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TIMBER CONNECTOR JOINTS: THEIR STRENGTH AND DESIGN
SCHOLTEN, J.H. 1 OF 2

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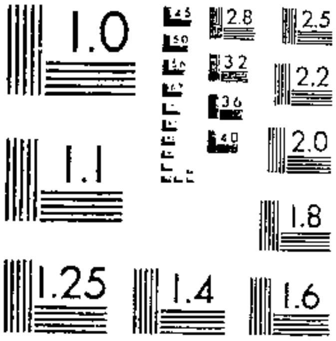

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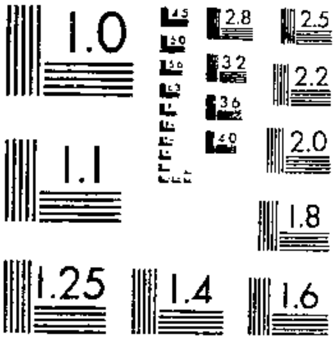

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Timber-Connector Joints: Their Strength and Design

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CONTENTS

INTRODUCTION

One of the outstanding characteristics of wood as a structural material is the facility with which it can be fabricated, and particularly the ease with which pieces can be joined together. Joints and fastenings, however, have always been the weakest part of timber construction, and for that reason the Forest Products Laboratory

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[1] Acknowledgment is made to L. J. Markwardt and the late J. A. Newlin, of the Forest Products Laboratory, under whose supervision this work has been carried out, and to R. F. Luxford, who conducted some of the initial tests. The connectors used in this investigation were furnished by the Timber Engineering Co.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

in the interest of improved utilization efficiency, has for some years been carrying on research in this field. Included were studies of joints employing such fastening mediums as nails, screws, bolts, lag screws, and driftpins.

When timber connectors, which are efficient mechanical devices—usually in the form of rings, plates, or disks—used in conjunction with bolts to develop timber joints of superior strength, were introduced into the United States in 1930, their possibilities were readily recognized; but information on relative efficiency, design data, and factors affecting their strength was lacking. In the initial investigation then undertaken by the Laboratory, the eight types of connectors which appeared most promising were selected from those available and tested with Douglas-fir and southern yellow pine. That investigation furnished basic design information on the strength of connector joints when used under optimum conditions in these two species. It also assisted in establishing tentative design values for other structural woods and in determining which types excelled under different conditions. The results of this early study are presented in a United States Department of Commerce bulletin entitled "Modern Connectors for Timber Construction" (*7*).[3]

The impetus to wood construction which followed publication of the results of this early connector study brought in its wake many additional problems. Structures which previously had been limited mainly to other materials could now be erected with wood. Connectors were redesigned for greater effectiveness by incorporating the most favorable features of those originally tested. Other new problems concerned additional sizes of timbers, more species of wood, the use of connectors in multiple, and the strength of joints for other than optimum design conditions, involving such variables as margins and spacing. Further investigation of the many variables introduced by these new problems and developments became imperative.

Accordingly, three widely used types of connectors, representing three distinct methods of application, were selected for more intensive study. They were the split-ring, toothed-ring, and claw-plate connectors.

Some of the outstanding principles developed as the study progressed have already been used to meet the increasing demand for information on this subject. The principal purpose of this bulletin is to present current design data for the three types of connectors in various sizes when used with different species of wood and to provide an analysis of the various factors which affect the strength of connector joints. The presentation of this information is particularly timely owing to the great increase in volume and rapidity with which structures employing connector joints must be erected to meet our wartime needs.

TIMBER-CONNECTOR TYPES, THEIR ADVANTAGES AND USES

The three general types of timber connectors discussed in this bulletin are described broadly as follows:

1. *Split rings*, which fit into precut grooves in the timber (fig. 1, *A* and *B*).

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[3] Italic numbers in parentheses refer to the Literature Cited, p. 106.

2. *Toothed rings,* which are forced into the timbers as the members are pressed or clamped together (fig. 2, *A* and *B*).

3. *Claw plates,* which fit into prebored recesses and have short teeth that are forced further into the wood. They are used singly in making timber-to-metal connections or in matched pairs (male and female) for timber-to-timber connections (fig. 3, *A, B,* and *C*). (See fig. 31.)

In a timber joint, split rings and toothed rings function similarly—part of the ring extends into the adjacent joint members, and the load is thus transmitted by shear somewhat independently of the bolt. The female claw plates are adapted to use when the connector must lie flush with the surface of the timber. In such a connection, a large bolt fits the connector and the attached metal plate snugly. Another type of flush connector that is somewhat similar to the female claw plate, but without teeth, is the shear plate. These flush types of connectors are dependent on the bolt for transmitting load by shear from member to member. Shear-plate tests are not included among those reported in this bulletin.

Timber connectors have established new horizons for wood construction. By facilitating the economical fabrication of large structural units, they have proved effective not only in retaining and recovering markets but in establishing new ones as well.

The principal advantages of connector joints include:

1. Relatively high joint efficiency.
2. Relatively simple and practical application.
3. A minimum number of units or pieces to handle.
4. Adaptability to prefabrication for subsequent field assembly.
5. Better performance when used under adverse conditions.
6. Improved appearance of joint with less exposed metal.
7. Greater fire resistance because embedment of connectors in wood reduces amount of metal exposed to fire temperatures.

The principal disadvantage, particularly on small jobs, is the need for special tools for their application—the split ring and claw plate require a special tool, preferably with power equipment, to fabricate the groove and recess; the toothed ring usually requires a special bolt and wrench to force the ring satisfactorily into the timber.

While connector joints have a relatively high efficiency, their other advantages account fully as much for their popularity and successful application. Actually, it is possible to achieve a high-strength joint with nails by literally stitching wood members together (*8, 10*). Such joints, however, not only require too much time and effort but are also much less reliable and dependable. Bolted joints can also be used effectively (*9, 14*); but, while their use removes the limitation with respect to size of member that use of nails involves, they still require more units and ordinarily a greater weight of metal than do connectors to develop a given strength.

Represented in figure 4 are three types of joints used to transmit loads acting parallel to the grain, each with approximately the same weight of metal. Specimen *B,* a bolted joint, takes the lowest design load; specimen *A,* a nailed joint with bolt, not a common type, is intermediate; and specimen *C,* a joint with two 4-inch connectors and a ¾-inch bolt, takes the largest load. There is nearly 1,200 pounds difference between the loads for the bolted joint and the connector joint.

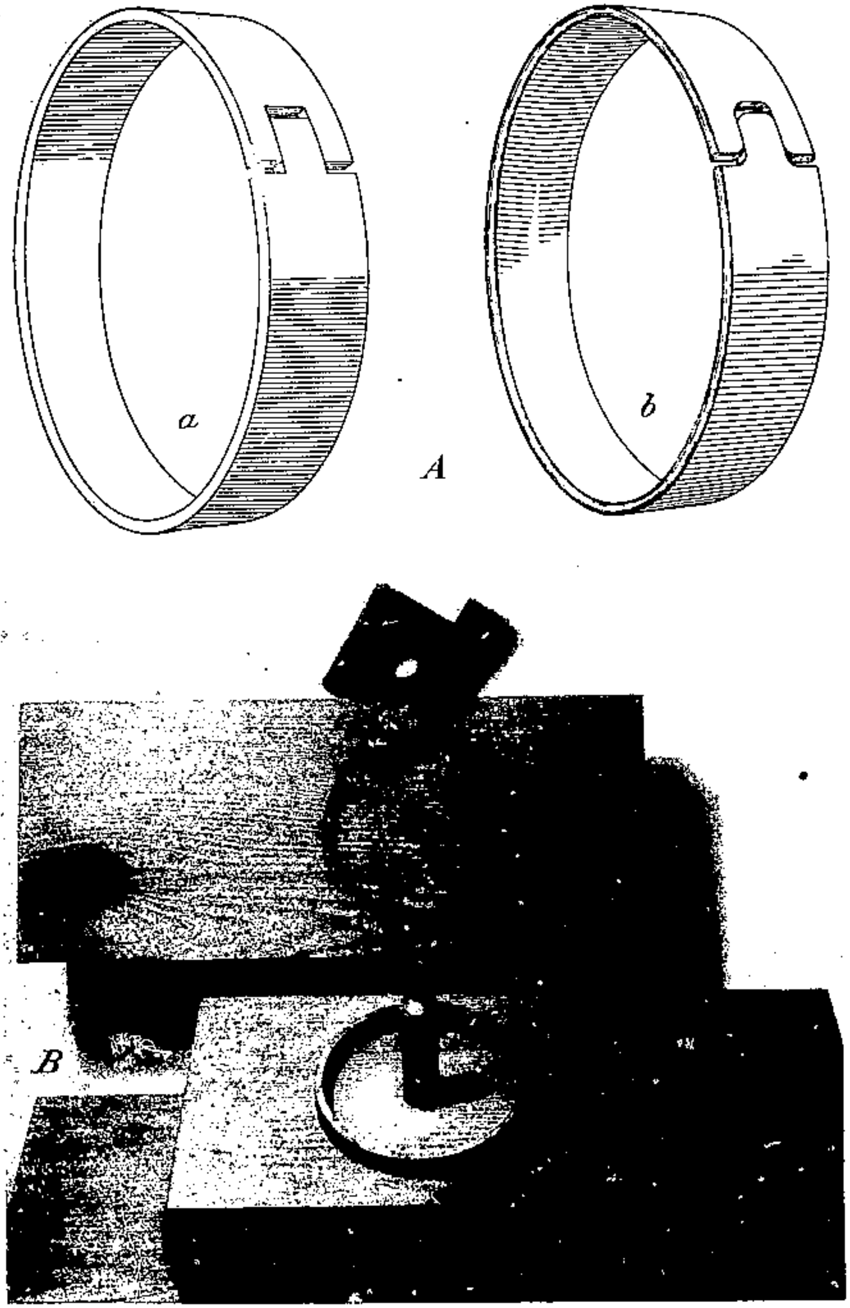

FIGURE 1.—*A*, Split-ring connector, (*a*) straight sided, (*b*) beveled; *B*, split-ring connector assembly—connector, precut groove, bolt, washer, and nut (M32889F).

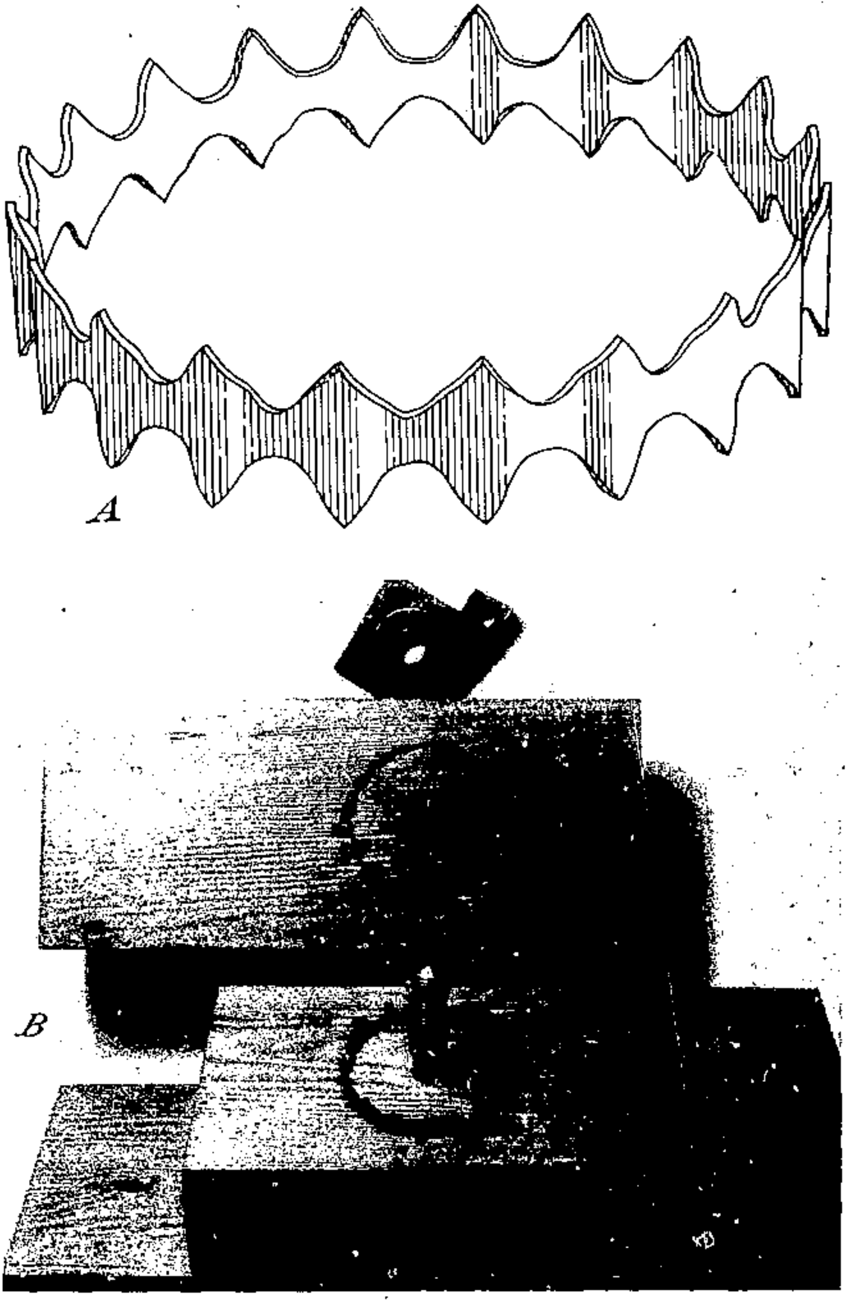

FIGURE 2.—*A*, Toothed connector joint; *B*, toothed connector assembly (M32890F).

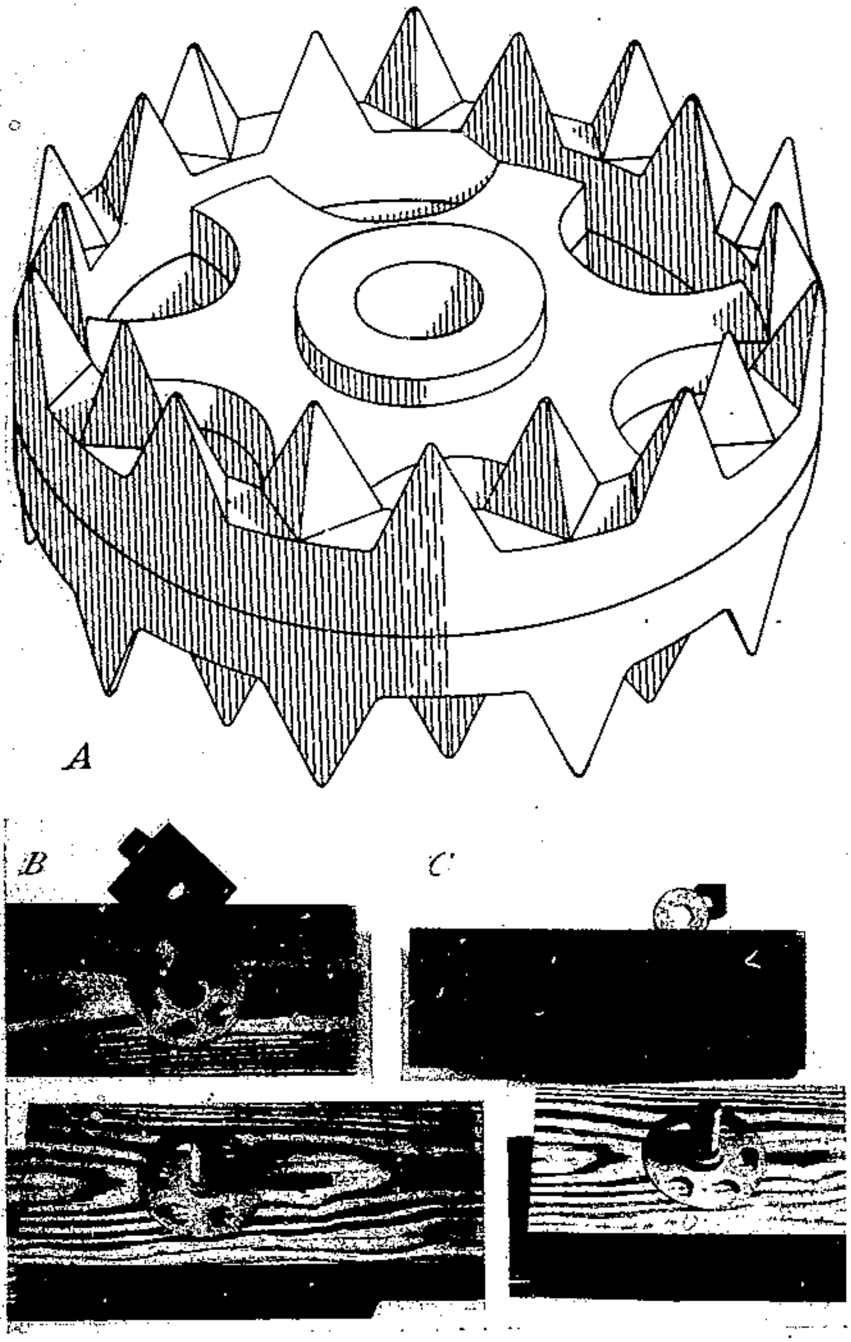

FIGURE 3.—*A*, Claw-plate connector; *B*, claw-plate connector assembly with wood side members; *C*, claw-plate connector assembly with metal side members (M39056–7F).

In the connector joint (fig. 4), the safe load for the bolt alone is 2,160 pounds, or about 23 percent of that for the complete connector joint.

Designs employing connectors permit an efficient structural arrangement of members so that smaller sizes may frequently be used to replace timbers of large cross section. This is of advantage both because better seasoned material may be used and because smaller sizes are more readily obtainable. It is also advantageous from the forestry standpoint, since in the future more of our structural material must come from smaller trees.

The advent of timber connectors has made possible the further development of prefabricated timber structures and structural units. Since wood is stable in its longitudinal dimension, individual members can be shop-fabricated to size and bored for bolts and connectors with such precision that, with due care, they can be assembled rapidly and efficiently on the job. An increasing number of fabricators are gaining experience and becoming familiar with these precision requirements.

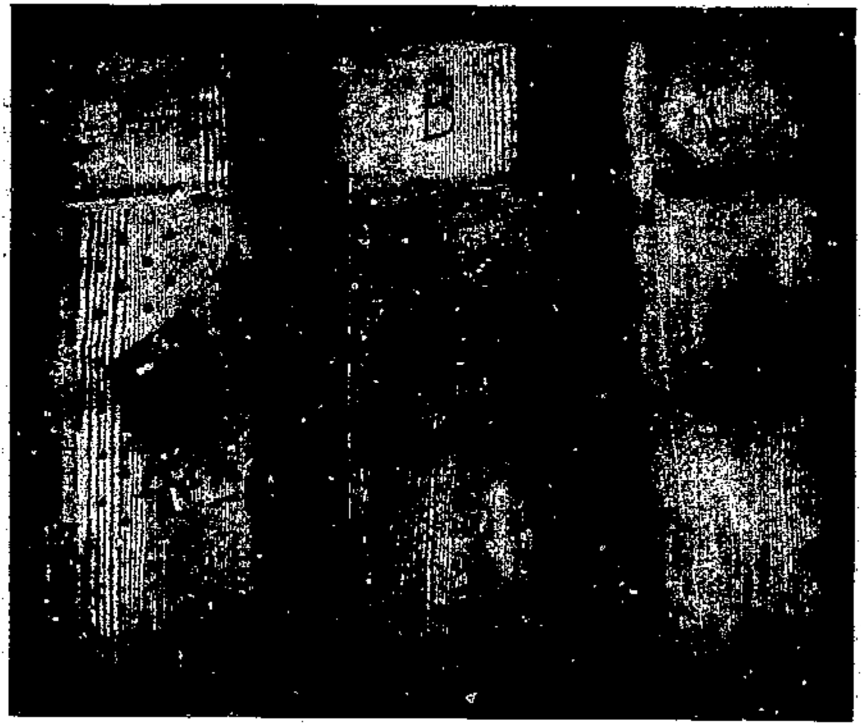

FIGURE 4.—Three types of joints, each with the same weight of metal. The design load with Douglas-fir or southern yellow pine for the nailed joint with bolt (*A*) is 9,000 pounds; for the bolted joint (*B*) it is 8,400 pounds; and for the connector with bolt (*C*) it is 9,560 pounds.

A further step supplementing shop fabrication is the possibility of treating timbers with creosote or other wood preservatives subsequent to fabrication. Such treatment given after rather than before the holes are bored or the fabrication completed, permits all surfaces to absorb an adequate amount of the preservative, assuring the full effectiveness of the preservative and long life and service of the timbers. Large numbers of cooling towers, oil derricks, shipyard structures, trestles, forest lookout towers, and other forms of timber construction have thus been prefabricated and treated. After treatment, the timbers are shipped to the construction site and erection proceeds without the need of any on-the-site framing.

Timber connectors are adapted primarily for transmitting loads in tension, compression, and shear. Hence, they are particularly suited for the development of efficient joints in framed timber structures where several members meet at a common panel point, or where members must be joined or spliced. Applications of timber connectors include roof trusses, bridges and trestles, towers (radio, forest lookout, water tank, and floodlighting), oil derricks, grandstands, ski jumps, warehouses, storage racks, mill buildings, piers and wharves, portable buildings (camp buildings), aircraft hangars, mine head frames, pylons, timber arch centering and framing, overhead cranes, coal docks, and walking beams.

Connector-built roof trusses have included many types and sizes. An interesting example of prefabricated trussed arch is that of the Plant High School gymnasium, Tampa, Fla. (fig. 5, *A*), which demonstrates the possibilities of using timber connectors where large bending moments must be provided for in the knees of the frame. The total roof span of this gymnasium is 104 feet, with a clear span between columns of 80 feet. The over-all height at the center is 35 feet and the clear height 28 feet 8 inches.

More spectacular in size are the bowstring trusses used in a new aircraft factory in Kansas (fig. 5, *B*). The connector-framed trusses in the main building have a span of 140 feet. The trusses, on 53-foot centers, are designed to carry a load of 180 tons each. They were prefabricated on the Pacific Coast and transported by rail to the building site. At the Golden Gate International Exposition in San Francisco, clear arch spans of 200 feet were used.

A mold loft for a shipbuilding company is shown in figure 5, *C*. The 14 trusses, which are spaced 24 feet apart, have a span of 116 feet 2 inches.

Figure 6, *A* illustrates the 60-foot pony truss highway bridge over Johnson Creek, Oreg. The bridge is 22 feet wide and is designed for H–15 loading in accordance with specifications of the American Association of State Highway Officials. The timbers are creosote-treated to insure long life under adverse exposure conditions.

Longer spans are, of course, possible. The Buffalo Creek Bridge at Lewisburg, Pa. (fig. 6, *B*), is a good example of a modern highway structure consisting of two 91½-foot spans and designed for H–20 loading. Another modern all-timber bridge using connectors is the three-hinged arch designed by United States Forest Service engineers and erected over the Umpqua River in the Umpqua National Forest, about 45 miles east of Roseburg, Oreg. (fig. 6, *C*). It is a three-hinged arch type of 135-foot span, designed for H–15 loading. Creosoted preframed timbers were used.

Trestles present an excellent opportunity for timber-connector design. The two Port Angeles, Wash., highway bridges furnish a good illustration of this type of structure. Each of the bridges is 755 feet long and is made up of 26 panels of 29 feet each (fig. 7). The maximum height is 100 feet. The bridge has a 24-foot roadway, with side-

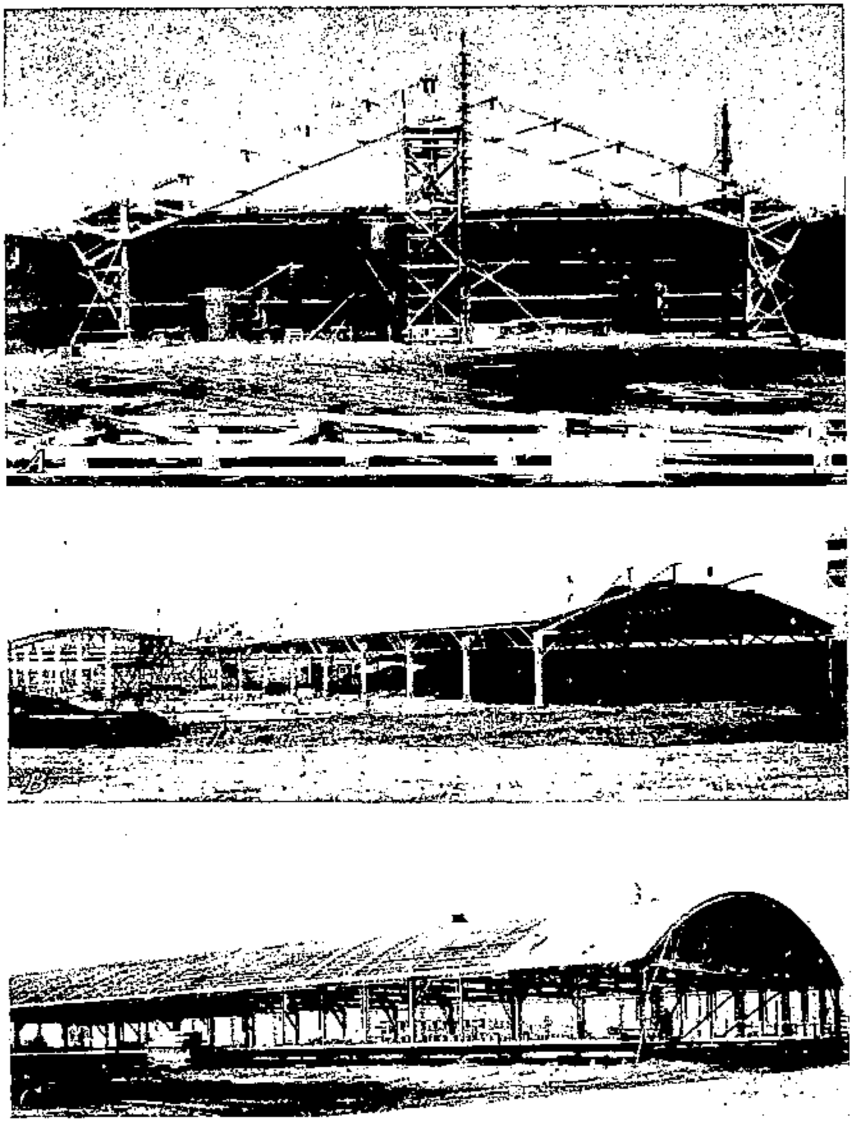

FIGURE 5.—*A*, Trussed arch of Plant High School gymnasium, Tampa, Fla. (total roof span, 104 feet; clear span, 80 feet; over-all height, 35 feet; clear height, 28¾ feet); *B*, bowstring trusses for an aircraft corporation in Kansas (span, 140 feet on 53-foot centers); *C*, mold loft of a shipbuilding company (span of 14 trusses spaced 24 feet is over 116 feet).

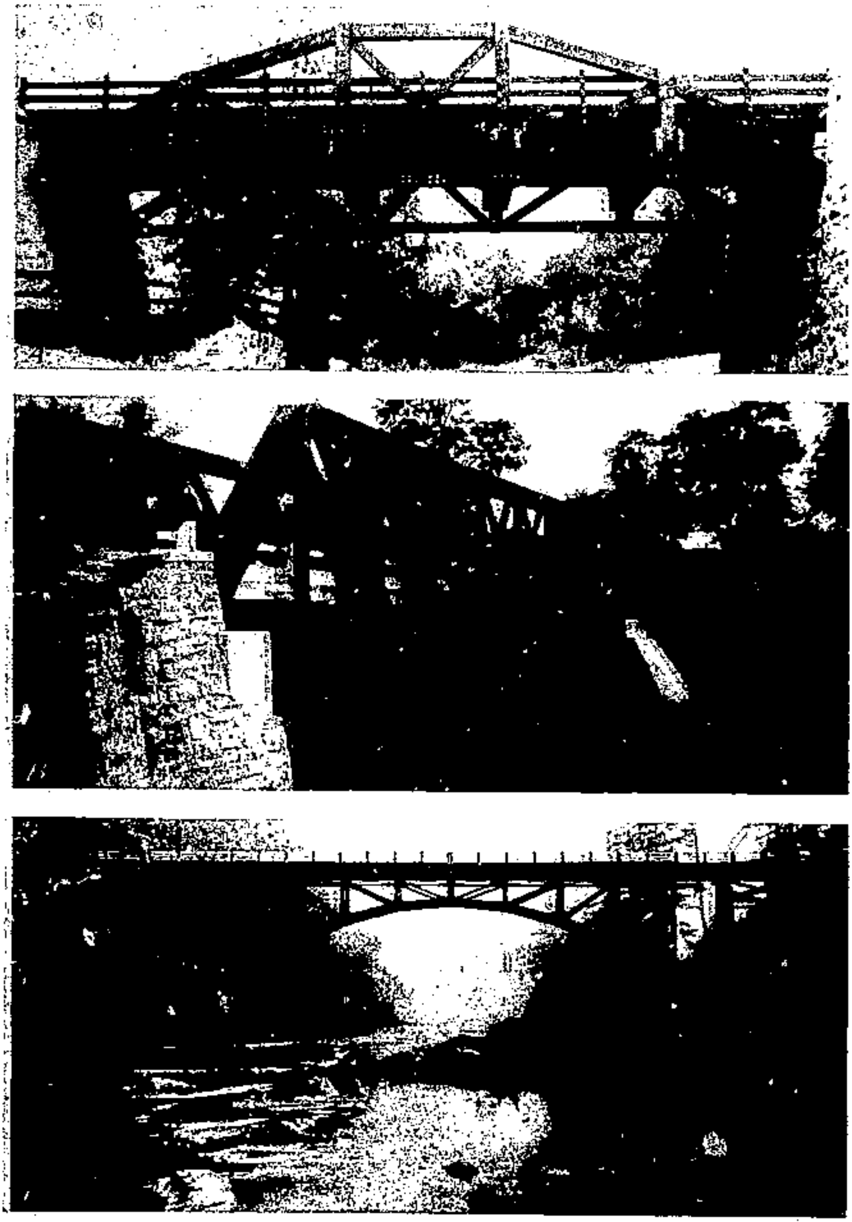

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FIGURE 6.—*A*, Pony truss bridge over Johnson Creek, Multnomah County, Oreg. (span, 60 feet); *B*, Buffalo Creek bridge at Lewisburg, Pa. (two low-truss, 91½-foot spans); *C*, three-hinged arch bridge in Umpqua National Forest, Oreg. (span, 135 feet).

walks, and is designed for H–20 loading. It was preframed, treated, and delivered on the job ready to erect.

Timber connectors are also used in providing form work for the erection of concrete arch bridges. In the timber-connector centering for the concrete arches over the Little Miami River at Foster, Ohio (fig. 8, *A*), the spans range from 155 feet to 175 feet, with a rise above the springing line of 72 feet. The timbers were cut to length before delivery, but the remainder of the fabrication was done on the job.

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FIGURE 7.—Composite trestle-type highway bridge at Port Angeles, Wash. (length, 755 feet; maximum height, 100 feet).

Because of the temporary nature of arch-centering structures, treated timbers were not used.

Lattice arch trusses with connector fastenings were used for the building erected for the Superior Curling and Skating Club, Superior, Wis. A clear span of 125 feet is provided in this construction.

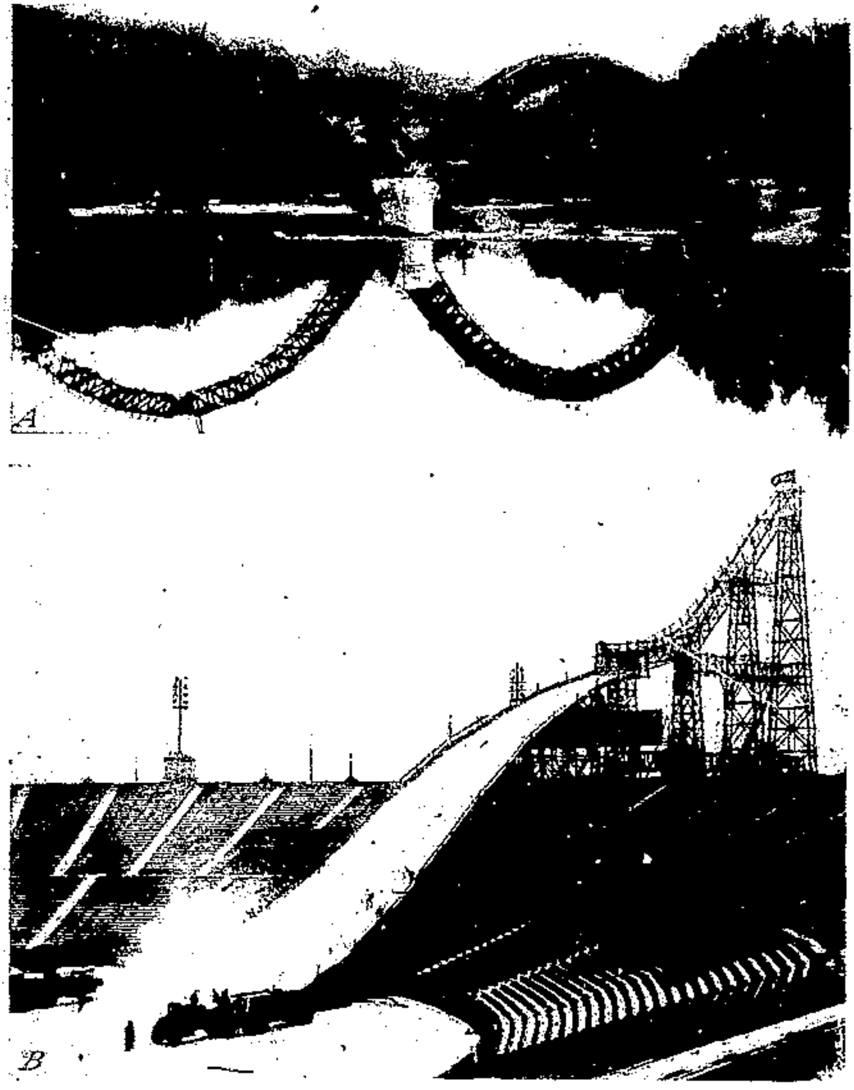

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FIGURE 8.—*A*, Timber arch centering for concrete highway bridge over Little Miami River, Foster, Ohio, consisting of six spans ranging from 155 to 175 feet. *B*, Ski jump at Soldiers Field, Chicago, with a height at top platform of 180 feet; designed to be taken down and stored after each season's use.

