5
7B	6196	1.44	10.3	29.2
8A	5028	1.50	10.8	28.6
8B	3695	1.55	11.7	28.0
9A	4539	1.41	11.1	28.3
9B	4070	1.55	11.0	28.5
10A	4393	1.39	10.8	28.1
10B	5363	1.48	11.3	28.3
B-11A	4415	1.56	10.6	29.8
B-11B	4281	1.57	10.6	29.6
B-12A	6309	1.59	10.0	29.4
B-12B	6231	1.69	10.5	30.4
B-13A	5869	1.75	10.4	30.4
B-13B	4691	1.76	10.4	29.8
B-14A	5004	1.52	9.9	30.1
B-14B	4227	1.47	10.5	29.6
B-15A	5450	1.50	10.2	29.9
B-15B	6570	1.65	10.5	29.6
B-16A	2975	1.48	10.3	30.2
B-16B	3460	1.52	10.5	29.7
B-17A	6865	1.63	10.0	30.5
B-17B	4992	1.61	10.7	30.1
B-18A	4389	1.48	9.7	29.4
B-18B	4516	1.56	10.7	29.3
B-19A	5710	1.67	10.3	30.4
B-19B	5027	1.87	9.7	30.0
B-20A	6315	1.66	10.3	31.4
B-20B	4771	1.63	9.9	31.3

TABLE 4: 15" JOIST DATA SUMMARY (FLEXURE)

BEAM NUMBER	M.O.R. (psi)	M.O.E. ($X10^6$psi)	MOISTURE CONTENT (%)	DENSITY (lbs./cu.ft.)
1A	5403	1.66	11.6	29.2
1B	4894	1.67	12.2	29.4
2A	4186	1.61	11.8	28.7
2B	4438	1.56	11.9	28.4
3A	4365	1.48	10.1	29.2
3B	4924	1.59	10.8	28.8
4A	5288	1.66	12.4	28.5
4B	5198	1.54	12.4	28.1
5A	2823	1.51	12.3	28.4
5B	3021	1.53	11.7	28.5
6A	5039	1.54	12.2	28.5
6B	5156	1.60	12.5	28.5
7A	5434	1.63	11.8	29.0
7B	4724	1.69	10.8	28.2
8A	4466	1.52	12.9	29.9
8B	3637	1.51	11.9	29.2
9A	3898	1.53	11.8	28.6
9B	3920	1.49	10.5	28.2
10A	5069	1.52	10.9	27.8
10B	3682	1.65	11.2	28.5
B-11-A	4666	1.50	9.6	27.6
B-11-B	4961	1.48	10.2	28.1
B-12-A	4233	1.45	10.4	29.8
B-12-B	4925	1.41	10.5	29.7
B-13-A	4591	1.49	9.4	29.2
B-13-B	4847	1.53	9.8	28.7
B-14-A	4868	1.71	10.4	28.5
B-14-B	4363	1.63	10.8	28.4
B-15-A	5002	1.50	10.1	27.5
B-15-B	4470	1.47	10.3	27.6
B-16-A	4694	1.56	10.4	28.0
B-16-B	4867	1.51	9.9	28.1
B-17-A	4410	1.62	10.0	28.1
B-17-B	5458	1.61	9.2	27.9
B-18-A	5364	1.55	10.4	28.7
B-18-B	5445	1.50	11.0	28.8
B-19-A	4769	1.57	8.5	28.3
B-19-B	4930	1.47	10.5	28.7
B-20-A	3624	1.50	9.7	27.9
B-20-B	3326	1.56	9.8	28.1
B-21-A	3943	1.46	10.3	28.3
B-21-B	4642	1.50	10.5	28.3
B-22-A	3129	1.49	9.5	28.0
B-22-B	3555	1.57	10.0	28.1
B-23-A	4515	1.49	10.8	27.7
B-23-B	3409	1.52	9.8	28.4
B-24-A	3921	1.58	9.6	28.2
B-24-B	4887	1.57	9.6	28.2
B-25-A	5742	1.59	10.2	28.7
B-25-B	4840	1.47	10.5	28.6
B-26-A	5728	1.62	10.9	27.5
B-26-B	4797	1.59	10.7	27.9
B-27-A	3924	1.47	11.2	28.6
B-27-B	5536	1.58	10.8	28.7
B-28-A	6104	1.64	11.0	28.0
B-28-B	5459	1.62	10.7	27.9
B-29-A	4186	1.59	9.7	27.9
B-29-B	5067	1.58	9.9	28.2
B-30-A	4459	1.42	9.9	28.7
B-30-B	3697	1.38	10.2	28.6

