AN INVESTIGATION IN THE REDUCTION OF TABULATED LOADS FOR BOLTED JOINTS FABRICATED OF GREEN DOUGLAS FIR

Thesis by

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INTRODUCTION

Because of restrictions and shortages of materials and labor caused by World War II, the lumber industry has been forced to place on the market a great deal of lumber that is in a green condition. Consequently designers and engineers have been required to make use of this material.

Specifications currently being used for the design of bolted joints in wood structures require that the allowable loads as tabulated therein be reduced when the material used is green. In most cases this reduction is in the order of two thirds the tabulated value, that is to say the allowable working stress is one third the tabulated value. The conservativeness of this requirement has been questioned and it has been the purpose of this investigation to attempt to arrive at a load reduction ratio which would give a greater allowable load and a subsequent saving in labor and materials.

TYPE OF TESTS

In order to obtain the necessary data for realizing the purpose of this investigation a series of tests was set up consisting of bolted joints subjected to a tensile load and tested to failure, descriptive tests of the material used, and moisture content tests. The main series of tests was composed of twenty Douglas Fir specimens. These were fabricated from six boards of nominal dimensions 3 in. by 6 in. by 20 ft. and consisted of two main members about 3 in. by 3 in. by 2 ft. 8 in. spliced with a wood plate on each side of about 1 1/2 in. by 3 in. by 1 ft. 9 1/2 in. having one bolt 3/4 in. in diameter through each member spliced. A detailed sketch of these specimens will be found in the appendix. These dimensions conform to paragraph 600-K-1 of the "National Design Specification for Stress-Grade Lumber and Its Fastenings, 1944" which is being used as the basic specification for purposes of comparison in this investigation.

These twenty specimens were divided into four types of five specimens each. Type "A" tests were fabricated green with the diameter of the bolt hole equal to 3/4 in. giving the 3/4 in. bolt a snug fit and were tested in the green condition. Type "B" tests were also fabricated green with snug fitting bolts but were tested after seasoning. Type "C" tests were fabricated green but the bolt holes were one-sixteenth larger than the diameter of the bolt or 13/16 inches in diameter, and the tests were made after seasoning.

Type "D" tests were made with the bolts fitting snugly and the fabrication and testing was carried out after seasoning.

The bolts used were common machine bolts 3/4 inches in diameter and 7 1/2 inches long with square heads and nuts. The washers used, one under the head and another under the nut, were standard washers for 3/4 inches bolts and were 2 inches in outside diameter. This material was chosen to approximate a field condition with regard to size.

The descriptive tests of the wood were Compression Parallel to the Grain, Static Bending, and Shear. Two sticks, each 3 in. by 3 in. by 4 ft., were cut from each board delivered and half were seasoned with the main test specimens. Each stick was marked with a letter "T" denoting "Test" and a number following denoting the number of the specimen, for example, T1, T2, etc. Just before testing these sticks were cut to a nominal 2 in. by 2 in. cross section to conform to A.S.T.M. Standard Designation D 143-27 entitled "Standard Methods of Testing Small Clear Specimens of Timber."

Moisture content tests were made of each rupture of all major tests "A", "B", "C", and "D"; the test piece being taken from the ruptured section at the point of failure. In addition, moisture content samples were taken from each of the descriptive tests at their points of failure.

DESCRIPTION OF APPARATUS

All the tests made in this investigation with the exception of the moisture content tests were made on a Tinius Olsen Semi-hydraulic, Universal Type, Testing Machine in the Materials Testing Laboratory of the California Institute of Technology. The capacity of this machine is 160,000 pounds ranging over three scales, one from 0 to 16,000 pounds, one from 0 to 80,000 pounds and the third from 0 to 160,000 pounds. Throughout these tests the 0 to 16,000 pounds range was used with the exception of the compression tests in which the 0 to 80,000 pound scale was used. The machine is loaded hydraulically and the load is weighed by means of a lever system in conjunction with a pendulum upon which weights are hung for each of the different ranges of operation. A photograph of this machine with a main test in progress appears below.

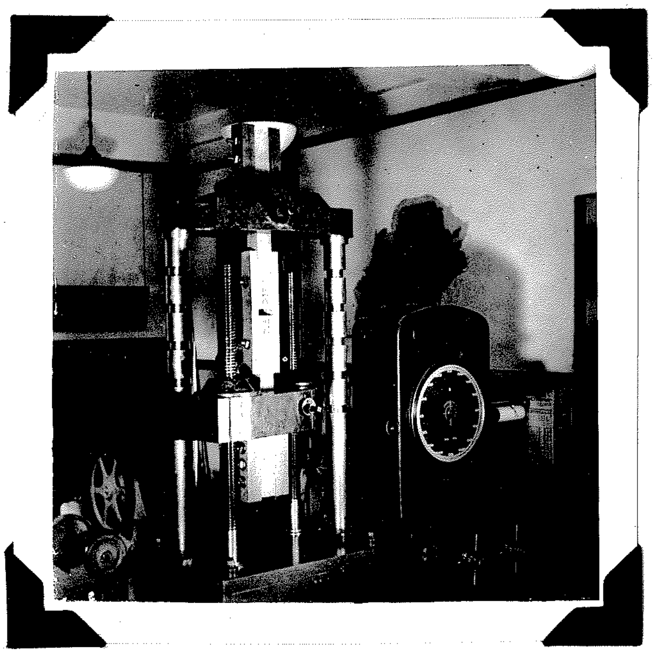

Figure 1.