The timber ski jump at Soldiers Field, Chicago, is an interesting structure, using timber connectors (fig. 8, *B*). Not only does this

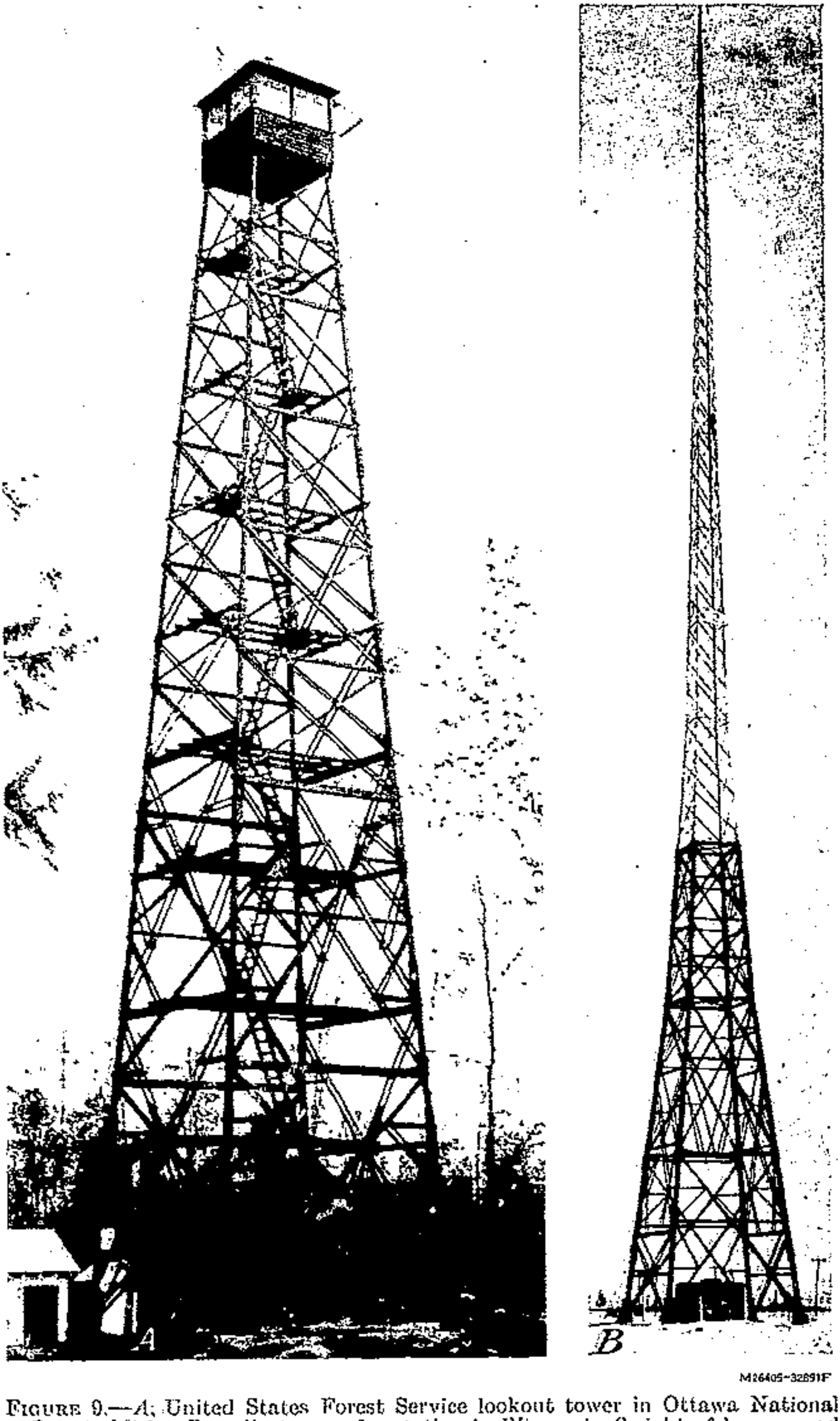

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FIGURE 9.—*A*, United States Forest Service lookout tower in Ottawa National Forest, Mich.; *B*, radio tower of a station in Wisconsin (height of lower wood section, 120 feet; over-all height, 350 feet).

structure employ prefabricated timber framing members, but it is also designed to be disassembled and stored away after each season's use. The top platform is 180 feet high. An 8-foot jump-off at an elevation of 92 feet is provided.

Forest lookout towers of both guyed and self-supporting construction have been used by the United States Forest Service, and by State and private agencies. The 100-foot self-supporting tower of standard type, shown in figure 9, *A*, was completely prefabricated in the shop, treated, and then delivered to the site for erection.

More spectacular than most uses is the application of connectors to radio tower design. The self-supporting three-legged tower erected for a radio station at Richmond, Va., is 326 feet high. When a radio station in Wisconsin decided to increase the height of its broadcasting tower, the station's old 230-foot steel structure was placed upon a new 120-foot tower built of creosoted timbers (fig. 9, *B*).

These examples, illustrating but a few of the many thousands of timber-connector structures that have been built, will at least serve to indicate the variety of uses for which such structures are adaptable.

DESIGN OF TIMBER-CONNECTOR JOINTS

The strength of a connector joint is dependent on the type and size of connector, species of wood, thickness and width of member, end distance and spacing of connectors, direction of application of the load with respect to the direction of the grain of the wood, and other factors.

Obviously the most efficient design of any structure employing connector joints necessitates the attainment as far as possible of balanced design, in which the size and arrangement of members are such as to secure maximum efficiency of material.

Considerable progress has been made in the theoretical stress analysis of connector joints and in correlating the results with basic data on the mechanical properties of the wood and metal (*2*, *11*, *12*). The fact remains, however, that the stress distribution is so complicated, and the assumptions involved are so often invalid, that actual tests must be relied on to provide the necessary design data. In spite of its limitations, a brief summary of such an analysis as it relates to observations during test may be both of interest and of value in providing a better conception of the behavior of a connector joint.

The primary stresses in the wood of the tension joint shown in figure 10 may be classified as shear, compression, and tension. The shaded areas indicate the principal part of the wood (*A*) subjected to shear, (*B* and *C*) subjected to compression, and (*D*) subjected to tension. For a tension joint with two split-ring connectors in opposite faces and a concentric bolt, bearing parallel to the grain of the wood, these areas can be expressed by the following formulas:

Shear area:

$$\text{Within core: } 2\frac{(\pi d_1^2)}{4}$$

$$\text{Below core: } 2\left[d_2e-\tfrac{1}{2}\left(\frac{\pi d_2^2}{4}\right)+2\left(\frac{ae}{2}\right)\right]$$

Compression area:

$$2\left(\frac{ad_2}{2}\right)+b(t_1-a)$$

Tension area:

$$t_1w-\left[2\left(\frac{ad_2}{2}\right)+b(t_1-a)\right]$$

in which—
d_1 represents inside diameter of connector,
d_2 represents outside diameter of connector,
e represents end distance from center of connector to end of member,
a represents the depth of connector,
b represents diameter of bolt,
t_1 represents thickness of member,
w represents width of member,
t_2 represents thickness of metal.

The strength of the joint, apart from that of the bolt and connector, is obviously controlled by one or another, or some combination, of these three properties.

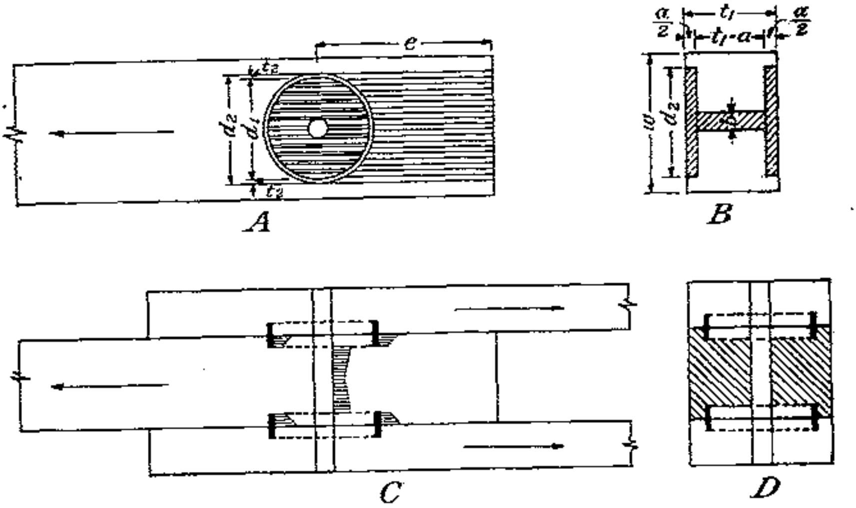

FIGURE 10.—Detail of a connector joint, showing portions of center member subject to shear (*A*), compression (*B*, *C*), and tension (*D*). Corresponding stresses, not shown, exist in the side members. The cross section of the split-ring connector is illustrated by the solid black rectangle. For explanation of symbols, see text.

In applying the theory of elasticity to the distribution of these stresses in a timber joint, nearly all the basic assumptions are upset by the anisotropic structure of the wood, by the presence of irregularities and defects such as knots and cross grain, and by the interaction between the wood and metal. A practical analysis of the stresses in the joint, therefore, resolves itself primarily into a correlation between the test loads, the character of failure, and the mechanical properties of the wood and metal. Such an analysis, while not complete or accurate, does provide a check on the test results and an aid in the interpretation of the data.

A few of the factors which affect the compressive, shear, and tensile stresses in a connector joint and their relationship to the standard properties of the material will be discussed with respect to different types of connectors. The more detailed discussion, however, pertains to the split-ring connectors when bearing parallel to the grain of the wood.

Compressive Stress

The area in compression in a connector joint is the projected area of the connector *plus* the *projected* area of the intervening bolt $[ad_2+b(t_1-a]$ in fig. 10, *B*. The maximum compressive strength of the material, however, is not usually developed on the full projected area. The actual stress developed is dependent on the species of wood, the size and type of connector, and such other factors as sizes of bolt, bolt hole, and member. For split-ring connectors bearing parallel to the grain, the load obtained when the projected area under the connectors only (ad_2 in fig. 10) is multiplied by the maximum crushing strength of the material parallel to grain would vary from 65 to about 100 percent of the maximum test load. The smallest connector, 2½ inches in diameter, produced the lowest ratios, and the largest, 8 inches, gave the highest ratios.

If the remaining portion of the load, apart from friction, is considered to be carried by the bolt, the average stress developed under the bolt, when used in an exact bolt-size hole, ranges from about 100 percent of the maximum crushing strength of the material with the thinner members to less than 25 percent with the thicker members. The maximum capacity of the bolt is seldom realized in most connector joints because the maximum compressive strength of the material is usually developed under a bolt only at a slip or movement in the joint which is considerably in excess of the slip at which the connector joint reaches its maximum load.

Shear Stress

The variations in behavior of different sizes of split-ring connectors can also be associated with the relative amounts of wood in shear and in compression. The ratio of the area in shear at the base of the core within the connector to the area in compression under the connector varies considerably for the different sizes of connectors. The core area is a function of the square of the diameter of the connector, whereas the area in compression varies directly as the diameter and depth of connector vary. For the 6-inch split-ring connector, the ratio of core area in shear to the area in compression is about 50 percent greater than for the 2½-inch split-ring connectors. Hence, when bearing parallel to the grain, the core of the 2½-inch connector shears completely at a load considerably below the maximum of the joint, while the core of the 6-inch connector fails in progressive shear at the maximum, or very nearly the maximum, load of the joint.

The load sustained in shear, however, is not solely a function of the shear area, since the average shear stress usually decreases as the area increases. It cannot be assumed, therefore, that, because the area of the core for the 6-inch connector is approximately six times that for the 2½-inch connector, the relative loads to produce shear failure of the core will be in the same proportion.

The same effect is also evident in tests with various end margins and spacings when the connectors are bearing parallel to the grain. The load required to produce shear failure outside the connector decreases with a reduction in spacing or margin, but the rate of decrease in load is not so great as the reduction in the spacing or margin.

When the connector is bearing perpendicular to the grain of the wood, both the resistance of the core to rolling shear and the bearing resistance of the wood perpendicular to the grain resist the load on the connector. While the shear area for the large connector is greater in proportion to its diameter than for the small connector, the load does not increase in the same proportion. As the load is applied to the joint, the upper portion of the core which shears is resisted by the lower portion, which remains intact. Mashing and splitting of the core is thus caused. The portion of the core which splits off or is above the compression failure is usually smaller, in relation to the total core area, for the larger connectors than it is for the smaller.

TENSILE STRESS

The strength of the wood member in tension at the joint is also limited by factors which are not subject to the usual theoretical analysis.

Tests of joints with metal fastenings show that the concentration of stress in the member caused by abrupt changes in the continuity of the grain produces failure in tension at a stress approximately equal to the compressive stress of clear material. In order to minimize the possibility of tension failure at the joint, therefore, the total uninterrupted tension area (fig. 10, *D*) of the member at the critical section of the joint should not be stressed in excess of the safe stress in compression parallel to the grain for clear material.

TOOTHED AND CLAW-PLATE CONNECTORS

The behavior of the toothed connector is affected by several additional factors not encountered with the split-ring connector. The distribution of the stresses for the toothed type is further complicated by the fact that the connector does not offer the same degree of resistance to distortion in all sections of the perimeter. At two sections on the perimeter that are at right angles to the direction of load, the corrugations and teeth on opposite sides of the connector are aligned parallel with the load and offer greater resistance to distortion than at the sections on the perimeter where they are edgewise to the direction of load.

Furthermore, since the thickness and depth of the metal are the same for the different diameters of the toothed connector, the effect of variations in resistance to distortion in different sections of the perimeter is more noticeable in the larger diameters. The test results show that the load conforms more nearly to the quality of the wood with the toothed connectors of smaller diameters than with those of large diameters. An analysis of the stresses in the toothed connector joints, therefore, must include all these variations, and an analysis of one size of connector is not directly applicable to other sizes.

A somewhat similar condition exists for the claw-plate connectors. When they are used with the softer woods, the joint strength is almost directly related to the strength of the wood; but in the denser woods, which sustain a higher load, failure in the connectors becomes more pronounced. This fact almost precludes the possibility of any reasonably accurate, detailed analysis of the stress distribution in the joint.

The best test, however, of any device is its capacity to perform effectively, and the timber connector is no exception. It is necessary, therefore, in the determination of the actual load capacity of a timber connector joint to rely upon the results of accurate and comprehensive tests from which, when correlated with the fundamental properties of the material, safe working loads for practical use may be developed.

DERIVATION OF SAFE WORKING LOADS FOR LONG-CONTINUED LOADING

The working loads for connectors are derived from tests of full-scale joints and interpretation of the resulting data in relation to other basic information on the behavior of timber. In establishing the values, particular consideration has been given to (1) the effect of long-continued loading as against the brief loading period involved in the tests of joints, and (2) allowance for variability in timber quality.

Duration of Load

It is well established that the magnitude of the loads required to cause failure of timber varies with the rate at which the loads are applied or with the length of time during which they act. When, for example, a wood beam is tested by a falling weight, as in impact tests, the fiber stress developed at proportional limit is fully twice as great as that found in standard static bending tests that occupy several minutes and are carried out at a uniform rate of deflection and with the load continuously increasing to the maximum. In fact, the fiber stress at the proportional limit of the beam under impact exceeds the modulus of rupture in the static test. On the other hand, the load at failure in a standard static test is much higher than the load which will cause failure when allowed to remain on a timber for a long time, and a beam will eventually fail under a constant load only about nine-sixteenths as great as the breaking load found in the standard static test (*4*, *15*, *17*). It is, therefore, essential in establishing safe working loads for long-continued or permanent loading (the safe stresses customarily given for timber) that the test loads be adjusted for duration of stress.

No adequate data are available on the effect of duration of stress on connector joints insofar as the wood is concerned. The relations for bending, as stated above, are assumed to apply.

Quality of Wood

Tests have demonstrated that the density or quality of the wood is often the controlling factor in determining the strength of the joint. Consequently, the load carried by a connector in the laboratory test employing an average quality of wood for a species must be adjusted to allow for the lower-than-average material likely to be used in service.

Loads for Connectors Bearing Parallel to Grain

The recommended working loads for connectors acting parallel to the grain were derived by applying to the ultimate load, as found in test, a reduction factor which averaged 4 for split-ring and claw-plate connectors and 4½ for toothed-ring connectors, with the additional provision that the working load for the split-ring and claw-plate connectors should not exceed five-eighths of the load at the proportional limit test load. Application of the reduction factor of 4 gives values for the split-ring that are consistently less than five-eighths the load at proportional limit, as found by test; and for the claw plate, approximately five-eighths of this load. Because load-slip curves for the toothed connector do not exhibit a well-defined proportional limit, no factor on proportional limit loads is considered, and the larger factor of 4½ was applied to ultimate load.

Loads for Connectors Bearing Perpendicular to Grain

Tests of connectors under loads bearing perpendicular to grain have been less extensive and less numerous than those for parallel bearing, but nevertheless sufficient to establish a generally applicable relation between the two directions. This relation has been used in deriving loads for perpendicular bearing.

The ultimate test loads for perpendicular bearing were quite variable in magnitude and were affected by such factors as the method of support and the length of transverse member used in the tests. Consequently, ultimate load has been given less consideration for perpendicular than for parallel bearing, and greater dependence has been placed on other factors, such as the load at proportional limit and at given slips of the joint. The recommended working loads for split-ring connectors average about one-half and those for claw-plate connectors slightly less than five-eighths of the respective proportional limit loads.

For toothed connectors the working loads bearing perpendicular to the grain have the same relation to the working loads for bearing parallel to the grain that existed in comparable tests for the two directions of grain at given slips of the joint. The resulting factor on ultimate load varies considerably with size of ring and different conditions, but averages about 4.

Actual Safety Factor

It will be realized from the preceding discussion that the figures quoted as the ratios between working loads and the loads found in test are in no instance true factors of safety. For example, the reduction factor of 4 includes allowances for duration of stress and for variability as well as a margin for safety. Thus, after multiplying values from test by a factor of nine-sixteenths as an allowance for a long-continued load, and by three-fourths to cover variability, the actual factor of safety for a connector joint is on the order of $1\frac{3}{4}$ ($4\times\frac{9}{16}\times\frac{3}{4}=1\frac{11}{16}$) if the working load acts over a long period. The tests from which working loads were derived were on specimens carefully made from seasoned material, under favorable conditions, and by experienced workmen. A lower standard of workmanship, or seasoning subsequent to the fabrication of a joint made in green or unseasoned timber, would further reduce the indicated factor of safety.

TABLES OF SAFE WORKING LOADS

SPECIES OF WOOD

The mechanical tests upon which the recommended working values are based were conducted on representative species covering a wide range in properties. By correlating these data with available data from standard tests of small, clear specimens (*3*, *4*), it has been possible to establish connector design loads for all the more important commercial species.

For convenience and simplicity in design, these species have been classified into four groups in accordance with their strength in connector joints, all species[4] in any one group taking the same working values. The groupings, from lowest to highest working values, are as follows:

GROUP 1 WOODS (WEAKEST)

Aspen, bigtooth.
Aspen, quaking.
Basswood, American.
Cottonwood, northern black.
Cottonwood, eastern.
Fir, balsam.
Fir, commercial white.
Hemlock, eastern.
Pine, ponderosa.
Pine, sugar.
Pine, eastern white.
Pine, western white.
Redcedar, western.
Spruce, Engelmann.

GROUP 2 WOODS

Baldcypress.
Chestnut, American.
Douglas-fir (Rocky Mountain region).[5]
Hemlock, western.
Pine, red.
Redwood.
Spruce, red.
Spruce, Sitka.
Spruce, white.
White-cedar, Port Orford.
Yellow-cedar, Alaska.
Yellowpoplar.

GROUP 3 WOODS

Douglas-fir (coast region).[5]
Elm, American.
Elm, slippery.
Larch, western.
Maple, red.
Maple, silver.
Pine, southern yellow.
Tupelo, black.
Tupelo, water.
Sweetgum.
Sycamore, American.

GROUP 4 WOODS (STRONGEST)

Ash, commercial white.
Beech, American.
Birch, sweet.
Birch, yellow.
Douglas-fir (dense).[6]
Elm, rock.
Hickory, true.
Hickory, pecan.
Maple, black.
Maple, sugar.
Oak, commercial red.
Oak, commercial white.
Pine, southern yellow (dense).[6]

The safe working loads for various sizes of split-ring, claw-plate, and toothed-ring connectors applicable to seasoned timbers used where they will remain dry are presented in tables 1 to 3. These loads are considered appropriate for long-continued or permanent application. It may be noted that loads vary with type and size of connector, with species and size of timber, and with direction of load relative to the grain of the timber.

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[4] The names of species are the standard common names employed by the Forest Service (*13*), as recently revised in Approved Changes in Sudworth's Check List, 98 pp. 1940. [Processed.]

[5] There is a distinct difference in the properties of Douglas-fir from the more arid Rock Mountain region and those of the Douglas-fir from the Pacific Northwest. For this reason, separate values are given for Douglas-fir from the Pacific coast and the Rocky Mountain regions.

[6] In order to qualify as "dense," Douglas-fir or southern yellow pine must average, on one end of the piece or the other, not less than six annual growth rings per inch and, in addition, must average not less than one-third summerwood (the darker, harder portion of the annual ring), both being measured along a radial line through the center of the end of the piece.

In tabulating the safe working load for a connector joint of any number of members, the unit is *one* connector with bolt in shear. For any joint assembly in which more than one connector unit are used in the contact faces with the same bolt axis, the total safe working load is the sum of the safe working loads of each connector unit. For example, in tables 1–3, in the last column, minimum actual thickness of member is given for a joint assembly of three members employing two connectors in opposite faces with a common bolt; this assembly is equivalent to two connector units, and therefore the safe working load will in each case be twice the corresponding value shown in the columns to the left.

The loads as given apply only when the end distance is equal to or exceeds a certain minimum, and apply to each of a number of connectors in one joint only when the spacing conforms to certain requirements. Such end distances and spacings are shown in tables 4, 5, and 6 for the three different types of connector. Load reductions for other end distances and spacings are also given in these tables.

TABLE 1.—*Safe working loads*[1] *for 1 split-ring connector and bolt (1 connector unit)*

LOADS FOR SPECIES IN GROUP 1 (WEAKEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—							Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	15°	30°	45°	60°	75°	90°	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2½-inch connector with ½-inch bolt	⅞	3⅝	1,100	1,110	1,030	945	865	785	705	1¼
		4⅝	1,190	1,120	1,050	980	910	845	775	
		5½	1,190	1,130	1,070	1,015	955	895	835	
	1	3⅝	1,490	1,385	1,285	1,185	1,080	980	880	1⅝
		4⅝	1,490	1,400	1,315	1,225	1,140	1,055	905	
		5½	1,490	1,415	1,340	1,265	1,190	1,115	1,045	
	1⅜	3⅝	1,755	1,605	1,540	1,420	1,300	1,175	1,055	2
		4⅝	1,785	1,680	1,575	1,470	1,370	1,265	1,160	
		5½	1,755	1,695	1,610	1.520	1,430	1,340	1,250	
4-inch connector with ¾-inch bolt	1	5½	2,295	2,135	1,975	1,815	1,650	1,490	1,330	1½
		6½	2,295	2,155	2.020	1.880	1,740	1,605	1,465	
		7½	2,295	2,180	2,060	1.045	1,830	1,715	1,595	
	1⅛	5½	2,415	2,245	2,080	1,910	1,740	1,570	1,400	1⅝
		6½	2,415	2,270	2,125	1,080	1,835	1,685	1,540	
		7½	2,415	2,205	2,170	2,050	1,925	1,805	1,680	
	1¼	5½	2,775	2.580	2,390	2,195	2,000	1,805	1,610	2
		6½	2,775	2,610	2,440	2,275	2,105	1,940	1,770	
		7½	2,775	2,635	2,495	2,355	2,215	2,075	1,930	
	1½	5½	3,380	3,145	2,005	2,670	2,435	2,195	1,960	2⅝
		6½	3,380	3,175	2,970	2,770	2,565	2,360	2,155	
		7½	3,380	3,210	3,035	2,865	2,695	2,525	2,360	
	1⅝	5½	3,445	3,200	2,960	2,720	2,480	2,240	1,995	3
		6½	3,445	3,235	3,030	2,820	2,610	2,405	2,195	
		7½	3,445	3,270	3,095	2,020	2,745	2,570	2,395	
6-inch connector with ¾-inch bolt	1⅜	7½	3,755	3,445	3,130	2,815	2,505	2,190	1,880	2
		9½	3,755	3,505	3,255	3,005	2,755	2,505	2,255	
		11½	3,755	3,570	3,380	3,190	3,005	2,815	2,630	
	1½	7½	4,480	4,105	3,730	3,360	2,985	2,610	2,240	2⅝
		9½	4,480	4,180	3,880	3,585	3,285	2,985	2,685	
		11½	4,480	4,255	4,030	3.805	3,585	3,360	3,135	
	1⅝	7½	4,910	4,505	4,095	3,685	3,275	2,865	2,455	3
		9½	4,910	4,585	4,255	3,930	3,600	3,275	2,945	
		11½	4,910	4,665	4,420	4,175	3,930	3,685	3,440	
	2	7½	5,635	5,165	4,695	4,225	3,755	3,285	2,815	3⅝
		9½	5,635	5,260	4,885	4,505	4,130	3,755	3,380	
		11½	5,635	5,350	5,070	4,790	4,505	4,225	3,945	

See footnotes at end of table.

TABLE 1.—*Safe working loads*[1] *for 1 split-ring connector and bolt (1 connector-unit)*—Continued

LOADS FOR SPECIES IN GROUP 2[1]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—							Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[2]
			0°	15°	30°	45°	60°	75°	90°	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2½-inch connector with ½-inch bolt	⅞	3⅝	1,390	1,295	1,200	1,105	1,010	915	820	1¼
		4⅝	1,390	1,310	1,225	1,145	1,065	985	900	
		5½	1,390	1,320	1,250	1,180	1,110	1,045	975	
	1	3⅝	1,735	1,615	1,500	1,380	1,260	1,145	1,025	1⅝
		4⅝	1,735	1,635	1,535	1,430	1,330	1,230	1,125	
		5½	1,735	1,650	1,565	1,475	1,390	1,305	1,215	
	1⅝	3⅝	2,085	1,940	1,800	1,655	1,515	1,370	1,230	2
		4⅝	2,085	1,960	1,840	1,720	1,595	1,475	1,350	
		5½	2,085	1,980	1,875	1,770	1,665	1,565	1,460	
4-inch connector with ¾-inch bolt	1	5½	2,655	2,470	2,285	2,100	1,915	1,725	1,540	1½
		6½	2,655	2,495	2,335	2,175	2,015	1,855	1,695	
		7½	2,655	2,520	2,385	2,255	2,120	1,985	1,850	
	1⅛	5½	2,795	2,600	2,405	2,210	2,015	1,815	1,620	1⅝
		6½	2,795	2,625	2,460	2,290	2,120	1,950	1,785	
		7½	2,795	2,655	2,510	2,370	2,230	2,085	1,945	
	1¼	5½	3,215	2,990	2,765	2,540	2,315	2,090	1,865	2
		6½	3,215	3,020	2,825	2,635	2,440	2,245	2,050	
		7½	3,215	3,050	2,890	2,725	2,565	2,400	2,240	
	1½	5½	3,915	3,640	3,365	3,090	2,820	2,545	2,270	2⅝
		6½	3,915	3,675	3,440	3,205	2,970	2,735	2,495	
		7½	3,915	3,715	3,515	3,320	3,120	2,920	2,725	
	1⅝	5½	3,985	3,705	3,425	3,150	2,870	2,590	2,310	3
		6½	3,985	3,745	3,505	3,265	3,025	2,785	2,545	
		7½	3,985	3,785	3,580	3,380	3,180	2,975	2,775	
6-inch connector with ¾-inch bolt	1⅜	7½	4,345	3,985	3,620	3,260	2,900	2,535	2,175	2
		9½	4,345	4,055	3,765	3,475	3,190	2,900	2,610	
		11½	4,345	4,130	3,910	3,695	3,475	3,260	3,040	
	1½	7½	5,185	4,750	4,320	3,885	3,455	3,025	2,590	2⅝
		9½	5,185	4,835	4,490	4,145	3,800	3,455	3,110	
		11½	5,185	4,925	4,665	4,405	4,145	3,890	3,630	
	1⅝	7½	5,685	5,210	4,735	4,265	3,790	3,315	2,840	3
		9½	5,685	5,305	4,925	4,550	4,170	3,790	3,410	
		11½	5,685	5,400	5,115	4,830	4,550	4,265	3,980	
	2	7½	6,520	5,975	5,435	4,890	4,345	3,805	3,260	3⅝
		9½	6,520	6,085	5,650	5,215	4,780	4,345	3,910	
		11½	6,520	6,195	5,870	5,545	5,215	4,890	4,565	

LOADS FOR SPECIES IN GROUP 3[1]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	0°	15°	30°	45°	60°	75°	90°	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt
2½-inch connector with ½-inch bolt	⅞	3⅝	1,655	1,540	1,430	1,320	1,205	1,095	985	1¼
		4⅝	1,655	1,560	1,460	1,370	1,270	1,175	1,080	
		5½	1,655	1,570	1,490	1,410	1,330	1,250	1,170	
	1	3⅝	2,065	1,930	1,790	1,650	1,510	1,370	1,230	1⅝
		4⅝	2,065	1,950	1,830	1,710	1,590	1,470	1,355	
		5½	2,065	1,965	1,865	1,765	1,665	1,560	1,460	
	1⅝	3⅝	2,480	2,315	2,145	1,980	1,810	1,645	1,475	2
		4⅝	2,480	2,335	2,195	2,050	1,910	1,765	1,625	
		5½	2,480	2,360	2,240	2,115	1,995	1,875	1,755	
4-inch connector with ¾-inch bolt	1	5½	3,190	2,905	2,740	2,520	2,295	2,070	1,850	1½
		6½	3,190	2,965	2,805	2,610	2,420	2,225	2,035	
		7½	3,190	3,025	2,865	2,705	2,540	2,380	2,220	
	1⅛	5½	3,355	3,120	2,885	2,650	2,415	2,180	1,945	1⅝
		6½	3,355	3,155	2,950	2,750	2,545	2,345	2,140	
		7½	3,355	3,185	3,015	2,845	2,675	2,505	2,335	
	1¼	5½	3,860	3,590	3,315	3,050	2,780	2,510	2,240	2
		6½	3,860	3,625	3,395	3,160	2,925	2,695	2,460	
		7½	3,860	3,660	3,465	3,270	3,075	2,880	2,685	
	1½	5½	4,695	4,365	4,040	3,710	3,380	3,050	2,725	2⅝
		6½	4,695	4,410	4,130	3,845	3,560	3,280	2,995	
		7½	4,695	4,455	4,220	3,980	3,745	3,505	3,270	
	1⅝	5½	4,780	4,445	4,115	3,780	3,445	3,110	2,775	3
		6½	4,780	4,495	4,205	3,915	3,630	3,340	3,050	
		7½	4,780	4,540	4,300	4,055	3,815	3,570	3,330	

See footnotes at end of table.

TABLE 1.—*Safe working loads*[1] *for 1 split-ring connector and bolt (1 connector unit)*—Continued

LOADS FOR SPECIES IN GROUP 3[2]—Continued

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—							Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	15°	30°	45°	60°	75°	90°	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
6-inch connector with ¾-inch bolt	1⅜	7½	5,215	4,780	4,345	3,910	3,480	3,045	2,610	2
		9½	5,215	4,870	4,520	4,175	3,825	3,480	3,130	
		11½	5,215	4,955	4,695	4,435	4,175	3,910	3,650	
	1½	7½	6,220	5,700	5,185	4,665	4,145	3,630	3,110	2⅝
		9½	6,220	5,805	5,390	4,975	4,560	4,145	3,730	
		11½	6,220	5,910	5,600	5,285	4,975	4,665	4,355	
	1⅝	7½	6,820	6,255	5,685	5,115	4,550	3,980	3,410	3
		9½	6,820	6,365	5,910	5,455	5,005	4,550	4,095	
		11½	6,820	6,460	6,140	5,800	5,455	5,115	4,775	
	2	7½	7,825	7,175	6,520	5,870	5,215	4,565	3,910	3⅝
		9½	7,825	7,305	6,780	6,260	5,740	5,215	4,695	
		11½	7,825	7,435	7,040	6,650	6,260	5,870	5,475	

LOADS FOR SPECIES IN GROUP 4 (STRONGEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	0°	15°	30°	45°	60°	75°	90°	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
2½-inch connector with ½-inch bolt	⅝	3⅝	1,915	1,700	1,600	1,535	1,405	1,260	1,150	1¼
		4⅝	1,915	1,810	1,700	1,590	1,480	1,375	1,265	
		5½	1,915	1,825	1,735	1,640	1,550	1,460	1,365	
	1	3⅝	2,395	2,235	2,075	1,915	1,755	1,595	1,435	1⅝
		4⅝	2,395	2,260	2,125	1,990	1,850	1,715	1,580	
		5½	2,395	2,280	2,165	2,050	1,935	1,820	1,705	
	1⅛	3⅝	2,875	2,680	2,490	2,300	2,105	1,915	1,725	2
		4⅝	2,875	2,710	2,550	2,385	2,220	2,060	1,895	
		5½	2,875	2,735	2,600	2,460	2,325	2,185	2,045	
4-inch connector with ¾-inch bolt	1	5½	3,720	3,460	3,200	2,940	2,680	2,415	2,155	1½
		6½	3,720	3,495	3,270	3,045	2,820	2,595	2,375	
		7½	3,720	3,530	3,340	3,155	2,965	2,775	2,590	
	1⅛	5½	3,915	3,640	3,365	3,090	2,820	2,545	2,270	1⅝
		6½	3,915	3,680	3,440	3,205	2,970	2,735	2,495	
		7½	3,915	3,715	3,515	3,320	3,120	2,920	2,725	
	1¼	5½	4,500	4,185	3,870	3,555	3,240	2,925	2,610	2
		6½	4,500	4,230	3,960	3,685	3,415	3,145	2,870	
		7½	4,500	4,275	4,045	3,815	3,590	3,360	3,135	
	1½	5½	5,480	5,095	4,710	4,325	3,945	3,560	3,175	2⅝
		6½	5,480	5,145	4,815	4,485	4,155	3,825	3,495	
		7½	5,480	5,200	4,920	4,645	4,365	4,090	3,810	
	1⅝	5½	5,580	5,190	4,800	4,405	4,015	3,625	3,235	3
		6½	5,580	5,240	4,905	4,570	4,235	3,895	3,560	
		7½	5,580	5,295	5,015	4,730	4,450	4,165	3,885	
6-inch connector with ¾-inch bolt	1⅜	7½	6,085	5,580	5,070	4,565	4,055	3,550	3,040	2
		9½	6,085	5,680	5,275	4,870	4,465	4,055	3,650	
		11½	6,085	5,780	5,475	5,175	4,870	4,565	4,260	
	1½	7½	7,255	6,650	6,045	5,440	4,835	4,235	3,630	2⅝
		9½	7,255	6,770	6,290	5,805	5,320	4,840	4,355	
		11½	7,255	6,895	6,530	6,165	5,805	5,440	5,080	
	1⅝	7½	7,960	7,295	6,630	5,970	5,305	4,640	3,980	3
		9½	7,960	7,430	6,900	6,365	5,835	5,305	4,775	
		11½	7,960	7,560	7,165	6,765	6,365	5,970	5,570	
	2	7½	9,130	8,370	7,605	6,845	6,085	5,325	4,565	3⅝
		9½	9,130	8,520	7,910	7,305	6,695	6,085	5,475	
		11½	9,130	8,670	8,215	7,760	7,305	6,845	6,390	

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[1] The safe working loads apply to seasoned timbers used in dry, inside locations for a long-continued load. It is assumed also that the joints are properly designed with respect to such features as centering of connectors, adequate end margin, and suitable spacing.

