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Assessment of Modification Factors for a Row of Bolts or Timber Connectors

Abstract

When bolts or timber connectors are used in a row, with load applied parallel to the row, load will be unequally distributed among the fasteners. This study assessed methods of predicting this unequal load distribution, looked at how joint variables can affect the distribution, and compared the predictions with data existing in the literature. Presently used design procedures were also assessed. The analytical methods were found to predict proportional limit loads but not joint strength.

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Assessment of Modification Factors for a Row of Bolts or Timber Connectors

BY
THOMAS LEE WILKINSON, Engineer

Introduction

When bolts or timber connectors are used in rows parallel to the direction of loading, there is an unequal distribution of load among the fasteners in the row. Thus, if the design load for the row of fasteners is based on the load for a single fastener times the number of fasteners, a modification factor must be applied for the unequal distribution of load. This modification factor may be a function of many joint variables; for purposes of design, it should be as simple as possible to apply while being sufficiently accurate and efficient.

Modification factors exist in the design procedures *(1,9)*[2] for a row of fasteners. These factors have been based on analytical methods of analysis for the distribution of load among the fasteners. The present study was initiated to determine the adequacy of the design procedures and the underlying assumptions used to arrive at the presently used modification factors.

Discussion of Analytical Methods of Analysis

Available Analytical Methods

Several investigators have developed methods of analysis for the distribution of load among fasteners in a row. These methods are based on the extensional stiffnesses of the joint members and the load-slip characteristics of an individual fastener. Lantos *(8)* assumed that the direct stresses in the joint members are uniformly distributed across their cross section, and that a linear relationship exists between fastener deformation and fastener load. His work contains no experimental verification.

Cramer *(2)* developed a similar approach, except he corrected for the nonuniform direct stress distribution in the members; Cramer established the value of the joint slip modulus with the aid of an analysis of the bearing stress distribution under the fasteners. He verified his analysis on a limited number of perfectly machined joints.

Isyumov *(6)* developed a method of analysis where the timber connectors and joint members were represented by a series of either linear or nonlinear springs. This work contains numerous test results for multiple fastener joints.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
[2] Italicized numbers in parentheses refer to Literature Cited at the end of report.

Foschi and Longworth (5) have developed a method of determining the load distribution (on griplam nailed connections) that can predict the ultimate load on the joint.

Present Design Procedures

Modification factors for application to a row of bolts, lag screws, or timber connectors are given in CSA Standard 086 *(1)* and in the NDS *(9).* These reduction factors can be defined as:

$$\alpha = \frac{F}{NP} \qquad (1)$$

where α = modification factor for the row

N = number of fasteners in the row

F = total load carried by the row

and P = maximum fastener load.

The ratio P/F is obtained by use of an analytical method of analysis. The values of P and F would be design loads when designing a joint. The presently listed values of α were based on the Lantos (8) method (appendix A). The joint variables involved in this method of analysis are:

E_1 = elastic modulus of the main member, pounds per square inch

E_2 = elastic modulus of the side members, pounds per square inch

A_1 = cross-sectional area of the main member, square inches

A_2 = cross-sectional area of the side members, square inches

P/δ = load-slip value for a single fastener, pounds per inch

N = number of fasteners in the row

and S = spacing of fasteners in the row, inches.

The present design procedure is: First, select the design load for a single fastener as listed in either *(1)* or *(9)*; second, multiply by the number of fasteners in the row; and third, multiply by the appropriate modification factor. This gives the design load for the row of fasteners.

The presently used modification factors are reproduced in tables **1** and **2.** The only variables listed in these tables are number of fasteners, N, and the member areas, A_1 and A_2. Some other variables involved in the analytical analysis are listed in table 3.[3] Reviewing the data in these tables, it appears the Lantos method of analysis was used to calculate modification factors for joints with 3 through 8 fasteners in a row; these results were then extrapolated to joints with **12** fasteners in a row and for joints with **2** fasteners in a **row.**[3]

For a row with two fasteners, it was assumed that the load is shared equally. This is not borne out by the Lantos analytical results. For a row with more than eight fasteners, the extrapolation resulted in modification factors smaller than the analytical results in some cases and larger in other cases. The factors for the larger

[3] Based on unpublished information obtained from the Canadian Wood Council.

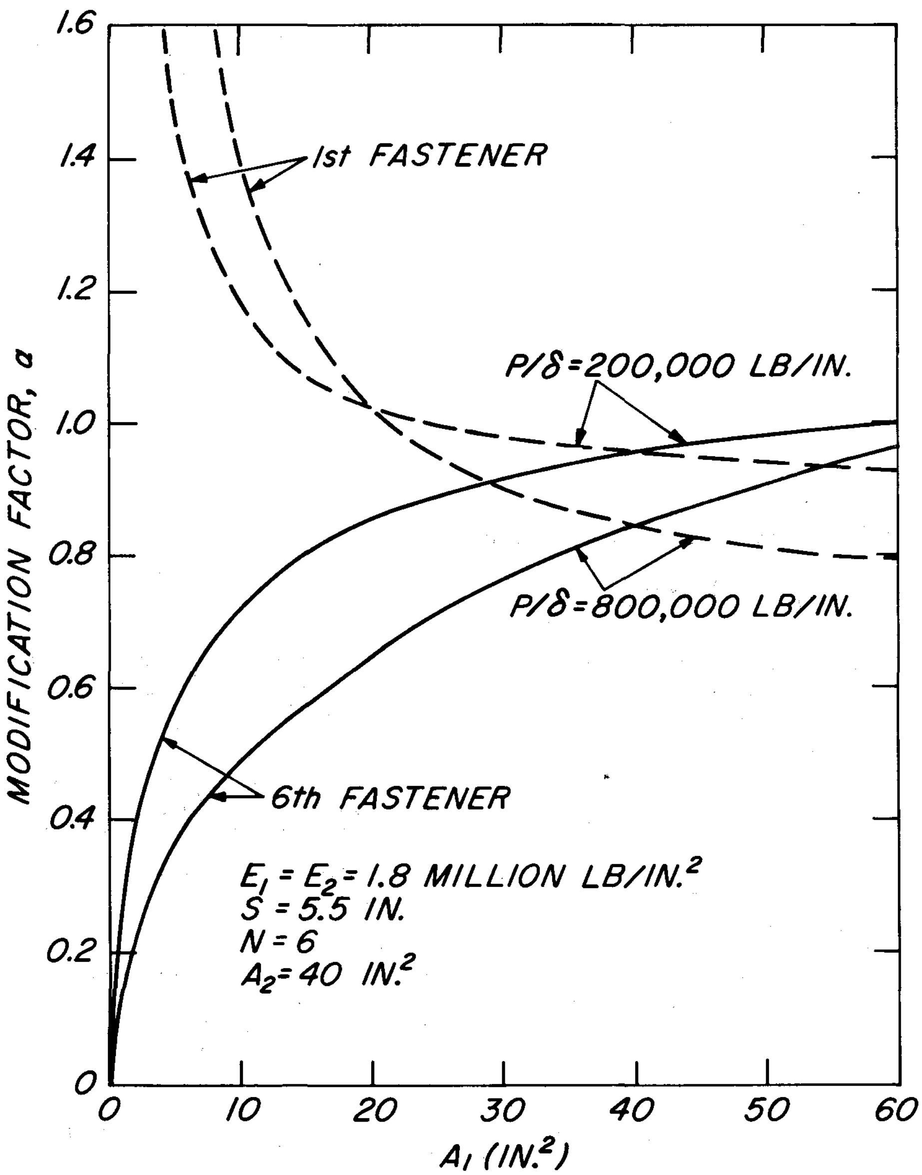

Figure 1. — Modification factors based on each of the end fasteners in a 6-fastener row for two values of the single fastener load-slip constant.

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evident in figures 10 and 11.

Figures 7 through 11 show that, when there is a large imbalance in stiffness between the side members and main member, the load will be unequally distributed among the fasteners in the row. In practice, when there is a large difference in elastic modulus of the members there can be a compensating difference in cross-sectional area of the members.

Comparison of Analytical Methods

The most applicable methods to use for calculating modification factors for design procedures are those by Lantos *(8)* (appendix A) and by Cramer *(2)* (appendix B). The difference in these methods is a correction by Cramer for the nonuniform direct stress distribution in the members.

A comparison of the modification factors calculated with the Lantos and Cramer methods is given in figure 12 for a joint with steel side plates and in figure 13 for a joint with wood side plates. A 1/2-inch-diameter bolt was arbitrarily chosen as the fastener for use with the Cramer method. (Use of a larger diameter bolt would result in a smaller modification factor, assuming that both bolts had the same load-slip value. For example, the modification factor for a 1-inch bolt is approximately 1 percent smaller than for the 1/2-inch bolt. The Schulz multiplying factor which causes this difference is explained in appendix B.) This comparison shows a difference of less than 2 percent in calculated modification factors by the two methods. The Cramer method gives slightly greater reduction. Because there is such a small difference between the two methods, the Lantos method would be-more favorable for use in calculating design factors because of its simpler nature.

Discussion of Experimental Load-Slip Values for Single Fasteners

A search of existing U.S. Forest Products Laboratory data for bolt and timber connector joints was made to gain an insight of the single fastener load-slip characteristics.

Some typical load-slip curves are shown in figures 14, 15, and 16. The slopes of the assumed linear portions that would be used in the analytical methods are indicated on the plots. It can be seen that a single value for a load-slip curve does not fully characterize the behavior of a single fastener. This is especially true if the analytical methods are to be used to predict the maximum load for a row of fasteners.

Many joint variables may affect the load-slip value for a single fastener joint. These variables include such things as kind and size of fastener, bearing length of the fastener in the members, species of wood, type of side plate (wood or metal), and direction of loading with respect to the wood grain. These variables also affect the proportional limit and maximum loads.

A comparison of load and load-slip values for some different kinds of fasteners is contained in table 4. As would be expected, the timber connectors have larger values than bolts. Size and type of connector appears to have a greater effect on load values than it does on the load-slip value.