In order to grip the specimens of the main tests and subject them to tensile loading, grips made of wood were found to be adequate. These grips consisted of two 3 in. by 3 in. blocks one foot long drilled to take three 3/4 inch bolts at three inch centers. One block was placed on each side of the specimen and allowed to bear on the top of the upper cross head in the testing machine and another grip was attached to the bottom of the specimen and allowed to bear on the bottom side of the lower crosshead. These grips can be seen clearly in Figure 1. and a detailed sketch appears in the appendix.

A two dial compressometer was used for the compression tests. The gage length on this instrument was five inches and the dials read a deformation as small as one one thousandth of an inch. A spherical bearing block was used under the specimen to insure axial loading as shown in Figure 2.

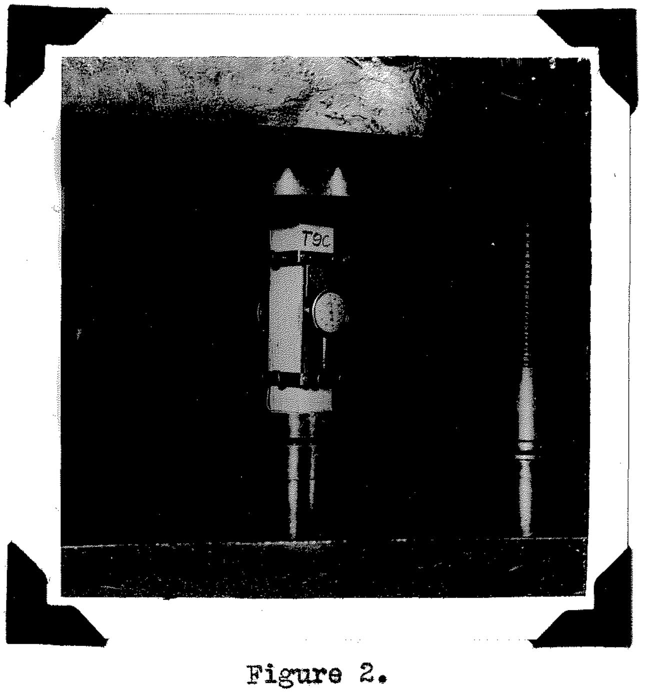

Figure 2.

For the Static Bending tests a deflectometer was used along with its supporting rack and bearing frame. The span of the bearing frame was set at 28 inches to conform to A.S.T.M. Designation D 143-27, and the deflectometer gave direct readings of deformation up to one half inch. The load was applied through a hard maple bearing block with a cylindrical surface to approximate point loading. Figure 3 gives a good view of this equipment.

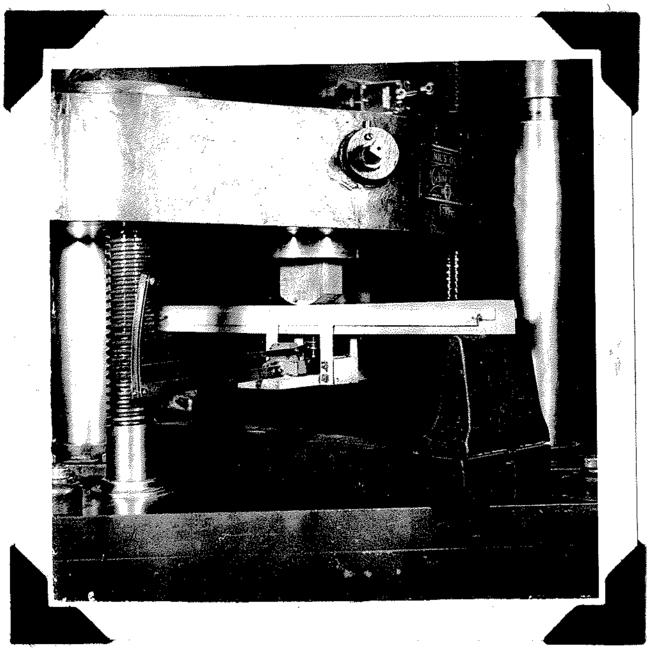

Figure 3.

The shear rig for testing the shear specimens was composed of a welded steel block with an opening two inches wide between the uprights and fitted with a loading piston in the top end block. The load was transferred to the test piece by means of a distributing plate and a bar one and one eighth inches by one half inch in cross section, the test piece being supported by another bar of the same dimensions. Figure 4 shows this rig in the testing machine.

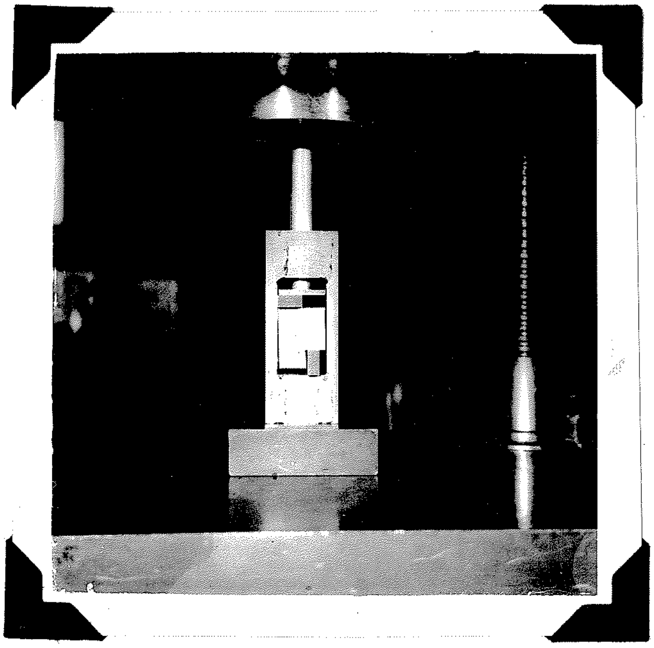

Figure 4.