[2] See p. 20.

[3] A 3-member assembly, with 2 connector units would therefore take double the safe working loads indicated in columns 4–10.

TABLE 2.—*Safe working loads*[1] *for 1 toothed connector and bolt (1 connector unit)*

LOADS FOR SPECIES IN GROUP 1 (WEAKEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—						Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	10°	20°	30°	40°	45–90°, inclusive	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2-inch connector with ½-inch bolt	1	2⅝	780	720	665	605	550	520	1⅝
		3	780	725	675	620	565	540	
		3⅝	780	735	690	640	595	570	
		4	780	740	695	655	610	590	
	1⅛	2⅝	860	795	730	665	605	570	2
		3	860	800	740	680	625	595	
		3⅝	860	805	755	705	655	630	
		4	860	810	765	720	675	650	
2⅝-inch connector with ⅝-inch bolt	1	3⅝	1,170	1,085	995	910	825	780	1⅝
		4	1,170	1,090	1,010	930	850	810	
		4⅝	1,170	1,100	1,030	960	890	860	
		5	1,170	1,105	1,045	980	920	885	
	1⅛	3⅝	1,295	1,200	1,105	1,005	910	865	2
		4	1,295	1,205	1,115	1,030	940	895	
		4⅝	1,295	1,220	1,140	1,065	990	950	
		5	1,295	1,225	1,155	1,085	1,015	985	
	1⅜	3⅝	1,400	1,355	1,245	1,135	1,030	975	2½
		4	1,400	1,360	1,260	1,160	1,060	1,010	
		4⅝	1,400	1,375	1,290	1,200	1,115	1,070	
		5	1,400	1,385	1,305	1,225	1,150	1,110	
3⅜-inch connector with ¾-inch bolt	1	4⅝	1,520	1,410	1,295	1,185	1,070	1,015	1⅝
		5½	1,520	1,430	1,335	1,240	1,150	1,105	
		6½	1,520	1,450	1,380	1,310	1,240	1,205	
	1⅛	4⅝	1,665	1,545	1,420	1,295	1,175	1,110	2
		5½	1,665	1,565	1,460	1,360	1,260	1,210	
		6½	1,665	1,590	1,510	1,435	1,355	1,320	
	1⅜	4⅝	1,910	1,765	1,625	1,485	1,345	1,270	2½
		5½	1,910	1,790	1,675	1,560	1,440	1,385	
		6½	1,910	1,820	1,730	1,645	1,555	1,510	
	1⅝	4⅝	2,055	1,900	1,750	1,595	1,445	1,370	3
		5½	2,055	1,930	1,805	1,675	1,550	1,490	
		6½	2,055	1,960	1,865	1,770	1,675	1,625	
4-inch connector with ¾-inch bolt	1	5½	1,835	1,695	1,560	1,425	1,290	1,220	1⅝
		6½	1,835	1,725	1,615	1,505	1,400	1,345	
		7½	1,835	1,750	1,670	1,590	1,505	1,465	
	1⅛	5½	1,985	1,835	1,690	1,540	1,395	1,320	2
		6½	1,985	1,865	1,750	1,630	1,515	1,455	
		7½	1,985	1,895	1,805	1,720	1,630	1,585	
	1⅜	5½	2,235	2,070	1,900	1,735	1,570	1,490	2½
		6½	2,235	2,100	1,970	1,835	1,705	1,640	
		7½	2,235	2,135	2,035	1,935	1,835	1,785	
	1⅝	5½	2,385	2,205	2,030	1,855	1,675	1,590	3
		6½	2,385	2,240	2,100	1,960	1,820	1,750	
		7½	2,385	2,275	2,170	2,065	1,960	1,905	

LOADS FOR SPECIES IN GROUP 2[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	0°	10°	20°	30°	40°	45–90°, inclusive	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt
2-inch connector with ½-inch bolt	1	2⅝	900	835	765	700	635	600	1⅝
		3	900	840	775	715	655	620	
		3⅝	900	845	795	740	685	660	
		4	900	860	805	755	705	680	
	1⅛	2⅝	990	915	845	770	695	660	2
		3	990	920	855	785	720	685	
		3⅝	990	930	870	815	755	725	
		4	990	935	885	830	760	750	
2⅝-inch connector with ⅝-inch bolt	1	3⅝	1,350	1,250	1,150	1,050	950	900	1⅝
		4	1,350	1,255	1,165	1,075	980	935	
		4⅝	1,350	1,270	1,190	1,110	1,030	990	
		5	1,350	1,275	1,205	1,135	1,060	1,025	
	1⅛	3⅝	1,495	1,385	1,275	1,165	1,050	995	2
		4	1,495	1,390	1,290	1,190	1,085	1,035	
		4⅝	1,495	1,405	1,320	1,230	1,140	1,095	
		5	1,495	1,415	1,335	1,255	1,175	1,135	
	1⅜	3⅝	1,690	1,565	1,440	1,315	1,185	1,125	2½
		4	1,690	1,570	1,455	1,340	1,225	1,165	
		4⅝	1,690	1,590	1,490	1,390	1,290	1,240	
		5	1,690	1,595	1,505	1,415	1,325	1,280	

See *footnotes at end of table.*

TABLE 2.—*Safe working loads*[1] *for 1 toothed connector and bolt (1 connector unit)*—Continued

LOADS FOR SPECIES IN GROUP 2[2]—Continued

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is— 0°	10°	20°	30°	40°	45–90°, inclusive	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
3⅜-inch connector with ¾-inch bolt	1	4⅝	1,755	1,625	1,495	1,365	1,235	1,170	1⅝
		5½	1,755	1,650	1,540	1,435	1,325	1,270	
		6½	1,755	1,675	1,590	1,510	1,430	1,390	
	1⅛	4⅝	1,920	1,780	1,640	1,495	1,355	1,280	2
		5½	1,920	1,805	1,685	1,570	1,450	1,395	
		6½	1,920	1,835	1,745	1,655	1,565	1,520	
	1½	4⅝	2,200	2,040	1,875	1,710	1,550	1,465	2⅝
		5½	2,200	2,065	1,930	1,795	1,660	1,595	
		6½	2,200	2,100	1,995	1,895	1,795	1,740	
	1⅝	4⅝	2,370	2,195	2,020	1,840	1,665	1,580	3
		5½	2,370	2,225	2,080	1,935	1,790	1,715	
		6½	2,370	2,260	2,150	2,040	1,930	1,875	
4-inch connector with ¾-inch bolt	1	5½	2,115	1,960	1,800	1,645	1,490	1,410	1⅝
		6½	2,115	1,990	1,865	1,740	1,615	1,550	
		7½	2,115	2,020	1,925	1,835	1,740	1,690	
	1⅛	5½	2,290	2,120	1,950	1,780	1,610	1,525	2
		6½	2,290	2,150	2,015	1,880	1,745	1,680	
		7½	2,290	2,185	2,085	1,985	1,880	1,830	
	1½	5½	2,575	2,385	2,195	2,005	1,815	1,720	2⅝
		6½	2,575	2,425	2,270	2,120	1,965	1,890	
		7½	2,575	2,465	2,350	2,235	2,120	2,060	
	1⅝	5½	2,750	2,545	2,345	2,140	1,935	1,835	3
		6½	2,750	2,585	2,425	2,260	2,100	2,015	
		7½	2,750	2,630	2,505	2,385	2,260	2,200	

LOADS FOR SPECIES IN GROUP 3[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	0°	10°	20°	30°	40°	45–90°, inclusive	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt
2-inch connector with ½-inch bolt	1	2⅝	1,000	925	850	780	705	665	1⅝
		3	1,000	930	865	795	725	690	
		3⅜	1,000	940	880	825	765	735	
		4	1,000	945	895	840	785	760	
	1⅛	2⅝	1,100	1,020	935	855	775	735	2
		3	1,100	1,025	950	875	800	760	
		3⅜	1,100	1,035	970	905	840	805	
		4	1,100	1,040	980	925	865	835	
2⅝-inch connector with ⅝-inch bolt	1	3⅜	1,500	1,390	1,280	1,165	1,055	1,000	1⅝
		4	1,500	1,395	1,295	1,190	1,090	1,040	
		4⅝	1,500	1,410	1,320	1,235	1,145	1,100	
		5	1,500	1,420	1,340	1,260	1,180	1,140	
	1⅛	3⅜	1,660	1,540	1,415	1,290	1,170	1,105	2
		4	1,660	1,545	1,435	1,320	1,205	1,150	
		4⅝	1,660	1,560	1,465	1,365	1,265	1,220	
		5	1,660	1,570	1,480	1,395	1,305	1,260	
	1⅝	3⅜	1,875	1,735	1,595	1,460	1,320	1,250	2½
		4	1,875	1,745	1,620	1,490	1,360	1,295	
		4⅝	1,875	1,765	1,655	1,540	1,430	1,375	
		5	1,875	1,775	1,675	1,575	1,470	1,420	
3⅜-inch connector with ¾-inch bolt	1	4⅝	1,950	1,805	1,660	1,515	1,370	1,300	1⅝
		5½	1,950	1,830	1,710	1,595	1,475	1,415	
		6½	1,950	1,860	1,770	1,680	1,590	1,545	
	1⅛	4⅝	2,135	1,980	1,820	1,660	1,505	1,425	2
		5½	2,135	2,005	1,875	1,745	1,615	1,550	
		6½	2,135	2,035	1,940	1,840	1,740	1,690	
	1½	4⅝	2,445	2,265	2,085	1,905	1,720	1,630	2⅝
		5½	2,445	2,295	2,145	2,000	1,850	1,775	
		6½	2,445	2,335	2,220	2,105	1,995	1,935	
	1⅝	4⅝	2,630	2,435	2,240	2,045	1,850	1,755	3
		5½	2,630	2,470	2,310	2,150	1,990	1,910	
		6½	2,630	2,510	2,390	2,265	2,145	2,085	
4-inch connector with ¾-inch bolt	1	5½	2,350	2,175	2,000	1,830	1,655	1,565	1⅝
		6½	2,350	2,210	2,070	1,935	1,795	1,725	
		7½	2,350	2,245	2,140	2,035	1,930	1,880	
	1⅛	5½	2,540	2,355	2,165	1,975	1,790	1,695	2
		6½	2,540	2,390	2,240	2,090	1,940	1,865	
		7½	2,540	2,430	2,315	2,205	2,090	2,035	
	1½	5½	2,865	2,650	2,440	2,225	2,015	1,910	2⅝
		6½	2,865	2,695	2,525	2,355	2,185	2,100	
		7½	2,865	2,735	2,610	2,480	2,355	2,290	
	1⅝	5½	3,055	2,830	2,650	2,375	2,150	2,035	3
		6½	3,055	2,875	2,695	2,510	2,330	2,240	
		7½	3,055	2,920	2,785	2,650	2,510	2,445	

See footnotes at end of table.

TABLE 2.—*Safe working loads*[1] *for 1 toothed connector and bolt (1 connector unit)*—Continued

LOADS FOR SPECIES IN GROUP 4 (STRONGEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—						Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	10°	20°	30°	40°	45–90°, inclusive	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2-inch connector with ½-inch bolt	1	2⅝	1,100	1,020	935	855	775	735	1⅝
		3	1,100	1,025	950	875	800	760	
		3⅝	1,100	1,035	970	905	840	805	
		4	1,100	1,040	980	925	865	835	
	1⅛	2⅝	1,210	1,120	1,030	940	850	805	2
		3	1,210	1,125	1,045	960	880	835	
		3⅝	1,210	1,140	1,065	995	925	890	
		4	1,210	1,145	1,080	1,015	950	920	
2⅝-inch connector with ⅝-inch bolt	1	3⅝	1,650	1,530	1,405	1,285	1,160	1,100	1⅝
		4	1,650	1,535	1,425	1,310	1,200	1,140	
		4⅝	1,650	1,550	1,455	1,355	1,260	1,210	
		5	1,650	1,560	1,475	1,385	1,295	1,250	
	1⅛	3⅝	1,825	1,690	1,555	1,420	1,285	1,220	2
		4	1,825	1,700	1,575	1,450	1,325	1,265	
		4⅝	1,825	1,720	1,610	1,500	1,395	1,340	
		5	1,825	1,730	1,630	1,530	1,435	1,385	
	1⅜	3⅝	2,060	1,910	1,755	1,605	1,450	1,375	2½
		4	2,060	1,920	1,780	1,640	1,500	1,425	
		4⅝	2,060	1,940	1,820	1,695	1,575	1,510	
		5	2,060	1,950	1,840	1,730	1,620	1,565	
3⅜-inch connector with ¾-inch bolt	1	4⅝	2,145	1,985	1,825	1,670	1,510	1,430	1⅝
		5½	2,145	2,015	1,885	1,750	1,620	1,555	
		6½	2,145	2,045	1,945	1,845	1,750	1,700	
	1⅛	4⅝	2,350	2,175	2,000	1,830	1,655	1,565	2
		5½	2,350	2,205	2,065	1,920	1,775	1,705	
		6½	2,350	2,240	2,135	2,025	1,915	1,860	
	1½	4⅝	2,600	2,400	2,290	2,095	1,895	1,795	2⅝
		5½	2,600	2,525	2,360	2,200	2,035	1,950	
		6½	2,600	2,565	2,440	2,320	2,195	2,130	
	1⅝	4⅝	2,895	2,680	2,465	2,255	2,040	1,930	3
		5½	2,895	2,720	2,540	2,365	2,190	2,100	
		6½	2,895	2,760	2,630	2,495	2,360	2,295	
4-inch connector with ¾-inch bolt	1	5½	2,585	2,305	2,200	2,010	1,820	1,725	1⅝
		6½	2,585	2,430	2,280	2,125	1,970	1,895	
		7½	2,585	2,470	2,355	2,240	2,125	2,070	
	1⅛	5½	2,795	2,590	2,380	2,175	1,970	1,865	2
		6½	2,795	2,630	2,465	2,300	2,135	2,050	
		7½	2,795	2,670	2,550	2,425	2,300	2,235	
	1½	5½	3,150	2,915	2,680	2,450	2,215	2,100	2⅝
		6½	3,150	2,960	2,775	2,590	2,400	2,310	
		7½	3,150	3,010	2,870	2,730	2,590	2,520	
	1⅝	5½	3,360	3,110	2,860	2,615	2,365	2,240	3
		6½	3,360	3,160	2,960	2,765	2,565	2,465	
		7½	3,360	3,210	3,060	2,910	2,765	2,690	

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[1] The safe working loads apply to seasoned timbers used in dry, inside locations for a long-continued load. It is assumed also that the joints are properly designed with respect to such features as centering of connectors, adequate end margin, and suitable spacing.

[2] See p. 20.

[3] A 3-member assembly, with to 2 connector units would therefore take double the safe working loads indicated in columns 4-9.

TABLE 3.—*Safe working loads for 1 claw-plate connector and bolt*[1] *(1 connector unit)*

LOADS FOR SPECIES IN GROUP 1 (WEAKEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—							Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	15°	30°	45°	60°	75°	90°	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2⅝-inch connector and ½-inch bolt (wood or metal side plates)	1¼	3⅝	1,750	1,615	1,485	1,350	1,220	1,085	950	2
		4⅝	1,750	1,635	1,515	1,400	1,280	1,165	1,045	
		5½	1,750	1,645	1,545	1,440	1,335	1,235	1,130	
	1⅝	3⅝	2,625	2,425	2,225	2,025	1,825	1,630	1,430	2⅝
		4⅝	2,625	2,450	2,275	2,100	1,920	1,745	1,570	
		5½	2,625	2,470	2,315	2,160	2,005	1,850	1,695	
3⅛-inch connector and ½-inch bolt (wood or metal side plates)	1¼	4⅝	2,260	2,085	1,910	1,735	1,555	1,380	1,205	2
		5½	2,260	2,100	1,945	1,785	1,630	1,470	1,310	
		6½	2,260	2,120	1,985	1,845	1,710	1,570	1,430	
	1½	4⅝	2,965	2,735	2,505	2,275	2,045	1,815	1,585	2⅝
		5½	2,965	2,760	2,550	2,345	2,135	1,930	1,720	
		6½	2,965	2,785	2,605	2,420	2,240	2,060	1,880	
	1⅝	4⅝	3,390	3,125	2,860	2,600	2,335	2,070	1,810	3
		5½	3,390	3,160	2,915	2,675	2,440	2,205	1,965	
		6½	3,390	3,180	2,975	2,770	2,560	2,355	2,150	
4-inch connector and ¾-inch bolt (wood or metal side plates)	1¼	5½	3,025	2,770	2,510	2,255	1,995	1,740	1,485	2
		6½	3,025	2,795	2,560	2,330	2,095	1,865	1,630	
		7½	3,025	2,815	2,610	2,400	2,195	1,985	1,780	
	1½	5½	3,655	3,345	3,035	2,725	2,410	2,100	1,790	2⅝
		6½	3,655	3,375	3,095	2,810	2,530	2,250	1,970	
		7½	3,655	3,405	3,155	2,900	2,650	2,400	2,150	
	1⅝	5½	4,035	3,690	3,350	3,005	2,665	2,320	1,975	3
		6½	4,035	3,725	3,415	3,105	2,795	2,485	2,175	
		7½	4,035	3,755	3,480	3,205	2,925	2,650	2,370	
	1⅞	5½	4,540	4,150	3,765	3,380	2,995	2,610	2,225	3½
		6½	4,540	4,190	3,840	3,490	3,145	2,795	2,445	
		7½	4,540	4,225	3,915	3,605	3,290	2,980	2,670	
LOADS FOR SPECIES IN GROUP 2[2]										
2⅝-inch connector and ½-inch bolt (wood or metal side plates)	1¼	3⅝	1,915	1,785	1,650	1,515	1,380	1,245	1,110	2
		4⅝	1,915	1,800	1,685	1,570	1,455	1,340	1,225	
		5½	1,915	1,820	1,720	1,620	1,520	1,420	1,320	
	1⅝	3⅝	2,875	2,675	2,475	2,270	2,070	1,870	1,670	2⅝
		4⅝	2,875	2,700	2,530	2,355	2,180	2,010	1,835	
		5½	2,875	2,725	2,575	2,430	2,280	2,130	1,980	
3⅛-inch connector and ½-inch bolt:										
Wood side plate	1¼	4⅝	2,435	2,260	2,090	1,915	1,745	1,570	1,395	2
		5½	2,435	2,280	2,130	1,975	1,825	1,670	1,520	
		6½	2,435	2,305	2,175	2,045	1,920	1,790	1,660	
	1½	4⅝	3,195	2,970	2,740	2,515	2,285	2,060	1,835	2⅝
		5½	3,195	2,995	2,795	2,595	2,395	2,195	1,995	
		6½	3,195	3,025	2,855	2,685	2,515	2,345	2,175	
	1⅝	4⅝	3,650	3,390	3,135	2,875	2,615	2,355	2,095	3
		5½	3,650	3,425	3,195	2,965	2,735	2,505	2,280	
		6½	3,650	3,460	3,265	3,070	2,875	2,680	2,490	
Metal side plate	1¼	4⅝	2,565	2,370	2,175	1,980	1,785	1,590	1,395	2
		5½	2,565	2,390	2,215	2,040	1,865	1,695	1,520	
		6½	2,565	2,415	2,260	2,110	1,960	1,810	1,660	
	1½	4⅝	3,365	3,110	2,855	2,600	2,345	2,090	1,835	2⅝
		5½	3,365	3,135	2,905	2,680	2,450	2,220	1,995	
		6½	3,365	3,165	2,970	2,770	2,575	2,375	2,175	
	1⅝	4⅝	3,845	3,550	3,260	2,970	2,680	2,385	2,095	3
		5½	3,845	3,585	3,320	3,060	2,800	2,540	2,280	
		6½	3,845	3,620	3,390	3,165	2,940	2,715	2,490	
4-inch connector and ¾-inch bolt:										
Wood side plate	1¼	5½	3,300	3,040	2,775	2,515	2,250	1,990	1,725	2
		6½	3,300	3,065	2,835	2,600	2,365	2,135	1,900	
		7½	3,300	3,095	2,890	2,685	2,480	2,275	2,070	
	1½	5½	3,990	3,670	3,355	3,040	2,720	2,405	2,085	2⅝
		6½	3,990	3,705	3,425	3,140	2,860	2,575	2,295	
		7½	3,990	3,740	3,495	3,245	3,000	2,750	2,505	
	1⅝	5½	4,400	4,050	3,700	3,350	3,000	2,650	2,300	3
		6½	4,400	4,090	3,780	3,465	3,155	2,845	2,530	
		7½	4,400	4,130	3,855	3,580	3,310	3,035	2,760	
	1⅞	5½	4,960	4,560	4,165	3,770	3,375	2,985	2,590	3½
		6½	4,960	4,600	4,250	3,900	3,550	3,200	2,850	
		7½	4,960	4,645	4,335	4,030	3,720	3,415	3,110	

See footnotes at end of table.

TABLE 3.—*Safe working loads for 1 claw-plate connector and bolt*[1] *(1 connector unit)*—Continued

LOADS FOR SPECIES IN GROUP 2[2]—Continued

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is—							Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
			0°	15°	30°	45°	60°	75°	90°	
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
4-inch connector and ¾-inch bolt—Con. Metal side plate	1¼	5½	3,475	3,185	2,890	2,600	2,310	2,020	1,725	2
		6½	3,475	3,210	2,950	2,685	2,425	2,160	1,900	
		7½	3,475	3,240	3,005	2,775	2,540	2,305	2,070	
	1½	5½	4,200	3,845	3,495	3,145	2,790	2,440	2,085	2⅝
		6½	4,200	3,880	3,565	3,245	2,930	2,610	2,295	
		7½	4,200	3,915	3,635	3,350	3,070	2,785	2,505	
	1⅝	5½	4,635	4,245	3,855	3,465	3,080	2,690	2,300	3
		6½	4,635	4,285	3,935	3,585	3,230	2,880	2,530	
		7½	4,635	4,320	4,010	3,695	3,385	3,075	2,760	
	1⅞	5½	5,210	4,775	4,340	3,900	3,465	3,025	2,590	3½
		6½	5,210	4,820	4,425	4,030	3,635	3,245	2,850	
		7½	5,210	4,860	4,510	4,160	3,810	3,460	3,110	
LOADS FOR SPECIES IN GROUP 3[2]										
2⅝-inch connector and ½-inch bolt (wood or metal side plates)	1¼	3⅝	2,025	1,905	1,790	1,670	1,555	1,435	1,315	2
		4⅝	2,025	1,930	1,835	1,735	1,640	1,545	1,450	
		5½	2,025	1,950	1,870	1,795	1,715	1,640	1,565	
	1⅝	3⅝	3,040	2,860	2,685	2,505	2,330	2,150	1,975	2⅝
		4⅝	3,040	2,895	2,750	2,605	2,460	2,315	2,170	
		5½	3,040	2,925	2,805	2,690	2,575	2,460	2,345	
3½-inch connector and ½-inch bolt:										
Wood side plate	1¼	4⅝	2,560	2,410	2,260	2,110	1,960	1,810	1,655	2
		5½	2,560	2,435	2,310	2,180	2,055	1,930	1,800	
		6½	2,560	2,460	2,365	2,265	2,165	2,065	1,970	
	1½	4⅝	3,360	3,165	2,965	2,770	2,570	2,370	2,175	2⅝
		5½	3,360	3,195	3,030	2,865	2,695	2,530	2,365	
		6½	3,360	3,230	3,100	2,970	2,840	2,710	2,580	
	1⅝	4⅝	3,840	3,615	3,390	3,165	2,935	2,710	2,485	3
		5½	3,840	3,650	3,460	3,270	3,080	2,890	2,700	
		6½	3,840	3,695	3,545	3,395	3,250	3,100	2,950	
Metal side plate	1¼	4⅝	2,845	2,650	2,450	2,250	2,055	1,855	1,655	2
		5½	2,845	2,670	2,500	2,325	2,150	1,975	1,800	
		6½	2,845	2,700	2,555	2,405	2,260	2,115	1,970	
	1½	4⅝	3,735	3,475	3,215	2,955	2,695	2,435	2,175	2⅝
		5½	3,735	3,505	3,280	3,050	2,820	2,590	2,365	
		6½	3,735	3,545	3,350	3,160	2,960	2,775	2,580	
	1⅝	4⅝	4,270	3,970	3,675	3,375	3,080	2,780	2,485	3
		5½	4,270	4,010	3,745	3,485	3,225	2,965	2,700	
		6½	4,270	4,050	3,830	3,610	3,390	3,170	2,950	
4-inch connector and ¾-inch bolt:										
Wood side plate	1¼	5½	3,610	3,350	3,090	2,830	2,570	2,310	2,045	2
		6½	3,610	3,385	3,160	2,930	2,705	2,480	2,250	
		7½	3,610	3,420	3,225	3,035	2,840	2,650	2,455	
	1½	5½	4,365	4,050	3,735	3,420	3,105	2,790	2,475	2⅝
		6½	4,365	4,090	3,815	3,540	3,270	2,995	2,720	
		7½	4,365	4,130	3,900	3,665	3,435	3,200	2,970	
	1⅝	5½	4,815	4,465	4,120	3,770	3,425	3,075	2,730	3
		6½	4,815	4,515	4,210	3,910	3,605	3,305	3,000	
		7½	4,815	4,560	4,300	4,045	3,790	3,530	3,275	
	1⅞	5½	5,415	5,025	4,635	4,245	3,850	3,460	3,070	3½
		6½	5,415	5,075	4,735	4,395	4,055	3,715	3,375	
		7½	5,415	5,130	4,840	4,550	4,260	3,975	3,685	
Metal side plate	1¼	5½	4,015	3,685	3,360	3,030	2,700	2,375	2,045	2
		6½	4,015	3,720	3,425	3,130	2,840	2,545	2,250	
		7½	4,015	3,755	3,495	3,235	2,975	2,715	2,455	
	1½	5½	4,850	4,455	4,055	3,660	3,265	2,870	2,475	2⅝
		6½	4,850	4,495	4,140	3,785	3,430	3,075	2,720	
		7½	4,850	4,535	4,220	3,910	3,595	3,280	2,970	
	1⅝	5½	5,350	4,915	4,475	4,040	3,605	3,165	2,730	3
		6½	5,350	4,960	4,565	4,175	3,785	3,395	3,000	
		7½	5,350	5,005	4,660	4,310	3,965	3,620	3,275	
	1⅞	5½	6,020	5,525	5,035	4,545	4,055	3,560	3,070	3½
		6½	6,020	5,580	5,140	4,700	4,260	3,815	3,375	
		7½	6,020	5,630	5,240	4,850	4,460	4,075	3,685	

See footnotes at end of table.

Table 3.—*Safe working loads for 1 claw-plate connector and bolt*[1] *(1 connector unit)*—Continued

LOADS FOR SPECIES IN GROUP 4 (STRONGEST SPECIES)[2]

Connector unit	Minimum thickness of member with 1 connector only	Minimum width, all members	Load when angle of load application to grain is— 0°	15°	30°	45°	60°	75°	90°	Minimum thickness of member with 2 connectors in opposite faces, 1 bolt[3]
	Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*
2⅝-inch connector and ½-inch bolt (wood or metal side plates)	1¼	3⅝	2,050	1,960	1,875	1,785	1,700	1,610	1,525	2
		4⅝	2,050	1,985	1,925	1,865	1,800	1,740	1,675	
		5½	2,050	2,010	1,970	1,930	1,890	1,850	1,810	
	1⅝	3⅝	3,075	2,945	2,810	2,680	2,550	2,415	2,285	2⅝
		4⅝	3,075	2,980	2,800	2,795	2,700	2,610	2,515	
		5½	3,075	3,015	2,955	2,895	2,835	2,775	2,715	
3⅛-inch connector and ½-inch bolt:										
Wood side plate	1¼	4⅝	2,665	2,540	2,415	2,290	2,165	2,040	1,915	2
		5½	2,665	2,565	2,470	2,375	2,280	2,180	2,085	
		6½	2,665	2,600	2,535	2,470	2,405	2,340	2,275	
	1½	4⅝	3,495	3,330	3,170	3,005	2,840	2,680	2,515	2⅝
		5½	3,495	3,370	3,240	3,115	2,990	2,860	2,735	
		6½	3,495	3,410	3,325	3,240	3,155	3,070	2,990	
	1⅝	4⅝	3,995	3,805	3,620	3,435	3,250	3,060	2,875	3
		5½	3,995	3,850	3,700	3,560	3,415	3,270	3,125	
		6½	3,995	3,895	3,800	3,705	3,605	3,510	3,415	
Metal side plate	1¼	4⅝	2,960	2,785	2,610	2,440	2,265	2,090	1,915	2
		5½	2,960	2,815	2,670	2,520	2,375	2,230	2,085	
		6½	2,960	2,845	2,730	2,615	2,505	2,390	2,275	
	1½	4⅝	3,885	3,655	3,425	3,200	2,970	2,745	2,515	2⅝
		5½	3,885	3,690	3,500	3,310	3,120	2,925	2,735	
		6½	3,885	3,735	3,585	3,435	3,285	3,135	2,990	
	1⅝	4⅝	4,440	4,180	3,915	3,655	3,395	3,135	2,875	3
		5½	4,440	4,220	4,000	3,785	3,565	3,345	3,125	
		6½	4,440	4,270	4,095	3,925	3,755	3,585	3,415	
4-inch connector and ¾-inch bolt:										
Wood side plate	1¼	5½	3,745	3,515	3,285	3,055	2,825	2,590	2,360	2
		6½	3,745	3,555	3,365	3,170	2,980	2,790	2,595	
		7½	3,745	3,595	3,440	3,290	3,140	2,985	2,835	
	1½	5½	4,525	4,250	3,970	3,690	3,410	3,130	2,855	2⅝
		6½	4,525	4,295	4,065	3,835	3,600	3,370	3,140	
		7½	4,525	4,345	4,160	3,975	3,790	3,610	3,425	
	1⅝	5½	4,995	4,690	4,380	4,070	3,765	3,455	3,150	3
		6½	4,995	4,740	4,485	4,230	3,975	3,720	3,465	
		7½	4,995	4,795	4,590	4,385	4,185	3,990	3,780	
	1⅞	5½	5,620	5,275	4,925	4,580	4,235	3,890	3,540	3½
		6½	5,620	5,335	5,045	4,760	4,470	4,185	3,895	
		7½	5,620	5,390	5,165	4,935	4,705	4,480	4,250	
Metal side plate	1¼	5½	4,410	4,065	3,725	3,385	3,045	2,700	2,360	2
		6½	4,410	4,105	3,805	3,500	3,200	2,900	2,595	
		7½	4,410	4,145	3,885	3,620	3,360	3,095	2,835	
	1½	5½	5,325	4,915	4,500	4,090	3,675	3,265	2,855	2⅝
		6½	5,325	4,960	4,595	4,230	3,865	3,505	3,140	
		7½	5,325	5,010	4,690	4,375	4,060	3,740	3,425	
	1⅝	5½	5,875	5,420	4,965	4,510	4,060	3,605	3,150	3
		6½	5,875	5,475	5,070	4,670	4,270	3,865	3,465	
		7½	5,875	5,525	5,175	4,825	4,480	4,130	3,780	
	1⅞	5½	6,610	6,100	5,590	5,075	4,565	4,055	3,540	3½
		6½	6,610	6,160	5,705	5,255	4,800	4,350	3,895	
		7½	6,610	6,220	5,825	5,430	5,035	4,645	4,250	

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[1] The safe working loads apply to seasoned timbers used in dry, inside locations for a long-continued load. It is assumed also that the joints are properly designed with respect to such features as centering of connectors, adequate end margin, and suitable spacing.

[2] See p. 20.

[3] A 3-member assembly, with to 2-connector units would therefore take double the safe working loads indicated in columns 4–10.

TABLE 4.—*Strength ratio for split-ring connectors for various end margins and spacings* [1]

END MARGIN: TENSION MEMBER

[Distance from center of connector to end of member]

Diameter of connector (inches)	Strength ratio (percent) when end distance is (inches)—								
	2¾	3¼	4½	5	5½	6	7	8	9
2½	62	73	86	93	100	100	100	100	100
4		62	73	79	84	89	100	100	100
6			62	67	71	75	83	92	100

END MARGIN: COMPRESSION MEMBER

[Distance from center of connector to end of member]

Diameter of connector (inches)	Strength ratio (percent) when end distance is (inches)—								
	2½	3¼	4	4¼	5	5½	6	7	7½
2½	62	81	100	100	100	100	100	100	100
4		62	75	79	92	100	100	100	100
6				62	71	77	83	94	100

SPACING

[Distance, center to center, of connectors]

Diameter of connector (inches)	Strength ratio (percent) when spacing is (inches)—								
	3⅜	4⅞	6	6¾	7	8	9	10½	12
2½	50	72	89	100	100	100	100	100	100
4		50	63	73	76	88	100	100	100
6					50	60	70	85	100

[1] Multiply the safe working load of table 1 by the appropriate strength ratio to obtain the design load for the split-ring connector when used with various end margins or spacings.