The effect of fastener bearing

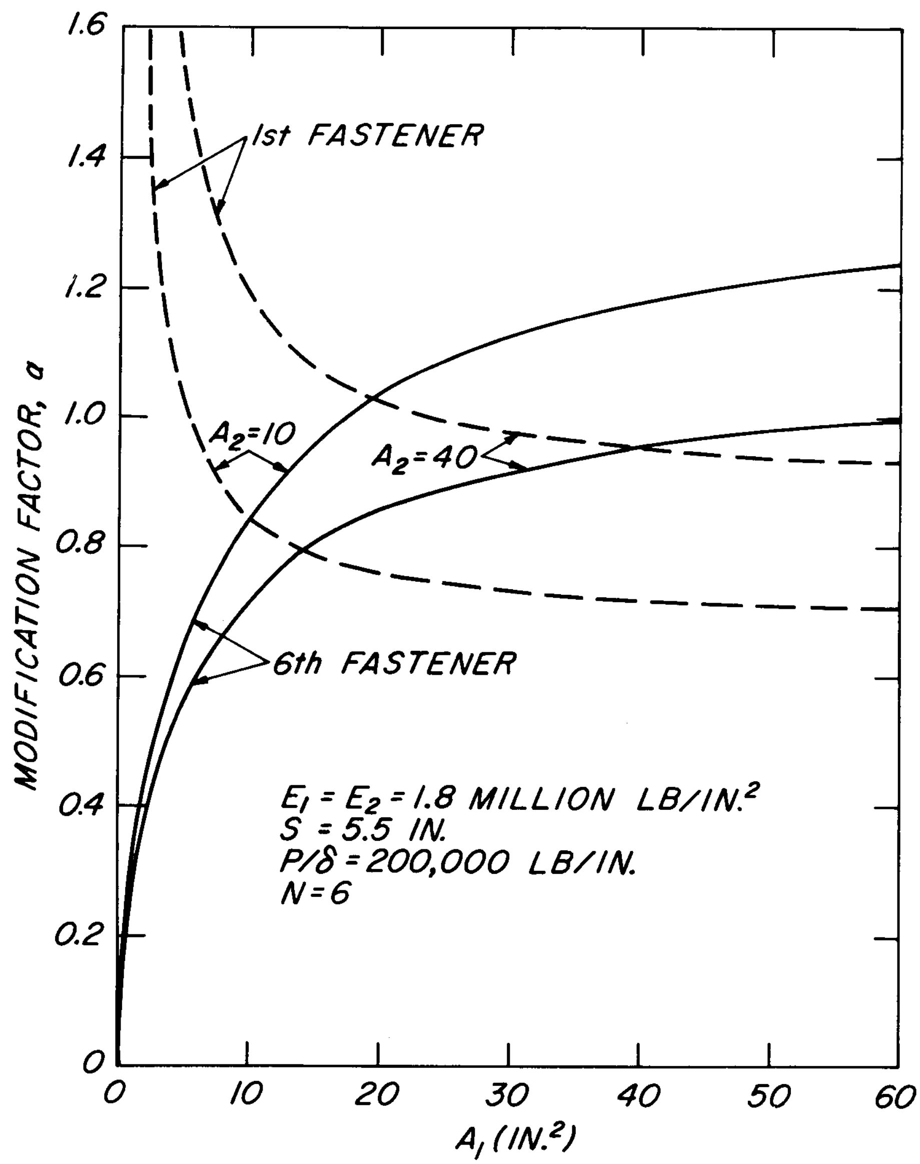

Figure 3.–Modification factors based on each of the end fasteners in a g-fastener row for two different side member areas.

(M 148 229)

length in the member is given in table 5 for a 4-inch shear plate and table 6 for a 1/2-inch bolt. The load-slip value appears to remain nearly constant with changes in bearing length for both fasteners. The greatest effect is upon the maximum load. Both maximum load and proportional limit load become fairly constant after a limiting bearing length is exceeded.

The effect of wood species is shown in table 7 for a 1/2-inch bolt and in table 8 for a 4-inch shear plate. This effect appears to be very slight except upon maximum load.

Table 7 also shows the effect of side member material upon load and load-slip values. All values are considerably larger for metal side members.

Table 9 shows the effect of grain direction upon proportional limit load and load-slip value. Values are considerably higher for parallel-to-grain loading than for perpendicular-to-grain loading.

Another fact observed in looking at the load-slip values for individual fasteners was the large range in values for supposedly matched specimens. This is illustrated by the values in table 10 for a 1/2-inch bolt in southern pine.

From the examined FPL data, the assumed load-slip values used to arrive at the modification factors in *(1)* and *(9)* are on the conservative side with the exception of 4-inch shear plates and 4-inch split rings. These larger timber connectors have load-slip values of about 400,000 pounds per inch. The assumed values may be overly conservative for most bolts and also for perpendicular-to-grain loading.

From the number of variables that may affect the load-slip value and its range, it is apparent that a means of predicting the load-slip value or distribution of load-slip values is desirable. It would be desirable to predict the entire load-slip curve up to maximum load. This would permit the prediction of load distribution for a row of fasteners up to maximum load.

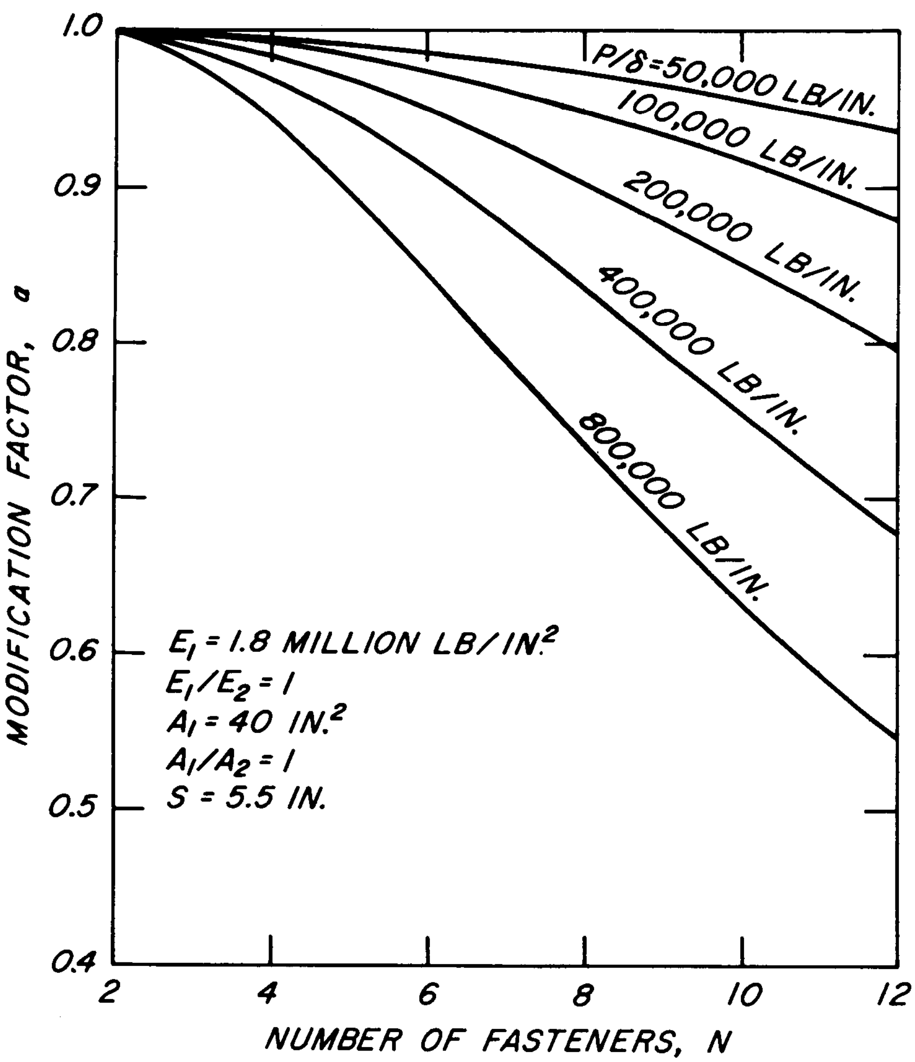

Figure 4.–Effect of single fastener load-slip value upon the multiple-fastener joint modification factor for a joint with wood side plates.

(M 148221)

Experimental Results for Rows of Fasteners

A limited number of experimental evaluations of multiple-fastener joints are listed in the literature *(4,6,7,9,10).* A comparison was made of the predicted loss in joint strength as given by the Lantos method of analysis and by the present design procedures with the experimental results in these studies. Tables 11 through 15 contain joint variables and modification factors for studies by Isyumov *(6),* Doyle *(4),* Kunesh and Johnson *(7),* Dannenberg and Sexsmith *(3),* and Stern *(10).* The information needed to calculate the modification factors was not always provided. Where it was lacking, estimated values (as indicated in the tables) were used. Some studies gave only maximum loads and others gave both maximum loads and proportional limit loads. Experimental modification factors are given for both loads where available.

In all cases, the Lantos method of analysis over-estimated the maximum strength of the joint. This can be seen by comparing the modification factors based on maximum test loads to the calculated factors. The present design factors also over-estimated the strength. This may be due to unequal contact between each of the fasteners and the fastener holes at zero load. This could cause some of the fasteners to carry more than their predicted amount of the joint load. Another possible contributing factor could be the mode of failure. This could possibly be different for the fasteners in a row than for a single fastener.

The Lantos method of analysis came closer to predicting the reduction in proportional limit loads. This is as expected because the single fastener load-slip value is that up to proportional limit load. In some studies the modification factors based on proportional limit test loads were higher than predicted by the Lantos method of analysis; in other studies, they were lower. This may be due to difficulties in determining what the proportional limit load is for a row of fasteners.

Reference *(3)* also contained information on the distribution of load among the connectors in a row. From these data, Dannenberg and Sexsmith concluded that *(1)* the connector loads of a multiconnector joint are nonuniform, and *(2)* the permissible dimensional tolerances in the manufacture of the specimen have a significant effect upon the load distribution and the ultimate load of the specimen. They suggest that any analysis of load distribution should include random errors for dimensional tolerances in order to accurately predict the connector loads. Their data not only showed erratic distribution of load among the fasteners (fig. 17), but it also showed that the distribution was different for each side plate (fig. 18).

A comparison of design loads (arrived at by following procedures in reference *(9)* and maximum test loads showed a ratio of test to design load of 4.5 to 5.8 for the joints in reference *(7)* and 4.3 to 6.1 for the joints in reference *(10).* Thus, even though the present recommended modification factors for multiple-fastener joints do not accurately predict, the loss in strength from test, the ratio of test to design loads appears adequate. It should be kept in mind that the tests reported herein do not reflect the entire range of joints listed in the design procedures.