The equipment used in the moisture content tests consisted of a ventilated drying oven maintaining a constant temperature of 105°C and a laboratory balance, the smallest increment of the scale being one one hundreth of a gram.

TEST PROCEDURES

MAJOR TESTS

Each joint member fabricated for the major tests was marked for identification with a letter signifying the type of test, "A", "B", "C", or "D", followed by a number denoting the sequence within the type and another letter indicating the position of the member in the joint. The meaning of these letters is as follows:

"T" - the top part of the main material.
"B" - the bottom part of the main material.
"R" - the right splice plate.
"L" - the left splice plate.

An example would be "A1R", indicating test one of type "A" and the right splice plate of that test.

Specimens of type "A" were tested right after fabrication while those of types "B", "C", were seasoned. Type "D" was seasoned and then fabricated. This seasoning was accomplished in a little over two months time in the plenum chamber of a large ventilating fan. The air that was passed over the specimens being cured averaged an approximate air temperature of 90°F. and a relative humidity of 30%. Since this fan was not in operation during the night the air was only kept in motion 12 hours each day during the curing period. Very little checking or other seasoning defects were noted at the end of the process.

In order to eleminate the variable conditions which might arise due to a variance in the tightness of the bolts in the member under test, each nut was tightened until it would sustain a torque of 203 in. lbs. without undergoing further rotation.

Immediately before testing each specimen, a line was inscribed with black ink on the front and back faces of the joint at the position of the center lines of each bolt in the joint. These lines allowed a qualitative measure of the deformations occuring at the bolts to be obtained.

The dimensions of each member of the joint were measured accurately, both in the direction of the bolt and perpendicular to the direction of the bolt, before inserting the test specimen in the testing machine. The autographic device was set and the load applied at a uniform rate of 600 pounds per minute. This rate was the slowest uniform one that could be attained with the testing machine.

After the specimen ruptured and was removed from the testing machine, the number of growth rings per inch and the percentage of summerwood for the part of the joint that failed was recorded. Also a part of this failed piece, usually the portion that sheared out, was set aside and used for a moisture content determination.

DESCRIPTIVE TESTS

The specimens for the compression test were eight inch pieces cut from the end of the 2 in. by 2 in. test sticks and were marked with the appropriate stick mark followed by the letter "C" denoting "compression". The number of growth rings per inch and the percentage of summerwood in each piece was recorded and each specimen was set up in the compressometer as shown in Figure 2. 1000 pound increments of load were selected as the basis for the strain measurements and the load was applied at a uniform rate of 3000 pounds per minute. This value was selected to conform to the requirements of the A.S.T.M. Designation D 143-27 and the tests were carried out after the manner specified therein.

The specimens for the bending tests were each thirty inches long and were cut from the test sticks and marked appropriately with the stick mark and with the letter "B" following to denote "bending". Again the number of growth rings per inch and the percentage of summerwood was recorded and each specimen was inserted in the deflectometer frame and placed in the testing machine as shown in Figure 3. The increment of loading for these specimens was 100 pounds and the rate of loading was 600 pounds per minute. The tests were run in accordance with the A.S.T.M. procedure.

Two shear specimens, each two and one half inches long, were cut from each test stick and notched with a standard 3/4 inch notch as shown in the A.S.T.M. Designation. This notching was done in such a manner that the load was applied parallel to the grain once in a tangential direction and once in a radial direction for each test stick. The markings applied to these specimens were made up of the test stick mark plus an "S" denoting "shear" and the letter "T" or "R" for tangential or radial loading. The photograph below shows a typical shear specimen with its markings.

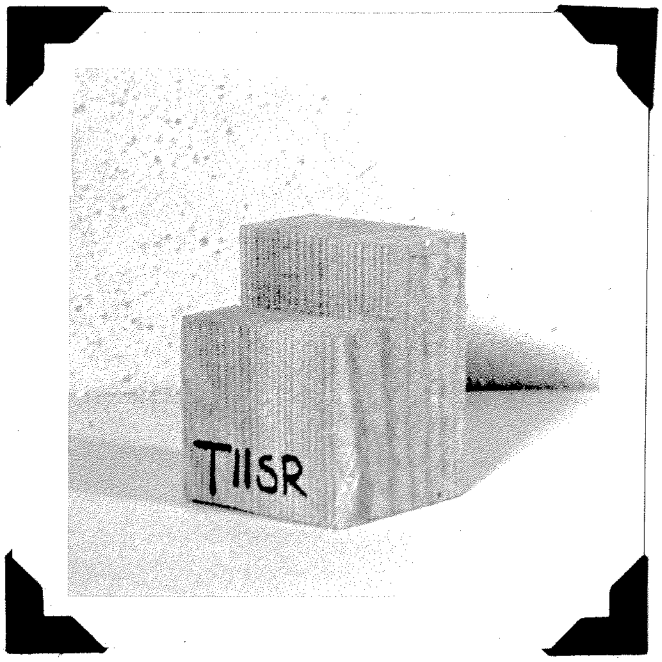

Figure 5.

After recording the number of growth rings per inch and the percentage of summerwood of each specimen, it was inserted in the shear rig, and the rig and specimen placed in the testing machine as pictured in Figure 4. The load was applied to the rig at a rate of 600 pounds per minute and the ultimate shearing value recorded as indicated in the A.S.T.M. Designation.