TABLE 5: 12" JOIST TESTS (SHEAR)

BEAM NUMBER	SHEAR STRESS (psi)	MOISTURE CONTENT (%)	DENSITY (lbs./cu.ft.)
B-1-A	701	10.5	28.3
B-1-B	807*	10.5	28.0
B-2-A	839	10.7	27.8
B-2-B	927*	11.0	27.8
B-3-A	765*	10.1	27.5
B-3-B	756	11.5	27.7
B-4-A	814	10.7	27.7
B-4-B	788*	8.9	28.6
B-5-A	813	11.2	27.8
B-5-B	714*	10.5	28.2
B-6-A	727*	10.6	28.3
B-6-B	685*	9.9	27.7
B-7-A	725	10.1	27.7
B-7-B	713	10.7	28.1
B-8-A	646*	10.3	27.5
B-8-B	709*	10.0	28.1
B-9-A	645*	10.8	27.7
B-9-B	620*	10.3	27.8
B-10-A	629	11.0	28.9
B-10-B	615	10.2	27.8
B-11-A	750	10.6	28.3
B-11-B	592	10.6	28.0
B-12-A	695*	9.8	28.7
B-12-B	703*	10.2	28.2
B-13-A	768*	10.2	28.4
B-13-B	680*	10.3	28.4
B-14-A	736*	9.2	28.0
B-14-B	672*	10.2	28.4
B-15-A	691	10.2	28.0
B-15-B	619	10.0	28.7
B-16-A	692*	10.9	28.4
B-16-B	640	10.3	27.6

* - JOISTS WHICH FAILED IN SHEAR

Table 6 presents a breakdown of the failure modes exhibited by the flexural test specimens and Figure 1 shows a typical failure.

TABLE 6: CLASSIFICATION OF FAILURES

	TOTAL NUMBER	FAILURE ASSOCIATED WITH				
		KNOT	END JOINT	COMBINED KNOT/JOINT	COMBINED JOINT/WOOD	OTHER
FAILURE OF OUTERMOST TENSION LAMINATION	94	56	28	2	4	4
LATERAL BUCKLING BETWEEN SUPPORTS	2	—	—	—	—	2
FAILURE OF OTHER THAN TENSION LAMINATION	4	4	—	—	—	—

Only 56% (18 out of 32) of the 12 inch joists designed to fail in shear did so. The main reason for this, which became apparent as testing proceeded, was that in order to develop the volume of load required to prompt a shear failure a severe bearing failure occurred first at either the load or the reaction points. (See Figure 2). Failure in 10 of the 32 test specimens was a result of either a shearing or tension perpendicular to grain failure beginning at the point of bearing failure. The remaining 4 specimens failed in flexure.

The moisture content as measured at the time of testing ranged from 8.5 to 12.9% with an average value of 10.6%. This is representative of the