Conclusions and Recommendations

The following conclusions apply to fasteners placed in a row parallel to the grain and loaded parallel to the grain:

1. Present methods of analysis appear to predict the proportional limit load for a row of fasteners. However, the actual proportional limit load can be difficult to determine experimentally.
2. Present analytical methods overestimate the strength (failure load) of a row of fasteners as would be expetted because the methods do not take into account the nonlinear load-slip behavior of a single fastener.
3. Assumed values of joint variables used to arrive at modification factors for use in design procedures are adequate to conservative. Fewer assumptions would be needed if tables of modification factors were based on EA rather than A.
4. It may be desirable to have separate tables for bolts and timber connectors due to (a) the large difference in single fastener stiffness, and (b) the different procedures by which design loads are developed.
5. It would be desirable to have an analytical method of predicting single fastener load-slip relations to failure.
6. It would be desirable to have an analytical method of predicting the distribution of load among fasteners in a row; such a method must account for fabrication tolerances and nonlinear load-slip relations for single fasteners.

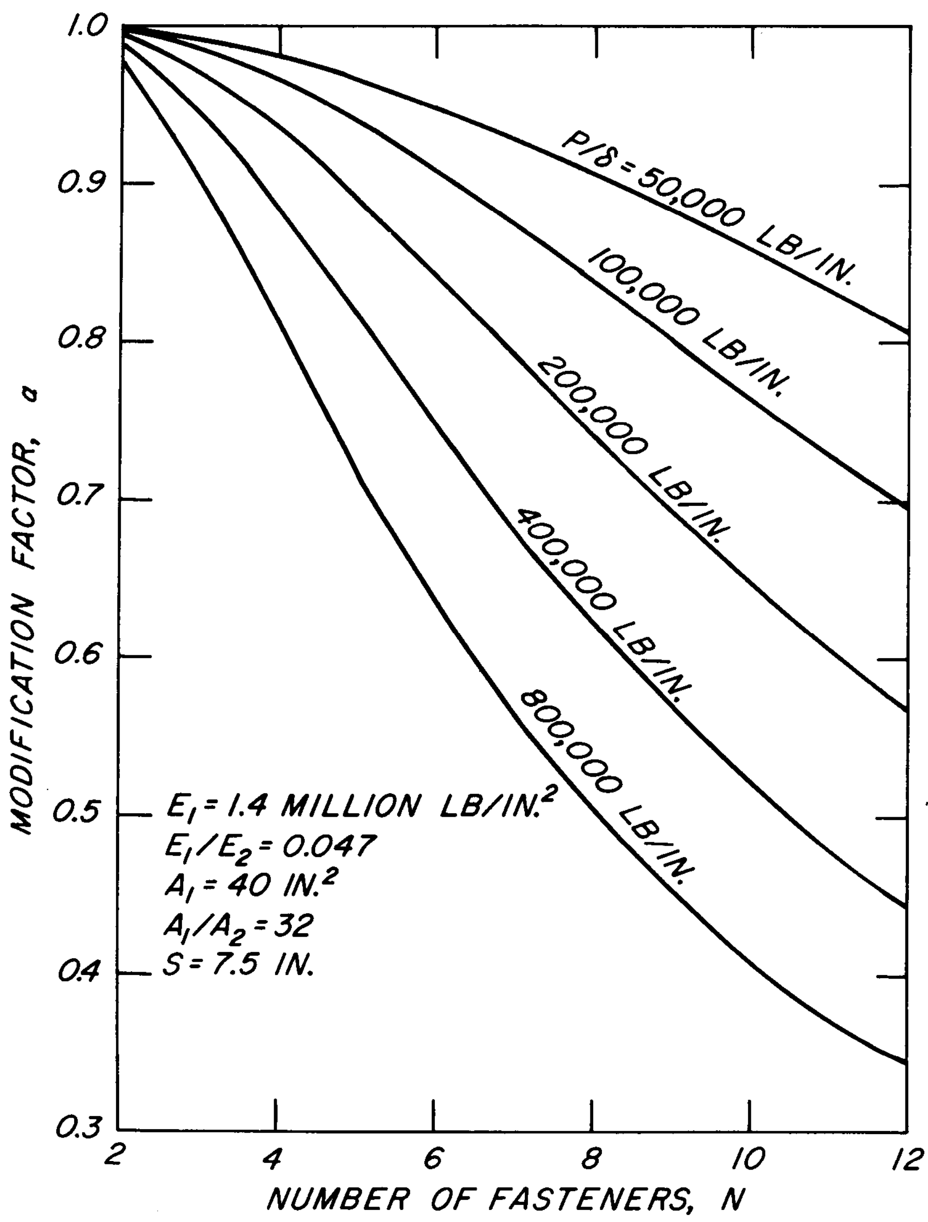

Figure S-Effect of single fastener load-slip value upon the multiple-fastener joint modification factor for a joint with steel side plates.

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Suggested Additional Work

From the preceding assessment of analytical methods of determining load distribution among fasteners in a row and of experimental data for single- and multiple-fastener joints, several areas for additional experimental and analytical work are apparent. The following list contains some of those areas:

1. Modify present methods of analysis to allow for different nonlinear load-slip relations for each fastener. These modifications could also include fabrication tolerance effects by allowing for slip without load.
2. Conduct a random simulation of nonlinear load-slip relations and fabrication tolerance for fasteners in a row to obtain statistical distributions of modification factors for design procedures.
3. Verify modified methods of analysis with experimental tests in which (a) the amount of slip before contact between the fasteners and members is measured, (b) the distribution of load among the fasteners is measured all the way to failure, (c) the slip of each fastener is measured, and (d) joints are evaluated over a range of member stiffnesses, EA, and number of fasteners per row.
4. Reassess the procedures for arriving at the values of design loads for single fastener joints.
5. Develop an analytical method of predicting the single fastener load-slip relation all the way to failure load.
6. Investigate the load distribution in rows of fasteners where the loading is perpendicular to the grain. This should include how to define joint area and also the effects of shrinkage.

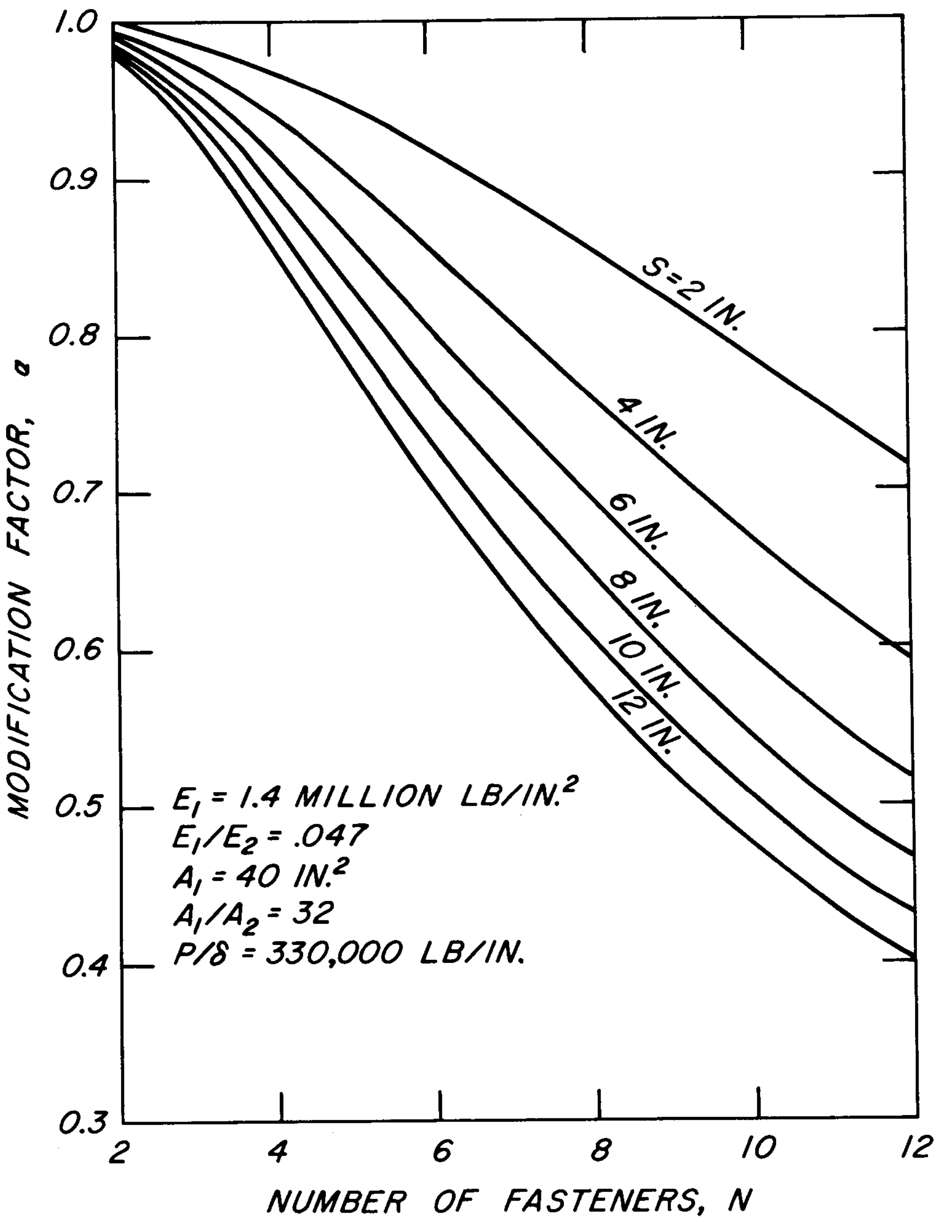

Figure 6.–Effect of fastener spacing upon the multiple-fastener joint modification factor for a joint with steel side plates.