MOISTURE CONTENT TESTS

After the specimen was selected for a moisture content determination as previously noted it was weighed and the weight obtained recorded as the wet weight. The specimen was then placed in the drying oven and reweighed each successive day for a period of four days. The difference in the wet weight and the dry weight expressed as a percentage of the dry weight was taken as the percent moisture content. The markings on these specimens corresponded to the test pieces from which they were taken.

DISCUSSION OF RESULTS

DESCRIPTIVE TESTS

A summary of the results of the descriptive tests for the wood is to be found in Tables V, VI, and VII in the Appendix. At the time of delivery the material used was classed as Douglas Fir (Coast Region)(Pseudotsuga taxifolia) and the subsequent tests confirmed this claim reasonably well. Using the values tabulated on pages 50 to 53 in the Wood Handbook[1] the values obtained from the tests for compression parallel to the grain appear somewhat low for Coast Region Douglas Fir and more nearly match that of the Rocky Mountain Region growth. The values obtained in shear and in the static bending tests agree favorably with the Coast Region material for both green and seasoned conditions.

Some typical failures of the compression specimens are shown in Figures 6 to 8 inclusive, and Figure 9 shows one bending specimen which split in a nearly vertical plane under test due to a long seasoning check in the material and a pitch pocket completely hidden from view until after failure.

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[1]"Wood Handbook, Basic Information on Wood as a Material of Construc- of Construction with Data for Its Use in Design and Specifications" Forest Products Laboratory, 1940.

Figure 6

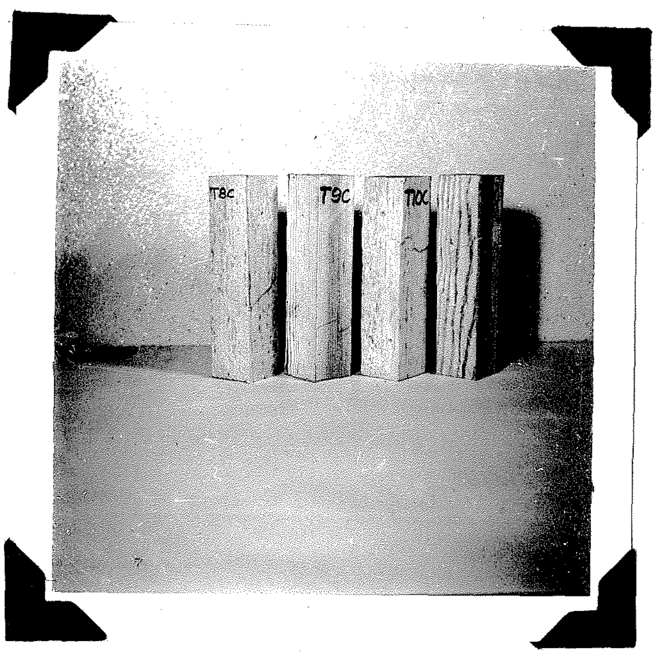

Figure 7

Figure 8

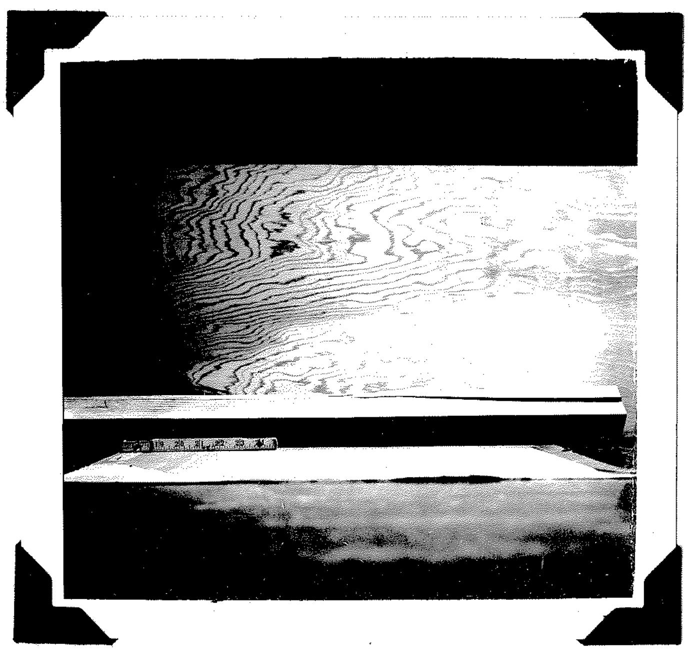

Figure 9

MAJOR TESTS

A summary of test results for the major tests will be found in Tables I to IV in the appendix.

It was noted throughout these tests that certain sticks gave consistently higher values for whatever condition to which they were subjected. These particular sticks came from a board whose annual growth rings averaged about 12 in number, whose summerwood composed about 25 percent of the total, and which was a light salmon color. It was also noted that this material was more difficult to work during fabrication.

No special attempt was made during fabrication to make measurements or establish centerings beyond the customary care consistent with good carpentry under field conditions, and as has been stated before, the size of materials used was selected to conform as nearly as possible to such field conditions.

In most of the tests failure occured in one of the splice plates. This failure was one of shear parallel to the grain. A piece about 3/4 inches in width and extending from the bolt to the end of the splice plate sheared out and in some cases caused the splice plate to split its entire length. Figure 10 shows a typical failure of the first kind and Figure 11 shows one of the second kind.

Because of the irregularities of the area under shear in such failures, only an average assumed area can be used to approximate the shearing stress in the material. The following values are based on a two plane shear section of one and one half by five and one quarter inches and the average adjusted ultimate strengths of the tested joints.