TABLE 5.—*Strength ratio for toothed connectors for various end margins and spacings* [1]

END MARGIN: TENSION MEMBER [2]

[Distance from center of connector to end of member]

Diameter of connector (inches)	Strength ratio (percent) when end distance is (inches)—							
	2	2⅝	3⅜	3½	4	4⅝	5⅞	7
2	67	81	96	100	100	100	100	100
2⅝		67	70	81	90	100	100	100
3⅜			67	68	75	83	100	100
4					67	74	87	100

SPACING

[Distance, center to center, of connectors]

Diameter of connector (inches)	Strength ratio (percent) when spacing is (inches)—							
	2	2⅝	3⅜	4	5¼	6	6¾	8
2	50	66	84	100	100	100	100	100
2⅝		50	64	76	100	100	100	100
3⅜			50	59	78	89	100	100
4				50	66	75	84	100

[1] Multiply the safe working load of table 2 by the appropriate strength ratio to obtain the design load for the toothed connector when used with various end margins or spacings.

[2] For a compression member, the end distance for full allowable load should not be less than the diameter of the connector.

TABLE 6.—*Strength ratio for claw-plate connectors for various end margins and spacings* [1]

END MARGIN: TENSION MEMBER

[Distance from center of connector to end of member]

Diameter of connector (inches)	Strength ratio (percent) when end distance is (inches)—								
	2¾	3	3½	4	4½	5	5⅝	6⅛	7
2⅝	62	66	72	70	85	92	100	100	100
3⅛	--------	62	68	74	80	86	94	100	100
4	--------	--------	62	68	73	79	85	91	100

END MARGIN: COMPRESSION MEMBER

[Distance from center of connector to end of member]

Diameter of connector (inches)	Strength ratio (percent) when end distance is (inches)—								
	2¾	3	3½	4	4⅛	4½	4⅝	5	5½
2⅝	62	69	83	--------	100	100	100	100	100
3½	--------	62	74	86	88	97	100	100	100
4	--------	--------	62	72	74	81	84	91	100

SPACING

[Distance, center to center, of connectors]

Diameter of connector (inches)	Strength ratio (percent) when spacing is (inches)—								
	3	3½	4	4½	5	6	7	7¾	9
2⅝	50	56	62	69	75	88	100	100	100
3⅛	--------	50	56	62	68	79	91	100	100
4	--------	--------	--------	50	56	67	78	86	100

[1] Multiply the safe working load of table 3 by the appropriate strength ratio to obtain the design load for the claw-plate connector when used with various end margins or spacings.

MODIFICATION OF WORKING LOADS AND FACTORS TO BE CONSIDERED IN THEIR USE

The factors which affect the safe working loads of connectors have either been included in deriving the tabular values or require modification of the values listed in accordance with the provisions outlined in subsequent paragraphs.

WIND OR EARTHQUAKE LOADS

In designing for wind or earthquake forces acting alone, or acting in conjunction with dead and live loads, the safe working loads for the various connectors may be increased by the following percentages, provided the number and size of connectors is not less than that required for the combination of dead and live load alone:

	Increase (percent)
Split-ring connector, any size, bearing in any direction	50
Claw-plate connector, any size, bearing parallel to grain	[2] 33⅓
Claw-plate connector, any size, bearing perpendicular to grain	[2] 50
Toothed-ring connector, 2-inch, bearing in any direction	[2] 50
Toothed-ring connector, 4-inch, bearing in any direction	[2] 25

[2] Proper percentages for claw-plate connectors bearing at intermediate angles and for toothed-ring connectors of other sizes may be obtained by interpolation.

IMPACT FORCES

Impact may be disregarded up to the following percentage of the static effect of the live load producing the impact:

	Impact allowance (percent)
Split-ring connector, any size, bearing in any direction	100
Claw-plate connector, any size, bearing parallel to grain	[3] 66⅔
Claw-plate connector, any size, bearing perpendicular to grain	[3] 100
Toothed-ring connector, 2-inch, bearing in any direction	[3] 100
Toothed-ring connector, 4-inch, bearing in any direction	[3] 50

[3] See footnote, p. 31.

One-half of any impact load that remains after disregarding the percent indicated above should be included with the other dead and live loads in obtaining the total force to be considered in designing the joint.

FACTOR OF SAFETY NOT REDUCED

The procedures described above for increasing the allowable loads on connectors for forces suddenly applied and forces of short duration do not reduce the actual factor of safety of the joint but are recommended because of the favorable behavior of wood under such forces. The differentiation among types and sizes of connector and directions of bearing is due to variations in the extent to which distortion of the metal, as well as the strength of the wood, affects the ultimate strength of the joint.

SPECIAL DESIGN CONSIDERATIONS

It is recognized that conditions of design may be encountered, with respect to the kind of load on a structure and the period of its continuation, which are neither "long continued" nor "suddenly applied" and hence require or justify special consideration and possible modifications, other than those that have been indicated, of the working loads listed in tables 1 to 3. For such conditions, it may be assumed that 90 and 80 percent of the stress which causes failure in 5 minutes (time usually assumed for wind load) will cause failure in 50 minutes and 10 hours, respectively.

EXPOSURE AND MOISTURE CONDITION OF WOOD

The loads listed in tables 1 to 3 apply to seasoned timbers used where they will remain dry. If the exposure is such that the timbers will be more or less continuously damp or wet, two-thirds of the tabulated values should be used (*14, 15, 19*). The amount by which the loads should be reduced to adapt them to other conditions of use is dependent upon the extent to which the exposure favors decay, required life of the structure or part, frequency and thoroughness of inspection, original cost and cost of replacements, proportion of sapwood and durability of heartwood of the species if untreated, and character and efficiency of the treatment if treated. These factors should be evaluated for each individual design. As a guide, it is suggested that, for exposure conditions of use where the timber will be occasionally wet but quickly dried, three-fourths of the tabulated working loads listed be used.

Ordinarily, before fabrication of connector joints, timbers should be seasoned to a moisture content corresponding as nearly as practical to that which they will attain in service. This is particularly desirable for material for roof trusses and other structural units used in dry locations, and in which shrinkage is an important factor. The exigencies of construction in wartime, however, have resulted in the erection of many timber connector structures and structural units employing green or inadequately seasoned lumber. Since such lumber in most building installations subsequently dries out, causing shrinkage and opening of the joints, it is essential that adequate maintenance measures be adopted. This maintenance should include inspection of the structural units, tightening of all bolts within 3 to 6 months after erection, and repetition of this procedure within about a year.

GRADE AND QUALITY OF LUMBER

The timber for which the working loads for connectors are applicable should conform to the general requirements in regard to the quality of timber specified by American Lumber Standards[9] (*16*). These requirements include provisions that all material shall be well manufactured, that no piece of exceptionally light weight shall be permitted, and that only pieces of sound wood free from any form of decay shall be acceptable.

With these recommended safe loads, it is assumed that the material at the joints is clear and relatively free from checks and shakes or splits. The material should be either free from knots, or, if knots are assumed to be present in the longitudinal projection of the net section within a length from the critical section of half the diameter of the connector, the area of the knots should be subtracted from the area of the critical section. It is also assumed that cross grain at the joint does not exceed a slope of 1 in 10.

LOADS AT AN ANGLE WITH THE GRAIN OF WOOD

The safe working loads for the split-ring and claw-plate connectors for intervening angles between direction of load and grain from 0° to 90° were obtained by using a lineal relationship between the parallel- and perpendicular-to-grain values. With the toothed connectors, the safe working load at an inclination to grain varies lineally, in conformity with test results, from 0° to 45° to the grain, between the working loads parallel with and perpendicular to the grain; but from 45° to 90° it is equal to the working load perpendicular to the grain.

SIZE OF MEMBER

The relationship between the loads for the different thicknesses and widths of lumber is based on the test results. The loads for wood members of thicknesses and widths intermediate to those listed can be obtained by direct interpolation.

WIDTH OF MEMBER

The smallest width of member listed for each type and size of connector is the minimum that should be used. When the connectors

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[9] Similar specifications are provided by American Society for Testing Materials (*1*).

are bearing parallel to the grain, no increase in load occurs with an increase in width over the minimum. When they are bearing at any other angle to the grain, the largest width listed is, with few exceptions, the maximum that permits an increase in load with an increase in width. The conditions under which a slightly greater width can be assumed to withstand an increase in load are discussed with the test results (pp. 56, 84, and 100). When the connector is placed off-center and the load is applied continuously in one direction only, the proper working load can be determined by considering the width of member equal to twice the edge distance (the distance between the

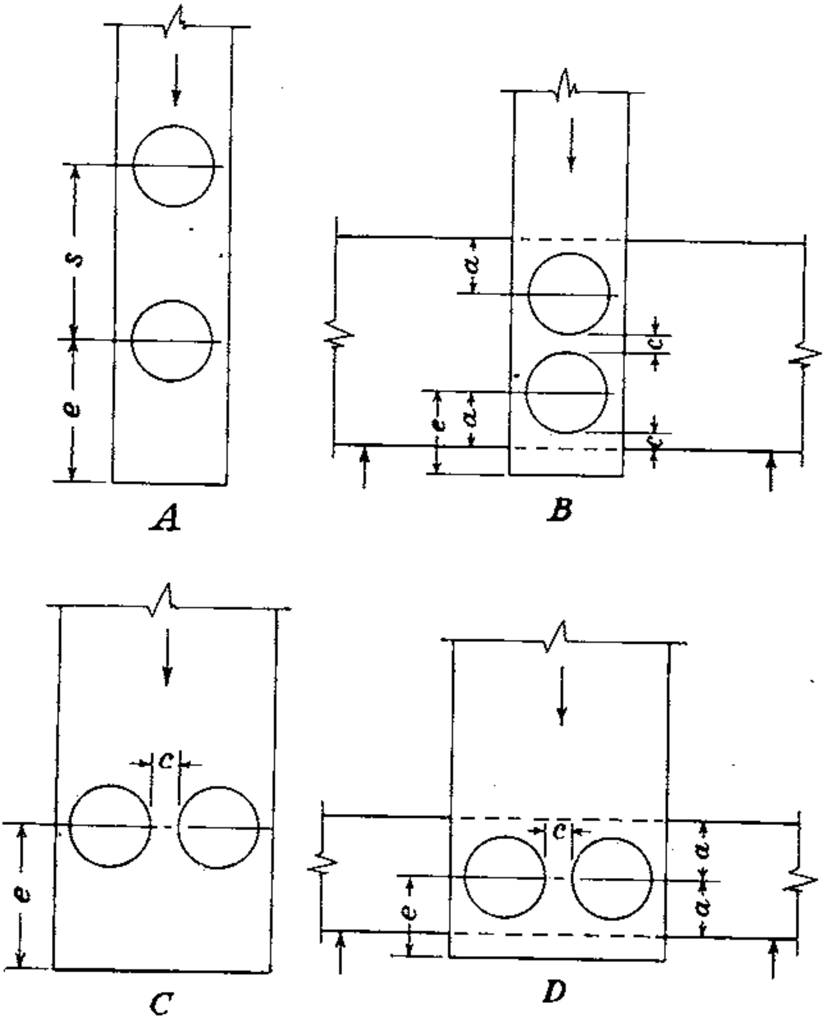

FIGURE 11.—Types of multiple-connector joints: *A*, Joint strength dependent upon end (*e*) and spacing (*s*) distances; *B*, joint strength dependent upon end (*e*), clear (*c*), and edge (*a*) distances; *C*, joint strength dependent upon end (*e*) and clear (*c*) distances; *D*, joint strength dependent upon end (*e*), clear (*c*), and edge (*a*) distances.

center of the connector and the edge of the member) toward which the load is acting, but the distance between the center of the connector and the opposite edge should not be less than half of the permissible minimum width of the member.

Thickness of Member

The least thickness of member given in tables 1–3 for the various sizes of connectors is the minimum which should be used, except that for toothed connectors, when placed in opposite faces of a member, minimum thickness may be 1½ inches, and 1 inch when in one face only. The load for members 1½ inches thick is only a few percent lower than for a thickness of 1⅝ inches. The loads listed for the greatest thickness of member in each type and size of connector unit are the maximum loads to be used for all thicker material.

END DISTANCE AND SPACING

The values in the tables apply when the distance of the connector from the end of the member (end distance) and the spacing between connectors in multiple joints are not factors in the strength of the joint (fig. 11, *A*, *e* and *s*). When the end distance or spacing for connectors bearing parallel to the grain is less than that required to develop the full load, the proper reduced working load for design may be obtained by multiplying the tabulated working loads by the appropriate strength ratio, given in tables 4, 5, and 6. For example the load for a 4-inch split-ring connector bearing parallel to the grain, when placed 7 or more inches from the end of a Douglas-fir tension member which is 1⅝ inches in thickness, is 4,780 pounds. When the end distance (distance between the end of the timber and the center of the connector) is only 4½ inches, the strength ratio (table 4) is 0.73 and the load equals 0.73×4,780=3,490 pounds. The method for determining the end distance when the end of the member is not at right angles to the length is given in the discussion of end margin (p. 63)

PLACEMENT OF MULTIPLE CONNECTORS

The placement of connectors in a multiple joint involves the consideration of several factors which have not been adequately determined. Preliminary investigations, however, together with the observed behavior of single connector joints tested with variables which simulate those in a multiple joint, furnish a basis for some suggested design practices.

When two or more connectors in the same face of a member are in a line at right angles to the grain of a member and are bearing parallel to the grain (fig. 11, *C*), the clear distance (*c*) between the connectors should not be less than one-half inch.

When two or more connectors are acting perpendicular to the grain and are spaced on a line at right angles to the length of the member (fig. 11, *B*), the rules for the width of member and edge distances (p. 33) used with one connector are applicable to the edge distances. The clear distance between the connectors (*c*) should be equal to the clear distance from the edge of the timber toward which the load is acting to the connector nearest this edge (*e*).

Investigation of multiple-connector joints bearing perpendicular to the grain have not been sufficiently comprehensive to include all of the variables of placement and loading conditions which may be encountered in service, and design procedure will depend on interconnecting elements and location of the joint in the structure. In a joint with two or more connectors spaced on a line parallel to the grain and with the load acting perpendicular to the grain (fig. 11, *D*), the available data indicate that the clear spacing between adjacent connectors (*c*) should not be less than 1 inch and that the total load used should be equal to the full load of one connector, plus one-third this amount for each additional connector.

In a joint of this type somewhat more favorable results are obtained in tests if the connectors are staggered so that they do not act along the same line with respect to the grain of the transverse member.

The placement of connectors in joints with members at right angles to each other is subject to the minimum limitation of either member. It is virtually impossible to set up general rules regarding the alignment, spacing, and margin of connectors to cover all possible directions of the applied load. The designer must rely upon a sense of proportion and fitness in applying the rules set forth to a condition of loading that is within the limits discussed.

CROSS BOLTS

The use of cross bolts at or near the end of timbers joined with connectors, or at intermediate panel points, may frequently be desirable to provide additional safety or to assist in reinforcing members that have, through change in moisture content in service, developed checks to an undesirable degree.

NET SECTION

The stress in the net area (whether in tension or compression), which is the area remaining at the critical section after subtracting the projected area of the connectors and bolt from the full cross-sectional area of the member, should not exceed the safe stress of clear material in compression parallel to the grain. Additional information on the method of determining the net sections for the different types of connectors is given on page 73, for the split-ring connectors; page 89, for the toothed connectors; and page 104, for the claw-plate connectors.

EXAMPLES OF CONNECTOR-JOINT DESIGN

(1) Calculate the safe working strength of a tension joint of seasoned coast-type Douglas-fir in which two pieces 3⅝ inches thick and 5½ inches wide are joined end to end by means of side plates 1⅝ inches thick, 5½ inches wide, and 28 inches long, when four 4-inch split-ring connectors and two ¾-inch bolts are used. In this arrangement, two connectors and a concentric bolt are placed symmetrically on either side of the butt joint at a distance of 7 inches from the ends of the members and side plates. This end distance, as shown in table 4, is adequate to develop the full design load.

The working load given in table 1 for one 4-inch split-ring connector, when used in one face of a Douglas-fir member 1⅝ inches thick or as one of two connectors used in opposite faces of a member 3 inches thick, is 4,780 pounds. The safe load of the joint for two connectors equals 2 × 4,780=9,560 pounds.

(2) Calculate the safe working strength of the joint in example (1) when the side plates are 16 inches instead of 28 inches in length. By placing the connectors halfway between the ends of the side plates and the butt joint, the end distance is 4 inches. The strength ratio as interpolated from values given in table 4 for a 4-inch end distance is 0.68, and the safe load accordingly equals 0.68 × 9,560=6,500 pounds.

(3) Calculate the safe working strength of a joint of seasoned southern yellow pine in which two tension side members 1⅝ inches thick and 5½ inches wide are joined at right angles to opposite faces of a center timber 3⅝ inches thick and 5½ inches wide by means of two 4-inch split-ring connectors and a ¾-inch bolt.

The load for one of two 4-inch split-ring connectors used in opposite faces of a member 3 inches thick and 5½ inches wide and bearing perpendicular to the grain is 2,775 pounds (table 1). The load for one connector bearing parallel to the grain in one face of a side member 1⅝ inches thick and with an end distance of 7 inches is 4,780 pounds (table 1). The safe load of the joint, which is governed by the load in the center member, equals 2 × 2,775, or 5,550 pounds.

(4) Calculate the safe working strength of the joint in example (3) when the end distance from the end of the side plates overlapping the center member to the center of the bolt hole is 3½ instead of 7 inches.

The strength ratio for an end distance of 3½ inches is 0.62 (table 4). The load for one 4-inch split-ring connector in the side member, hence, equals 0.62 × 4,780=2,964 pounds. This is larger than the working load for one connector in the center member. The strength of the joint, therefore, is still governed by the load in the center member and, as before, is 5,550 pounds.

TESTS OF FUNDAMENTAL FACTORS AFFECTING CONNECTOR-JOINT STRENGTH

The detailed information that follows, obtained primarily from tests of split-ring, toothed, and claw-plate connectors, involves such variables, aside from the connector itself, as species of wood, thickness and width of member, end margin, spacing, and moisture content. Some of these factors affect the strength of the joint regardless of the direction of the applied load with respect to the grain of the wood, while others are involved only when the load is applied either parallel or perpendicular to the grain. In addition to the investigation of these factors, others which are peculiar to each type of connector, such as the groove diameter for the split-ring connectors, were also studied. Supplementary tests, made to determine the effect of some experimental variables involved in the test methods, as, for example, length of span between the blocks supporting the transverse member when the load is applied perpendicular to the grain of the wood, are not discussed in detail here.

The tests were of two general types. In one, the load was applied parallel to the grain of the wood; in the other, perpendicular to the grain.

Each test assembly consisted of three members—one center and two side members. All members were of wood except for the metal side plates tested with claw-plate connectors. Figure 12 illustrates typical parallel and perpendicular arrangements of test assemblies. For tests at other angles to the grain, the center member was supported at different angles to the side members.

In the parallel-to-grain tests, the load was applied in either compression or tension, depending on the variable studied. For the perpendicular-to-grain tests, the center timber rested upon supports near its ends, and the load was applied to the side members.

Two connector units, one between each of the side members and the center timber, were used in all tests except when four connectors were used to determine the effect of spacing.

The specimens were of seasoned material, with the exception of those used to determine the effect of variations in moisture content of the wood on the strength of the joints. All timbers were practically clear and free from checks. When possible, the specimens were carefully matched in quality for all tests made on a given variable. Control specimens cut from each member were tested in accordance with standard laboratory procedure to determine the strength characteristics of the material. These control tests consisted of a determination of the specific gravity, moisture content, and the compression strength of the wood parallel to grain. For some members, shear tests and tests of compression perpendicular to the grain were also included.

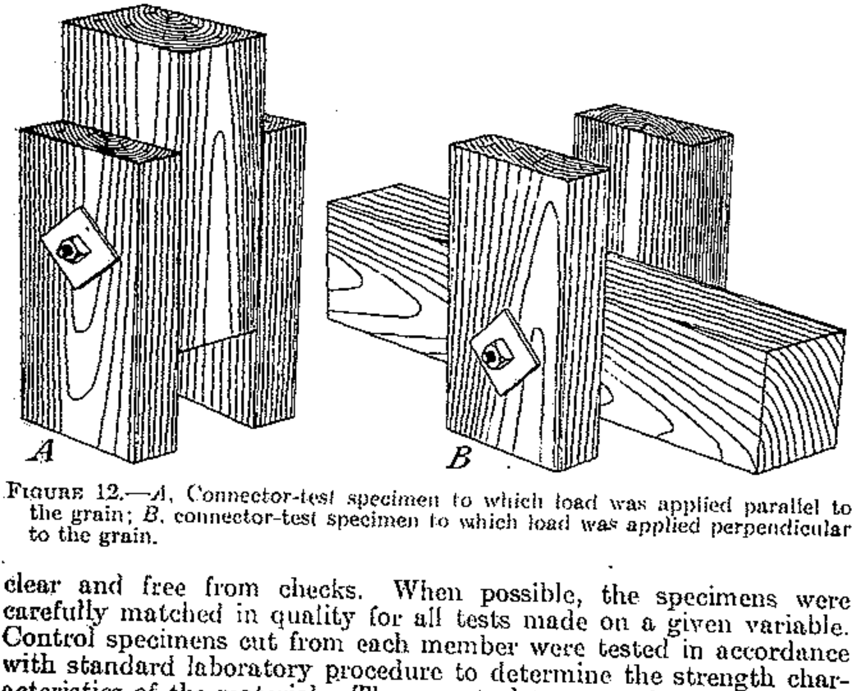

FIGURE 12.—*A*, Connector-test specimen to which load was applied parallel to the grain; *B*, connector-test specimen to which load was applied perpendicular to the grain.

The amount of slip in the joint between each of the side timbers and the center timber was determined with dial gages graduated to 0.001 inch. In most of the tests, the slip was measured from the beginning of the application of load, but in some the dials were set at zero at an initial load of 250 to 500 pounds, depending upon the ultimate capacity of the joint. Load was applied continuously, and readings of the slip were taken at increments of such magnitude as to give a suitable load-slip curve. The rate of descent of the movable head of the testing machine was within the range of 0.283 to 0.382 inch per minute, the exact speed used depending upon the type of test. The general behavior of the joint under load, the first drop of the beam of the testing machine, the kind of failure, and similar details were noted and recorded. The loads recorded at the first drop of the beam mark the first interruption of the increase in load and appear to be associated with shear of the core within the connector. The loads listed as maximum are the highest loads obtained within or at a slip in the joint of 0.60 inch, beyond which tests were not continued.

The bolts used with the connectors were of the common type, with square heads, obtained from hardware suppliers.

With few exceptions, the split-ring, toothed, and claw-plate connectors are considered separately in the following presentation. Various types and sizes of connectors developed in Europe, and tested with Douglas-fir and southern yellow pine under standard conditions at the Forest Products Laboratory, are discussed in an earlier publication (7). Some of these connectors were similar in design to American types, and the results of these earlier tests are, when applicable, included in this publication.

FACTORS AFFECTING SPLIT-RING CONNECTOR JOINTS

The split-ring connectors used in this investigation are plain, low-carbon steel[10] rings of rectangular cross section, with a tongue-and-slot junction in the perimeter. They are fitted to half their depth into precut grooves in the contacting faces of overlapping wood members.

The dimensions of the connectors used in the tests, and the dimensions of all grooves except those in which the effect of differences in groove diameter was studied, are set forth in table 7.

TABLE 7.—*Dimensions of connectors and grooves used in tests of split-ring connectors*

Dimensions of connectors			Dimensions of grooves		
Inside diameter, closed (inches)	Depth	Thickness of metal	Inside diameter[1]	Depth	Width
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
2.5	0.75	0.150	2.56	0.375	0.18
4.0	1.00	.187	4.08	.500	.21
6.0	1.25	.250	6.12	.625	.27
8.0	1.50	.312	8.16	.750	.34

[1] For southern yellow pine in species tests bearing parallel to the grain, the inside diameters of the ring grooves were varied from the dimensions given here, as follows: 2½-inch connector, 2.52 to 2.60 inches by 0.02-inch increments; 4-inch connector, from 4.00 to 4.12 inches by 0.03-inch increments; 6-inch connector, from 6.02 to 6.18 inches by 0.04-inch increments, separate tests being made for each. Grooves for the 8-inch connector were the same size for all species.

The factors affecting the strength of the joint, studied with different sizes of split-ring connectors, were (1) species of wood; (2) the direction of the applied force with reference to the grain of the wood; (3) the thickness and (4) width of timber; (5) edge and (6) end

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[10] The specifications for the connectors tested require that the steel conform to A. S. T. M. Standard Specifications for Carbon Steel A17-29, Type A, Grade 1.

margins; (7) spacing between connectors; (8) size of ring groove; (9) position of the tongue-and-slot junction of the connector with respect to direction of the grain of the wood (position in the groove); (10) size of bolt hole; (11) moisture condition of the timber, and (12) the effect of checks.

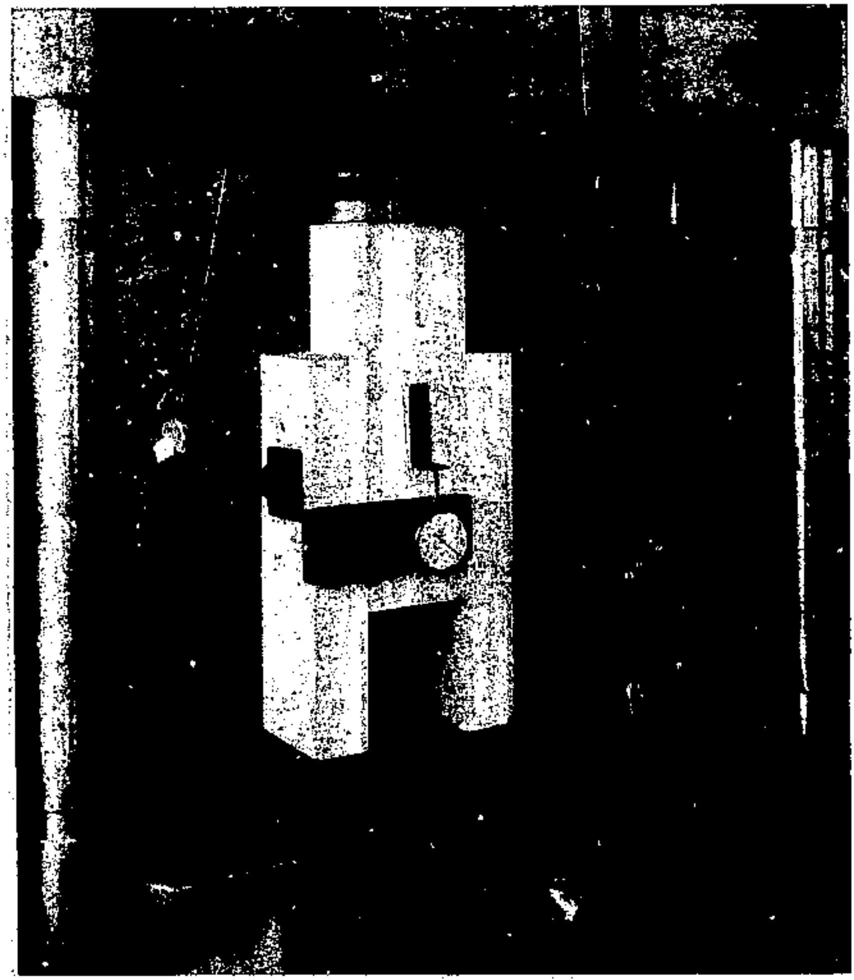

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FIGURE 13.—Method of conducting compressive test of connector joint with load applied parallel to the grain of the wood. In preparing test specimens for some of the larger connector sizes, the required wood thickness was obtained by laminating the members as shown.

SPECIES OF WOOD

BEARING PARALLEL TO GRAIN

To determine the strength of the joint using various sizes of split-ring connectors with different species of wood when bearing parallel to the grain, tests were made using redwood, baldcypress, Douglas-fir, southern yellow pine, white oak, and yellow birch. The baldcypress and southern yellow pine used came from two different shipments which had a particularly wide range in density.

The widths of the specimens were 3⅝, 5½, 7½, and 9½ inches for the 2½-, 4-, 6-, and 8-inch connectors, respectively. The thickness of the center member for the 2½-inch connector varied from 4 to 5 inches and the thicknesses of the side members from 2 to 2½ inches. The thicknesses of the center and side members for all other connector sizes were 5 and 2½ inches.

The length of the members for the 2½-inch connector was 13 inches, with the side members overlapping the center member by 8 inches. The bolt and connectors were placed in the center of the overlapped length as shown in figure 13. For the 4-, 6-, and 8-inch connectors, the side and center members were 17, 21, and 24 inches long, respectively, and were overlapped by 11, 15, and 20 inches, respectively.

As indicated in table 7, the inside diameters of the grooves were the same for all species except southern yellow pine. The same number of tests was made for each different inside groove diameter for that species as for each connector size of the other species. These tests provided information on the effect of variations in the diameter of the ring groove, which will be discussed elsewhere in that connection.

With these exceptions, five tests were made for each species of wood and size of connector. The material for each species was of approximately the same quality for all connectors. After completion of the main test of the connector joint, moisture and specific-gravity determinations were made on the material. Also, compression-parallel-to-grain tests were made on standard specimens cut from pieces which adjoined the major test specimens in the member. Tests of control specimens, which are not included in the tables, were also made for some of the species in shear parallel to the grain.

Although a number of the different strength properties of wood determine the resistance to lateral displacement of connectors, the tests show that the specific gravity of wood is a better criterion of the strength of the joint than any other single property (*6*). For example, when a connector joint is bearing parallel to the grain, the maximum crushing strength of the wood is an important property affecting the strength of the joint, but the specific gravity of the wood affords a more satisfactory criterion of the actual test load. Both the proportional limit loads and the maximum loads increase directly with specific gravity, as shown by figures 14, 15, and 16. The relationships are expressed by the general equation:

$$P=KG$$

in which—

P=the load, in pounds, for two connectors and one bolt, obtained in a test of short duration.

K=a constant derived by test.

G=specific gravity of the wood, oven dry, based on volume at test.

By this equation, working loads for the different sizes of split-ring connectors can be established for any one species from the specific gravity. Inherent characteristics may, however, cause some species to give values somewhat above or below the equation values.

Differences in specific gravity within a species are, in general, reflected by about the same relationship in load that is obtained among species.

The proportional limit load is approximately one-half to two-thirds of the maximum load for various species of wood and sizes of connectors (fig. 17). This proportional limit load was obtained at an average slip of approximately 0.06 inch for the species tested. The average slip at the maximum loads was 0.55, 0.42, 0.20, and 0.13 for the 2½-, 4-, 6-, and 8-inch connectors, respectively.

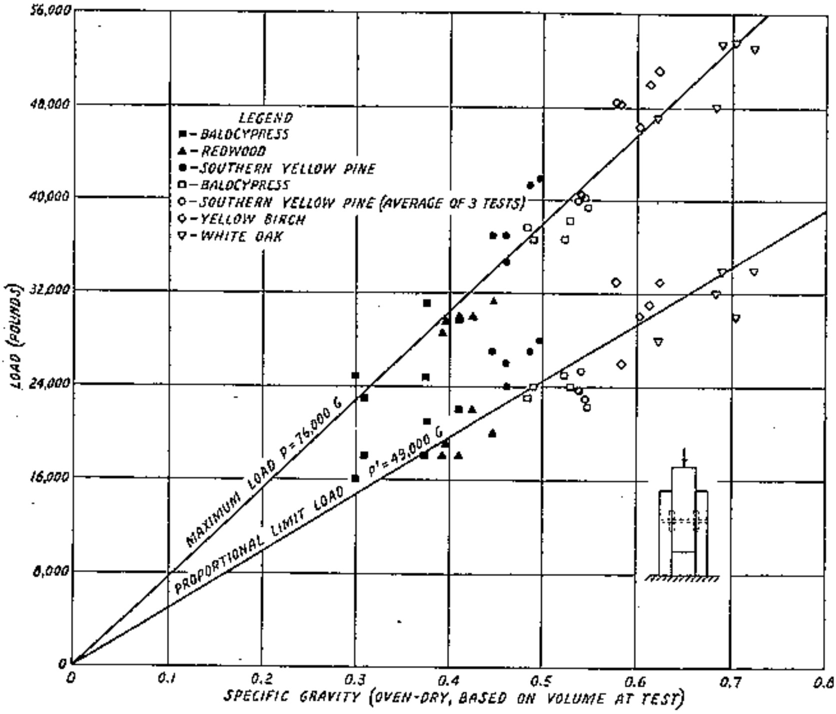

FIGURE 14.—Relation between load bearing parallel to the grain and specific gravity of air-dry wood for a split-ring connector joint consisting of two 4-inch connectors and a ¾-inch bolt. The solid and open symbols for the same species indicate marked differences in specific gravity.

The loads at first drop for the 2½-inch connectors were about 25 percent higher than the proportional limit loads and averaged about 75 percent of the maximum loads. As the size of connector increased, however, the loads at first drop approached the maximum, until the two were almost equal for the 8-inch connector.

After the cores had sheared, the split-ring connectors continued to function as metal bands around solid wood cores, the final joint failure at maximum load for the smaller connectors consisting of bending of the bolt and crushing of the wood on the faces of the members under the connectors and the bolt.

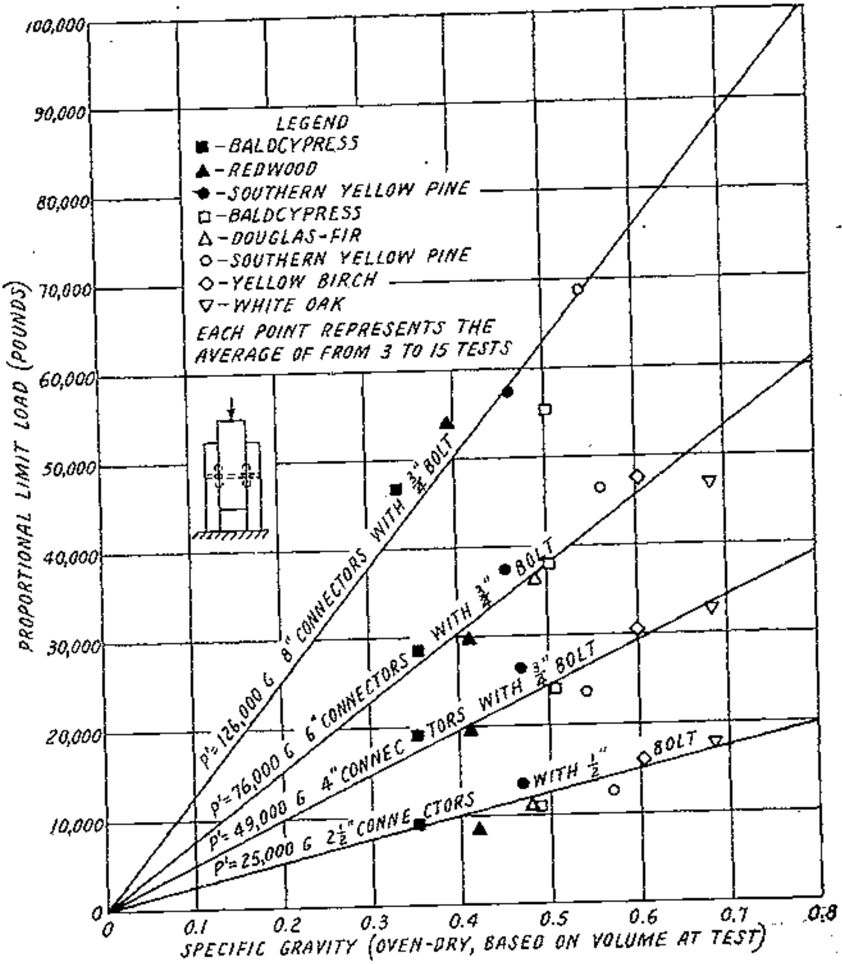

FIGURE 15.—Relation between proportional limit load bearing parallel to the grain and specific gravity of air-dry wood for split-ring connector joints consisting of two connectors and a single bolt, in each of four sizes. The solid and open symbols for the same species indicate marked differences in specificr gavity

When the slip at maximum load exceeded 0.60 inch, the load at this slip was taken as the maximum. The actual maximum load was only slightly greater, since the load at this point was increased very little with relatively large increases in slip.