(M 148 223)

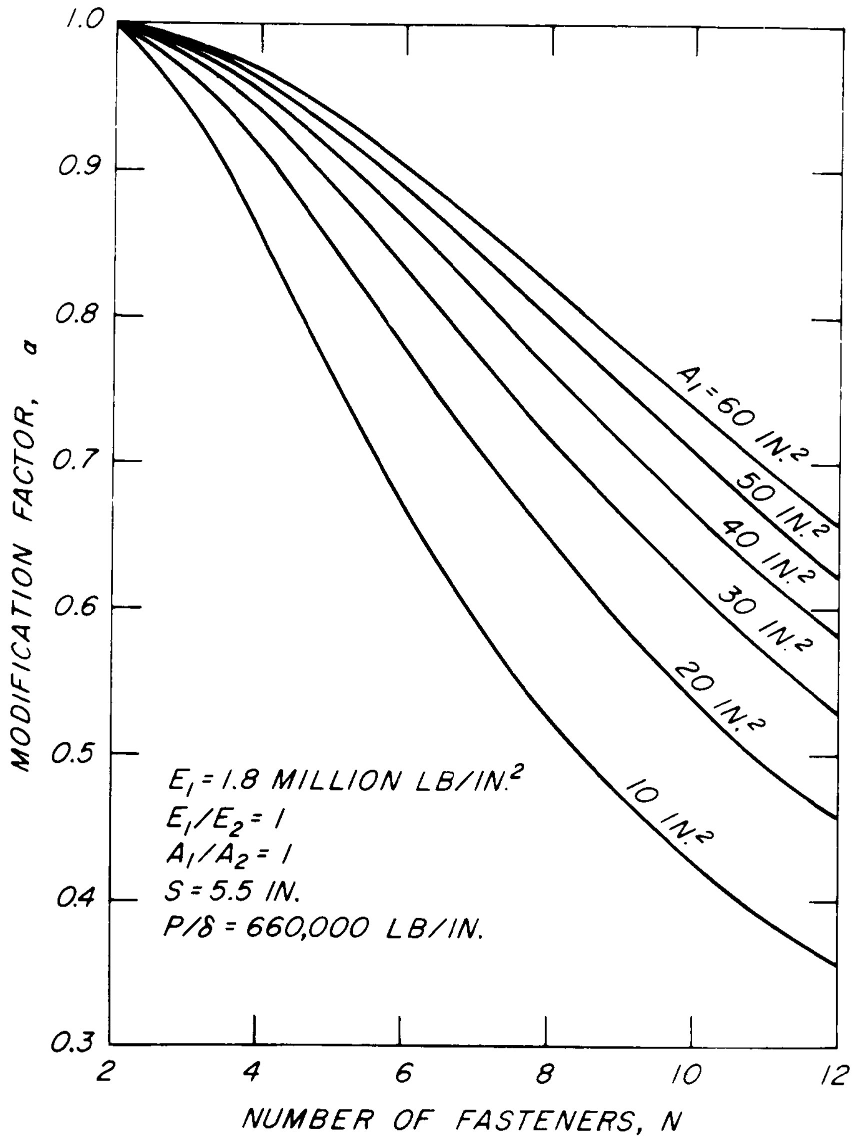

Figure 7.—Effect of joint member area upon the multiple-fastener joint modification factor for a joint with wood side plates and stiff fasteners.

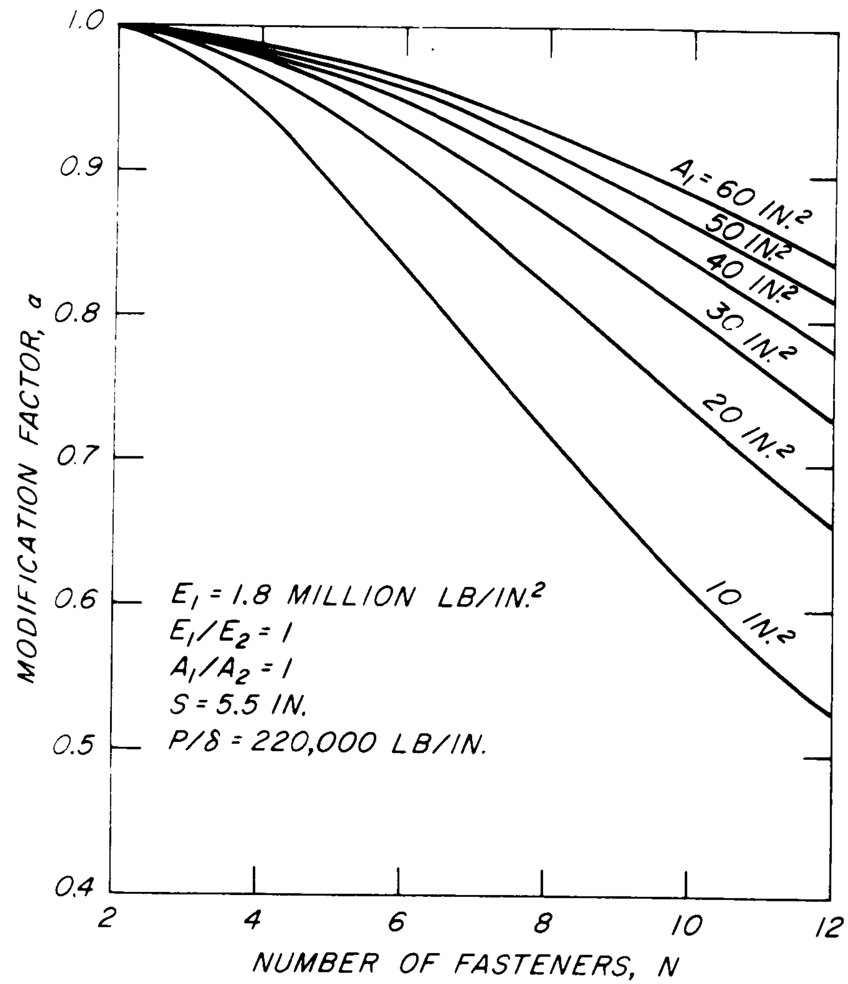

Figure 8.—Effect of joint member area upon the multiple-fastener joint modification factor for a joint with wood side plates and medium stiff fasteners.

(M 148 225)

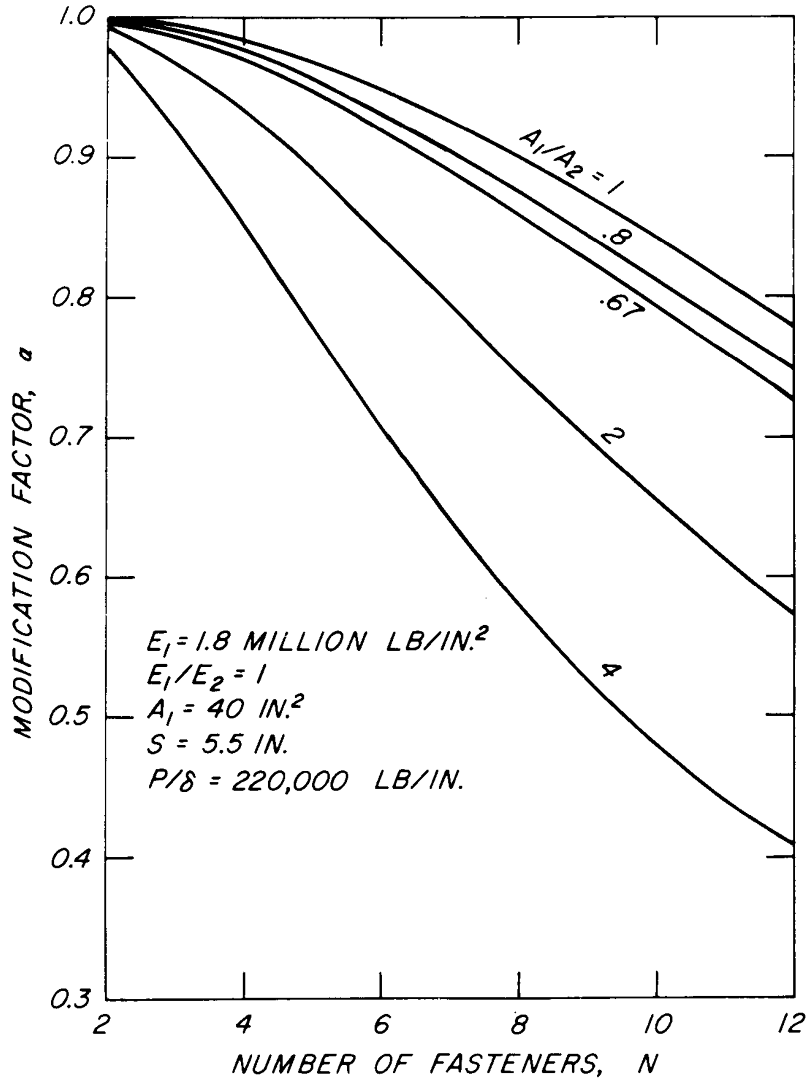

Figure 9.–Effect of relative member area upon the multiple-fastener joint modification factor for a joint with wood side plates. Curves for $A_1/A_2 > 1$ are governed by first fastener in the row, while curves for $A_1/A_2 < 1$ are governed by the last fastener.

(M 148 224)

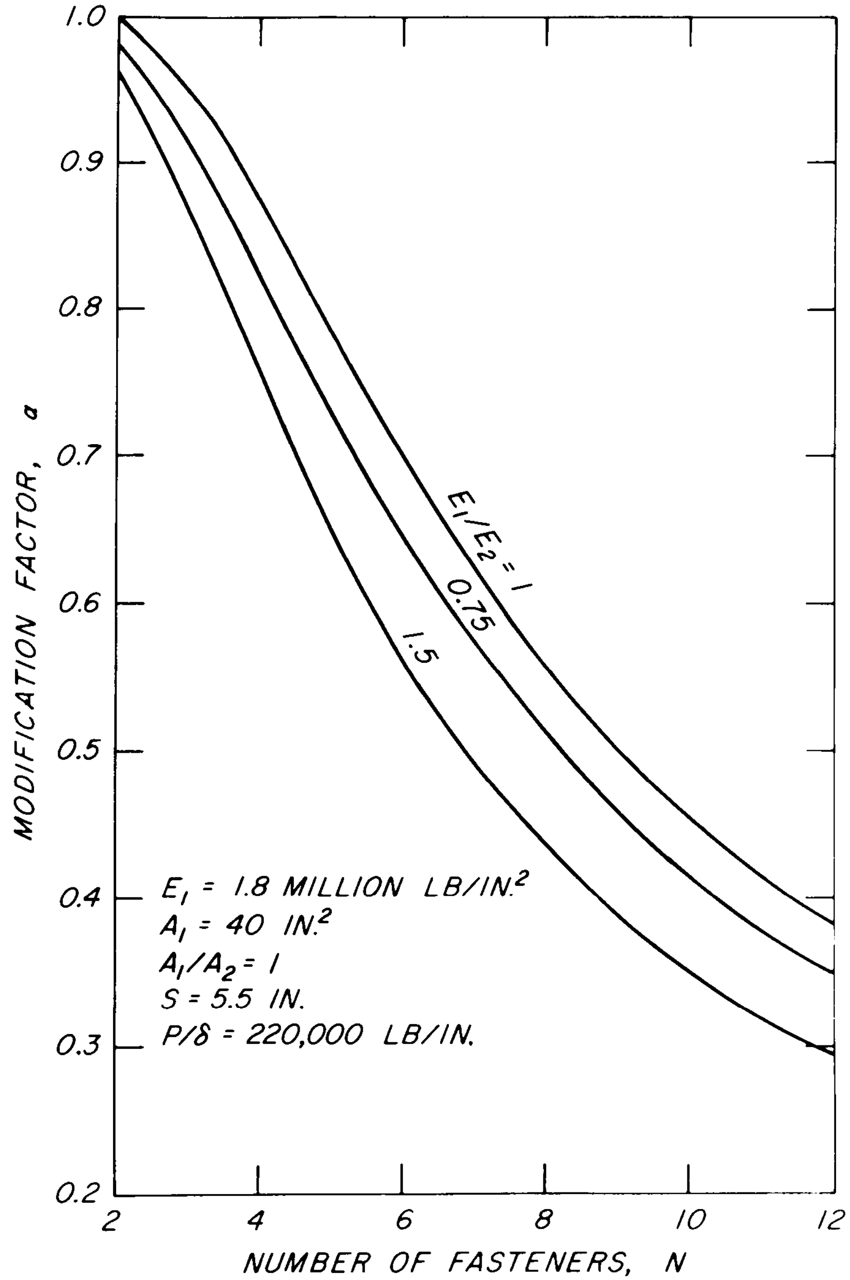

Figure 10.–Effect of relative member elastic modulus upon the multiple-fastener joint modification factor for a joint with wood side plates. The curve for $E_1/E_2 = 1.5$ is governed by the first fastener in the row, while the curve for $E_1/E_2 = 0.75$ is governed by the last fastener.