Tests "A" - 390 lbs./sq. in.
Tests "B" - 240 lbs./sq. in.
Tests "C" - 268 lbs./sq. in.
Tests "D" - 330 lbs./sq. in.

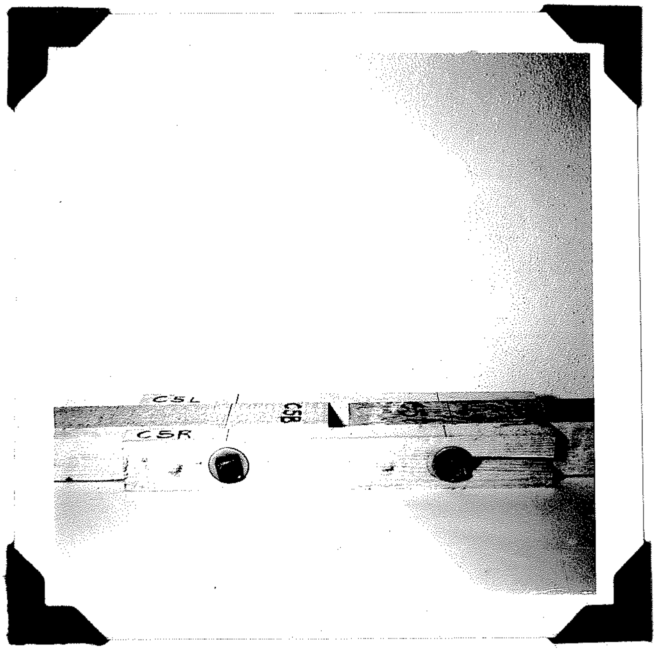

Figure 10

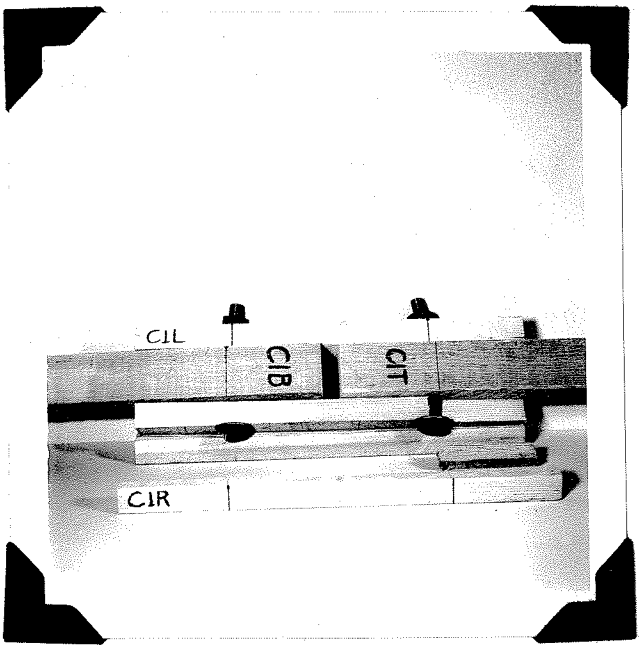

Figure 11

These values are considerably lower than the values as obtained by means of the descriptive tests of the wood. Undoubtedly this can be explained by the fact that as the load comes on the joint and rupture approaches, the unit stress in bearing on the inner edge of the splice plate increases rapidly. This increase can be as much as ten times the average unit stress according to Gayer[2] and it is reasonable to expect the shearing unit stress which accompanies the bearing unit stress to be likewise increased. Failure therefore occures when the inner edge is overstressed, and the subsequent failure progresses outwardly.

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[2] "Bolted Timber Joints" by Martin R. Gayer, Thesis for Master of Science Degree, California Institute of Technology, 1944.

The bending of the bolts can also account for the lack of failures in the main material being spliced. (Only one test, "A1", failed in this manner). As the bolt bends, the head, nut, and washers, force the material closer together in the region between the bolts and allow the open ends of the splice plates to remain free and actually to move outward in some cases. This compressive restraint in the main material reduces the concentration of stress at the edges and gives a more uniform distribution of stress across the joint. The magnitude of this reduction however, is beyond the scope of this paper.