In those tests in which the maximum load was reached at a slip greater than 0.20 inch, the load as a rule did not increase appreciably with additional increases in slip.

The initial slip, or that part of the slip which, when the ring is coming into full bearing, is not associated with elastic distortion, averaged about 0.019 inch. Starting at the origin, the load-slip curve fillets into the elastic portion of the curve at about 0.03-inch slip and about one-third of the proportional limit load. With initial slip, load at 0.03-inch slip, and the load and slip at proportional limit given, it is possible to obtain the approximate slip in the joint for given loads

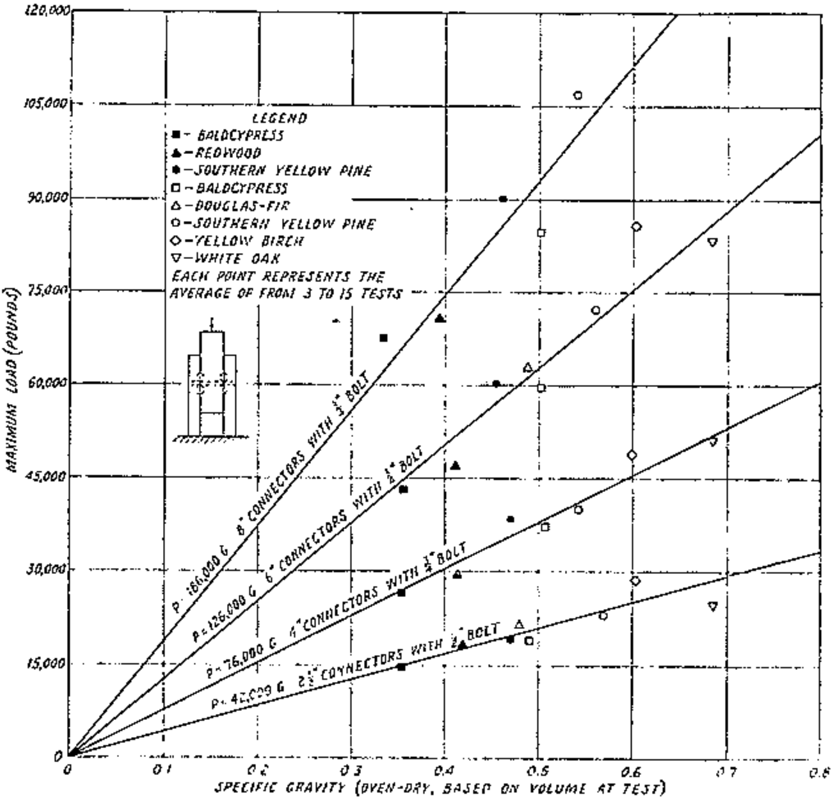

FIGURE 16.—Relation between maximum load bearing parallel to the grain and specific gravity of air-dry wood for split-ring joints consisting of two connectors and a bolt, in each of four sizes. The solid and open symbols for the same species indicate marked differences in specific gravity.

below the proportional limit. The amount of initial slip and the slip at proportional limit, however, vary somewhat with species, being slightly greater in the softer than in the denser woods, especially for the larger size rings. The size of the ring groove diameter and that of the bolt hole, discussed elsewhere, also have an effect on the amount of slippage in the joint.

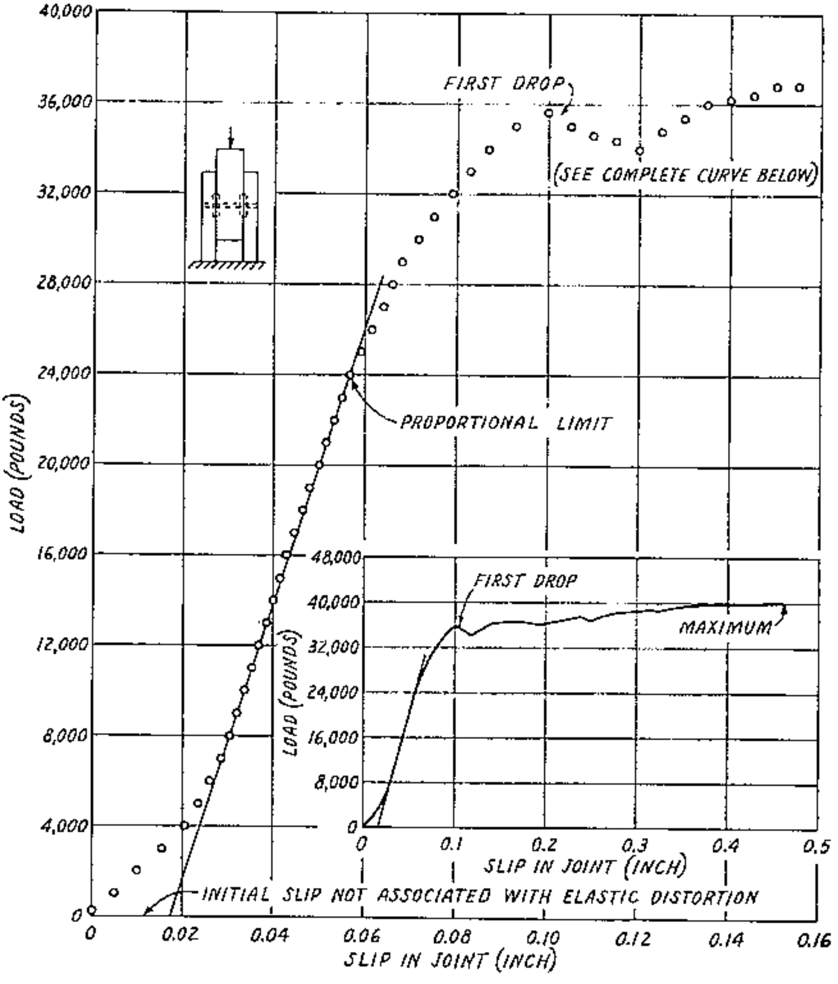

FIGURE 17.—Relation between load and slip in split-ring connector joint, for an individual test specimen; bearing parallel to the grain of air-dry wood.

The average results of the tests on different species are presented in table 8.

TABLE 8.—*Effect of wood species on strength of 3-member, split-ring connector joints, bearing either parallel or perpendicular to grain* [1]

LOADS ACTING PARALLEL TO THE GRAIN

Size of connector unit;[2] and species of wood (in order of specific gravity of specimens)	Width of members	Thickness of members[3]		Properties of specimens			Initial slip[5]	Load at 0.03 inch slip	Proportional limit		First drop		Maximum or load at 0.60 inch slip	
		Center	Sides	Moisture content	Specific gravity[4]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip	Load	Slip
	Inches	*Inches*	*Inches*	*Percent*		*Pounds per square inch*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*	*Pounds*	*Inch*
2½-inch connectors; ½-inch bolt:														
Baldcypress	3⅝	4½	2¼	12.2	0.354	4,365	0.021	3,056	9,000	0.060	10,738	0.08	14,574	0.60
Redwood	3⅝	4	2	11.9	.420	6,150	.021	3,240	8,300	.052	9,300	.06	18,090	.60
Southern yellow pine	3⅝	5	2½	10.4	.470	5,472	.010	8,100	13,400	.043	17,730	.08	19,000	.36
Baldcypress	3⅝	4½	2¼	9.9	.490	7,494	.017	5,150	10,750	.045	12,804	.06	18,832	.44
Douglas-fir [5]	3⅝	4½	2¼	11.4	.480	7,960	.028	3,417	10,830	.072	12,175	.09	21,567	.60
Southern yellow pine [6]	3⅝	4	2	12.5	.570	8,273	.012	8,196	12,400	.041	17,900	.08	22,938	.60
Yellow birch	3⅝	4½	2¼	10.4	.604	8,379	.027	3,696	15,900	.060	20,164	.09	28,470	.60
White oak	3⅝	4½	2¼	11.6	.685	8,124	.024	4,275	17,600	.057	24,754	.09	25,766	.60
4-inch connectors; ¾-inch bolt:														
Baldcypress	5½	5	2½	12.0	.354	3,609	.032	3,216	19,000	.082	23,800	.12	26,300	.50
Redwood				12.1	.414	6,075	.022	5,020	19,400	.074	20,250	.08	29,350	.47
Southern yellow pine				10.4	.470	5,426	.018	7,960	26,400	.062	36,000	.10	38,340	.37
Baldcypress [7]				10.4	.507	7,708	.028	4,800	24,000	.062	28,190	.07	37,240	.22
Southern yellow pine [6]				11.5	.542	8,428	.019	8,232	23,600	.052	36,420	.10	40,100	.46
Yellow birch				10.3	.600	8,458	.023	7,600	30,400	.059	46,110	.11	48,880	.59
White oak				11.4	.684	8,236	.021	10,420	32,670	.053	50,040	.13	51,110	.30
6-inch connectors; ¾-inch bolt:														
Baldcypress	7½	5	2½	12.0	.356	3,962	.030	4,952	28,600	.077	41,946	.12	43,040	.16
Redwood				12.0	.412	6,035	.015	12,020	29,600	.051	38,000	.08	47,030	.19
Southern yellow pine				10.2	.454	5,296	.005	23,740	37,400	.044	60,260	.13	60,260	.13
Baldcypress				10.4	.502	7,623	.015	15,340	38,000	.053	53,030	.09	59,480	.20
Douglas-fir [5]				11.0	.488	8,397	.024	8,000	36,330	.065	51,567	.10	62,830	.30
Southern yellow pine [6]				10.8	.561	8,570	.013	20,408	46,450	.053	68,612	.10	72,100	.16
Yellow birch				10.4	.604	8,255	.009	32,980	47,600	.040	85,824	.15	85,850	.24
White oak				11.4	.684	8,236	.008	32,120	46,800	.041	80,110	.11	83,350	.19
8-inch connectors; ¾-inch bolt:														
Baldcypress [8]	9½	5	2½	12.3	.335	4,004	.027	7,070	46,670	.083	66,790	.13	67,410	.14
Redwood [8]				12.2	.395	5,984	.008	31,000	54,000	.049	67,130	.06	70,640	.14
Southern yellow pine [5]				10.9	.461	5,342	.009	29,530	57,330	.051	90,080	.10	90,120	.10
Baldcypress				10.5	.502	7,631	.026	9,020	55,200	.074	81,150	.11	84,730	.19
Southern yellow pine [5]				13.0	.541	7,820	.013	40,670	68,670	.041	106,780	.09	106,780	.09

LOADS ACTING PERPENDICULAR TO THE GRAIN

2½-inch connectors; ½-inch bolt:														
Redwood	3⅝	4½	2¼	12.2	0.409	----------	0.010	1,710	5,470	0.082	6,860	0.13	6,960	0.15
Douglas-fir	3⅝	4½	2¼	11.2	.482	----------	.009	2,030	6,400	.084	8,110	.15	8,320	.29
Southern yellow pine [9]	3⅝	2⅝; 4½	1 5/16; 2¼	12.3	.536	----------	.010	2,200	7,120	.076	10,050	.14	10,050	.14
4-inch connectors; ¾-inch bolt:														
Redwood	5½	5	2½	10.7	.380	----------	.004	2,810	8,530	.087	10,690	.15	10,880	.17
Southern yellow pine [9]	5½	3⅝; 5	1⅞; 2½	11.9	.568	----------	.008	4,860	15,208	.082	21,100	.16	21,610	.18
6-inch connectors; ¾-inch bolt; Douglas-fir	7½	5	2½	11.1	.490	----------	.006	6,400	17,830	.074	25,320	.16	25,430	.23

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[1] Values are averages of 5 tests of loads acting parallel and 3 tests perpendicular, except as noted.

[2] Connector diameter is that of inside of ring when closed; bolt hole equals nominal diameter of bolt.

[3] Where 2 thicknesses are given, one-half of the tests were made with each thickness.

[4] Based on the weight of oven-dry wood and the volume at time of test.

[5] The initial part of the slip not associated with elastic distortion.

[6] Average of 15 tests.

[7] Average of 4 tests.

[8] Average of 3 tests.

[9] Average of 6 tests.

BEARING PERPENDICULAR TO GRAIN

The test set up for a joint with the load applied perpendicular to the grain of the principal chord member is shown in figure 18. The widths of the specimens were 3⅝, 5½, and 7½ inches for the 2½-, 4-, and 6-inch connectors, respectively. As will be pointed out in greater detail later, the loads perpendicular to the grain vary considerably with the widths of the members and the distance the connector is placed from the edge of the transverse chord timber toward which the load is acting. The widths of members are the same as those used in the tests, with the load acting parallel to the grain of all members, and are considered the minimum widths in which connectors of the various diameters should be used.


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FIGURE 18.—Method of conducting compressive test of connector joint with load applied perpendicular to grain of transverse member.

The distances between the blocks supporting the center member in test were 13, 16, and 20 inches for the 2½-, 4-, and 6-inch connectors, respectively. Tests of connector joints with different span lengths have shown that the distance between the blocks supporting the center member has no material effect on the load, providing it is greater than twice the width of the members. The side members bearing at right angles to the transverse chord member were of sufficient length to eliminate all effects of end margin. The inside diameters of the grooves used with the 2½-, 4-, and 6-inch connectors averaged 2.56, 4.08, and 6.12 inches, respectively.

The loads for connector joints bearing perpendicular to the grain reflect, in general, the same relation to specific gravity as when the bearing is parallel with the grain. Other factors, such as the direction of the growth rings with respect to the applied load, tend to make the values more erratic; but an analysis of all the tests made perpendicular to the grain, including those of table 8, shows that, when other factors are comparable, the loads vary almost directly as the specific gravity of the wood.

The values for joints in which the load was perpendicular to the grain were appreciably lower than those in which the load was parallel to the grain. The slope of the load-slip curve is also less. This was reflected in the lower initial slip and the larger slip at the proportional limit, as well as in the decrease in the ratio of perpendicular to parallel values with an increase in slip.

The maximum load and the load at first drop of the beam of the testing machine were usually the same, but occasionally a drop accompanied a minor failure before the maximum load was reached. Increases in load beyond the proportional limit produced a series of small splits in the side faces of the transverse chord member that extended longitudinally from the connector. Some bulging and splitting below the connectors in the lower face of the transverse chord member also occurred. In continuing the test beyond the maximum load, the transverse chord member usually sheared from the center to one end along a split near the center of the height at a load corresponding to about three-fourths the maximum, and at a slip about twice that at maximum load. The cores, as a rule, did not shear off completely in the transverse chord member. Rather, the upper half sheared off as far as the horizontal split, while the lower half remained intact. No perceptible failures occurred in the core or other parts of the side members.

While several factors were given consideration in determining the relationship between the loads when bearing perpendicular to the grain and when bearing parallel to the grain, most significance was attached to the values at proportional limit. When the bearing is parallel to grain, the load at the first drop is comparatively low for the smaller connectors and, consequently, the ratios between the perpendicular and parallel values are very high. The ratios between the perpendicular and parallel values at given slips and at maximum serve as an indication of the relative working loads but are often affected by other factors, such as method of test and fit of the connectors in the grooves.

An analysis of the results of the tests recorded in table 8 and of tests made in connection with other studies shows that, for the width of member used, the perpendicular-to-grain values are 58 percent of the parallel-to-grain values for the 2½- and 4-inch connectors, and 50 percent for the 6-inch connectors.

While no tests of the 8-inch connector were included in this series, previous tests on a similar connector, and the general relationship between the perpendicular and parallel values for rings of other diameters, give a ratio of 42 percent between the two directions of grain when used in timbers which are 9½ inches in width.

BEARING AT VARIOUS ANGLES TO GRAIN

Previous tests made on the Locher integral split-ring connectors with the load applied at angles of 0°, 22½°, 45°, 67½°, and 90° with the grain of the center chord member show that, while the data are rather erratic, the assumption of a uniform reduction in load from 0° to 90° with the grain is not appreciably in error (7). While similar tests were not made on the split-ring connector used in this study, the two types function in much the same manner. It appears reasonable, therefore, that, for the split-ring connectors used, a uniform reduction in load is applicable from 0° to 90° with the direction of the grain of the center member. The values for various grain directions presented in tables 1 to 3 were prepared on this basis.

THICKNESS OF MEMBER

The tests to determine the effect of thickness of member were made in tension with 2½- and 4-inch split-ring connectors bearing parallel to the grain of southern yellow pine specimens. The test specimens consisted of two short side members attached to opposite sides of a long center member near one end.

The thickness of the center, or main member, was varied from ¾ inch to 3 inches, by ¼- or ½-inch increments, for the 2½-inch connectors; and from 1 inch to 6 inches, by ½- or 1-inch increments, for the 4-inch connectors. In the center members of minimum thickness the grooves severed the connection between the core and the remaining timber. When the center member was 3 inches or more in thickness, the side pieces were half as thick. When it was less than 3 inches they were 1½ inches. The width of the members was kept constant at 3⅝ and 5⅝ inches for the 2½- and 4-inch connectors, respectively.

In the test, one end of the center member was suspended from the upper head of the testing machine and load was applied through the ends of the overlapping side members. The influence of variation in material was minimized by using the same center member for several tests, the used portion being removed after each test. Ample end margin was provided in all members to eliminate the effect of this variable.

It may be seen from table 9 and figure 19 that the maximum load increases with an increase in thickness of member to approximately 2 inches for the 2½-inch connectors, and to 3 inches for the 4-inch connectors. For greater thicknesses the maximum load remains fairly constant. The proportional limit load also increases with an increase in thickness of the member but reaches a constant value at a relatively smaller thickness.

In a similar series of tests in which the center piece as well as the side pieces was subjected to compression, the loads at proportional limit and maximum were comparable to the values given in table 9 for all thicknesses greater than 1 inch for the 2½-inch connectors and 1½ inches for the 4-inch connectors.

TABLE 9.—*Effect of thickness of members on the strength of 3-member split-ring connector joints, bearing parallel to grain, southern yellow pine* [1]

2½-INCH CONNECTORS; ½-INCH BOLT;[2] MEMBERS 3⅝ INCHES WIDE

Thickness of members center and side (inches)	Properties of specimens			Initial slip [4]	Load at 0.03 inch slip	Proportional limit		First drop		Maximum or load at 0.60 inch slip	
	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip	Load	Slip
	Percent		*Pound per square inch*	*Inch*	*Pound*	*Pound*	*Inch*	*Pound*	*Inch*	*Pound*	*Inch*
¾—1½	11.5	0.528	7,642	----	3,425	5,500	0.046	5,765	0.05	5,765	0.05
1—1½	11.5	.528	7,642	0.011	7,250	11,250	.042	12,575	.06	14,565	.13
1½—1½	11.5	.528	7,642	.006	9,000	11,250	.036	13,260	.07	16,615	.24
2—1½	11.5	.528	7,642	.010	7,600	11,500	.041	14,435	.06	19,400	.53
2½—1½	11.5	.528	7,642	.016	5,250	11,750	.050	15,120	.08	19,300	.60
3—1½	11.5	.528	7,642	.015	6,100	11,750	.048	15,330	.09	19,980	.60

4-INCH CONNECTORS; ¾-INCH BOLT;[2] MEMBERS 5⅝ INCHES WIDE

Thickness of members center and side (inches)	Moisture content	Specific gravity	Maximum compressive strength parallel to grain	Initial slip	Load at 0.03 inch slip	Proportional limit Load	Proportional limit Slip	First drop Load	First drop Slip	Maximum Load	Maximum Slip
1—1½ [5]	12.9	0.580	7,272	0.014	4,200	10,000	0.052	10,190	0.06	10,190	0.06
1½—1½	12.6	.580	7,357	.009	11,500	24,000	.052	28,635	.08	30,660	.14
2—1½	12.6	.580	7,357	.011	12,000	26,000	.054	30,765	.08	35,205	.20
2½—1½ [6]	12.6	.563	7,242	.005	15,830	27,670	.049	37,650	.11	39,800	.23
3—1½	12.8	.563	7,238	.004	16,100	27,500	.050	37,395	.10	40,610	.40
4—2	12.8	.563	7,238	.004	15,250	27,000	.050	34,480	.11	40,850	.60
5—2½	12.8	.563	7,238	.011	13,300	27,000	.050	33,165	.08	40,070	.45
6—3	12.8	.563	7,238	.010	17,650	28,000	.043	38,025	.08	42,500	.38

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[1] Values are averages of 2 tests, except as noted.

[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.

[3] Based on the weight of the oven-dry wood and the volume at time of test.

[4] The initial part of the slip not associated with elastic distortion.

[5] 1 test only.

[6] 3 tests.

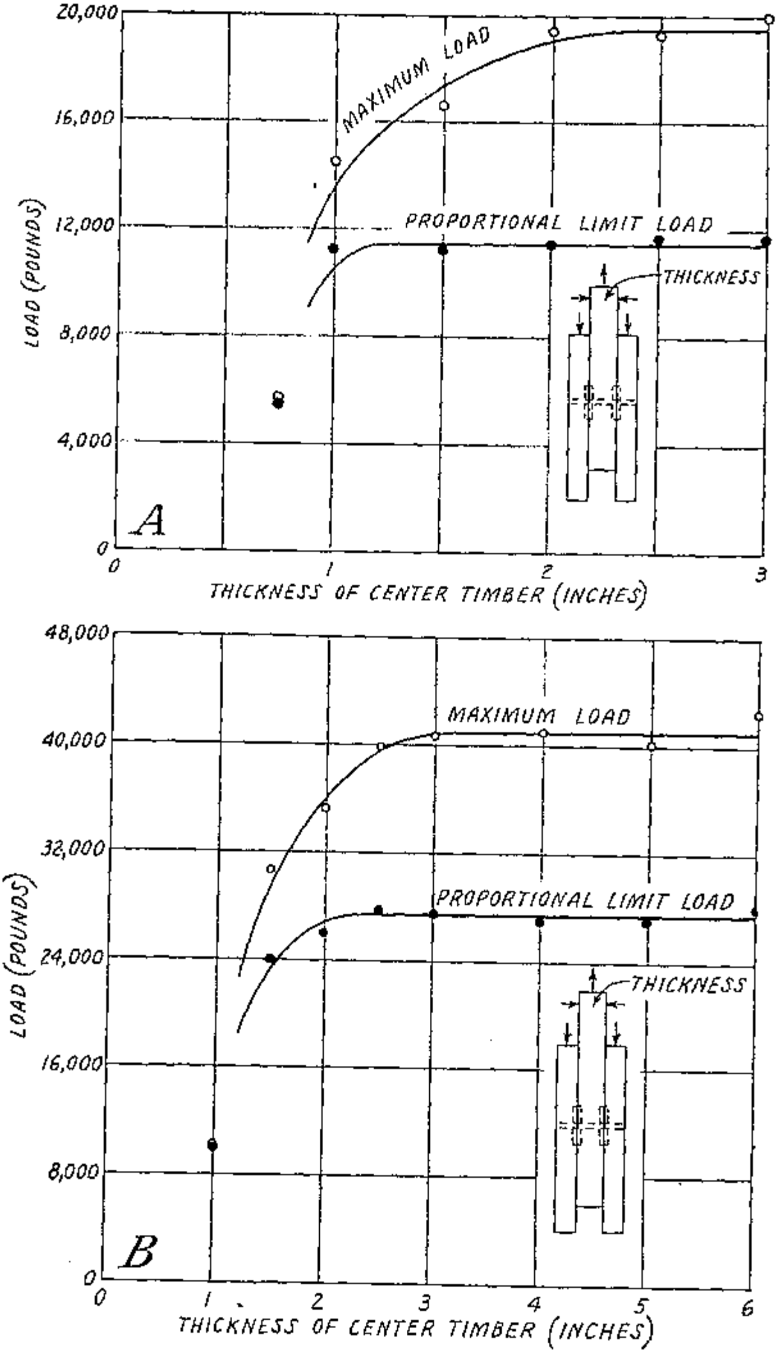

FIGURE 19.—Relation between load and thickness of timber for three-member split-ring connector joints bearing parallel to the grain of air-dry southern yellow pine: *A*, With 2½-inch connectors; *B*, with 4-inch connectors.

The failure consisted, in general, of shearing of the cores when there was one-fourth inch or more of material between the grooves in opposite faces, bending of the bolt, and crushing of the wood under the bolt and connectors. With the 2½-inch connectors, the crushing was accompanied by splitting in members 2 to 1⅝ inches and less in thickness; and, with the 4-inch connectors, in members approximately 2⅝ inches or less in thickness. In some auxiliary tests made with insufficient end margins, shearing of the members below the connectors, accompanied by some splitting, occurred for nearly all thicknesses at lower loads.

LOADS FOR OPTIMUM THICKNESS

The load on the connector joint consists of the load on the connectors supplemented by that on the bolt. Since the slip of the joint at the proportional limit and that at maximum loads are usually different for the bolt from those for the connectors, the full load of both is not always developed when the two are used together. Tests made with bolts show that the load and slip at the proportional limit for a given-size bolt are approximately the same for all thicknesses of member greater than four or five times the diameter of the bolt (*14*). The maximum load on the bolt increases almost in proportion to the increase in thickness of member but occurs at an increasingly greater slip. When the bolt is used in conjunction with connectors, the slip of the joint determines the extent to which the bolt supplements the load on the connectors. The portion of the maximum load of the joint carried by a ½-inch bolt when used with a pair of 2½-inch connectors apparently increases very little with additional increases in thickness of member over 2 inches. The amount contributed to the maximum load by a ¾-inch bolt when used with a pair of 4-inch connectors appears to have reached a constant value with a member 3 inches in thickness. With decreases in thickness below these values, the maximum load of the joint decreases at an increasing rate, since the bearing area under the bolt is less and splitting occurs in the members under the connectors.

From an analysis of these tests of three-member assemblies, showing that a 2-inch thickness of member is required to develop the optimum load with the 2½-inch connectors and ½-inch bolt and a 3-inch thickness with the 4-inch connectors and ¾-inch bolt, it may be reckoned that the thickness required to attain the optimum load with two 6-inch connectors and a ¾-inch bolt is 3⅝ inches. When connectors are placed in only one face of a member, the thickness required to develop the optimum load for one connector is one-half of these values, plus one-eighth inch.

LOAD REDUCTION FOR REDUCED THICKNESS

For loads less than the optimum the member should not be reduced in thickness below a certain absolute minimum. When 2½- or 4-inch connectors are used in pairs, this minimum thickness should be one-half inch greater than the sum of the depths of the two oppositely placed ring grooves. With the 6-inch connectors, the net distance between the bottom of the ring grooves should be three-fourths inch. When connectors are placed in only one face of a timber, the ring grooves for the 2½- and 4-inch connectors at the minimum thickness should lack one-half inch, and for the 6-inch connector, three-fourths inch, of penetrating the piece.

The safe load at these minimum thicknesses should be about two-thirds of the optimum load. For intermediate thicknesses, the load for the 2½- and 6-inch connectors can be obtained by straight-line interpolation. For the 4-inch connector used in opposite faces of a member, the load for thicknesses between 2⅝ inches and the minimum of 1½ inches can be obtained by straight-line interpolation, the load at 2⅝ inches being taken as 98.2 percent of the optimum load.

WIDTH OF MEMBER

BEARING PARALLEL TO GRAIN

The minimum width of member recommended for use with the 2½-, 4-, and 6-inch split-ring connectors is nominal 4-, 6-, and 8-inch material. Tests on joints with connectors bearing parallel to the grain were made to determine the effect of variations in width above and below these requirements. The study included both 2½- and 4-inch connectors, which were placed in the center of the width of southern yellow pine specimens. The widths used in the tests with the 2½-inch connectors were 2⅞, 3⅝, and 4⅝ inches; and with the 4-inch connectors, 4⅝, 5½, and 6½ inches. The smallest width of specimen tested for each size of connector was equal to the outside diameter of the connectors.

The results (table 10) show that an increase in width over the minimum widths recommended is accompanied by a small increase in maximum load. The increase in the proportional limit load is not significant, and the loads at given slips are about the same. The slight bulging or spreading of the specimen at the connectors, which frequently occurs at maximum load when the 2½- and 4-inch connectors are tested with the recommended nominal 4- and 6-inch material, respectively, is not present when the specimens are wider.

TABLE 10.—*Effect of width of members on strength of 3-member, split-ring connector joints, bearing parallel to grain, southern yellow pine* [1]

2½-INCH CONNECTORS WITH ½-INCH BOLT [2]

[Thickness of members (inches): Center 2⅝; sides 1$\frac{5}{16}$]

Width of members (inches)	Properties of specimens			Initial slip [4]	Load at 0.03-inch slip	Proportional limit		First drop		Maximum or load at 0.60-inch slip	
	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip	Load	Slip
	Pct.		*Lb. per sq. in.*	*In.*	*Lb.*	*Lb.*	*In.*	*Lb.*	*In.*	*Lb.*	*In.*
2⅞	12.2	0.562	8,020	0.013	5,130	11,330	0.051	15,620	0.11	18,280	0.31
3⅝	12.2	.574	8,473	.017	5,040	11,830	.048	15,850	.09	22,250	.60
4⅝	12.4	.562	8,500	.009	8,600	12,000	.039	16,280	.07	23,600	.60

4-INCH CONNECTORS WITH ¾-INCH BOLT [2]

[Thickness of members (inches): Center, 3⅝; sides 1$\frac{13}{16}$]

Width of members (inches)	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	Initial slip [4]	Load at 0.03-inch slip	Proportional limit Load	Proportional limit Slip	First drop Load	First drop Slip	Maximum or load at 0.60-inch slip Load	Maximum or load at 0.60-inch slip Slip
4⅝	11.7	0.564	8,660	0.015	7,930	24,000	0.061	30,350	0.09	33,970	0.20
5½	11.6	.568	8,851	.015	9,000	26,670	.063	33,470	.09	40,200	.49
6½	11.8	.576	8,586	.018	7,700	27,000	.062	34,870	.09	43,040	.60

[1] Values are averages of 3 tests.

[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] The initial part of the slip not associated with elastic distortion.

When the specimens were 2⅞ and 4⅜ inches in width for the 2½- and 4-inch connectors, respectively, the maximum loads were from 80 to 85 percent of those obtained with widths of 3⅝ and 5½ inches. The proportional limit loads were also somewhat reduced, the values ranging from 90 to 95 percent of those obtained in nominal 4- and 6-inch material, respectively. The use of narrow members, where the connector protrudes through the edges of the timber, is not, however, recommended, even when allowance is made in design for a reduction in load. This type of joint is too readily accessible to moisture and its attendant evils. The tests indicate that when the connector is not precisely centered on the timber, the strength of the joint, apart from the effect of eccentricity, is not greatly impaired.

When two or more connectors are placed side by side in the same parallel joint, the edge margin (distance from the center of the connector nearest the edge to the edge of the timber) should be 1¹³⁄₁₆, 2¾ and 3¾ inches, respectively, for the 2½-, 4-, and 6-inch connectors. The clear, lateral spacing between connectors in adjacent rows should be at least one-half inch. When the width of the member exceeds these minimum requirements for edge margin and spacing, the connectors should preferably be placed so that the excess width is distributed proportionately.

BEARING PERPENDICULAR TO GRAIN

The heterogeneous character of wood causes a considerably different behavior of connectors when bearing perpendicular to the grain than when bearing parallel to the grain. This is, in general, reflected in the difference in load on connectors between the two directions of grain and is also evident in such variables as width of member.

The tests with split-ring connectors bearing parallel to the grain have demonstrated that the loads for the various sizes increase very little with increases in width of member over the minimum nominal lumber widths required. When bearing is perpendicular to the grain, however, increases in width of member are accompanied by a definite increase in load.

Tests to determine the effect of width of member on the strength of joints bearing perpendicular to the grain were made with 2½- and 4-inch connectors in matched specimens of southern yellow pine. The connectors were placed in the center of the width of the transverse member, which ranged in width from 2⅞ to 5⁵⁄₃₂ inches for the 2½-inch connector and from 4⅜ to 7 inches for the 4-inch connector. The thicknesses of the transverse chord member and side members were constant for all tests with each size of connector, and the widths of the side members were always sufficient to develop the full strength of the transverse member. The span length, or distance between the inside edges of the blocks supporting the center member, was 13 and 16 inches for the 2½- and 4-inch connectors, respectively (fig. 18).

In the smallest width of transverse chord member used which was equal to the outside diameter of the connector, the center piece split out below the connectors at maximum load, and compression and tension failures in the specimens were frequent. For greater widths at loads beyond the proportional limit, a series of surface splits occurred which extended longitudinally along the sides of the center piece each way from the connector. As the test progressed, splitting continued up to and beyond the maximum load, finally culminating in shear to one end of the specimen well after the maximum load had been passed. The upper half of the core usually sheared free in the transverse chord member, while the portion below the center of the connector continued to adhere to the timber.

The results of the tests of split-ring connectors employed with different widths of specimens appear in table 11 and are shown graphically in figure 20. The values are somewhat erratic, but, when differences in quality of material are taken into consideration, a comparison of the loads for different widths at slips of 0.04 and 0.08 inch, and at the proportional limit and maximum load, show an average increase of about 10 percent for each 1-inch increase in width of member over the minimum widths required for each size of connector. The increase in load at proportional limit was somewhat less than 10 percent but at maximum was correspondingly greater. Tests made on members wider than those included in this series indicate that this relationship applies at least up to a width of 6 inches for the 2½-inch connector and up to 8 inches for the 4-inch connector. Tests which are not included in the table have also shown that it is applicable up to a width of 10 inches with the 6-inch connector.

The values at given slips less than 0.03 inch were approximately the same for all except the smallest widths tested, which were lower. The first drop in load occurred at the maximum load for nearly all tests except those for the smallest widths, where the load at first drop of beam was slightly below the maximum.