(M 148 219)

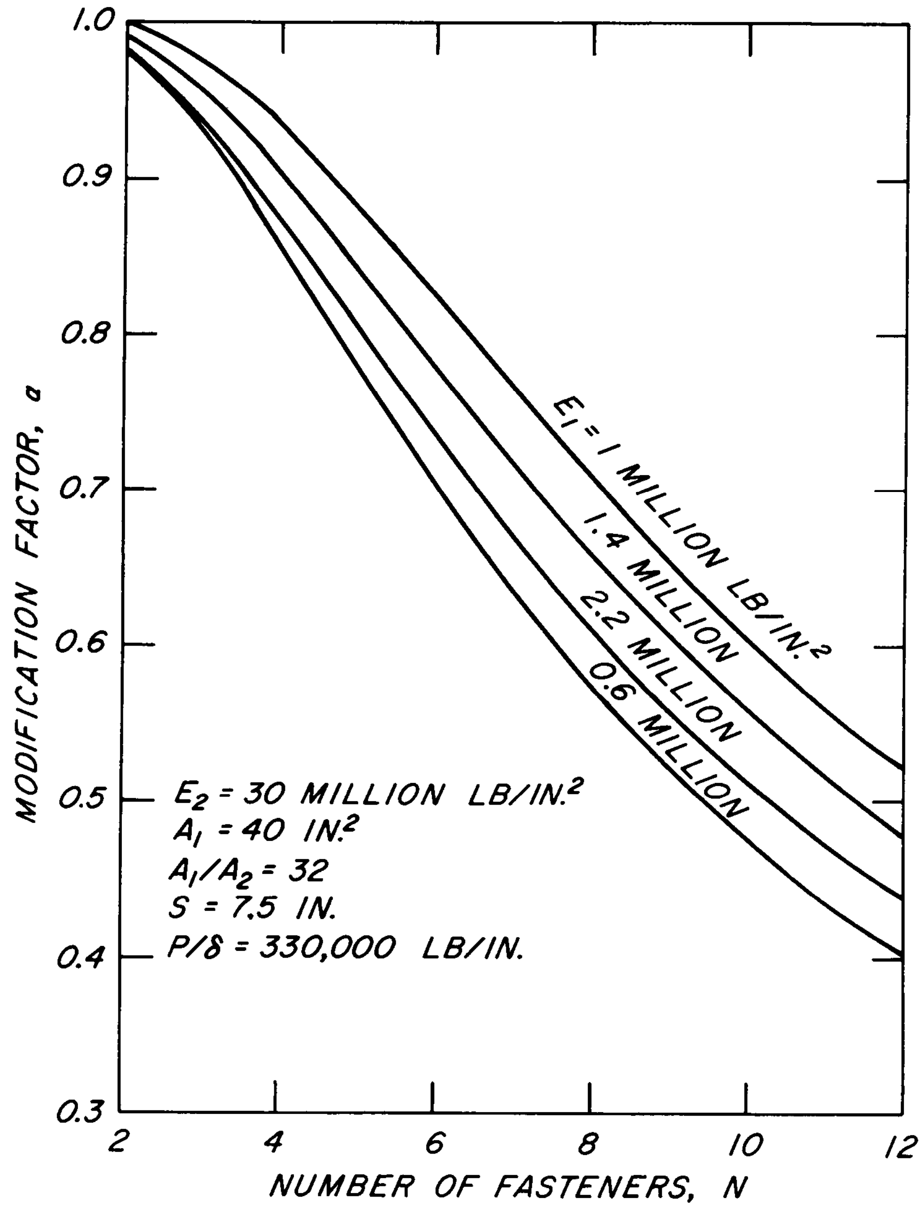

Figure 11.–Effect of main member elastic modulus upon the multiple-fastener joint modification factor for a joint with steel side plates. The curve for E_1 = 0.6 x 10^6 lb/in^2 is governed by the last fastener in the row while the other curves are governed by the first fastener.

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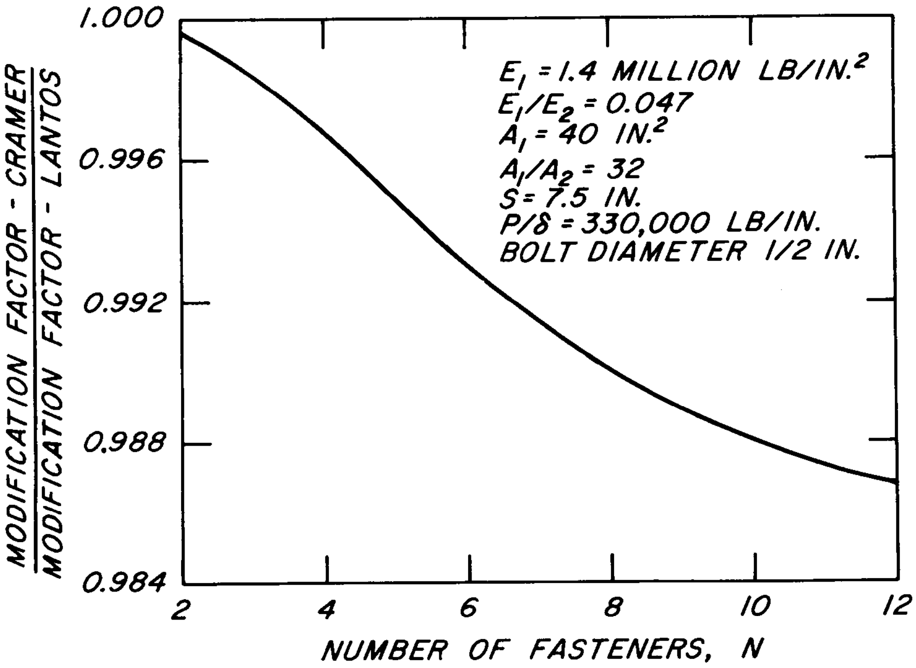

Figure 12.–Comparison of the Cramer and Lantos methods of calculating modification factors for rows of fasteners in a joint with steel side plates.

(M 148 218)

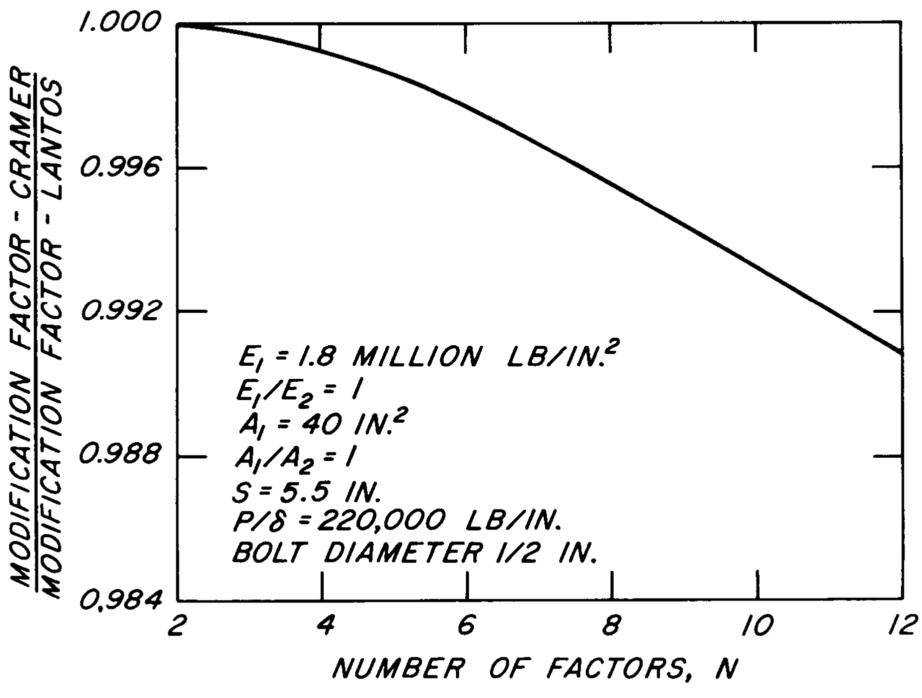

Figure 13.–Comparison of the Cramer and Lantos methods of calculating modification factors for rows of fasteners in a joint with wood side plates.

(M 148 217)

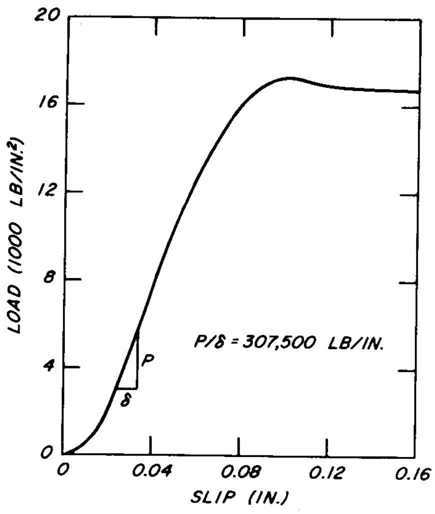

Figure 14.– Typical load-slip curve for a 2-5/8-inch shear plate in white pine. (3/4-in. bolt; 3/8- by 4-in. steel side plates, and 3.0- by 3.6-in. main member).