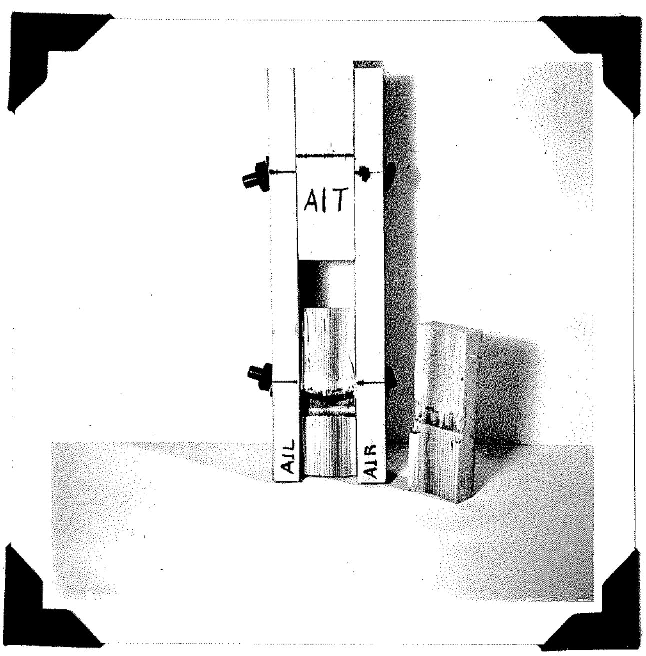

Figure 12

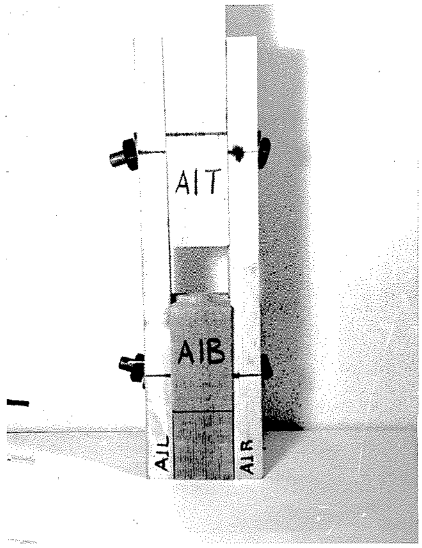

Figure 13

Figures 12 and 13 show the failure of test "A1" and give an idea as to the magnitude of the bending in the bolts. It should be kept in mind that this is really typical of only the green specimens, but that the seasoned ones also showed a bending of the bolt to a lesser degree. This can be observed in figure 11.

The greatest amount of displacement of lines indicating deformation in the joint was found to occur in test type "A" which is to be expected of the tough green material. Tests "B" showed the least amount of displacement of lines. Below are given the values of displacement at the top and bottom bolt for the four types of tests.

Test Type	Top Bolt	Bottom Bolt
A	0.69 in.	0.70 in.
B	0.21 in.	0.18 in.
C	0.28 in.	0.22 in.
D	0.35 in.	0.33 in.

The L/D value of all the specimens tested was 4.0.

The Wood Handbook[3] on page 130 states the following:

"The slip in a bolted timber joint is proportional to the load up to a certain point, which may be regarded as a proportional limit even though in the true sense of the word it is not one, since the joint will have a slight set if the load is removed"; and also that: "The properties of the wood and of the bolt both play a part in producing the proportional limit."

Trayer[4] states the following in addition:

"Although the strength properties of the bolt control to a considerable extent the magnitude of the proportional limit load on a bolted joint, within the limits of the investigation the maximum load appeared to be controlled almost entirely by the strength characteristics of the wood; this fact is important."

The reader is referred to the tables in the appendix for the proportional limit loads that were found during these tests. In the types of tests that were made after seasoning, these values have been adjusted to a constant moisture content value of 12 percent for ease in comparison. The equations actually used in this adjustment are also given on the table page and are based on the method as given in the Wood Handbook on page 62.

It is to be noted that a considerable reduction in the strength of the tests "B" from that of tests "A" is shown. This reduction was anticipated inasmuch as tests "B" were fabricated green and then

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[3]Op. cit. footnote 1.
[4]"The Bearing Strength of Wood Under Bolts" U.S. Dept. of Agriculture Bulletin #332 by George W. Trayer

seasoned. Tests of type "C" in which the bolts were inserted loose in the holes showed a hegher value for both the ultimate load and the proportional limit load than that of tests "B" in which the bolts were snug. These values still fell well under the green tests. One explanation for this difference is that there was probably some tendency for the wood around the tight bolt to check more severely and cause a splitting action in the wood fibres, while the wood around the loose bolts had a small amount of room in which to shrink.

The values obtained from tests "D" showed a higher proportional limit load but a lower ultimate strength than the tests "A". This too, would seem to be in line with the seasoning properties of the material in that the proportional limit would be expected to be higher in the seasoned wood because of the lower moisture content. The increased brittleness of the wood upon drying would account for the reduction in the ultimate strength.

The tabulated load for bolted joints of the type used from Table 12 in the National Design Specification is 2,590 lbs. If section 600-F-2 is applied to this value, the allowable design load becomes 864 lbs., (the two thirds reduction previously referred to).

In a letter to Mr. Charles MacKintosh, Chairman, Timber Research Committee of the Structural Engineers Association of Southern California, Mr. G.E. Heck, Engineer for the Forest Products Laboratory states:

"A summary of our data which form the basis of paragraph 600-F-2 is given on pages 37 and 38 of U.S. Dept. Agr. Tech. Bull. 332, "The Bearing Strength of Wood Under Bolts," enclosed. The tests were made on joints consisting of four 1/2 inch bolts bearing perpendicular to the grain of Douglas-fir. Five tests were made in each of five thicknesses ranging from 2 to 6 inches. The individual results varied considerably, but the average ratio between the proportional limit of the joints assembled when green and allowed to season and that of the proportional limit of joints made of dry material was 42, 26, 30, 51, and 32 percent for L/D's of 4, 6, 8, 10, and 12, respectively. The average of these ratios is 36 percent."

It is clear from this statement that the use of this paragraph in the design of bolted joints in which the load is parallel to the direction of the grain is in error.

If a one third reduction in the tabulated load is used the allowable design load becomes 1728 lbs. Also if a factor of safety of 1.66 is applied to the proportional limit of the worst type condition of these tests, that of type "B", the allowable load value based on the test becomes 1990 lbs. which is greater than that allowed by the one third reduction used above. This 1.66 factor of safety has been applied to the proportional limit loads of the other tests and is shown in their respective summary tables.

CONCLUSIONS

The author draws the following conclusions from the results of these tests:

1. Since in every case the allowable load value obtained from these tests exceeded that of the allowable load value obtained from the specifications with a reduction of only one third, it is the author's opinion that a one third reduction in the tabulated loads for bolted joints fabricated of green Douglas Fir is adequate for designing timber structures.