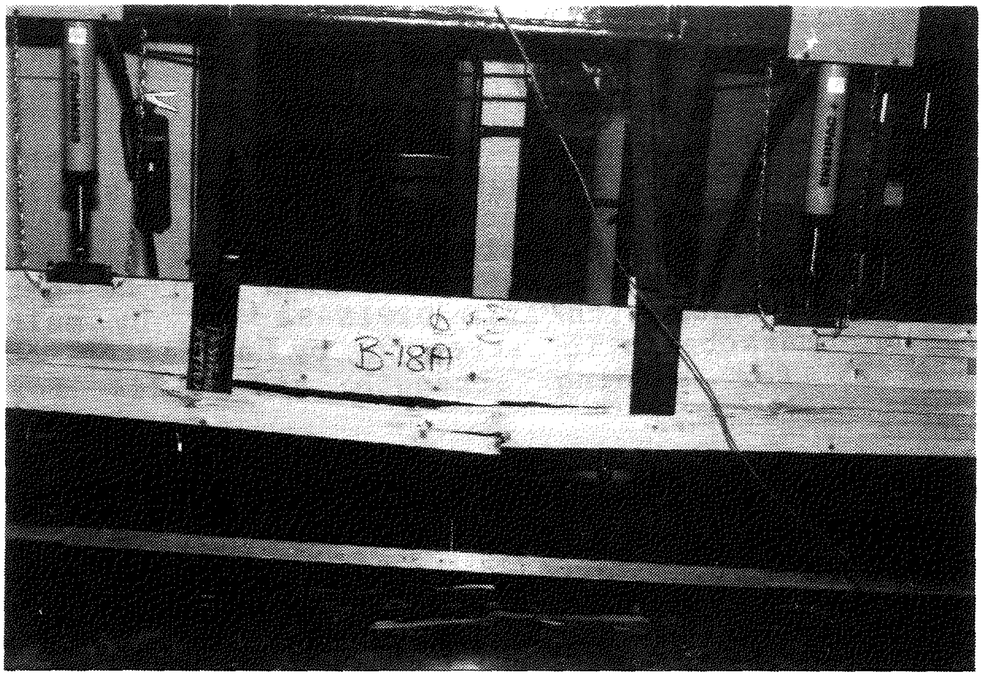

FIGURE 1: TYPICAL FLEXURAL FAILURE

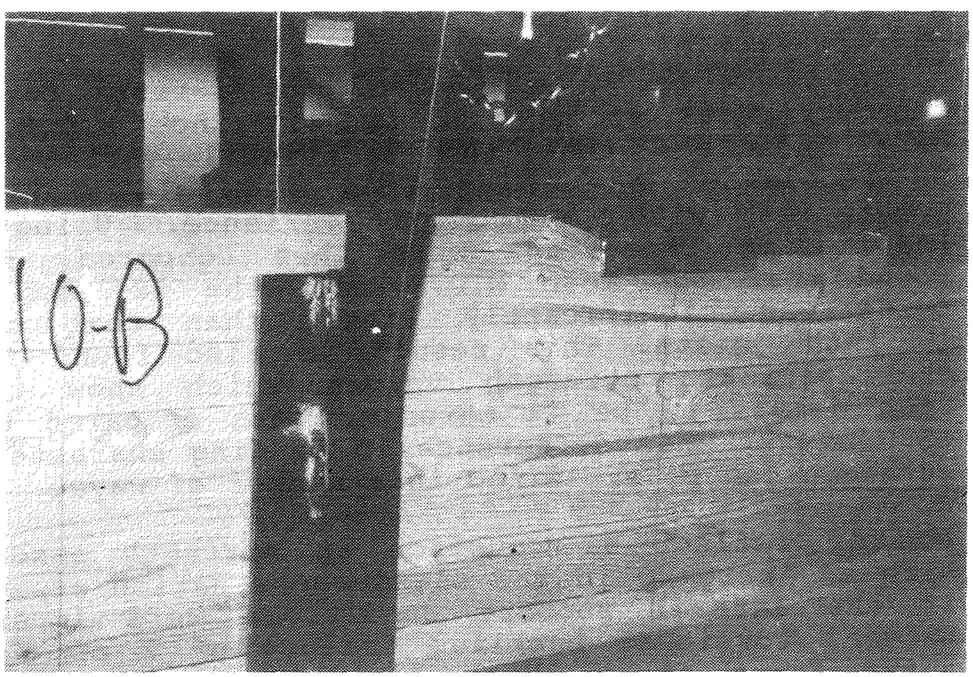

FIGURE 2: BEARING FAILURE OF SHEAR SPECIMENS

equilibrium moisture content that one would expect under most dry service conditions.