(M 148 214)

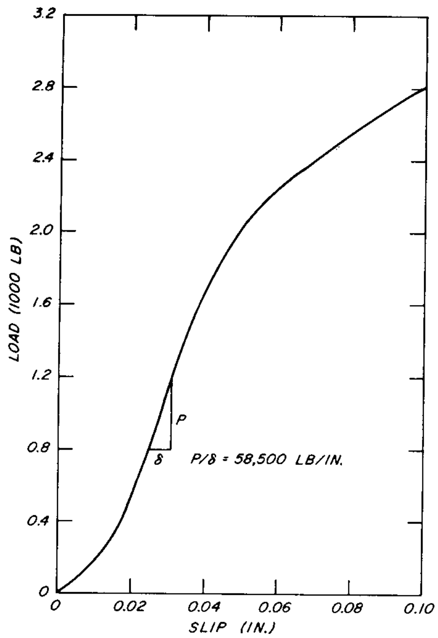

Figure 15.–Typical partial load-slip curve for a 1/2-inch bolt in Sitka spruce with loading parallel to the grain. (2- by 3-in. wood side plates; 4-by 3-in. main member; maximum load = 9,100 lb.; L/D = 8.)

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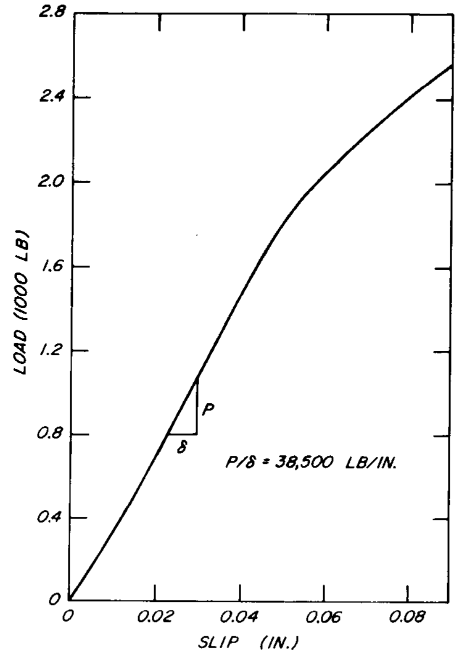

Figure 16.–Typical partial load-slip curve for a 1/2-inch bolt in Sitka spruce with loading perpendicular to the grain in the main member. (2-by 3-in. side members; 4- by 3-in. main member; maximum load = 4,400 lb.; L/D = 8.)

(M 148 216)

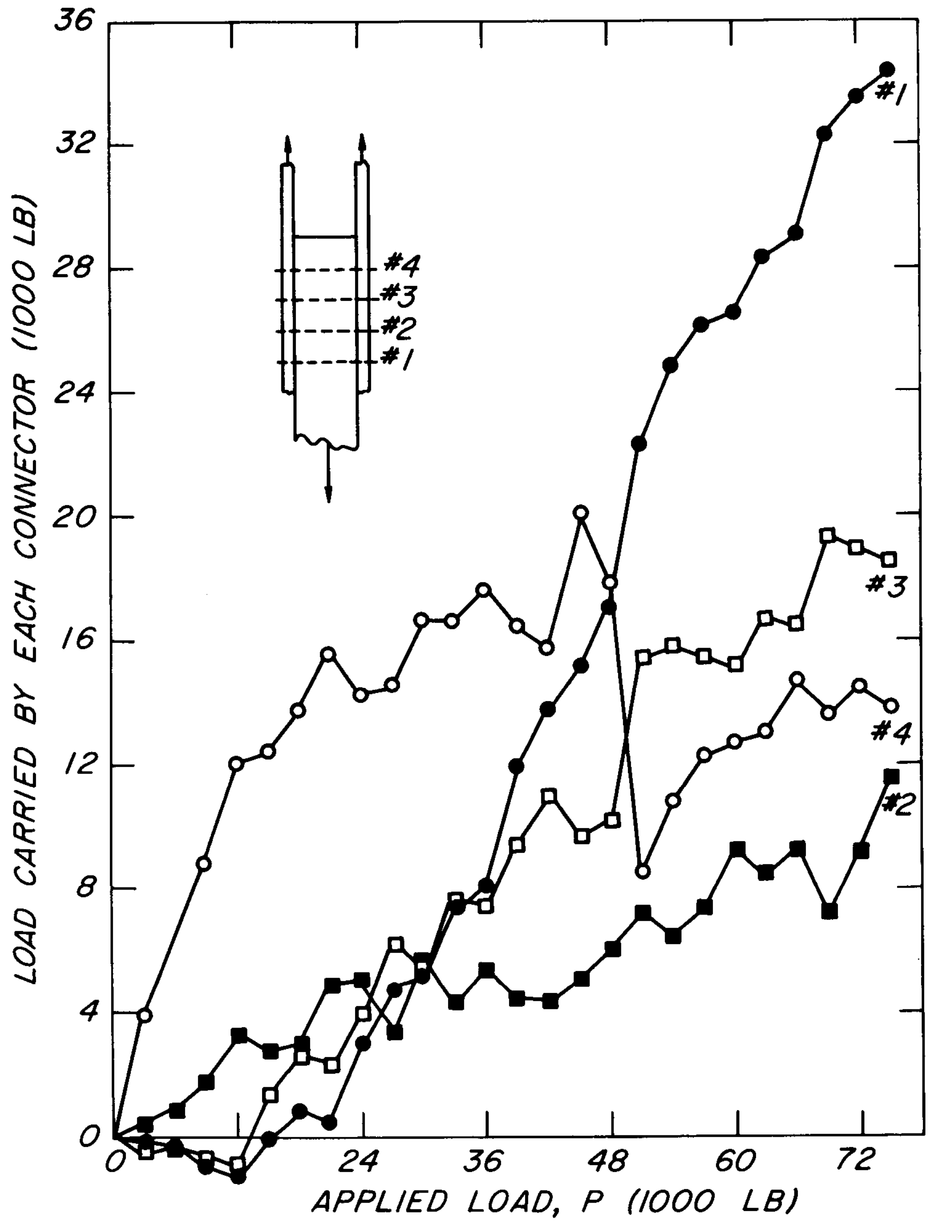

Figure 17.–Distribution of load among four connectors in a row as measured by Dannenberg and Sexsmith (3).

(M 148231)

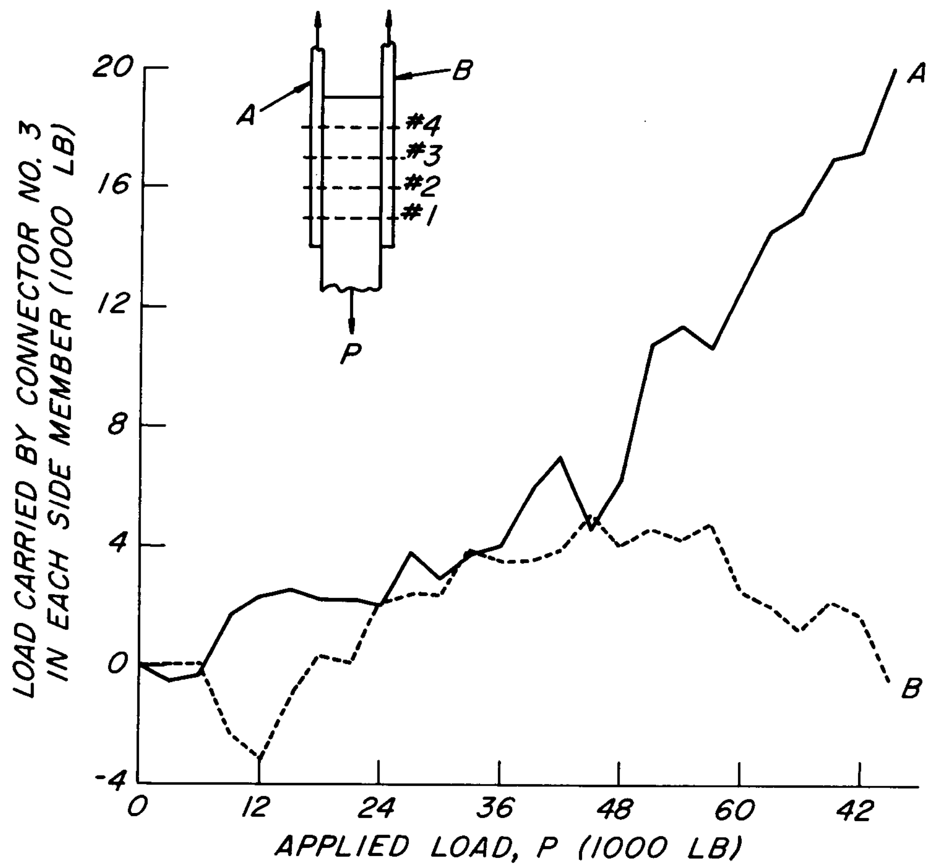

Figure 18.–Load in each side plate carried by connector number 3 as determined by Dannenberg and Sexsmith (3).

(M 148 230)

Table 1.–Modification factors for timber connector, bolt, and laterally loaded lag-screw joints with wood side plates as listed in (1) and (2)

A_1/A_2[(1)]	A_1[(2)]	Number of fasteners in a row										
		2	3	4	5	6	7	8	9	10	11	12
	$In.^2$											
0.5[(3,4)]	<12	1.00	0.92	0.84	0.76	0.68	0.61	0.55	0.49	0.43	0.38	0.34
	12-19	1.00	.95	.88	.82	.75	.68	.62	.57	.52	.48	.43
	>19-28	1.00	.97	.93	.88	.82	.77	.71	.67	.63	.59	.55
	>28-40	1.00	.98	.96	.92	.87	.83	.79	.75	.71	.69	.69
	>40-64	1.00	1.00	.97	.94	.90	.86	.83	.79	.76	.74	.72
	>64	1.00	1.00	.98	.95	.91	.88	.85	.82	.80	.78	.76
1.0[(3,4)]	<12	1.00	.97	.92	.85	.78	.71	.65	.59	.54	.49	.44
	12-19	1.00	.98	.94	.89	.84	.78	.72	.66	.61	.56	.51
	>19-28	1.00	1.00	.97	.93	.89	.85	.80	.76	.72	.68	.64
	>28-40	1.00	1.00	.99	.96	.92	.89	.86	.83	.80	.78	.75
	>40-64	1.00	1.00	1.00	.97	.94	.91	.88	.85	.84	.82	.80
	>64	1.00	1.00	1.00	.99	.96	.93	.91	.88	.87	.86	.85

[(1)] A_1 = Cross sectional area of main members before boring or grooving; A_2 = sum of the cross-sectional areas of side members before boring or grooving.
[(2)] When A_1/A_2 exceeds 1.0, use A_2 instead of A_1.
[(3)] When A_1/A_2 exceeds 1.0, use A_2/A_1.
[(4)] For A_1/A_2 between 0 and 1.0, interpolate or extrapolate from the tabulated values.