TABLE 11.—*Effect of width of members on strength of 3-member, split-ring connector joints, bearing perpendicular to grain, southern yellow pine* [1]

2½-INCH CONNECTORS WITH ½-INCH BOLT [2]

[Thickness of members (inches): Center, 2⅝; sides, 1⅝]

Width of members, center and side (inches)	Properties of center members		Properties of side members			Initial slip [4]	Load at 0.03-inch slip	Proportional limit		Maximum [5]	
	Moisture content	Specific gravity [3]	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip
	Pct.		*Pct.*		*Lb. per sq. in.*	*In.*	*Lb.*	*Lb.*	*In.*	*Lb.*	*In.*
2⅝—2⅝	13.0	0.559	12.0	0.577	8,050	0.004	2,270	5,067	0.065	8,200	0.15
3⅝—3⅝	13.4	.520	11.0	.573	9,020	.004	2,510	6,933	.076	10,250	.15
4⅝—3⅝	11.7	.507	11.8	.550	8,553	.007	2,350	7,067	.076	10,790	.16
5⅝—3⅝	12.1	.497	11.9	.580	8,742	.007	2,980	7,467	.065	11,760	.17

4-INCH CONNECTORS WITH ¾-INCH BOLT [2]

[Thickness of members (inches): Center, 3⅝, sides, 1⅝]

Width of members, center and side (inches)	Moisture content	Specific gravity	Moisture content	Specific gravity	Maximum compressive strength parallel to grain	Initial slip	Load at 0.03-inch slip	Proportional limit load	Proportional limit slip	Maximum load	Maximum slip
4⅝—4⅝	11.7	0.542	11.2	0.582	8,808	0.019	2,250	10,067	0.087	17,500	0.21
5 —5¼	12.1	.567	11.3	.554	8,608	.010	2,630	13,167	.091	19,850	.20
5½—5½	12.2	.573	11.1	.553	8,032	.012	3,700	13,833	.084	19,330	.15
6¼—5½	12.3	.534	11.1	.548	9,107	.017	3,180	14,667	.090	21,700	.18
7 —5½	11.9	.535	11.4	.534	8,527	.016	3,770	15,600	.083	20,120	.18

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[1] Values are averages of 3 tests.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Based on the weight of oven-dry wood and the volume at time of test.
[4] The initial part of the slip not associated with elastic distortion.
[5] The load and slip at first drop were approximately the same as that at the maximum.

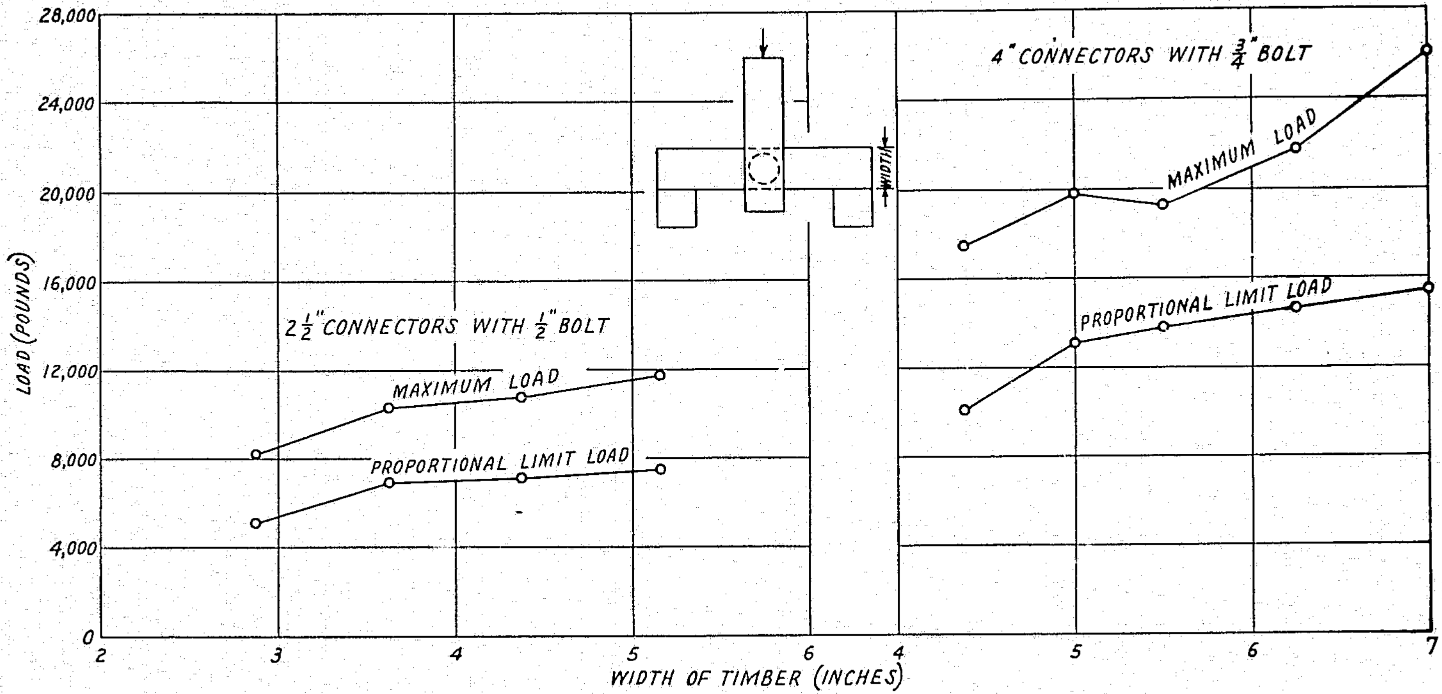

FIGURE 20.—Relation between load and width of timber for 3-member, split-ring connector joints bearing perpendicular to the grain of air-dry southern yellow pine.

The loads for specimens with transverse chord members equal in width to the outside diameter of the connectors average about three-fourths of the loads for the 2½- and 4-inch connectors in widths of 3⅝ and 5½ inches, respectively. Widths of members less than the nominal lumber widths of 4, 6, and 8 inches are not recommended, however, for use with the various sizes of connectors. The type of failure does not warrant the use of smaller widths, even with reduced design loads.

EDGE MARGIN (BEARING PERPENDICULAR TO GRAIN)

The edge margin, or the distance the connector is placed from the edge of the timber when bearing perpendicular to the grain of the wood has a significant influence on the strength of the joint.

For 2½-, 4-, and 6-inch connectors centered in members with minimum nominal widths of 4, 6, and 8 inches, respectively, the proper edge margin is half the width of the timber, or 1¹³⁄₁₆, 2¾, and 3¾ inches, respectively. This is the minimum edge margin recommended, either at the edge of the member toward which the load is acting or at the opposite edge.

TABLE 12.—*Effect of edge margin on strength of 3-member, split-ring connector joints, bearing perpendicular to grain, southern yellow pine*[1]

2½-INCH CONNECTORS: ½-INCH BOLT[2]

[Member dimensions (inches): Width, 3⅝; thickness, center 4½, sides 2¼]

Edge[3] margin (inches)	Properties of center members		Properties of side members			Initial slip[5]	Load at 0.03-inch slip	Proportional limit		Maximum[6]	
	Moisture content	Specific gravity[4]	Moisture content	Specific gravity[4]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip
	Percent		*Percent*		*Pounds per square inch*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*
1.46	12.6	0.465	13.6	0.553	7,312	0.005	2,470	6,670	0.05	9,020	0.17
1.63	11.5	.486	13.0	.563	7,330	.012	2,540	7,330	.09	9,430	.28
1.80	10.8	.468	13.2	.566	7,365	.015	2,070	7,170	.07	9,850	.14
1.97	11.7	.498	13.0	.566	7,483	.015	2,520	8,330	.07	12,200	.15
2.14	11.6	.511	13.3	.576	7,004	.013	3,120	9,000	.07	14,530	.32

4-INCH CONNECTORS; ¾-INCH BOLT[2]

[Member dimensions (inches): Width, 5½; thickness, center 5, sides 2½]

Edge[3] margin (inches)	Center moisture content	Center specific gravity[4]	Side moisture content	Side specific gravity[4]	Maximum compressive strength parallel to grain	Initial slip[5]	Load at 0.03-inch slip	Proportional limit load	Proportional limit slip	Maximum[6] load	Maximum[6] slip
2.25	12.3	0.569	11.9	0.552	8,506	0.003	5,540	12,830	0.07	21,050	0.18
2.45	12.4	.566	12.0	.558	8,773	.007	4,500	15,330	.09	22,020	.23
2.65	12.4	.569	12.1	.570	8,738	.006	5,260	15,500	.08	23,730	.24
2.85	12.0	.567	12.0	.562	8,551	.002	6,770	16,330	.07	24,030	.16
3.05	13.1	.567	12.0	.573	8,548	.006	5,000	17,000	.08	26,350	.20
3.25	13.0	.574	12.4	.573	8,487	.008	5,930	19,500	.08	30,330	.24

[1] Values are averages of 3 tests.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Distance from edge of timber toward which load is acting to center of bolt hole.
[4] Based on the weight of oven-dry wood and the volume at time of test.
[5] The initial part of the slip not associated with elastic distortion.
[6] The load and slip at first drop were approximately the same as that at the maximum.

The tests to determine the effect of variation in edge margin beyond these limits were made with southern yellow pine specimens in which the margin was varied by small increments from 1.46 inches to 2.14 inches for the 2½-inch connector in a member 3⅝ inches wide, and from 2.25 to 3.25 inches for the 4-inch connector in a member 5½ inches wide.

Minimum margins brought the outside edge of the connector flush with the edge of the timber.

The results (table 12) show that the increase in load on the connectors for edge margins greater than the recommended minimum is dependent primarily on the amount of edge margin in the direction toward which the load is acting and is not lowered by the lack of an equivalent margin on the opposite edge. When the connector is placed off-center, the load corresponds approximately to that obtained in a member which is twice the width of the edge margin on the side of the members toward which the load is acting, provided the margin on the opposite edge is at least equivalent to the recommended minimum.

At intermediate angles to the grain, the load may be obtained by using a straight-line relationship between the load at 0° and 90°, as given in table 1, where the effect of differences in width and edge margins have been included.

END MARGIN (BEARING PARALLEL TO GRAIN)

The end margin, or distance between the center of the bolt hole and the end of the timber, has considerable influence on the behavior of the joint when the connectors are bearing parallel to the grain of the wood. To evaluate the magnitude of this influence, three series of tests were made on the 2½- and 4-inch split-ring connectors in southern yellow pine specimens with variable end margins.

In one series, both the side and center members were in tension (fig. 21); in the other two, the center member was in tension and the side members were in compression. In the first series, equivalent end margins were used for both the side and center members, the side members overlapping the center by twice the end margin. In the second and third series, the long center member was held in tension while the load was applied in compression to the ends of the shorter, overlapping side pieces. The connectors were placed in the center of the length of the side pieces, the end margin being effective only in the center piece. The end margins tested ranged from 1½ to 7½ inches for the 2½-inch connectors and from 2¼ to 8¼ inches for the 4-inch connectors. The smallest end margin brought the outside edge of the connector flush with the end of the timber.

The material for each series was matched throughout the entire range of end margins tested, but the end margins used with the different methods of testing did not always correspond. In table 13, the three series are grouped. The thicknesses and widths of the members used in these tests were ample to eliminate any deleterious effect of these variables.

Figure 22 shows the proportional limit and maximum loads for 2½- and 4-inch connectors with different end margins. The maximum load increases approximately as the end margin increases, from the smallest margin which incorporates the entire connector in the timber to about 6 inches for the 2½-inch connectors and 7¼ inches for the 4-inch connectors. For end margins greater than 6 and 7¼ inches for the 2½- and 4-inch connectors, the maximum load remains fairly constant. The proportional limit load remains constant for end margins greater than 4 and 5¼ inches for the 2½- and 4-inch connectors but decreases with a decrease in end margin below these limits.

The failures which accompanied the maximum load when the end margin was small consisted of shear along the projection of the connectors and bolt. Shear along the projection of the connectors was frequently accompanied by splitting through the bolt hole. When the end margin was sufficient to overcome shear failure and splitting through the bolt hole, failure occurred as crushing below the connectors and bolt.

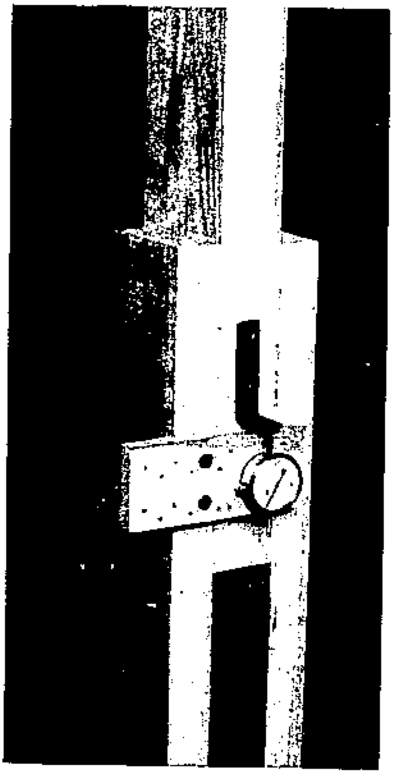

FIGURE 21.—Method of conducting tension tests of connector joint with load applied parallel to the grain of the wood.

An analysis of the individual tests shows that a normal load-slip curve was produced and that for the 2½-inch connector failure consisted primarily of crushing at an average end margin of about 5½ inches, though slightly higher loads were obtained with larger end margins. For the 4-inch connector, normal load-slip curves and crushing of the wood were produced at an average end margin of about 7 inches.

Tests were also made with the 2½- and 4-inch connectors in different thicknesses of timber at end margins of 1½ and 2¼ times the connector diameter. With an end margin of 1½ times the diameter of the connector, the failure at maximum load consisted of shear along the projection of the connectors for all thicknesses of timber and frequently was accompanied by splitting through the bolt hole. When the end

TABLE 13.—*Effect of end margin on strength of 3-member, split-ring connector joints bearing parallel to grain, southern yellow pine*

2½-INCH CONNECTORS WITH ½-INCH BOLT[1]

End margin [2] (inches)	Dimensions of specimens [3]			Properties of specimens			Number of tests	Initial slip [5]	Load at 0.03-inch slip	Proportional limit		First drop		Maximum	
	Width	Thickness		Moisture content	Specific gravity [4]	Maximum compressive strength parallel to grain				Load	Slip	Load	Slip	Load	Slip
		Center	Sides												
	Inches	*Inches*	*Inches*	*Percent*		*Pounds per square inch*		*Inches*	*Pounds*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
1½	3⅝	2⅝	1½ and $1\frac{5}{16}$	13.4	0.610	8,047	3	0.007	3,580	6,150	0.046	7,630	0.11	7,640	0.11
2			1½ and $1\frac{5}{16}$	13.4	.610	8,047	3	.003	5,560	7,730	.041	10,830	.07	10,830	.07
2½			1½ and $1\frac{5}{16}$	13.4	.610	8,047	3	.001	7,820	9,930	.040	12,890	.09	12,890	.09
3			1½	13.8	.606	7,459	2	.007	5,300	10,500	.055	13,025	.09	13,140	.10
3½			1½ and $1\frac{5}{16}$	13.4	.610	8,047	3	.005	7,850	10,270	.037	14,000	.10	14,960	.12
4			1½	13.8	.606	7,459	2	.004	8,250	11,500	.042	14,915	.07	16,455	.17
4½			1½ and $1\frac{5}{16}$	13.4	.610	8,047	3	.004	9,820	10,870	.032	15,940	.08	18,080	.26
5¼			1½	13.8	.606	7,459	2	.006	8,600	12,000	.040	14,680	.09	18,915	.51
5½			$1\frac{5}{16}$	12.4	.618	9,222	1	.008	8,550	11,200	.036	19,110	.13	19,430	.19
6½			$1\frac{5}{16}$	12.4	.618	9,222	1	.003	11,600	11,600	.030	20,000	.15	20,000	.15
7⅛			1½	13.8	.606	7,459	2	.000	10,300	12,000	.036	15,305	.08	20,970	.58
7½			$1\frac{5}{16}$	12.4	.618	9,222	1	.005	9,400	11,200	.035	15,600	.07	19,170	.13

4-INCH CONNECTORS WITH ¾-INCH BOLT[1]

End margin [2] (inches)	Width	Center	Sides	Moisture content	Specific gravity [4]	Maximum compressive strength parallel to grain	Number of tests	Initial slip [5]	Load at 0.03-inch slip	Proportional limit Load	Proportional limit Slip	First drop Load	First drop Slip	Maximum Load	Maximum Slip
2¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	0.550	7,153	3	0.006	6,270	14,170	0.062	18,500	0.10	19,280	0.13
2¾	5½	2⅝	1⅝	13.0	.542	8,124	1	.020	3,500	16,500	.075	18,000	.08	18,440	.14
3¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	.550	7,153	3	.004	8,980	19,670	.058	25,050	.10	25,250	.26
4¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	.550	7,153	3	.009	9,430	21,330	.059	28,160	.11	28,160	.11
4¾	5⅝	3	1½	12.1	.558	6,668	2	.009	10,800	22,500	.053	31,385	.11	31,405	.13
5¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	.550	7,153	3	.012	10,330	23,670	.059	32,890	.12	32,890	.12
6¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	.550	7,153	3	.012	10,380	23,330	.057	33,010	.13	34,340	.21
7¼	5⅝ and 5½	3 and 2⅝	1½ and 1⅝	12.5	.550	7,153	3	.012	12,520	23,000	.053	31,860	.12	35,670	.42
8¼	5⅝	3	1½	12.1	.558	6,668	2	.003	17,600	24,500	.040	34,415	.08	36,910	.48

---

[1] The diameter of the bolt hole was the same as the nominal diameter of bolt.

[2] Distance from end of timber to center of bolt hole.

[3] When two dimensions are given, 2 tests were made with the first size and 1 with the second size of specimen.

[4] Based on the weight of oven-dry wood and the volume at time of test.

[5] The initial part of the slip not associated with elastic distortion.

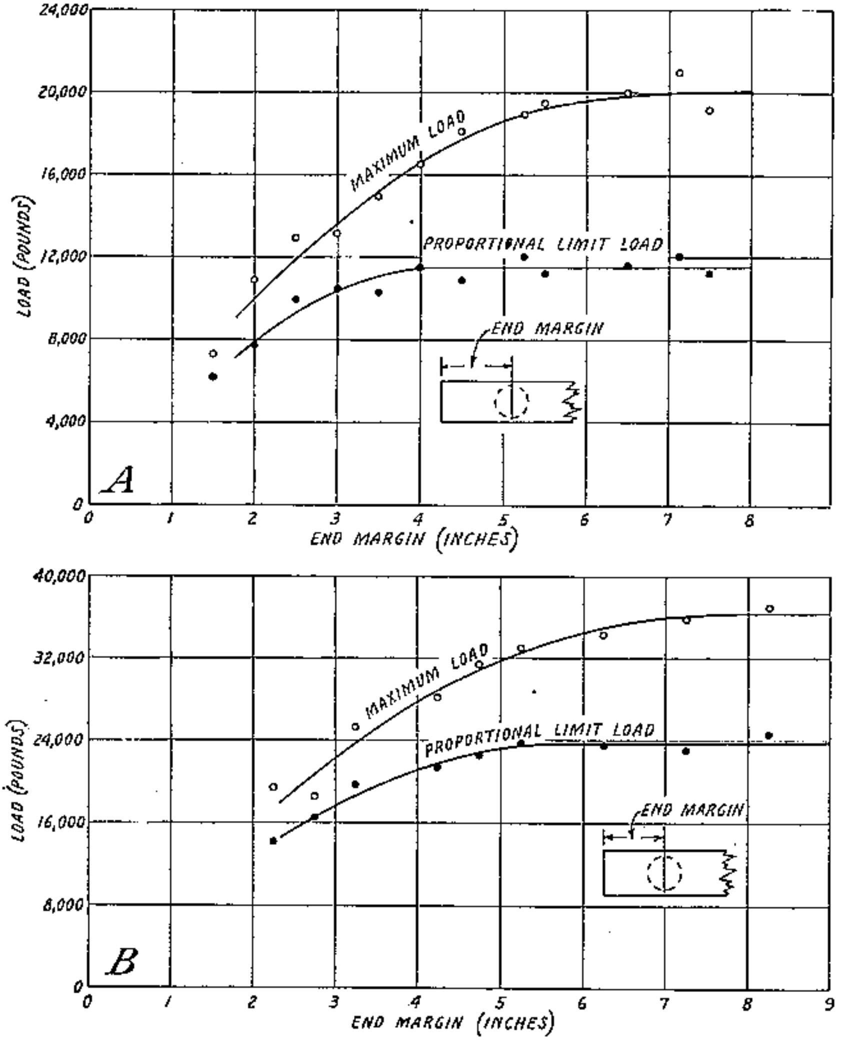

FIGURE 22.—Relation between load and end margin for a split-ring connector joint bearing in tension parallel to the grain of air-dry southern yellow pine. *A*, two 2½-inch connectors and a ½-inch bolt; *B*, two 4-inch connectors and a ¾-inch bolt.

margin was 2¼ times the diameter of the connector, shear and splitting occurred at maximum load in the thinner members; but the failure in the members 3 inches or more in thickness with the 2½-inch connector consisted primarily of crushing. The ratios between the loads at end margins of 1½ and 2¼ times the diameter of the connector with the thicker members correspond to those given in table 13.

The results of the tests, and an analysis of compression and shear stresses in the joints made of seasoned unchecked material, show that the end margin required to produce a maximum load beyond which an increase in end margin is no longer an important factor is equal to the nominal diameter of the connector, plus 3 inches.

When the end margin is less than this optimum, the safe working load is obviously lower. The tests show that the load is reduced very uniformly from unity to 62.5 percent at half the optimum end margins; hence the load for intervening end margins may be obtained by direct interpolation between these values. It is not advisable to use end margins having less than half the optimum values.

When the end surface of a timber is not at right angles to the length, the end margin, measured parallel to the center line of the piece from any point in the center half of the connector diameter that is perpendicular to the center line of the piece, shall not be less than the end margin required for a square-cut member. The clear distance between the connector and any point on the sloping end of the timber should at no time be less than the permitted edge margin.

SPACING OF MULTIPLE CONNECTORS (BEARING PARALLEL TO GRAIN)

The longitudinal spacing between split-ring connectors when bearing parallel to the grain of the member was investigated with the 2½- and 4-inch sizes in southern yellow pine specimens. Four connectors were used in each joint, two being placed symmetrically between each side member and the center member. The longitudinal center-to-center spacing between the 2½-inch connectors was varied from 3 to 7 inches by 1-inch increments and between the 4-inch connectors from 4½ to 10½ inches by 1½-inch increments. In the control tests made in conjunction with this series, only two connectors were used in each joint. The specimens were of sufficient size to eliminate the effect of thickness of member and end margin.

The failures of the joints varied with the different spacings. With the 2½-inch connectors, the wood sheared between the connectors at 3-, 4-, and 5-inch center-to-center spacings. At a 6-inch spacing the shear failure was less pronounced, and at 7 inches it was almost entirely eliminated. With the 4-inch connectors, the wood sheared at spacings of 4½, 6, and 7½ inches in all tests. At a spacing of 9 inches only a few specimens sheared, and at 10½ inches the shear failure was eliminated.

The results of the tests, with supplementary information, are given in table 14. The relation between the maximum loads and the different spacings is shown graphically in figure 23. Since it was impossible to avoid slight variations in the quality of the material used for the various spacings, the maximum loads shown on the curves were adjusted from the test values by a direct ratio of the specific gravity of the material used with each spacing to the average specific gravity of the group. With an increase of spacing, the maximum load increases from the smallest spacing to a constant value at a spacing of approximately 6½ inches with the 2½-inch connectors and of slightly more than 9 inches with the 4-inch connectors. The proportional limit load also increases with an increase in spacing but reaches a constant value at a smaller spacing than does the maximum.

TABLE 14.—*Effect on strength of joints of longitudinal spacing of 2 pairs of symmetrically placed split-ring connectors bearing parallel to grain, southern yellow pine* [1]

2½-INCH CONNECTORS WITH ½-INCH BOLT

[Member dimensions (inches): Width, 3⅝; thickness, center 2⅝, sides 1⅝]

Spacing [2] of connectors	Properties of specimens: Moisture content	Properties of specimens: Specific gravity[3]	Properties of specimens: Maximum compressive strength parallel to grain	Initial slip [4]	Load at 0.03-inch slip	Proportional limit: Load	Proportional limit: Slip	First drop: Load	First drop: Slip	Maximum or load at 0.60-inch slip: Load	Maximum or load at 0.60-inch slip: Slip
	Percent		*Pounds per square inch*	*Inches*	*Pounds*	*Pounds*	*Inches*	*Pounds*	*Inches*	*Pounds*	*Inches*
Control:	11.4	0.544	8,344	0.013	5,700	11,830	0.048	13,770	0.06	20,930	0.60
3	11.8	.549	8,527	.011	9,870	21,670	.052	24,870	.07	31,280	.60
4	11.4	.542	8,306	.012	10,600	21,830	.048	27,330	.07	32,480	.60
5	11.2	.544	8,664	.010	11,870	23,330	.049	30,070	.05	35,850	.31
6	11.3	.550	8,200	.011	11,770	23,500	.049	30,030	.08	40,320	.39
7	11.4	.525	7,868	.012	10,500	23,330	.053	30,700	.08	39,320	.51

4-INCH CONNECTORS WITH ¾-INCH BOLT

[Member dimensions (inches): Width, 5½; thickness, center 4, sides 2⅝]

Spacing [2] of connectors	Properties of specimens: Moisture content	Properties of specimens: Specific gravity[3]	Properties of specimens: Maximum compressive strength parallel to grain	Initial slip [4]	Load at 0.03-inch slip	Proportional limit: Load	Proportional limit: Slip	First drop: Load	First drop: Slip	Maximum or load at 0.60-inch slip: Load	Maximum or load at 0.60-inch slip: Slip
Control:	12.4	0.538	7,786	0.020	8,670	26,670	0.056	37,680	0.12	40,680	0.54
4½	12.2	.543	8,034	.016	15,100	46,670	.063	63,070	.10	63,070	.10
6	12.4	.552	7,931	.016	18,400	53,000	.061	69,720	.09	69,720	.09
7½	12.4	.560	7,884	.016	18,800	51,330	.059	72,280	.09	74,220	.20
9	12.9	.570	7,883	.013	24,533	56,000	.054	80,470	.09	83,600	.32
10½	12.4	.524	7,106	.014	19,670	51,000	.057	74,520	.10	78,770	.43

[1] Values are averages of 3 tests for each spacing and control.

[2] Distance from center to center of bolt holes. Control tests were made with only 2 symmetrically placed connectors. In all cases the diameter of the bolt hole was the same as the nominal diameters of bolt.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] The initial part of the slip not associated with elastic distortion.

The results of the tests and an analysis of the stresses in the member at the joint show that the center-to-center spacing required for the full load on the connectors is approximately 3 inches plus 1½ times the nominal diameter of the connectors. For spacings less than this the safe working load for the second pair of connectors should be reduced uniformly from unity at the optimum spacing to 50 percent at a spacing equal to the nominal diameter of the connectors plus seven-eighths inch for the 2½-and 4-inch connectors and 1 inch for the 6-inch connectors. For example, when two 2½-inch connectors are spaced 3⅜ inches longitudinally (with the grain) and adequate end margin is provided, the safe load is 100 percent of the design load for one connector plus 50 percent of the design load for the second connector; i. e., the total load on the joint is 75 percent of the design load for two connectors.

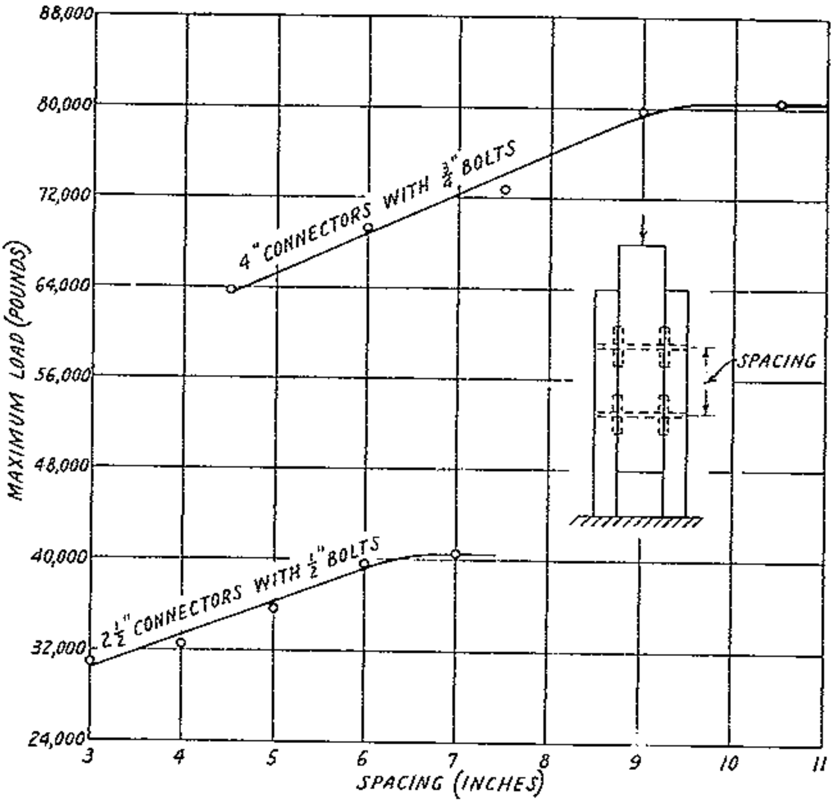

FIGURE 23.—Relation between maximum load and longitudinal spacing for a split-ring joint consisting of four connectors and two bolts, bearing parallel to the grain of air-dry southern yellow pine. (Corresponding maximum load for two 2½-inch connectors with bolt is 20,930 pounds, and for two 4-inch connectors with bolt is 40,680 pounds.)

RELATIVE CONTRIBUTION OF BOLT AND CONNECTOR

To determine how much of the joint strength of 2½- and 4-inch split-ring connectors is dependent on the bolt and how much on the connector, matched specimens of southern yellow pine were tested with the bolt alone, the connector alone, and the bolt and connector together. A ½-inch bolt was used with the 2½-inch split-ring connectors and a ¾-inch bolt with the 4-inch connectors. For the 2½-inch connectors, the width of the specimens was 3⅝ inches; the thickness of the center piece was 2⅝ inches and that of the sides 1¼ inches. For the 4-inch connectors, the width of specimens was 5½ inches, the thickness of the center piece was 3⅝ inches, and that of each side piece 1⅞ inches.

In the tests with the connectors alone, the pieces were held in place with bolts passing on the outside of the specimens through metal plates projecting beyond the outer edges of the side pieces.

For the joints with the 2½-inch connectors and ½-inch bolt (table 15), the sum of the load on the bolt and connectors, tested separately, was about 10 percent greater in the larger slips than the load for the two when tested together. At small slips of 0.01 to 0.03 inch, it was 25 to 50 percent greater.

TABLE 15.—*Test results of split-ring connectors showing respective contributions to joint strength by bolt and connectors*

Test		½-inch bolt	2½-inch connector	Bolt and connector
Load at 0.04-inch slip	pounds	2,750	7,100	8,800
Load at proportional limit	do	2,800	9,600	11,000
Slip at proportional limit	inches	0.041	0.053	0.048
Load at maximum	pounds	8,170	15,200	21,000
Slip at maximum	inches	0.600	0.302	0.600
		¾-inch bolt	4-inch connector	Bolt and connector
Load at 0.04-inch slip	pounds	3,900	11,300	11,300
Load at proportional limit	do	5,200	23,000	27,000
Slip at proportional limit	inches	0.05	0.065	0.069
Load at maximum	pounds	15,270	33,070	40,650
Slip at maximum	inches	0.60	0.100	0.60

The load on the bolt and connector joint at a slip of 0.04 inch is about three times that obtained on the bolt alone; at the proportional limit it is 4, and at the maximum it is somewhat less than 3. Compared with the load on the connectors alone, the complete joint assembly carried about 24 percent greater load at 0.04-inch slip, 15 percent at proportional limit, and 38 percent at maximum.

For the 4-inch connectors, the ratio between the load on the bolt and connector joint and that on the bolt alone is about 5 at the proportional limit and somewhat less than 3 at the maximum.

In these tests, the sum of the loads on the bolt and on the connectors used separately was larger than the load for a joint containing both connectors and bolt. An apparent reason for this is that the bearing area under the bolt in a connector joint is reduced when the cores fail by shear. The friction element may also be involved to some extent, since it was not completely isolated.

The slip in the joint associated with the maximum loads is much smaller for the connectors alone than for the bolt alone. After the connectors have reached their maximum load, they continue to carry about the same load with an increase in slip. The load on the bolt, however, continues to increase with an increase in slip until it reaches its maximum at a much larger distortion. As a result, the bolt carries a somewhat greater proportion of the total load at the larger slips than it does at the smaller slips.

The ratio between the safe working loads for a split-ring connector joint and for a bolted joint is not a constant, primarily because the safe working loads for the connectors are generally based on the maximum test loads, while the safe loads for bolts are determined by the proportional limit load. Other factors which affect the ratio are the size of connector and bolt, thickness of member, and direction of application of the load with respect to the grain of the wood. While the tests show that the load at proportional limit for a bolt and connector joint is from four to five times that for a bolt alone, and at maximum is about three times that for a bolt alone, the ratio between the assigned safe loads is not necessarily comparable. The safe load on a ½-inch bolt bearing parallel to the grain in southern yellow pine specimens of 2⅝-inch thickness and connected with wood splice plates is 1,050 pounds (*14*). The safe load for a pair of 2½-inch split-ring connectors and a ½-inch bolt, as given in table 1, is 4,960 pounds, or 4.7 times that of a bolt alone. The safe load on a ¾-inch bolt in a 3⅝-inch piece connected with wood splice plates is 2,325 pounds. The safe load for a pair of 4-inch split-ring connectors and a ¾-inch bolt bearing parallel to the grain is 9,560 pounds, or 4.1 times that of the bolt alone.

DIAMETER OF THE GROOVE

The circular grooves for the split-ring connectors are usually cut slightly larger in diameter than the connector and are 0.02 to 0.03 inch wider than the thickness of the metal. When inserted into the grooves, the connectors must therefore be spread. The opening at the tongue-and-slot joint in the perimeter permits changes in the diameter of the connector, with subsequent changes in the dimension of the wood.