For the purposes of this report the term characteristic strength is defined statistically as "the lower 75% confidence limit on the estimate of the lower 5% level of population strength." The allowable stress used in design can be determined in accordance with ASTM D2915-84 (4) by multiplying the characteristic strength by a factor equal to 0.475 for bending strength and 0.244 for shear strength.

To support the use of a statistical approach based on the assumption of normally distributed data, a CHI-SQUARE "goodness of fit" test was performed on the M.O.R. data from the sixty 15 inch joist tests.Using 12 classes a CHI-SQUARE value of 7.38 was calculated which compares to the tabulated value corresponding to 9 degrees of freedom at the 5% level of 16.92.(5) Therefore, the assumption of normally distributed data is accepted.

5.1 BENDING STRENGTH

A summary of the mean, standard deviation, characteristic strength, and allowable stress is given in Table 7. Results of an "f-test" comparing the variances of the 12 and 15 inch M.O.R. test data indicates that the individual variances can be considered as coming from a single statistical population with a common variance. Using this information the means were then compared. It was found that the mean M.O.R. of the 12 inch joist tests was significantly larger than that of the 15 inch joists. This result is also found in the characteristic strength values which show the 12 inch joists to be 7% stronger when compared to the 15" joists. This difference in bending characteristic strength can be explained in a number of ways.

It may reflect a reduction in strength associated with an increase in the slenderness ration especially if the lateral support conditions were imperfect. Lateral torsional buckling failure of 2 of the 15" joist tests gives physical evidence that this may be occuring. Design equations given in CAN3-086-M84 (6) were applied to examine the loss of strength predicted when going from a width to a depth ratio of 8 to 10 with lateral supports at the fifth points (as per test set up). This method indicates a 15% loss in bending strength could be expected due solely to a loss in lateral stability.

TABLE 7: SUMMARY OF STATISTICAL DATA

(FLEXURAL TESTS)

JOIST DEPTH	MODULUS OF RUPTURE				MODULUS OF ELASTICITY	
	MEAN (psi)	STANDARD DEVIATION (psi)	CHARACTERISTIC STRENGTH (psi)	ALLOWABLE STRESS (psi)	MEAN ($X10^6$ psi)	STANDARD DEVIATION ($X10^6$ psi)
12"	5113	880	3499	1666	1.55	0.122
15"	4582	727	3273	1559	1.55	0.072

Because the equations given in CAN-086-M84 are not meant to predict the behaviour of beams with a buckled shape consistant with 4 intermediate points of lateral support this result should be viewed with caution. Nevertheless, reasoning along this line, although difficult to quantify, cannot be entirely ignored because of the physical evidence of failures due to lateral instability.

A second explanation would be to accept the concept of depth factor which relates the allowable stress in belonging to the beam depth. The equation given by the American Institute of Timber Construction design specification 117-85 may be expressed as:

$$\text{Allowable stress at a given depth} = \left[\text{Allowable stress at a depth of 12"}\right] \times C$$

$$\text{where;}\quad C_f = \left[\frac{12}{d}\right]^{\frac{1}{9}} \qquad d = \text{beam depth in inches}$$

Using this expression a loss in strength of 2.5% could be expected when increasing depth from 12 to 15 inches. This is far less than the 7% loss indicated by the test data and therefore does not adequately explain the difference.

A third explanation lies in an examination of the grade combinations used to manufacture the test joists. Referring to Table 1, it can be seen that the 15 inch joists were made with a lower percentage of high grade"B" lumber (i.e. 1/10 vs 1/8) and therefore one would expect their strength to be lower due to this "grade combination" factor. The degree to which this factor explains the loss in strength is also difficult to quantify, however I believe it remains the most likely explanation for the trend indicated by the test data.

5.2 SHEAR STRENGTH

Although only 18 of the 32 test joists failed in pure shear, it can be assumed that the shear strength of those joists which failed in some other way was at least equal to the shearing stress existing at the time of failure. By comparing the mean, standard deviation and characteristic shear strength calculated using only the 18" "shear failures" to that which is calculated using all 32 test data it became clear that all 32 may be used in the statistical analysis. (see Table 8).