Table 2.–Modification factors for timber connector, bolt, and laterally loaded lag-screw joints with metal side plates as listed in (7) and (9)

A_1/A_2[(1)]	A_1	Number of fasteners in a row										
		2	3	4	5	6	7	8	9	10	11	12
	$In.^2$											
2-12	25-39	1.00	0.94	0.87	0.80	0.73	0.67	0.61	0.56	0.51	0.46	0.42
	40-64	1.00	.96	.92	.87	.81	.75	.70	.66	.62	.58	.55
	65-119	1.00	.98	.95	.91	.87	.82	.78	.75	.72	.69	.66
	120-199	1.00	.99	.97	.95	.92	.89	.86	.84	.81	.79	.78
12-18	40-64	1.00	.98	.94	.90	.85	.80	.75	.70	.67	.62	.58
	65-119	1.00	.99	.96	.93	.90	.86	.82	.79	.75	.72	.69
	120-199	1.00	1.00	.98	.96	.94	.92	.89	.86	.83	.80	.78
	200	1.00	1.00	1.00	.98	.97	.95	.93	.91	.90	.88	.87
18-24	40-64	1.00	1.00	.96	.93	.89	.84	.79	.74	.69	.64	.59
	65-119	1.00	1.00	.97	.94	.93	.89	.86	.83	.80	.76	.73
	120-199	1.00	1.00	.99	.98	.96	.94	.92	.90	.88	.86	.85
	200	1.00	1.00	1.00	1.00	.98	.96	.95	.93	.92	.92	.91
24-30	40-64	1.00	.98	.94	.90	.85	.80	.74	.69	.65	.61	.58
	65-119	1.00	.99	.97	.93	.90	.86	.82	.79	.76	.73	.71
	120-199	1.00	1.00	.98	.96	.94	.92	.89	.87	.85	.83	.81
	200	1.00	1.00	.99	.98	.97	.95	.93	.92	.90	.89	.89
30-35	40-64	1.00	.96	.92	.86	.80	.74	.68	.64	.60	.57	.55
	65-119	1.00	.98	.95	.90	.86	.81	.76	.72	.68	.65	.62
	120-199	1.00	.99	.97	.95	.92	.88	.85	.82	.80	.78	.77
	200	1.00	1.00	.98	.97	.95	.93	.90	.89	.87	.86	.85
35-42	40-64	1.00	.95	.89	.82	.75	.69	.63	.58	.53	.49	.46
	65-119	1.00	.97	.93	.88	.82	.77	.71	.67	.63	.59	.56
	120-199	1.00	.98	.96	.93	.89	.85	.81	.78	.76	.73	.71
	200	1.00	.99	.98	.96	.93	.90	.87	.84	.82	.80	.78

[(1)] A_1 = Cross-sectional area of main member before boring or grooving; A_2 = sum of cross-sectional areas of metal side plates before drilling

Table 3.–Values of variables used in Lantos' method of analysis to arrive at modification factors for rows of fasteners(1)

Joints with	E_1	E_2	P/δ	S
	Million lb/in.^{2}	Million lb/in.^{2}	Million lb/in.	In.
Wood side members	1.8	1.8	0.22	6.5
Metal side members	1.4	30.0	.33	5.75

(1) Moduli and load-slip values are from unpublished information obtained from the Canadian Wood Council.

Table 4.–A comparison of load and load-slip values for some different kinds of fasteners in southern pine with loading parallel to the grain

Fastener type	Main member		Side member material	Load at		Load-slip value
	Thickness	Width		Proportional limit	Maximum	
	In.	In.		Lb	Lb	Lb/in.
4-inch split ring	3	5-1/2	wood	27,000	40,440	422,660
4-inch shear plate	3	5-1/2	metal	17,670	43,050	431,240
2-5/8-inch shear plate	3-1/2	3-1/2	metal	9,670	25,830	390,160
1/2-inch bolt	3	3	wood	2,100	8,730	86,840

Table 5.–Effect of fastener bearing length in the main member upon load and load-slip values for a 4-inch shear plate in southern pine with loading parallel to the grain

Main member (1)		Load at		Load-slip value
Width	Thickness	Proportional limit	Maximum	
In.	In.	Lb	Lb	Lb/in.
5-1/2	1-1/4	14,330	24,860	442,820
5-1/2	2	15,330	36,360	413,290
5-1/2	3	17,670	43,050	431,240
5-1/2	4-1/4	19,330	44,070	409,970
5-1/2	5-1/2	19,330	42,730	382,460
5-1/2	7	20,000	44,310	482,080

(1) Side members were steel

Table 6.–Effect of bolt bearing length upon load and load-slip values for a 1/2-inch bolt in southern pine with loading parallel to the grain

Main member		Side member		Load at		Load-slip value
Width	Thickness	Width	Thickness	Proportional limit	Maximum	
In.	In.	In.	In.	Lb	Lb	Lb/in.
3	2	3	1	1,900	5,720	78,400
3	3	3	1-1/2	2,100	8,730	86,840
3	4	3	2	2,180	9,240	79,890
3	5	3	2-1/2	2,000	9,720	68,560

Table 7.–Effect of species and side member material upon load and load-slip values for a 1/2-inch bolt with loading parallel to the grain

Species	Main member Width	Main member Thickness	Load at Proportional limit	Load at Maximum	Load-slip value
	In.	In.	Lb	Lb	Lb/in.
METAL SIDE MEMBERS					
Oak	3	3	2,440	—	136,890
Maple	3	3	3,280	—	121,730
Southern pine	3	3	2,880	—	121,810
WOOD SIDE MEMBERS (1- BY 3-INCH)					
Oak	2	3	2,120	6,980	98,860
Sitka spruce	2	3	1,820	5,010	76,200
Southern pine	2	3	1,900	5,720	78,400
Maple	2	3	2,150	9,620	83,500

Table 8.–Effect of species upon load and load slip values for a 4-inch shear plate with loading parallel to the grain (3.1/2. by 5-1/2-inch main member, steel side members)

Species	Load at Proportional limit	Load at Maximum	Load-slip value
	Lb	Lb	Lb/in.
Oak	20,670	50,280	369,650
White pine	16,830	35,870	425,680

Table 9.–Effect of grain direction upon load and load-slip values for a 1/2-inch bolt with metal side members (3- by 3-inch main members)

Species	Proportional limit with loading with respect to the grain: Parallel	Proportional limit with loading with respect to the grain: Perpendicular	Load-slip value with loading with respect to the grain: Parallel	Load-slip value with loading with respect to the grain: Perpendicular[1]
	Lb	Lb	Lb/in.	Lb/in.
Maple	3,280	1,950	143,870	80,940
Southern pine	2,880	2,280	121,810	108,790

(1) Main member only.

Table 10.–Variation in load and load-slip values for matched specimens of southern pine with a 1/2-inch bolt and metal side members

Main member Thickness	Main member Width	Load at Proportional limit	Load at Maximum	Load-slip value
In.	In.	Lb	Lb	Lb/in.
1	3	2,100	3,360	150,000
		1,900	3,290	126,670
		2,300	3,450	109,520
		2,500	3,240	104,170
		2,100	3,380	123,530
Average		2,200	3,340	122,780
2	3	2,600	7,080	144,440
		2,400	6,830	133,330
		2,600	6,680	216,670
		2,800	6,640	140,000
Average		2,600	6,810	158,610

Table 11.–Experimental results by Isyumov (6) for a row of timber connectors in Douglas-fir with steel side members and loading parallel to the gram

Shear plate size	Number of fasteners N	Spacing S	Single fastener: Load-slip value P/δ	Single fastener: Maximum load	Elastic modulus of main member E_1 [1]	Ratio of elastic moduli of members $E_1/_2$ [1]	Area of main member A_1	Ratio of member areas A_1/A_2	Maximum load for row of fasteners	Modification factor, *a*: Based on maximum test loads	Modification factor, *a*: From Lantos' analysis	Modification factor, *a*: Present design factor[2]
In.		In.	Lb/in.	Lb	Million lb/in.^{2}		In.^{2}		Lb			
4	7	9.00	344,830	29,250	2	0.067	48.56	9.71	160,300	0.78	0.82	0.75
2-5/8	6	6.75	185,190	22,500	2	.067	24.28	8.09	—	—	.88	(3)—
4	7	9.00	357,140	30,840	2	.067	45.09	9.02	—	—	.80	.75
2-5/8	6	6.75	138,890	19,080	2	.067	22.55	7.52	50,800	.44	.89	(4)—
2-5/8	4	6.75	(1)138,890	(1)19,080	2	.067	22.55	7.52	43,500	.57	.96	(4)—

(1) No values were given for the modulus of elasticity, therefore a value of 2 million lb/in.^{2} was assumed for dry Douglas-fir and 30 million lb/in.^{2} for steel.
(2) Values taken from table 2.
(3) The main member area for these joints is smaller than any listed in table 2.
(4) No test of single fastener joints was made with this size member. Single fastener values from previous joint listed in the table were used.

Table 12.–Experimental results by Doyle (4) for a row of bolts in laminated Douglas-fir with steel side members and loading parallel to the grain

Bolt diameter	Number bolts N	Spacing S	Single fastener[1]: Load-slip value P/δ	Single fastener[1]: Proportional limit load	Maximum load	Elastic modulus of main member E_1	Ratio of elastic moduli member E_1/E_2	Area of main member A_1	Ratio of member areas A_1/A_2	Proportional limit load for row of fasteners	Maximum load for row of fasteners	Modification factor ? [2]: Based on proportional limit test load	Modification factor ? [2]: Based on maximum test load	Modification factor ? [2]: From Lantos' analysis
In.		In.	Lb/in.	Lb	Lb	Million lb/in.^{2}		In.^{2}		Lb	Lb			
3/4	4	3.0	348,750	5,580	13,350	1.93	0.064	12.19	4.06	23,000	32,440	1.03	0.61	0.89
3/4	4	4.5	368,820	6,270	14,480	2.46	.082	12.19	4.06	26,000	35,960	1.04	.62	.88
3/4	4	3.0	360,590	6,130	13,930	2.16	.072	12.19	4.06	24,320	38,560	.99	.69	.90
3/4	4	3.0	360,590	6,130	13,320	1.89	.063	12.19	4.06	26,200	41,400	1.07	.78	.89
3/4	4	3.0	300,370	6,600	13,180	2.13	.071	12.19	4.06	24,840	33,160	.94	.63	.91
1/2	4	3.0	202,140	2,830	9,800	2.01	.067	12.19	4.06	14,000	30,920	1.24	.79	.94
1/2	4	4.5	176,110	3,170	12,130	2.62	.087	12.19	4.06	14,520	42,080	1.15	.87	.94
1/2	4	3.0	111,030	3,220	9,330	2.02	.067	12.19	4.06	13,320	34,520	1.03	.92	.96

(1) Member dimensions for the single fastener test were 3-1/4 by 3-1/4 in. as compared to 3-1/4 by 3-3/4 for the multiple fastener test.
(2) All main member areas are smaller than listed in table 2, table of modification factors used in design.