2. As a secondary conclusion, it is the author's opinion that for bolted joints fabricated of green material it would be wise to use bolt holes 1/16 in. larger than the nominal size of the bolts being used.

It is realized that these tests are only a small fragment of the testing needed to obtain general conclusions for all types of timber under the many varied conditions which are met in the every-day practice of the designer and engineer. Therefore the author wishes to point out that these results apply only to the materials and conditions as used in this investigation and while not general enough to be applied in every case, they give an insight into what may take place using other types of wood and other conditions.

APPENDIX

TABLE I

TESTS "A"

Material Green
Fabrication Green
Bolts Snug

Test Piece	Rings per Inch	Summerwood %	% Moisture Content	Proportional Limit(lbs.)	Ultimate Strength(lbs)
A1	10	25	18.7	4300	13,700
A2	23	20	15.3	3600	10,800
A3	10	25	15.0	3850	13,080
A4	11	30	20.0	4400	11,420
A5	14	30	13.6	3800	12,440
Average			16.5	3990	12,288

Allowable load determined with factor of safety of 1.66 on Proportional Limit equals 2332 lbs.

TABLE II

TESTS "B"

Material Seasoned After Fabrication
Fabrication Green
Bolts Snug

Test Piece	Rings per Inch	Summerwood %	% Moisture Content	Proportional Limit (lbs.)	Ultimate Strength(lbs.)
B1	15	20	8.4	3650	9690
B2	13	30	7.5	4200	8100
B3	14	25	7.7	3400	8150
B4	11	30	8.7	4000	8650
B5	14	30	8.3	3550	9320
Average			8.1	3760	8782
Adjusted to 12% moisture content				3312	7551

Allowable load determined with factor of safety of 1.66 on Proportional Limit equals 1990 lbs.

Adjusting Equations

Proportional Limit: $\text{Log } S = \text{Log } T + (M_T - 12)\ \frac{\text{Log } 1.50}{12}$

Ultimate Strength: $\text{Log } S = \text{Log } T + (M_T - 12)\ \frac{\text{Log } 1.60}{12}$

TABLE III

TESTS "C"

Material Seasoned After Fabrication
Fabrication Green
Bolts Loose

Test Piece	Rings per Inch	Summerwood %	% Moisture Content	Proportional Limit (lbs.)	Ultimate Strength (lbs)
C1	11	20	9.0	4450	9460
C2	12	25	8.7	4400	9100
C3	11	30	8.4	4200	9770
C4	12	20	9.3	4200	8650
C5	14	25	10.2	4000	9520
Average			9.1	4250	9300
Adjusted to 12% Moisture Content				3854	8445

Allowable load determined with factor of safety of 1.66 on Proportional Limit equals 2320 lbs.

Adjusting Equations

Proportional Limit: $\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.50}{12}$

Ultimate Strength: $\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.60}{12}$

TABLE IV

TESTS "D"

Material Seasoned
Fabrication After Seasoning
Bolts Snug

Test Piece	Rings per Inch	Summerwood %	%Moisture Content	Proportional Limit (lbs.)	Ultimate Strength(lbs)
D1	16	30	12.0	4670	11,160
D2	16	30	11.1	5100	11,150
D3	14	25	9.9	4250	10,910
D4	13	30	12.2	5050	10,690
D5	14	25	9.7	4400	10,270
Average			10.9	4694	10,836
Adjusted to 12% Moisture Content				4523	10,379

Allowable load determined with factor of safety of 1.66 on Proportional Limit Equals 2720 lbs.

Adjusting Equations

Proportional Limit: $\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.50}{12}$

Ultimate Strength: $\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.60}{12}$

TABLE V

SUMMARY OF COMPRESSION TESTS

PARALLEL TO THE GRAIN

Green Material

Test Piece	Rings per Inch	Summerwood %	% Moisture Content	Proportional Limit (lbs/in^2)	Ultimate Strength (lbs/in^2)
T1C	44	20	24.6	1525	2797
T2C-2	13	30	25.4	1985	3336
T3C	27	20	31.1	2200	3280
T4C-2	23	25	25.4	1264	2790
T5C	13	30	23.0	2550	4836
T6C	14	30	22.8	3550	4618
Average			25.4	2179	3609

Seasoned Material

Test Piece	Rings per Inch	Summerwood %	% Moisture Content	Proportional Limit (lbs/in^2)	Ultimate Strength (lbs/in^2)
T7C	23	30	10.4	2900	6520
T8C	30	30	10.8	3900	6140
T9C	14	25	10.7	5400	8650
T10C	35	30	10.4	3250	5690
T11C	14	25	10.8	7500	9330
T12C	12	20	9.2	4000	8340
Average			10.4	4491	7445
Adjusted to 12% Moisture Content				4150	6806

Adjusting Equations

Proportional Limit Stress:

$$\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.81}{12}$$

Ultimate Strength Stress:

$$\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.96}{12}$$

TABLE VI

SUMMARY OF SHEAR TESTS

PARALLEL TO GRAIN

Green Material

Test Stick	Rings per Inch	Summerwood %	% Moisture Content	Shear Stress Tangential Loading	Shear Stress Radial Loading
T1	40	30	17.8	884 #/in^2	988 #/in^2
T2	13	25	18.4	720	923
T3	25	20	21.7	743	882
T4	23	30	22.0	784	888
T5	13	25	21.7	885	1028
T6	14	25	17.9	935	1170
Average			19.9	826	979