TABLE 8: SHEAR STRESS DATA

	MEAN (psi)	STANDARD DEVIATION (psi)	CHARACTERISTIC STRENGTH (psi)	ALLOWABLE STRESS (psi)
"SHEAR FAIL" SAMPLES ONLY (18)	721	72	580	142
ALL DATA (32)	715	75	575	140

An allowable stress of 140 psi agrees very well with the value of 145 currently given by CAN3-086-M84. However the design method given in CAN3-086-M84 recognizes the influence of volume and load configuration on the shear capacity of glued-laminated beams. The equation given by clause 4.5.2.3.2 is:

$$V = f_v \left(\frac{2}{3}\right)\left(A \quad K_D \quad K_{SV} \quad K_T \quad K_{ZV}\right) \quad K_H \; K_N \geqslant W \quad (2)$$

Where (for the test case):

W = sum of all loads acting on the beam (lbs.)

f_v = allowable shear stress (psi)

A = cross-sectional area (sq. in.)

K_D = load duration factor = 1.60

K_{SV} = K_T = K_H = K_N = 1.0

K_{ZV} = size factor

The size factor, K_{ZV}, for the specific loading configuration, width to depth ratio and volume of wood used in the joist testing can be calculated as being equal to 5.28.

By using the allowable stress value obtained from the test data the maximum volume of load which should be able to be supported by the test joists before a shear failure would occur can now be calculated as 14,900 pounds. The ratio of total load applied during the joist tests to the predicted capacity of 14,900 lbs. gives a value which can be called an "overload factor". For the 32 test joists the value of the overload factor ranges from 1.02 to 1.56. Traditionally an acceptable minimum overload factor for structural wood products has been taken to be 1.3. To achieve this level of overload protection for the joist product tested an allowable stress of 110 psi would be required.

5.3 MODULUS OF ELASTICITY (M.O.E.)

The M.O.E. measurements summarized in Table 7 were taken during the testing of the flexural specimens and represent an apparent M.O.E. (i.e. including the effect of internal shear stresses on deformation). Because the mean M.O.E. values of the 12 and 15 inch joist tests show no significant difference the data was pooled to establish the lower 95% confidence limit on the mean which is the value traditionally used in design. This value was calculated to be 1.53×10^6 psi.

6.0 CONCLUSIONS

The glued-laminated joists provided for testing were produced in accordance with WESTERN ARCHRIB's WESTLAM MANUFACTURING STANDARD.

Test data suggests a difference in the bending strength between the 12 and 15 inch joists. This can best be explained as reflecting differences in the grade combinations used in manufacture (i.e. layup). As a result, two values for the allowable bending stress depending on which grade combination is used would be appropriate.

The low variability with respect to M.O.E. indicates that a uniformly manufactured product has been made.

7.0 RECOMMENDATIONS

Two values for allowable stress in bending are recommended. These values corresponding to the "one eighth" and "one tenth" lay up and are 1650 psi and 1550 psi respectively.

An allowable shear stress of 110 psi is recommended for use in conjunction with the design equation given by clause 4.5.2.3.2 of CAN3-086-M84.

A modulus of elasticity value of 1.53×10^6 psi is recommended.

8.0 COMMERCIAL SIGNIFICANCE

Test data indicates that WESTLAM JOISTS manufactured in accordance with WESTERN ARCHRIB's plant standard can provide a structural product of predictable performance with respect to both strength and serviceability.

Since the market for WESTLAM JOISTS will almost exclusively lie in applications where a system effect could apply, the somewhat lower values of bending strength, when compared to WESTLAM beams, is not considered to be a significant disadvantage. With flexural and stiffness prperties now established, WESTERN ARCHRIB believes that WESTLAM JOISTS can be successfully introduced into the structural wood frame marketplace and provide a natural complimentary product line to WESTLAM BEAMS.

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