Table 13.–Experimental results by Kunesh and Johnson (7) for a row of 3/4-inch bolts in 1-5/8-inch thick Douglas-fir members with loading parallel to the grain

Number of bolts N	Spacing S[(1)]	Single fastener: Load-slip value P/δ[(2)]	Single fastener: Propor-tional limit load(s)	Single fastener: Maximum load[(3)]	Elastic modulus of main member E[(4)]	Ratio of elastic moduli of members E_1/E_2	Area of main member A_1	Ratio of member areas A_1/A_2	Propor-tional limit load for row of fastenners	Maximum load for row of fasteners	Modification factor ?: Based on propor-tional limit load test loads	Modification factor ?: Based on test loads	Modification factor ?: From Lantos' analysis	Modification factor ?: Present design factor[(5)]
	In.	Lb/in.	Lb	Lb	Million lb/in.^{2}		In.^{2}		Lb	Lb				
2	3.0	150,000	4,680	8,580	2	1	5.21	0.5	7,840	13,170	0.84	0.77	0.99	1.00
3	3.0	150,000	4,680	8,580	2	1	6.20	.5	12,910	18,160	.92	.71	.97	.92
2	3.0	150,000	4,680	8,580	2	1	5.89	.5	8,340	14,840	.89	.86	.99	1.00
2	3.0	150,000	4,680	8,580	2	1	5.89	.5	5,000	8,920	.53	.52	1.00	1.00
2	3.0	150,000	4,680	8,580	2	1	5.89	.5	6,400	16,380	.68	.95	.99	1.00

(1) This spacing is less than the minimum permitted in design and may cause a different mode of failure than occurred in the single fastener test.
(2) No slip values were given, therefore an assumed value of 150,000 lb/in.^{2} was assumed.
(3) These values are from a specimen which was 1-5/8 by 3-13/16 in.
(4) No values were given for the modulus of elasticity, therefore a value of 2 million lb/in^2 was assumed for dry Douglas-fir.
(5) Values taken from table 1.

Table 14.–Experimental results by Dannenberg and Sexsmith (3) for a row of special pressed shear plates in laminated southern pine with steel side members and loading parallel to the grain

Number of connectors	Spacing S	Single fastener: Load-slip value P/δ[(1)]	Single fastener: Maximum load[(1)]	Elastic modulus of main member E_1[(2)]	Ratio of elastic moduli of members E_1/E_2[(2)]	Area of main member A_1	Ratio of member areas A_1/A_2	Maximum load for row of connectors	Modification factor ?: Based on maximum test loads	Modification factor ?: From Lantos' analysis	Modification factor ?: Present design factor[(3)]
	In.	Lb/in.	Lb	Million lb/in.^{2}		In.^{2}		Lb			
2	9	152,000	33,820	2	0.067	56.25	8.65	48,700	0.72	1.00	1.00
4	9	152,000	33,820	2	,067	105.62	10.83	81,600	.60	.99	.95

(1) Single fastener values were obtained on a joint with main member of 6-1/4 by 5 inches.
(2) No values were given for the modulus of elasticity, therefore a value of 2 million lb/in^2 was assumed for dry southern pine and 30 million lb/in.^{2} for steel.
(3) Values taken from table 2.

Table 15.–Experimental results by Stern (10) for a row of 2-1/2-inch split rings in Douglas-fir with loading parallel to the grain

Number of connectors	Spacing S	Single fastener[1] Load-slip value P/δ	Single fastener[1] Proportional limit load	Single fastener[1] Maximum load[3]	Elastic modulus of main member E[2]	Ratio of elastic moduli of members E_1/E_2	Area of main member A_1	Ratio of member A_1/A_2	Proportional limit load for row of connectors	Maximum load for row of connectors	Modification factor *a* Based on proportional limit test load	Modification factor *a* Based on maximum test load	Modification factor *a* From Lantos' analysis	Modification factor *a* Present design factor[3]
	In	Lb/in.	Lb	Lb	Million lb/in.^{2}		In.^{2}		Lb	Lb				
2	5.5	182,000	9,700	18,400	2	1	5.89	0.50	16,800	27,700	0.87	0.75	0.98	1.00
2	5.5	182,000	9,700	18,400	2	1	14.95	.50	18,200	33,500	.94	.91	.99	1.00
3	5.5	182,000	9,700	18,400	2	1	14.95	.50	27,400	41,500	.94	.75	.97	.95
3	5.5	182,000	9,700	18,400	2	1	5.89	.50	28,300	36,200	.97	.66	.93	.92
3	5.5	182,000	9,700	18,400	2	1	14.95	.79	28,000	51,300	.96	.93	.98	.96
4	5.5	182,000	9,700	18,400	2	1	9.52	1.24	40,300	53,000	1.04	.72	.92	.89
4	5.5	182,000	9,700	18,400	2	1	14.95	.79	39,206	51,800	1.01	.70	.95	.92
2	5.5	182,000	9,700	18,400	2	1	9.66	.83	19,400	23,759	1.00	.66	1.00	1.00
2	5.5	182,000	9,700	18,400	2	1	10.75	.50	18,300	31,300	.94	.85	.99	1.00
3	5.5	182,000	9,700	18,400	2	1	10.75	1.21	27,200	39,250	.93	.71	.97	.95
3	5.5	182,000	9,700	18,400	2	1	10.75	.50	27,250	40,650	.94	.74	.96	.92
3	5.5	182,000	9,700	18,400	2	1	10.25	.50	29,200	46,000	1.00	.83	.96	.92

(1) Single fastener values are the average of three specimens, two of which had main and side members of 2-9/16 by 4-15/16 in and one which had a main member of 1-5/8 by 5-9/16 in. and side members of 2-11/16 by 5-9/16 in.
(2) No modulus of elasticity value was given, therefore a value of 2 million lb/in.^{2} was assumed for dry Douglas-fir.
(3) Values taken from table 1.

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APPENDIX A
Lantos' Method of Analysis *(8)*

The modification factor for a row of fasteners as given by Lantos' method is the smaller value of

$$\alpha_1 = \frac{1}{nC_1} \tag{A1}$$

or

$$\alpha_2 = \frac{1}{nC_2} \tag{A2}$$

where
n = the number of fasteners

and

$$C_1 = 1 - m_1 (1 + \mu) + \mu + (m_1 - m_2) \frac{m_1^n (1 + \mu) - \mu}{m_1^n - m_2^n} \tag{A3}$$

and

$$C_2 = -\mu + m_1^{(n-1)} (1 + \mu) - (m_1^{(n-1)} - m_2^{(n-1)}) \frac{m_1^n (1 + \mu) - \mu}{m_1^n - m_2^n} \tag{A4}$$

The quantities in equations A3 and A4 are defined as

$$\mu = \frac{-1}{1 + \frac{E_i A_i}{E_o A_o}} \tag{A5}$$

where
E_i, E_o = modulus **of** elasticity **of** the main and side members, respectively.

and
A_i, A_o = cross sectional area of the main and side members, respectively.

$$m_1 = \frac{\omega + \sqrt{\omega^2 - 4}}{2} \tag{A6}$$

and

$$m_2 = \frac{\omega - \sqrt{\omega^2 - 4}}{2} \tag{A7}$$

where

$$\omega = 2 + \gamma S \left[\frac{1}{E_i A_i} + \frac{1}{E_o A_o} \right] \tag{A8}$$

In equation **A8,**
γ = the single fastener load-slip value

and
S = the fastener spacing.

APPENDIX B
Cramer's Method of Analysis *(2)*

The modification factor for a row of fasteners as given by Cramer's method is the smaller of

$$\alpha_1 = \frac{F}{nP_1} \qquad (B1)$$

or

$$\alpha_2 = \frac{F}{nP_n} \qquad (B2)$$

Where

n = the number of fasteners,

F = total load on the row of fasteners,

P_1 = load carried by first fastener in the row, and

P_n = load carried by nth fastener.

P_1 and P_n are obtained by solving the following set of simultaneous equations for the individual fastener loads, P_i.

$$\gamma P_1 - P_2 = K_w F \qquad (B3)$$

$$P_{i-1} - (1 + \gamma)P_i + P_{i+1} = 0 \quad (i = 2, \ldots, n-1) \qquad (B4)$$

and

$$P_{n-1} - \gamma P_n = -K_P F \qquad (B5)$$

The quantities in equations B3 through B5 are given by

$$\gamma = 1 + K_P + K_w \qquad (B6)$$

$$K_p = \frac{\beta_p r}{2 b_p t_p E_p Y} \qquad (B7)$$

and

$$K_w = \frac{\beta_w r}{b_w t_w E_w Y} \qquad (B8)$$

where

r = fastener spacing,

Y = slip-load value (i.e. δ_i/P) for a single fastener,

b_p = width of side plate,

b_w = width of main member,

t_p = thickness of one side plate,

t_w = thickness of main member,

E_p = modulus of elasticity of the side plates,

E_w = modulus of elasticity of the main member,

β_p = Schulz multiplying factor for the side plates, and

β_w = Schulz multiplying factor for the main member.

The Schulz multiplying factor is shown in figure B1 and is a function of bolt diameter, d.

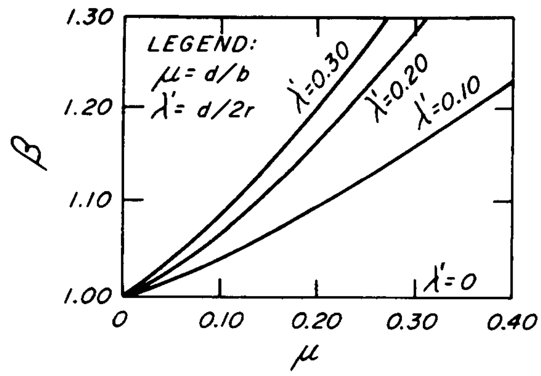

Figure B1.–Schulz multiplying factor.
(M 148 237)

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Metric Conversion Factors

1 in. = 25.4 mm

1 in.^{2} = 645.16 mm^2

1 lb = 4.4482 N

1 lb/in. = 0.175 N/mm

1 lb/in.^{2} = 6894.7 Pa

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