The effect of different groove diameters was determined by tests on the 2½-, 4-, and 6-inch connectors bearing parallel and perpendicular to the grain of southern yellow pine specimens (table 16). In these tests the width of the groove was constant for each size of connector, while the inside diamters of the grooves were varied by five increments from approximately 100 to 104 percent of the inside diameters of the connectors.

The tests show that the diameter of the groove has no appreciable effect on either the proportional limit or maximum loads of the connectors, providing some spread exists and the diameter of the groove is not so large as to disengage the tongue-and-slot joint in the perimeter of the connector. When the load is acting parallel to the grain, the slips associated with the proportional limit loads and with given loads of less than the proportional limit are somewhat greater for the larger groove diameters. When the load is acting perpendicular to the grain, this difference is not evident.

Any variation in the moisture content of the wood subsequent to fabrication should be anticipated when the groove is cut. With seasoned material, and for most practicable purposes, an inside groove diameter of approximately 102 percent of the inside ring diameter can be used.

PLACEMENT OF SLOT OPENINGS

Tests to determine the effect of the orientation of the tongue-and-slot opening with respect to the direction of application of load were made with the 4-inch split-ring connectors bearing parallel to the grain of southern yellow pine specimens.

The specimens were prepared in the usual manner from matched material. The tongue-and-slot joints in the connectors were placed at angles of 0°, 45°, and 90° to a line through the center of the face of the member and parallel to the direction of the applied load.

TABLE 16.—*Effect of diameter of groove on strength of 3-member, split-ring connector joints, bearing either parallel or perpendicular to grain, southern yellow pine* [1]

LOADS ACTING PARALLEL TO GRAIN

Connector size [2] and inside diameter of groove (inches)	Dimensions of members			Properties of specimens [3]			Initial slip [5]	Load at 0.03-inch slip	Proportional limit		First drop		Maximum or load at 0.60-inch slip	
	Width	Thickness		Moisture content	Specific gravity [4]	Maximum compressive strength parallel to grain			Load	Slip	Load	Slip	Load	Slip
		Center	Sides											
2½-inch connector; ½-inch bolt:	*Inches*	*Inches*	*Inches*	*Percent*		*Pounds per square inch*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*	*Pounds*	*Inch*
2.52	3⅝	4	2	12.0	0.572	8,084	0.012	8,370	12,500	0.038	17,280	0.07	23,580	0.60
2.54				12.6	.570	8,134	.017	6,270	12,330	.043	18,100	.08	22,600	.60
2.56				12.8	.570	8,296	.004	11,670	12,170	.031	17,780	.07	22,870	.60
2.58				12.6	.570	8,651	.008	9,570	12,830	.038	18,500	.08	23,070	.60
2.60				12.6	.568	8,341	.018	5,100	12,170	.050	17,870	.09	22,570	.60
4-inch connector; ¾-inch bolt:														
4.00	5½	5	2½	11.4	.539	8,196	.012	10,000	23,670	.043	35,270	.08	40,580	.36
4.03				11.4	.540	8,476	.019	9,030	25,330	.052	38,130	.11	40,450	.49
4.06				11.6	.538	8,578	.022	7,030	23,670	.055	36,050	.11	39,050	.60
4.09				11.1	.544	8,684	.017	9,370	23,000	.051	37,720	.10	40,190	.34
4.12				11.9	.548	8,202	.025	5,730	22,330	.058	34,950	.11	39,350	.53
6-inch connector; ¾-inch bolt:														
6.02	7½	5	2½	10.6	.590	8,805	.001	38,370	48,000	.038	66,570	.07	74,220	.13
6.06				10.5	.560	8,644	.013	23,770	46,300	.047	65,270	.08	68,400	.16
6.10				10.9	.554	8,625	.021	13,770	50,300	.064	69,420	.10	73,280	.16
6.14				11.0	.551	8,488	.017	14,130	41,330	.057	70,630	.12	71,220	.16
6.18				11.4	.550	8,286	.021	12,000	46,330	.064	71,170	.12	73,380	.19

LOADS ACTING PERPENDICULAR TO GRAIN

2½-inch connector; ½-inch bolt:														
2.50	6	5	2½	12.9	0.528	....	0.010	3,330	8,500	0.063	13,880	0.16	16,440	0.60
2.52				13.0	.534	....	.015	2,600	8,000	.071	11,370	.14	15,440	.60
2.54				13.2	.535	....	.017	2,400	7,330	.066	11,510	.14	15,790	.60
2.56				13.4	.542	....	.016	2,370	8,000	.070	11,960	.13	15,140	.60
2.58				13.1	.555	....	.011	2,800	7,830	.065	12,535	.16	16,260	.60
4-inch connector; ¾-inch bolt:														
4.00	8	5	2½	11.2	.537	....	.014	3,870	15,300	.079	26,170	.24	26,170	.24
4.03				11.1	.538	....	.013	4,170	16,670	.085	27,260	.25	28,120	.33
4.06				10.9	.544	....	.013	4,500	16,670	.076	27,850	.23	29,130	.30
4.09				10.6	.548	....	.022	3,300	18,000	.103	30,330	.24	31,360	.30
4.12				13.7	.526	....	.011	4,570	16,000	.083	29,650	.29	29,650	.29
6-inch connector; ¾-inch bolt:														
6.02	10	5	2½	11.1	.541	....	.006	9,230	23,330	.067	43,580	.24	43,590	.24
6.06				11.1	.545	....	.007	7,770	25,000	.085	43,030	.28	43,030	.28
6.10				9.8	.544	....	.001	10,300	23,330	.066	42,630	.20	43,290	.22
6.14				10.4	.535	....	.004	8,570	23,670	.076	42,520	.24	42,520	.24
6.18				10.9	.548	....	.005	8,230	23,670	.077	42,980	.25	42,980	.25

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[1] Values are averages of 3 tests.

[2] Inside diameter of connector closed; diameter of bolt hole same as nominal diameter of bolt.

[3] For loads acting perpendicular to grain the properties are for the center timber only; those for the side timbers were approximately the same.

[4] Based on the weight of oven-dry wood and the volume at time of test.

[5] The initial part of the slip not associated with elastic distortion.

The results of the tests show that the proportional limit and maximum values are not greatly affected by the position of the tongue-and-slot joint. At the proportional limit load of 24,000 pounds, the slip of the joint was slightly less when the tongue-and-slot was placed at 90°, or nearest the edge of the timber; but, for given loads of less than 18,000 pounds, the slip was somewhat less at 0° than at the other positions.

Small variations caused by the position of the tongue and slot were eliminated in all other tests by placing it nearest the edges of the members which were stressed parallel to the grain.

SIZE OF BOLT HOLE

In the majority of tests made with the split-ring connector, the bolt hole was equal in diameter to the nominal diameter of the bolt. This permitted a small clearance between the bolt and the bolt hole, since the actual diameter of the bolt is usually somewhat smaller than its nominal diameter. In practice, however, the bolt holes are often bored slightly larger than the nominal diameter of the bolt to facilitate assembly.

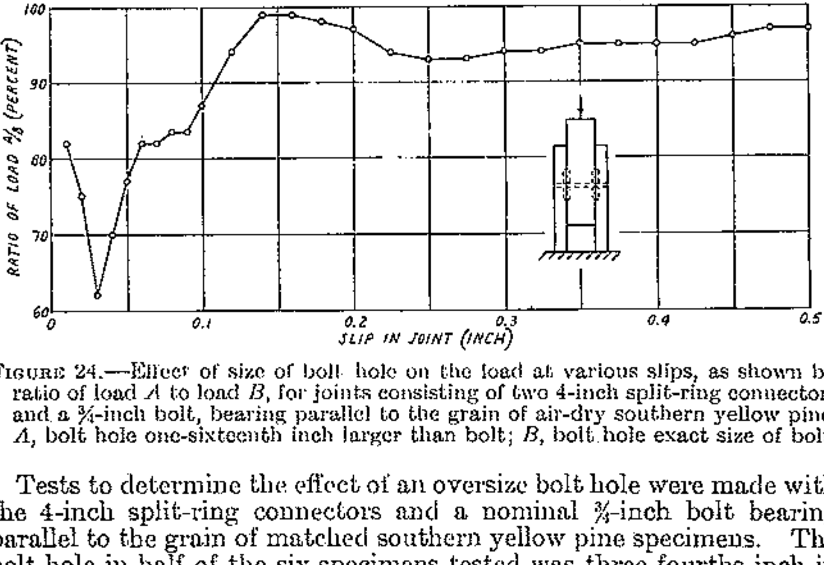

FIGURE 24.—Effect of size of bolt hole on the load at various slips, as shown by ratio of load *A* to load *B*, for joints consisting of two 4-inch split-ring connectors and a ¾-inch bolt, bearing parallel to the grain of air-dry southern yellow pine. *A*, bolt hole one-sixteenth inch larger than bolt; *B*, bolt hole exact size of bolt.

Tests to determine the effect of an oversize bolt hole were made with the 4-inch split-ring connectors and a nominal ¾-inch bolt bearing parallel to the grain of matched southern yellow pine specimens. The bolt hole in half of the six specimens tested was three-fourths inch in diameter and, in the other half, thirteen-sixteenths inch in diameter.

There is no appreciable difference in loads for the two types of joint at given slips greater than 0.12 inch, or after the first drop in load (table 17 and fig. 24). For smaller slips, the loads for the joint with the oversized bolt hole are lower. Conversely, the slips at a given load are greater. At 11,000 pounds, the slip in the joint with the oversized bolt hole was 0.048 inch, or about 17 percent more than the slip of 0.041 inch with the exact-size bolt hole.

The load at the proportional limit and the maximum load for the joint with the oversized bolt hole were each about 95 percent of the corresponding load with the exact-size bolt hole and came at a slightly greater slip.

TABLE 17.—*Effect of 1/16-inch oversized bolt hole on strength of 3-member, split-ring connector bearing parallel to grain, southern yellow pine* [1]

Item	¾-inch bolt hole (0.736-inch bolt)	13/16-inch bolt hole (0.733-inch bolt)
Properties of specimens:		
Moisture content .... percent	11.6	11.6
Specific gravity [2]	0.604	0.568
Maximum compressive strength parallel to grain ... Pounds per square in.	9,131	9,207
Results of tests:		
Initial slip [3] .... inches	0.029	0.030
Load at 0.03-inch slip .... pounds	6,830	4,220
Proportional limit:		
Load .... do.	28,330	26,670
Slip .... inches	0.068	0.074
First drop:		
Load .... pounds	43,400	41,780
Slip .... inches	0.12	0.14
Maximum or load at 0.60-inch slip:		
Load .... pounds	45,350	43,900
Slip .... inches	0.54	0.60

[1] Values are averages of 3 tests with 4-inch connectors (inside diameter when connector is closed). Size of members (inches): Width 5½; thickness, center 5, sides 2½.

[2] Based on the weight of oven-dry wood and the volume at time of test.

[3] The initial part of the slip not associated with elastic distortion.

SEASONING CHECKS

For the study of the effect of checks on the strength of split-ring connector joints, it was difficult to obtain material with natural checks that in other respects closely matched unchecked material. In order to secure satisfactory matching, saw kerfs were cut lengthwise through the center of the adjoining faces of the center and side members of some of the specimens to simulate natural checking. These saw kerfs were approximately one-sixteenth inch wide and ½, ¾, 1, and 1½ inches deep for the different tests. The tests were made in compression with the 4-inch split-ring connectors bearing parallel with and perpendicular to the grain of southern yellow pine specimens. The width of the specimens was 5½ inches, and the thicknesses of the center and side pieces were 5 and 2½ inches, respectively.

The tests showed that the saw kerfs had practically no effect on the immediate strength of the joints. The effect of duration of stress was not determined; neither was the behavior of specimens with saw kerfs studied to determine whether it resembled that of checked specimens.

MOISTURE CONDITION OF THE WOOD

The properties of wood change considerably with changes in moisture content. For a property such as maximum compressive strength parallel to the grain, the strength when green (or above the fiber-saturation point) is about one-half that at a moisture content of 12 percent. With other properties, the difference in strength between green and dry wood is usually not so great.

In a connector joint, several properties of the wood function simultaneously and the property that controls with relation to the variation in moisture content cannot be readily isolated.

TABLE 18.—*Effect of moisture condition of members on strength of 3-member, split-ring connector joints bearing either parallel or perpendicular to grain* [1]

LOADS ACTING PARALLEL TO GRAIN

Size of connector unit [2] and species of wood	Condition of members—			Dimensions of members when tested			Properties of specimens when tested			Initial slip [5]	Load at 0.03-inch slip	Proportional limit		First drop		Maximum or load at 0.60 inch slip	
	When assembled		When tested	Width	Thickness		Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain [4]			Load	Slip	Load	Slip	Load	Slip
	Center	Sides			Center	Sides											
				Inches	*Inches*	*Inches*	*Percent*		*Pounds per square inch*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*	*Pounds*	*Inch*
2½-inch connector; ½-inch bolt: Redwood.	Air dry	Air dry	Air dry	3⅝	4½	2¼	16.5	0.392	5,800	0.020	2,970	9,000	0.060	10,420	0.08	17,800	0.60
	Green	Green	do	3⅝	4½	2¼	11.3	.398	5,924	.010	3,070	5,670	.046	6,500	.06	18,270	.60
	do	do	Green	3⅝	4½	2¼	126.0	.402	4,113	.016	3,120	7,820	.064	11,200	.25	16,110	.60
4-inch connector; ¾-inch bolt: Redwood.	Air dry	Air dry	Air dry	5½	5	2½	9.2	.396	5,888	.026	3,670	17,000	.076	18,130	.08	27,800	.43
	Green	Green	do	5½	5	2½	13.4	.386	4,844	.015	4,930	15,670	.068	17,100	.08	27,920	.58
	do	do	Green	5½	5	2½	170.8	.386	3,700	.023	4,430	16,500	.081	19,220	.11	25,730	.60
4-inch connector; ¾-inch bolt: Southern yellow pine.	Air dry	Air dry	Air dry [6]	6	2⅞	1⅝	12.1	.552	7,922	.020	7,770	24,900	.058	35,685	.10	41,135	.20
	Green	do	do [7]	5⅞	2⅞	1⅝	10.8	.550	8,300	.012	8,730	20,900	.056	28,790	.09	32,945	.19
	do	Green	do [7]	5¾	2¾	1⅝	10.8	.552	8,497	.011	9,155	19,600	.050	28,135	.10	32,755	.20
	do	do	Green [6]	6	2⅞	1⅝	32.5	.521	4,000	.000	12,520	19,200	.046	26,190	.10	26,500	.16
LOADS ACTING PERPENDICULAR TO GRAIN																	
2½-inch connector; ½-inch bolt: Redwood.	Air dry	Air dry	Air dry	3⅝	4½	2¼	12.2	0.409	6,027	0.010	1,710	5,470	0.082	6,860	0.13	6,960	0.15
	Green	Green	do	3⅝	4½	2¼	12.3	.400	5,903	.000	1,860	3,870	.061	5,060	.10	5,760	.22
	do	do	Green	3⅝	4½	2¼	161.8	.398	3,910	−.022	2,570	5,230	.096	6,130	.16	6,130	.16
4-inch connector; ¾-inch bolt: Redwood.	Air dry	Air dry	Air dry	5½	5	2½	10.7	.380	6,328	.004	2,810	8,530	.087	10,690	.15	10,880	.17
	Green	Green	do	5½	5	2½	13.6	.362	5,159	−.007	3,430	5,870	.058	8,810	.12	9,170	.25
	do	do	Green	5½	5	2½	157.0	.354	3,419	−.010	3,060	7,730	.093	9,630	.15	9,630	.15

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[1] Values are averages of 3 tests, unless otherwise specified. When the specimens were assembled and tested in the same condition, the tests were made immediately after assembly; all others were made from 6 to 17 months after assembly.

[2] Connector diameter is inside diameter when connector is closed. Bolt hole equals nominal diameter of bolt.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] For loads acting perpendicular to the grain, the compressive strength is for side members only.

[5] The initial part of the slip not associated with elastic distortion.

[6] Averages of 5 tests.

[7] Averages of 10 tests.

The majority of the tests on split-ring connectors were made in specimens that had an average moisture content of approximately 12 percent. To determine the effect of differences in moisture content, tests were made with matched specimens of green and dry redwood and southern yellow pine. Tests were also made of specimens in which all or part of the members in the joint were assembled when green and seasoned to an air-dry condition before tests. The tests on southern yellow pine were made with the 4-inch split-ring connectors bearing parallel with the grain, and on redwood with the 2½- and 4-inch connectors bearing parallel with the perpendicular to the grain of the wood.

The results given in table 18 show that the relation between the loads on the joint for green and dry material is erratic but approximately proportional to the square root of the ratio of the crushing strength of the wood parallel to the grain. In other words, properties of the wood other than the crushing strength parallel to the grain, and, to a minor extent, the properties of the metal, determine the variation in the joint load with differences in moisture content of the material (*18*). The slip in the joint at the smaller loads was somewhat less for the green than for the dry material.

The loads at proportional limit and maximum of southern yellow pine specimens assembled while green, seasoned, and tested in an air-dry condition, were somewhat higher than for the joints assembled of green material and tested immediately, but not so high as for those assembled dry. When green and dry material were combined in a joint which was tested after drying, the results were about the same as for the joints made entirely of green material and tested after seasoning.

For redwood, which differs from most species in its moisture-strength relations, [11] the loads at the proportional limit of joints made of green material and tested after seasoning were lower than those of joints made of unseasoned material. The maximum load for the joints bearing parallel to the grain, however, was somewhat higher. Considerable splitting occurred in all tests of joints assembled of green material and tested after drying. Because of the unusual moisture-strength characteristics of redwood, which are apparently due to high extractive content, the results with this species should not be regarded as necessarily applicable to other woods.

NET SECTION OF MEMBER

In the design of members employing connectors, consideration must be given to the strength of the member itself between joints, to the strength of the joint, and, when the bearing is parallel to the grain, to the area of the net section at the joint. The net section may be defined as that section of the member, taken at right angles to the direction of the load, which is subjected to maximum stress—in other words, the net area remaining after the reduction for bolt holes and the insertion of connectors at that section. Tests have shown that the concentration of stresses in the net section causes failure in tension at stresses approximately equal to the maximum compressive stress of the material parallel to the grain (*14*). Translated into safe stresses,

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[11] Redwood differs from most other species in its moisture-strength relations in that its strength when green is somewhat higher than would be expected for the density and its increase in strength with seasoning is less than normal.

this corresponds to a value which is equal to the safe stress in compression parallel to the grain for clear material. In using this stress, it is assumed that knots do not occur in the longitudinal projection of the net section within a length of half the diameter of the connector from it.

The net area at the critical section may be determined by subtracting the projected area of the connector grooves and the intervening bolt hole in the member from the full cross-sectional area of the member. For example, to calculate the safe strength at the critical section of a seasoned, coast-type Douglas-fir member 2⅝ inches thick and 5½ inches wide, in which two 4-inch split-ring connectors are placed in opposite faces with a ¾-inch bolt extending through the member concentric to the connectors: The outside diameter of the connector grooves is 4.50 inches and the combined depth of the connector grooves in the member is 1 inch, giving a projected area of 4.50 square inches. The length of the bolt hole between the connectors is 2⅝ inches minus 1 inch, or 1⅝ inches. If the diameter of the bolt hole is equal to the bolt diameter of three-fourths inch, the projected area for the bolt hole is 1.22 square inches. The total projected area of 5.72 square inches for the connector grooves and bolt hole is then subtracted from the cross-sectional area of 14.44 square inches for the member, leaving an area of 8.72 square inches at the net section. This area is multiplied by the basic stress in compression parallel to the grain for coast-type Douglas-fir of 1,466 pounds per square inch and increased by 25 percent (because a seasoned member less than 4 inches in thickness is used) to 1,832 pounds per square inch. A load of 15,975 pounds that can be sustained by the net section is thus obtained. Since the safe load for one pair of 4-inch split-ring connectors in a member 2⅝ inches thick is 9,390 pounds (table 1), the strength of the connection would be limited by strength of the connectors. If two pairs of connectors were spaced at an optimum distance longitudinally along the same member, however, the load that could be sustained by the net section would be the same as that given above, but the load for the connectors would be twice as great, or 18,780 pounds. The strength of the member, therefore, would be limited by the safe load at the net section.

As the width of member used with a given size of connector is increased, the thickness required to provide ample area at the net section is, of course, reduced. The maximum width used in determining the net section area should, however, be not greater than twice the diameter of the connector, and the minimum thickness of member irrespective of width should be not less than that recommended in the discussion on the thickness of member.

FACTORS AFFECTING TOOTHED-CONNECTOR JOINTS

The toothed connector consists of a corrugated circular band of 16-gage, low carbon steel[12] with sharp teeth. The toothed connector is placed between the contact faces of the members to be joined and embedded into the wood with pressure.

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[12] The specifications for the connectors tested required that the steel conform to A. S. T. M. Standard Specifications for carbon steel A17-29, Type A, Grade 1.

This connector, which was originally known as the "alligator" and made in Europe in 2⅛-, 2¾-, 3¾-, 4½-, 5½-, and 6¼-inch diameters, is now made in the United States in 2-, 2⅝-, 3⅜-, and 4-inch diameters and in a ¹⁵⁄₁₆-inch height. All sizes 4 inches or less in diameter have been used in this investigation, but the results obtained for the 2⅛-, 2¾-, and 3¾-inch European sizes are applicable, with modifications, to those sizes now available in the United States.

The study of toothed connectors involved the factors of (1) size of connector; (2) species of wood; (3) direction of the applied force with reference to the grain of the wood; (4) thickness and (5) width of timber; (6) end margin; (7) size of bolt hole; and (8) moisture condition of the wood.

SPECIES OF WOOD

BEARING PARALLEL TO GRAIN

In the tests to determine the influence of species, 2⅛-, 2¾-, and 3¾-inch connectors were used with matched specimens of redwood, baldcypress, and two grades of southern yellow pine, and 2-, 2⅝-, 3⅜-, and 4-inch connectors with Douglas-fir, redwood, and southern yellow pine. The average moisture content of the material was about 11 percent.

The joints, made up of two side pieces and a center piece, all of the same length, were tested in compression parallel to the grain (fig. 13). The side pieces overlapped the center piece by about two-thirds of their length, which varied from 12 to 17 inches, depending upon the size of the connector to be tested. The width of the specimens varied from 2⅝ inches for the 2-inch connectors to 5½ inches for the 4-inch connectors. The thickness of the center member was 1⅝ inches and that of the side members 1¹⁄₁₆ inches for all sizes.

Two connectors were symmetrically placed in opposite sides of the center piece, concentric to the bolt hole and in the center of the overlapped length. The diameter of the bolt hole was the nominal diameter of the bolt to be used.

These connectors were embedded in the wood by applying pressure to the sides of the specimen with a testing machine until the pieces were in contact. After the pressure was removed, heavy plate washers were inserted and the bolt drawn up tightly.

The pressures in pounds required to embed the connectors in average and dense southern yellow pine specimens were approximately as recorded in table 19.

TABLE 19.—*Pressures required to embed toothed connectors in southern yellow pine*

Material	Diameter of connector (inches)—		
	2⅛	2¾	3¾
	Pounds	*Pounds*	*Pounds*
Average	5,000	6,500	9,000
Dense	6,000	8,000	11,000

The results of the tests for each species and connector size tested are given in table 20.

Since no definite proportional limit load is evident on the load-slip curves (fig. 25), the load for slips of 0.02, 0.04, and 0.08 inch are listed. Some distortion of the connectors, under load, was discernible almost from the beginning of the test, and this distortion is accompanied by crushing of the wood under the teeth and under the bolt.

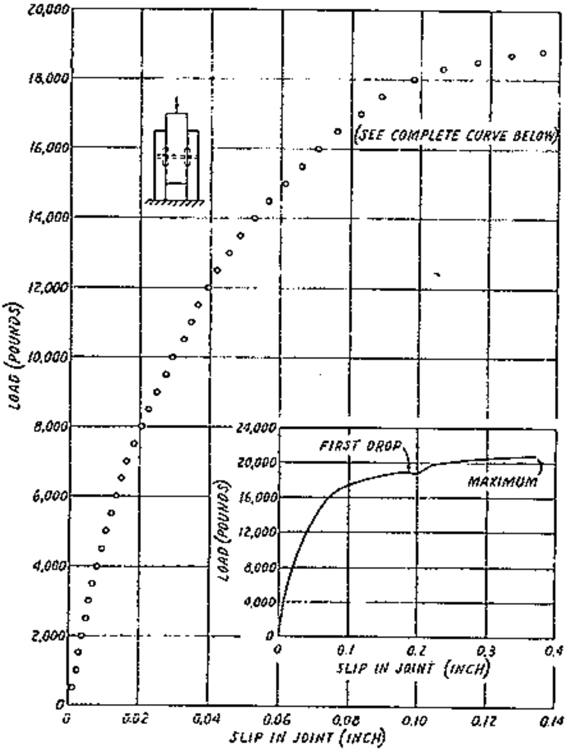

FIGURE 25.—Relation between load and slip in the joint for an individual test specimen of toothed connectors bearing parallel to the grain of air-dry wood.

The material used in the tests furnished a wide variation in specific gravity, but does not necessarily represent the average for a species. In figure 26 the individual test results for the 2⅝- and 2¾-inch connectors are plotted with relation to the specific gravity of the wood. The values for the 2⅝- and 2¾-inch connectors were so nearly alike that they were combined in the same curves. The curves show that, for the species and sizes of specimens tested, the maximum load and the load at a given slip vary almost directly as the specific gravity of the wood. Similar curves plotted for the other ring sizes show approximately the same relationship, although the maximum load of the joint tends to increase somewhat less rapidly with the specific gravity of the wood as the diameter of the connector increases.

TABLE 20.—*Effect of wood species on strength of 3-member, toothed-connector joint bearing parallel to grain* [1]

Size of connector unit;[2] and species of wood (in order of specific gravity of specimens)	Width of members[3]	Properties of specimens			Load at slip of—			First drop		Maximum	
		Moisture content	Specific gravity[4]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip	Load	Slip
	Inches	*Percent*		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*
2-inch connectors; ½-inch bolt: Southern yellow pine [5]	2⅝	13.2	0.556	7,222	4,715	7,020	9,515	11,105	0.30	11,105	0.30
2⅝-inch connectors; ½-inch bolt:											
Redwood	2⅝	10.8	.390	6,250	4,050	6,215	8,190	8,680	.11	8,940	.29
Southern yellow pine		12.0	.412	5,060	3,650	5,540	7,610	8,800	.32	8,800	.32
Baldcypress		9.2	.460	6,910	3,930	5,970	8,845	10,500	.19	10,850	.32
Southern yellow pine		10.9	.528	7,800	5,350	7,870	10,270	11,710	.23	11,710	.23
2⅝-inch connectors; ⅝-inch bolt:											
Redwood [6]	3⅝	7.6	.407	7,002	4,750	6,950	9,910	11,810	.23	12,480	.34
Douglas-fir [6]		11.4	.475	7,238	6,000	9,030	12,300	15,070	.39	15,070	.39
2¾-inch connectors; ⅝-inch bolt:											
Redwood	3⅝	9.6	.388	6,410	4,970	7,670	11,015	13,220	.20	13,620	.27
Southern yellow pine		12.2	.416	5,210	5,090	7,530	10,015	11,500	.29	11,605	.35
Baldcypress		10.1	.466	6,990	5,790	8,680	12,465	14,830	.23	15,200	.28
Southern yellow pine		9.4	.534	8,600	7,090	10,335	14,110	15,830	.25	16,200	.28
3⅜-inch connectors; ¾-inch bolt:											
Douglas-fir [6]	4⅝	11.5	.480	7,715	7,820	11,600	15,330	17,650	.28	17,700	.41
Southern yellow pine [6]	5	11.4	.536	8,164	8,010	12,250	16,900	19,400	.18	20,970	.37
3¾-inch connectors; ¾-inch bolt:											
Redwood	5½	9.8	.388	6,490	7,680	11,285	15,200	18,190	.17	19,775	.35
Southern yellow pine		12.0	.418	5,120	6,510	9,460	12,710	15,235	.26	15,430	.31
Baldcypress		10.5	.470	6,380	7,040	10,855	15,910	18,545	.13	19,800	.31
Southern yellow pine		10.5	.538	7,910	10,100	14,810	19,710	22,900	.26	23,070	.32
4-inch connectors; ¾-inch bolt:											
Redwood [6]	5½	7.8	.370	6,504	6,533	9,850	14,700	16,750	.14	18,540	.35
Southern yellow pine [7]		13.5	.571	7,390	11,008	15,958	20,592	25,492	.33	25,565	.35

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[1] Values are averages of 5 tests, except as noted.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Thickness of all center members, 1⅝ inches; sides, 1⅟₁₆.
[4] Based on the weight of oven-dry wood and the volume at time of test.
[5] Average of 4 tests.
[6] Average of 3 tests.
[7] Average of 6 tests.

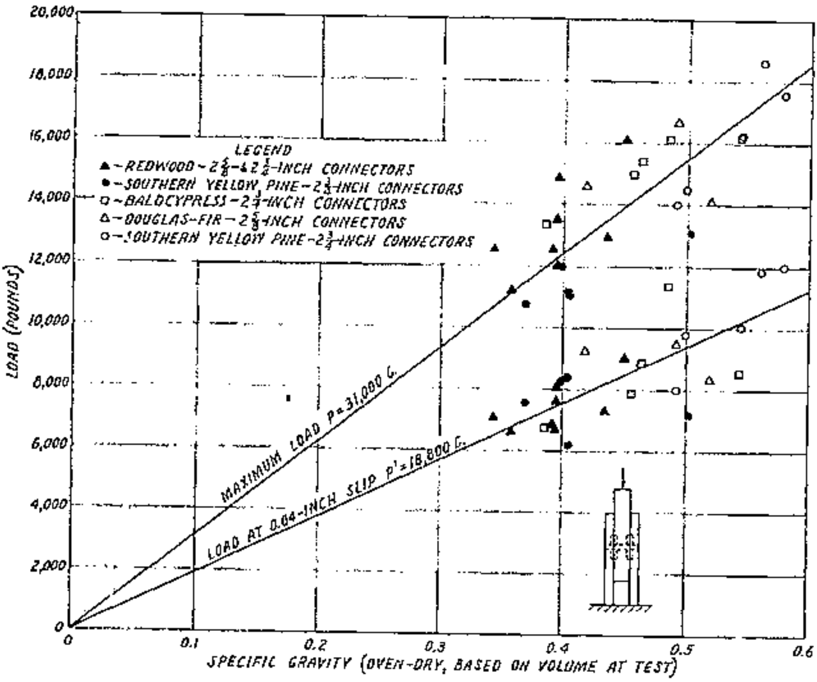

FIGURE 26.—Relation between load bearing parallel to the grain and specific gravity of air-dry wood for a joint consisting of two toothed connectors (2⅝ or 2¾ inches in diameter) and a ⅝-inch bolt. The solid and open symbols for the same species indicate marked differences in specific gravity.

BEARING PERPENDICULAR TO GRAIN

The tests for connectors bearing perpendicular to the grain were made in southern yellow pine, Douglas-fir, and redwood. The specimens were approximately the same size as those used in the tests made parallel to the grain, differing only in thickness and in the length of the center member. The center member varied in length from 20 to 26 inches, depending on the size of connector, and was supported horizontally in the testing machine by wood blocks spaced from 10 to 16 inches apart. The load was applied in compression to the vertical side members (fig. 18).

Each joint assembly contained two connectors, one between each side member and the center member. The bolt diameters used are those recommended by the manufacturers for the various sizes of connectors. The diameter of the bolt hole was equal to the nominal bolt diameter.

In the results of the tests (table 21), the individual values for bearing perpendicular to the grain vary directly with the specific gravity of the wood, just as in the parallel arrangement. The effect of the thickness of members is also reflected in the loads in approximately the same manner as when the bearing is parallel to the grain.

A comparison of the loads for the perpendicular and parallel arrangements at slips of 0.02, 0.04, and 0.08 inch shows that the average ratio is about 60 percent for equal thicknesses of members and for

TABLE 21.—*Effect of wood species on strength of toothed-connector joints bearing perpendicular to grain* [1]

Size of connector unit;[2] and species of wood	Width of members	Thickness of members		Properties of center members		Properties of side members			Load at slip of—			Maximum [4]	
		Center	Sides	Moisture content	Specific gravity [3]	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
	Inches	*Inches*	*Inches*	*Percent*		*Percent*		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*
2-inch connectors; ½-inch bolt: Southern yellow pine	2⅝	3	1½	11.8	0.477	10.0	0.499	8,239	2,790	4,750	7,080	8,970	0.17
2⅛-inch connectors; ½-inch bolt:													
Douglas-fir [5]	3	2	1	12.4	.499	11.6	.491	7,710	3,975	5,950	7,400	8,050	.12
Southern yellow pine				11.5	.487	11.1	.510	7,322	3,900	5,815	7,810	8,370	.11
2⅝-inch connectors; ⅝-inch bolt:													
Redwood	3⅝	1⅝	1 3/16	8.1	.412	7.5	.412	7,316	2,440	4,240	------	5,750	.07
Douglas-fir	3⅝	1⅝	1 1/16	12.6	.490	11.4	.486	7,811	3,800	5,950	------	8,190	.08
Southern yellow pine	3⅝	3	1½	11.8	.554	10.7	.546	8,177	4,255	6,940	10,300	13,410	.17
2¾-inch connectors; ⅝-inch bolt:													
Douglas-fir [5]	4	2½	1¼	13.0	.473	12.6	.466	7,050	4,850	7,400	10,000	10,610	.12
Southern yellow pine				14.5	.549	15.2	.548	7,225	5,500	8,180	10,670	12,810	.18
3⅜-inch connectors; ¾-inch bolt:													
Douglas-fir	4⅝	1⅝	1 1/16	12.0	.465	11.4	.468	7,465	4,680	7,830	9,670	10,340	.10
Southern yellow pine	4⅝	3	1½	12.5	.558	11.1	.530	7,806	4,980	8,440	12,920	16,880	.16
3¾-inch connectors; ¾-inch bolt:													
Douglas-fir [5]	5	3	1½	12.6	.430	12.4	.456	6,759	7,175	10,075	13,050	15,910	.18
Southern yellow pine				12.0	.566	11.6	.530	7,295	8,370	11,920	16,000	18,630	.12
4-inch connectors; ¾-inch bolt:													
Redwood	5½	1⅝	1 1/16	8.2	.368	7.8	.358	6,083	3,400	5,370	------	7,690	.08
Southern yellow pine	5½	3	1½	13.8	.567	11.0	.525	7,599	6,540	10,550	15,117	21,200	.22

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[1] Values are averages of 3 tests, except as noted.