Seasoned Material

Test Stick	Rings per Inch	Summerwood %	% Moisture Content	Shear Stress Tangential Loading	Shear Stress Radial Loading
T7	29	20	12.0	1068 #/in^2	1137 #/in^2
T8	27	20	12.2	1119	1160
T9	14	30	11.0	1135	1680
T10	40	30	10.7	917	960
T11	13	30	10.9	1172	1100
T12	12	25	10.3	1175	1600
Average			11.2	1098	1273
Adjusted to 12% Moisture Content				1075	1245

Adjusting Equation:

$$\text{Log } S = \text{Log } T + (M_T - 12)\frac{\text{Log } 1.40}{12}$$

TABLE VII

SUMMARY OF STATIC BENDING TESTS

Green Material

Test Stick	Rings per Inch	Summerwood %	% Moisture Content	Medulus of Rupture
T1	40	30	21.5	5790 $\#/in^2$
T2	13	25	25.4	7280
T3	25	20	24.4	5870
T4	23	30	27.1	8020
T5	13	30	23.0	7580
T6	14	30	22.0	8600
Average			23.9	7190

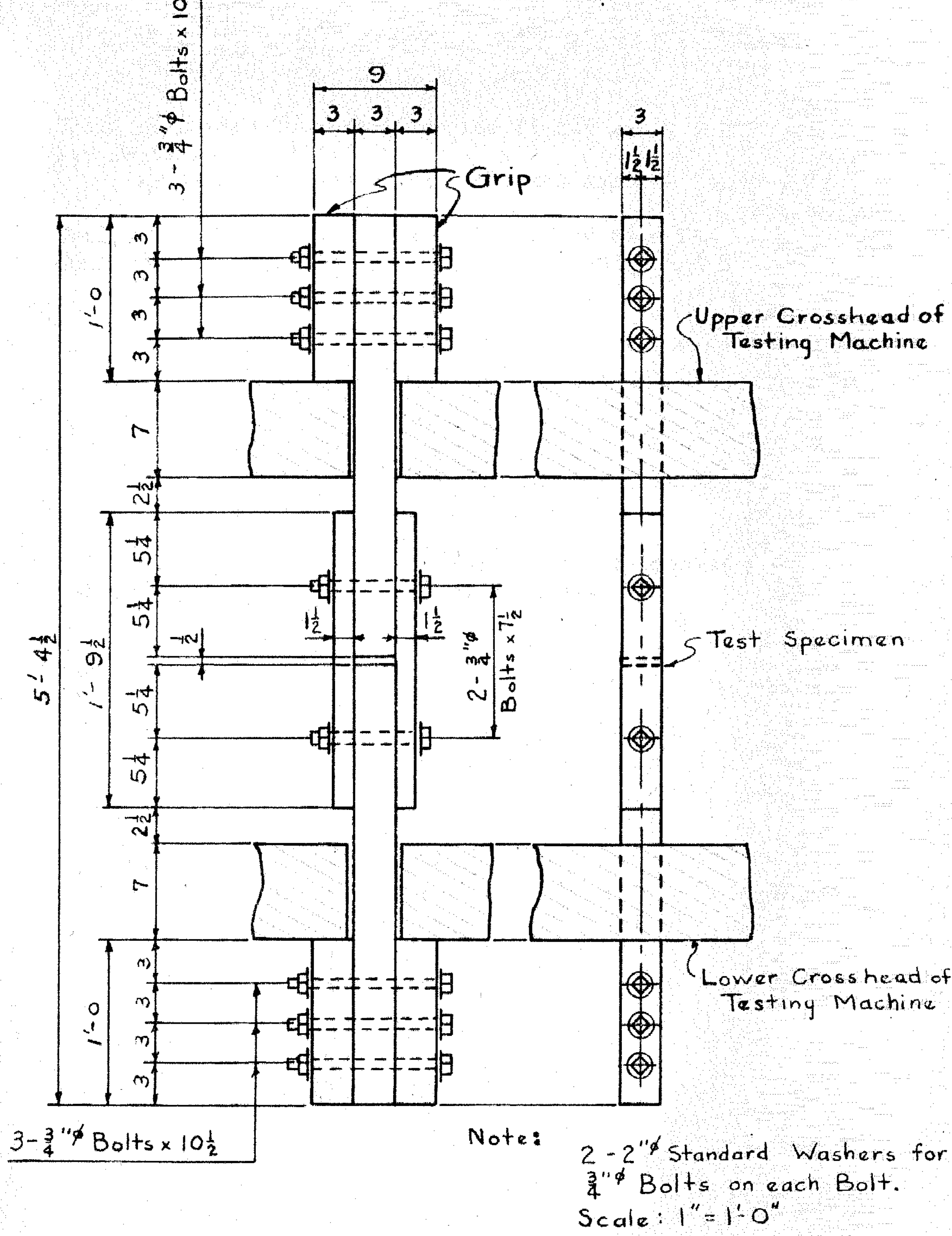
Seasoned Material

Test Stick	Rings per Inch	Summerwood %	% Moisture Content	Medulus of Rupture
T7	25	30	11.0	11,920 $\#/in^2$
T8	30	30	11.0	10,130
T9	13	25	10.4	12,980
T10	40	30	10.5	8,980
T11	13	30	10.8	15,180
T12	13	25	9.0	13,050
Average			10.4	12,040
Adjusted to 12% Moisture Content				11,308

Adjusting Equation:

$$\text{Log } S = \text{Log } T + (M_T - 12)\,\frac{\text{Log } 1.60}{12}$$

SKETCH A



DETAILS OF TEST SPECIMENS AND GRIPS

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