[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] The load and slip at first drop were approximately the same as that at the maximum.

[5] Average of 2 tests.

the widths used in the tests. The ratio of the maximum loads and of loads at slips less than 0.02 inch is somewhat less. When bearing perpendicular to the grain, the center member often failed in bending or shear during the test at slips of 0.1 to 0.2 inch. The maximum loads, therefore, do not furnish a suitable criterion for comparison, except when considered in conjuction with the type of failure. The slip associated with the maximum loads is much less for the perpendicular than for the parallel arrangement.

When the several factors which influence the load on a connector joint are considered, it appears that the values for the toothed connectors bearing perpendicular to the grain, in the minimum permissible width of timber, can be taken as approximately two-thirds of the corresponding parallel values. However, the design values for connectors bearing parallel to the grain, unlike those bearing perpendicular, do not increase with an increase in width of member over the required minimum. Consequently the ratio between the perpendicular and parallel values is not constant at two-thirds but increases over this ratio with an increase in width of member.

BEARING AT VARIOUS ANGLES TO GRAIN

Toothed connectors carry the greatest load when bearing parallel to the grain of the wood; for any other direction of bearing, the load is less. Tests made with 4½-inch alligator connectors in previous investigations (7) bearing at various angles to the grain of Douglas-fir specimens have demonstrated that the load decreases uniformly from the highest value at a bearing of 0° with the grain to a minimum value at 45° with the grain and remains constant from 45° to 90°. This relation between the load and the angle of bearing should apply without appreciable error to the various sizes of toothed connectors now manufactured.

THICKNESS OF MEMBER

Tests to determine the effect of thickness of member were made with four sizes of toothed connectors. The 2- and 4-inch connectors were tested with southern yellow pine specimens in tension parallel to the grain and the 2⅝- and 3⅜-inch connectors with Douglas-fir specimens in compression parallel to the grain. The end margin, or the distance between the center of the connector and the ends of both the side and center members in the tests, was ample to eliminate the effect of this variable.

The thickness of the center or main member of the joint was varied from 1¼ to 3 inches for the 2- and 4-inch connectors. With the 2⅝-inch connectors, the thickness of the center member was 1⅝ and 2½ inches, and with the 3⅜-inch connectors it was 1⅝ and 3 inches. The thickness of the side members was approximately two-thirds that of the center member. The widths of the specimens used for each size of connector were approximately 1⅓ times the diameter of the connector.

The results of the tests are given in table 22, and the values for the maximum loads are shown graphically in figure 27. With a pair of 2-inch connectors and a ½-inch bolt, the maximum load increases with an increase in thickness of center member up to about 2 inches. Beyond this thickness, the decrease in load on the connector itself appears to balance the increase in maximum load on the bolt. With a pair of 4-inch connectors and a ¾-inch bolt, a thickness of at least 3 inches is required to develop such a constant maximum load. Tests with the 2⅝- and 3⅜-inch connectors were made with only two thicknesses of material but indicate that a constant maximum load is reached at thicknesses of 2½ and 3 inches, respectively. The loads at given slips of the joint, while quite erratic for the different sizes of connectors, correspond in general to the relationship obtained for the maximum load.

TABLE 22.—*Effect of thickness of members on strength of 3-member, toothed-connector joints, bearing parallel to grain* [1]

Thickness of members, center and side (inches)	Properties of specimens			Load at slip of—			Maximum [4]	
	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
2-INCH CONNECTORS; ½-INCH BOLT;[2] SOUTHERN YELLOW PINE MEMBERS 2⅝ INCHES WIDE								
	Percent		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*
1¼—⅞	13.2	0.557	7,236	4,500	6,405	8,250	8,765	0.13
1⅝—1¹/₁₆	13.2	.557	7,236	5,625	7,675	9,485	10,400	.18
2 —1⅜	13.2	.557	7,236	5,525	7,490	9,550	11,325	.30
2½—1¹¹/₁₆	13.2	.557	7,236	5,675	7,190	8,890	11,275	.58
3 —2	13.2	.557	7,236	5,780	7,600	9,105	11,630	.60
2⅝-INCH CONNECTORS; ⅝-INCH BOLT;[2] DOUGLAS-FIR MEMBERS 3⅝ INCHES WIDE[5]								
1⅝—1¹/₁₆	11.4	0.475	7,238	6,000	9,030	12,300	15,070	0.39
2½—1½	11.4	.475	7,526	8,000	11,370	14,130	19,060	.54
3⅜-INCH CONNECTORS; ¾-INCH BOLT;[2] DOUGLAS-FIR MEMBERS 4⅝ INCHES WIDE[5]								
1⅝—1¹/₁₆	11.5	0.480	7,716	7,820	11,600	15,330	17,700	0.41
3 —1½	11.6	.496	7,966	7,230	10,480	15,070	23,500	.53
4-INCH CONNECTORS; ¾-INCH BOLT;[2] SOUTHERN YELLOW PINE MEMBERS 5½ INCHES WIDE								
1¼—⅞	13.4	0.572	7,373	8,675	12,950	17,450	19,635	0.10
1⅝—1¹/₁₆	13.4	.572	7,373	10,350	15,425	20,550	25,440	.25
2 —1⅜	13.4	.572	7,373	11,650	16,650	21,800	28,990	.33
2½—1¾	13.4	.572	7,373	12,725	18,025	24,075	30,820	.44
3 —2	13.4	.572	7,373	13,700	19,150	25,000	31,035	.50

[1] Values are averages of 2 tests, except as noted.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Based on the weight of oven-dry wood and the volume at time of test.
[4] The load and slip at first drop were approximately the same as that at the maximum.
[5] 3 tests.

The failures generally consisted of a twisting or bending over of the connectors, accompanied by crushing of the wood under the bolt and connectors, and some splitting in the center member. With a thickness of 1¼ inches, some shear and tension failures also occurred in the center member.

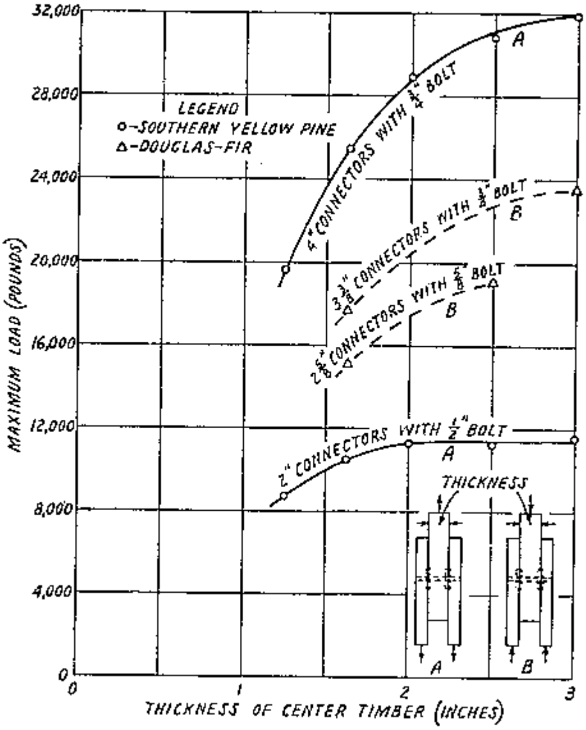

FIGURE 27.—Relation between maximum load and thickness of member for toothed-connector joints bearing parallel to the grain of air-dry wood; two connectors and bolt to each joint.

The maximum loads for a timber thickness of 2 inches for the 2-inch connectors and 2½ inches for the 2⅝-inch connectors are about 110 and 125 percent of the load, with a timber thickness of 1⅝ inches, and the loads for a timber thickness of 3 inches for the 3⅜- and 4-inch connectors are about 135 and 130 percent. The load for intermediate thicknesses may be obtained without appreciable error by direct interpolation. A member should not be less than 1½ inches thick when connectors are used in opposite faces; at this thickness, the load is about 4 percent lower than at 1⅝ inches.

When the connectors are in one face only, the thickness of the timber should not be less than 1 inch. For a thickness of 1⅛ inches and a 2-inch connector, the load can be 10 percent higher than for 1 inch; for a 2⅝-inch connector and a thickness of 1⅜ inches, the load can be 25 percent greater; and for the 3⅜- and 4-inch connectors and a thickness of 1⅝ inches, the load can be increased 35 and 30 percent.

WIDTH OF MEMBER (BEARING PERPENDICULAR TO GRAIN)

Tests with the minimum width of specimens—about 1⅓ times the diameter of the connectors—have shown that the values when bearing perpendicular to the grain are approximately two-thirds of the values when bearing parallel to the grain. The loads of connectors bearing perpendicular to the grain, however, vary with the width of the member.

Tests to determine the effect of this variation were made with the four United States sizes of toothed connectors in southern yellow pine specimens, in which all the dimensions of the specimens except the width of the center member were constant for each size of connector. The width of the center member was varied from a minimum equal to the diameter of the connector to a width 3 inches greater than the diameter of the connector. The connector was always centered on the width of the member.

The failures generally consisted of bending of the bolt and twisting or bending over of the connectors, accompanied by crushing of the wood. As the test progressed, splitting occurred in the center member at the bolt and connectors, and finally, after the maximum load, the failure culminated in shear to the end of the member. With the narrower widths, compression and tension failures occurred in the center member at maximum load.

The results of the tests are given in table 23 and shown graphically in figure 28. The relative increase in load with an increase in width of member was about the same at given slips and at maximum. Furthermore, the percentage increase in load was approximately the same for the different sizes of connectors.

TABLE 23.—*Effect of width of timber on strength of 3-member, toothed-connector joints, bearing perpendicular to grain, southern yellow pine* [1]

2-INCH CONNECTORS; ½-INCH BOLT [2]

[Thickness of members (inches): Center, 3; sides, 1½]

Width of members, center and side (inches)	Properties of specimens					Loads at slip of—			Maximum [4]	
	Center		Sides							
	Moisture content	Specific gravity [3]	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
	Percent		*Percent*		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*
2 —2⅝	11.8	0.477	10.0	0.499	8,239	2,410	4,120	6,140	7,460	0.15
2¼—2⅝	11.8	.477	10.0	.499	8,239	2,540	4,280	6,370	8,040	.17
2½—2⅝	11.8	.477	10.0	.499	8,239	2,600	4,650	6,970	8,860	.17
3 —2⅝	11.8	.477	10.0	.499	8,239	3,080	5,040	7,400	9,310	.19
3½—2⅝	11.8	.477	10.0	.499	8,239	3,150	5,070	7,530	9,620	.23
4 —2⅝	11.8	.477	10.0	.499	8,239	3,400	5,480	7,640	10,380	.25
5 —2⅝	11.8	.477	10.0	.499	8,239	4,110	6,290	8,480	11,580	.36

2⅝-INCH CONNECTORS; ⅝-INCH BOLT [2]

[Thickness of members (inches): Center, 3; sides, 1½]

Width of members, center and side (inches)	Center moisture content	Center specific gravity	Sides moisture content	Sides specific gravity	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
2⅝—3⅝	11.8	0.554	10.7	0.546	8,177	3,200	5,600	8,350	10,160	0.15
3 —3⅝	11.8	.554	10.7	.546	8,177	3,880	6,490	9,620	11,630	.17
3½—3⅝	11.8	.554	10.7	.546	8,177	4,190	6,890	10,240	13,040	.16
4⅛—3⅝	11.8	.554	10.7	.546	8,177	4,510	7,120	10,540	14,880	.21
4⅝—3⅝	11.8	.554	10.7	.546	8,177	4,650	7,580	10,930	15,130	.34
5⅝—3⅝	11.8	.554	10.7	.546	8,177	5,640	8,750	12,240	17,120	.42

See footnotes at end of table.

TABLE 23.—*Effect of width of timber on strength of 3-member, toothed-connector joints, bearing perpendicular to grain, southern yellow pine* [1]—Continued

3¾-INCH CONNECTORS; ¾-INCH BOLT [2]

[Thickness of members (inches): Center, 3; sides, 1½]

Width of members, center and side (inches)	Properties of specimens					Loads at slip of—			Maximum [4]	
	Center		Sides							
	Moisture content	Specific gravity [3]	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
	Percent		*Percent*		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*
3⅜—4⅝	12.5	0.558	11.1	0.530	7,806	3,870	6,740	10,610	14,120	0.16
3⅞—4⅝	12.5	.558	11.1	.530	7,806	3,892	6,780	10,900	14,550	.16
4½—4⅝	12.5	.558	11.1	.530	7,806	4,617	8,070	12,825	16,450	.15
4⅞—4⅝	12.5	.558	11.1	.530	7,806	5,700	9,180	13,500	17,730	.17
5⅜—4⅝	12.5	.558	11.1	.530	7,806	5,200	8,750	13,220	18,820	.24
6⅜—4⅝	12.5	.558	11.1	.530	7,806	5,975	9,710	13,920	20,750	.47

4-INCH CONNECTORS; ¾-INCH BOLT [2]

[Thickness of members (inches): Center, 3; sides, 1½]

Width of members, center and side (inches)	Center moisture content	Center specific gravity	Sides moisture content	Sides specific gravity	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Maximum load	Maximum slip
4 —5½	13.8	0.567	11.0	0.525	7,599	5,117	8,420	12,680	17,210	0.18
4¾—5½	13.8	.567	11.0	.525	7,589	6,017	9,830	14,490	20,020	.21
5 —5½	13.8	.507	11.0	.525	7,599	6,325	10,110	14,800	20,730	.21
5½—5½	13.8	.567	11.0	.525	7,599	6,542	10,550	15,120	21,200	.22
6 —5½	13.8	.567	11.0	.525	7,509	6,833	11,020	15,875	22,430	.21
7 —5½	13.8	.567	11.0	.525	7,599	7,550	12,110	16,950	24,700	.33

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[1] Values are averages of 3 tests.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Based on the weight of oven-dry wood and the volume at time of test.
[4] The load and slip at first drop were approximately the same as that at the maximum.

In general, the loads increase 10 percent with each 1-inch increase over the minimum width of member for each connector size. When the connectors are placed off center, the width of member may be taken as twice the distance between the center of the connector and the load-bearing edge of the member if the margin or width on the non-load-bearing edge is at least one-third greater than half the diameter of the connector. The tests show that the load continues to increase with an increase in width of member to at least twice the diameter of the connectors.

END MARGIN (BEARING PARALLEL TO GRAIN)

Tests to determine the effect of end margin (the distance between the end of the member and the center of the nearest connector when bearing is parallel to the grain) were made with the 2-inch and 3¾-inch toothed connectors in southern yellow pine specimens. The specimens, which consisted of two side members overlapping the opposite faces of a center member, were tested in tension (fig. 21). The thickness of each side member was 1⅙ inches; and that of the center member, 1⅝ inches. The width of members for the 2-inch connectors was 2⅝ inches; and for the 3¾-inch connectors, 5½ inches. The end margins, which were the same for both side and center members, varied by

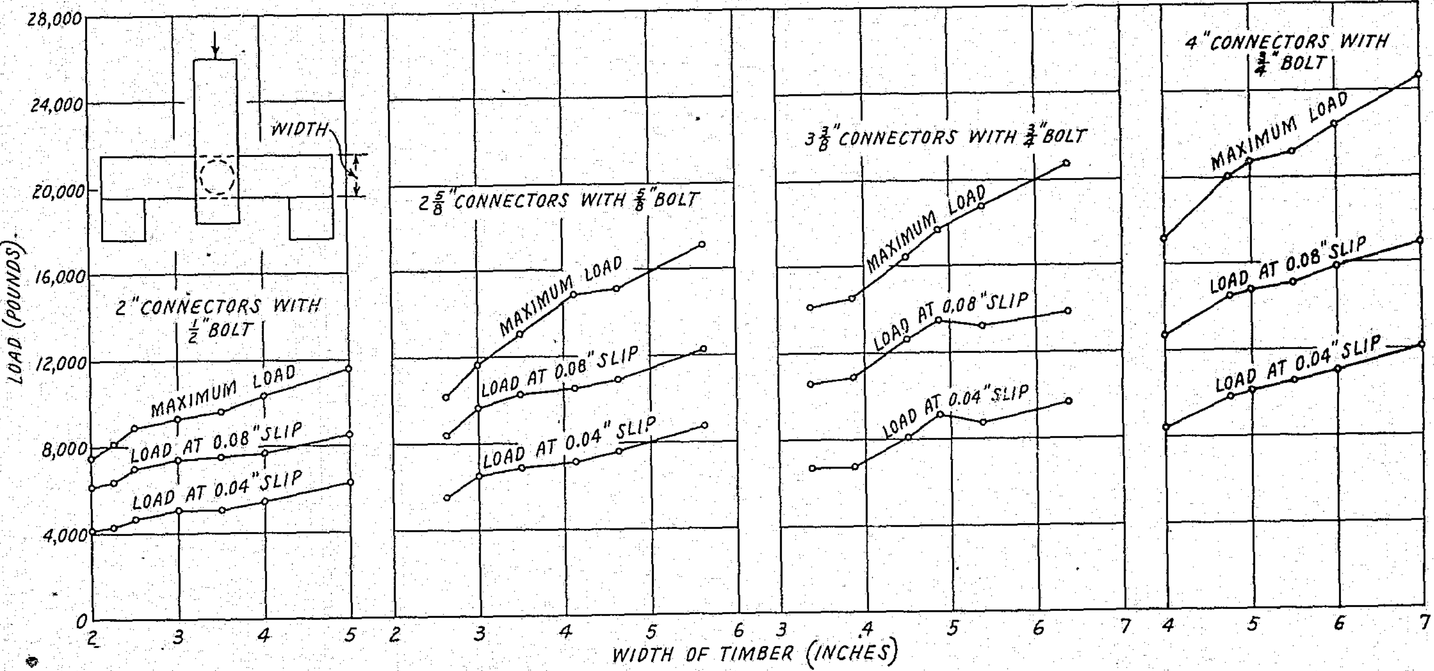

FIGURE 28.—Relation between load and width of timber for 3-member toothed connector joints, bearing perpendicular to the grain of air-dry southern yellow pine.

1-inch increments from half the diameter of the connector to 6 inches for the 2-inch connectors and 7⅞ inches for the 3¾-inch connectors. The smallest end margin placed the connector flush with the end of the member.

The failures were about the same in the side pieces as in the center piece. They consisted of bending of the bolt and bending and breaking of the connectors with crushing and splitting of the wood, and shear to the end of the member with the smaller end margins. Less splitting and no shear occurred with the larger end margins, but the crushing of the wood was more pronounced.

The results of the tests are given in table 24, and the values for the maximum loads for various end margins are shown in figure 29. The maximum loads increase with an increase in margin to approximately a constant value at an end margin of about 3½ inches for the 2-inch connectors and 6½ inches for the 3¾-inch connectors. The loads at given slips reach approximately a constant value at a somewhat smaller end margin than the maximum loads.

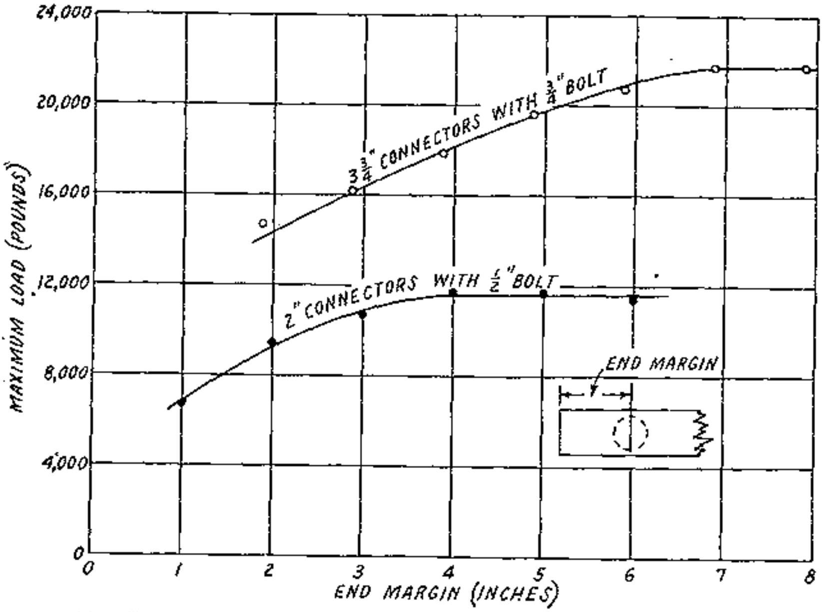

FIGURE 29.—Relation between maximum load and end margin for a 3-member toothed connector joint bearing in tension parallel to the grain of air-dry southern yellow pine.

An analysis of the test results shows that the end margin required to develop the full load of the toothed connectors in tension is 1¾ times the diameter of the connector, and that reduction in load varies quite uniformly from unity at that point to about two-thirds at an end margin equal to the diameter of the connector. The load for intervening end margins can therefore be obtained by direct interpolation. The end margin required to develop the full load of the toothed connectors in compression is equal to the diameter of the connector. End margins less than the diameter of the connector are not recommended in either tension or compression.

TABLE 24.—*Effect of end margin on strength of 3-member, toothed connector joints, bearing parallel to grain, southern yellow pine* [1]

2-INCH CONNECTORS; ½-INCH BOLT [2]

[Member dimensions (inches): Width, 2⅝; thickness, center 1⅝, sides 1¹⁄₁₆]

End margin [3] (inches)	Properties of specimens: Moisture content	Properties of specimens: Specific gravity [4]	Properties of specimens: Maximum compressive strength parallel to grain	Load at slip of— 0.02 inch	Load at slip of— 0.04 inch	Load at slip of— 0.08 inch	Maximum [5]: Load	Maximum [5]: Slip
	Percent		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inch*
1	10.9	0.565	9,201	3,810	5,700	6,500	6,800	0.09
2	10.9	.565	9,201	5,070	7,410	8,140	9,420	.10
3	10.9	.565	9,201	4,900	7,100	9,590	10,660	.22
4	10.9	.565	9,201	4,850	7,290	9,030	11,710	.24
5	10.9	.565	9,201	5,110	7,210	9,750	11,740	.34
6	10.9	.565	9,201	4,680	6,680	9,320	11,390	.38

3⅝-INCH CONNECTORS; ¾-INCH BOLT [2]

[Member dimensions (inches): Width, 5½; thickness, center 1⅝, sides 1¹⁄₁₆]

End margin [3] (inches)	Moisture content	Specific gravity [4]	Maximum compressive strength parallel to grain	0.02 inch	0.04 inch	0.08 inch	Load	Slip
1⅞	11.4	0.559	8,606	6,580	10,020	13,730	14,680	0.12
2⅞	11.4	.559	8,606	7,850	11,720	15,360	16,200	.11
3⅞	11.4	.559	8,606	7,050	11,580	15,990	17,910	.14
4⅞ [6]	11.3	.558	8,390	8,470	12,440	16,660	19,620	.25
5⅞	11.4	.559	8,606	7,700	12,410	16,860	20,770	.35
6⅞	11.4	.559	8,606	9,250	13,240	17,570	21,790	.32
7⅞	11.4	.559	8,606	9,540	13,540	17,500	21,790	.32

[1] Values are averages of 3 tests, except as noted.
[2] The diameter of the bolt hole was the same as the nominal diameter of bolt.
[3] Distance from end of timber to center of bolt hole.
[4] Based on the weight of oven-dry wood and the volume at time of test.
[5] The load and slip at first drop were the same as that at the maximum.
[6] 4 tests.

A theoretical analysis of the stresses in a toothed connector joint, when the rigidity of the connector is given proper consideration, affords values that conform closely to those obtained in the tests. The toothed connectors under stress are more rigid at the ends of the diameter at right angles to the direction of load than at the ends of the diameter parallel to the direction of load; the larger the diameter of the ring, the more pronounced this difference becomes.

SPACING OF MULTIPLE CONNECTORS (BEARING PARALLEL TO GRAIN)

The spacing required between connectors along the length of the timber when the bearing is parallel to the grain was not determined by specific tests on this variable. An analysis of the stresses in the member based on auxiliary tests, however, indicates that the center-to-center spacing required to develop the full load should be at least two times the diameter of the connectors. For spacings less than this the load should be reduced uniformly to 50 percent at a spacing equal to the diameter of the connectors, page 63 and table 5.

SIZE OF BOLT HOLE

The effect of an oversized bolt hole was determined for joints containing two 3⅝-inch toothed connectors and a ¾-inch bolt bearing parallel to the grain of southern yellow pine specimens. The bolt hole in half of the specimens was three-fourths and in the other half thirteen-sixteenths inch in diameter.

The results of the tests (table 25 and fig. 30) show that for given slips of less than 0.1 inch the loads for the joints with an oversized bolt hole were about 80 percent of those for joints with a bolt hole equal in diameter to the bolt. The loads at given slips greater than 0.15 inch were about the same for the two types of joints; but the slip associated with the maximum loads was slightly greater when the bolt was in an oversized hole.

TABLE 25.—*Effect of 1/16-inch oversized bolt hole on 3-member, toothed-connector joints, bearing parallel to grain, southern yellow pine*[1]

Item	¾-inch bolt hole (0.739 inch bolt)	13/16-inch bolt hole (0.735 inch bolt)
Properties of specimens:		
Moisture content ... percent	11.4	11.6
Specific gravity[2]	.537	.580
Maximum compressive strength parallel to grain, pounds per square inch	8,164	8,390
Result of tests:		
Load at slip of—		
0.02 inch ... pounds	8,007	6,490
0.04 inch ... do	12,250	9,650
0.08 inch ... do	16,900	13,750
First drop:		
Load ... do	19,400	20,450
Slip ... inches	0.18	0.19
Maximum:		
Load ... pounds	20,970	21,437
Slip ... inches	0.37	0.41

[1] Values are averages of 3 tests with 3⅜-inch connectors. Size of members (inches): Width 5; thickness, center 1⅝, sides 1 5/16.

[2] Based on the weight of oven-dry wood and the volume at time of test.

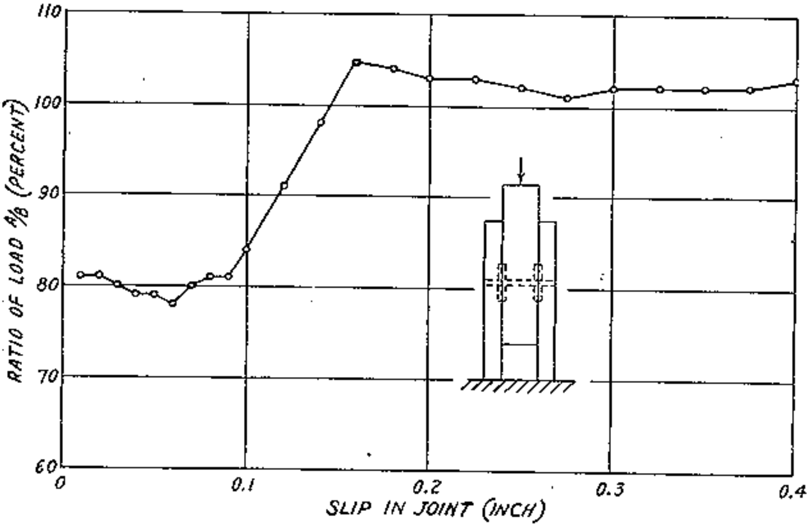

FIGURE 30.—Effect of size of bolt hole on the load at various slips; bolt hole for load A being one-sixteenth inch larger than bolt, and that for load B being exact size of bolt (3-member, toothed connector joints, using 3⅜-inch connectors and ¾-inch bolts, bearing parallel to the grain of air-dry southern yellow pine).

The matching of the material, as indicated by the control specimens, was not sufficiently close to provide specimens of the same quality for the two types of joints. The specimens with the oversized bolt hole were of slightly better intrinsic quality. This may account for the fact that at the larger slips for the joints the loads with the oversized bolt hole exceeded those with the actual-size bolt hole, rather than being the same or slightly lower.

MOISTURE CONDITION OF THE WOOD

Tests to determine the effect of variations in moisture content of the wood were made with 2⅝- and 4-inch toothed connectors and redwood specimens [13] of standard dimensions, in typical 3-member joints.

Some of the assemblies were of green material and some of dry. The latter were tested immediately after assembly. Those made of green material were divided into two groups, one of which was tested immediately after assembly and the other after the material had been seasoned to an air-dry condition. With each size of connector, the specimens were matched for the three conditions tested and for bearing parallel and perpendicular to the grain.

The results of the tests (table 26) show that the maximum loads for the connectors when bearing parallel to the grain of green material are from 70 to 75 percent of those obtained for the dry material tested. This is somewhat higher than the ratio of the maximum parallel compressive strength of the green and dry material. When the bearing is perpendicular to the grain, the loads obtained with green material more nearly approach those obtained with dry material.

The results for the joints that were made up green and allowed to season before test are not analogous with those tested green. The loads bearing parallel to the grain were approximately equal to those obtained with dry material, allowing for differences in moisture content at the time of test. Loads bearing perpendicular to the grain were somewhat lower than those obtained with green material.

NET SECTION OF MEMBER

The net section requirements for toothed connectors conform, in general, to those established for split-ring connectors (p. 73). The projected area used for the toothed connectors is equivalent to that for a cylinder extending to the points of the teeth. In the calculations for the net section, the connector is assumed to penetrate equally into the two adjacent members.

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[13] See footnote, p. 73.

TABLE 26.—*Effect of moisture condition of members on strength of 3-member, toothed connector joints, bearing either parallel or perpendicular to grain, redwood* [1]

LOADS ACTING PARALLEL TO GRAIN

Size of connector	Condition of specimens [2]		Dimensions of members			Properties of specimens when tested			Load at slip of—			First drop		Maximum	
	When assembled	When tested	Width	Thickness		Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain [4]	0.02 inch	0.04 inch	0.080 inch	Load	Slip	Load	Slip
				Center	Sides										
			Inches	*Inches*	*Inches*	*Percent*		*Pounds per square inch*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*	*Pounds*	*Inches*
2 ⅝-connector; ⅝-inch bolt [5]	Air-dry	Air-dry	3⅝	1⅝	1 1/16	7.6	0.407	7,000	4,750	6,950	9,910	11,810	0.23	12,480	0.34
	Green	do	3⅝	1⅝	1 1/16	11.1	.388	5,710	3,280	5,670	8,880	11,260	.30	11,260	.30
	do	Green	3⅝	1⅝	1 1/16	114.1	.397	4,142	3,320	4,850	6,700	8,820	.38	9,020	.51
4-inch connector; ¾-inch bolt [5]	Air-dry	Air-dry	5½	1⅝	1 1/16	7.8	.370	6,504	6,530	9,850	14,700	16,750	.14	18,540	.35
	Green	do	5½	1⅝	1 1/16	11.2	.368	5,782	5,470	9,080	12,330	13,900	.22	14,860	.42
	do	Green	5½	1⅝	1 1/16	98.8	.356	3,766	4,130	6,330	9,410	12,630	.30	13,050	.53
LOADS ACTING PERPENDICULAR TO GRAIN															
2⅝-inch connector; ⅝-inch bolt [5]	Air-dry	Air-dry	3⅝	1⅝	1 1/16	7.8	0.412	7,316	2,440	4,240	--------	5,750	0.07	5,750	0.07
	Green	do	3⅝	1⅝	1 1/16	11.0	.417	6,550	1,830	3,140	--------	4,400	.07	4,510	.09
	do	Green	3⅝	1⅝	1 1/16	114.6	.402	4,255	2,780	3,990	--------	4,840	.09	4,840	.09
4-inch connector; ¾-inch bolt [5]	Air-dry	Air-dry	5½	1⅝	1 1/16	8.0	.363	6,083	3,400	4,480	--------	7,690	.08	7,690	.08
	Green	do	5½	1⅝	1 1/16	11.3	.354	5,384	2,360	3,770	--------	5,730	.08	5,780	.08
	do	Green	5½	1⅝	1 1/16	110.5	.343	3,444	2,910	4,510	--------	7,150	.11	7,150	.11

[1] Values are averages of 3 tests.

[2] When the specimens were assembled and tested in the same condition, the tests were made immediately after assembly; all others were made 17 months after assembly.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] For loads acting perpendicular to the grain, the compressive strength is for side members only.

[5] The diameter of the bolt hole was the same as the nominal diameter of bolt.

FACTORS AFFECTING CLAW-PLATE CONNECTOR JOINTS

The claw-plate connectors are malleable iron[14] circular plates 2⅝, 3⅛, and 4 inches in diameter, having a hole in the center and a row of triangular teeth forming a toothed flange on one side. The other side is flat and has either an enlarged hole or a projecting hub at the center, so that, when used in pairs, this male and female unit affords a metal-to-metal bearing. The depth of the plate from the flat surface to the tip of the teeth is three-fourths inch for all diameters. In the type with the projecting hub, the hub is three-eighths inch deep. When used singly, the plate with a hub acts as a stress distributor between a wood member and a metal plate or strap. The plate portion of the connector and its toothed flange fit into a circular groove or dap cut into the timber, and the teeth are forced into the wood by pressure (using a maul, and follower or a press) so that the face opposite the teeth is flush with the surface of the timber.

The factors which affect the strength of joints using claw-plate connectors, as investigated, include (1) size of connector; (2) species of wood; (3) metal and wood side members; (4) direction of applied load with reference to the grain of the wood; (5) thickness of timber; (6) edge and (7) end margins; (8) size of bolt hole; and (9) moisture condition of timber. A summary of the results of this study is presented in the following discussion.

SPECIES OF WOOD

METAL SIDE MEMBERS BEARING PARALLEL TO GRAIN

Tests of joints using claw-plate connectors were made with eastern white pine, redwood, basswood, southern yellow pine, and white oak, which are representative species of hardwoods and softwoods having a wide range in density. Each test assembly consisted of a center wood member, two metal side plates, a bolt, and a male claw-plate connector at each plane of contact (fig. 31). The widths of center members used with the 2⅝-, 3⅛-, and 4-inch connectors were 4½, 5, and 5⅞ inches, respectively, and the thickness for all sizes was 4 inches.

For each species except redwood, the wood in the center member was matched for the three sizes of connectors. Redwood was used only with the 3⅛-inch connector. The tests were made in compression parallel to the grain, with ample end margins provided on the specimens to eliminate the effect of this variable.

The proportional limit load in most of the tests, particularly with the denser species, was not clearly defined (fig. 32).

In the lighter species, usually only one portion of the load-slip curve was a straight line, but in the denser woods the load-slip curves frequently contained two straight portions. When the curves exhibited more than one straight-line portion, the point of departure from the second straight line was recorded as the proportional limit.

The type of failure at maximum load varied considerably with the different species. In the lighter species the failure consisted primarily of crushing of the wood under the connector and bolt, accompanied by

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[14] The specifications for the connectors tested required that the castings conform to A. S. T. M. Standard Specifications A47–33, Grade 35018.

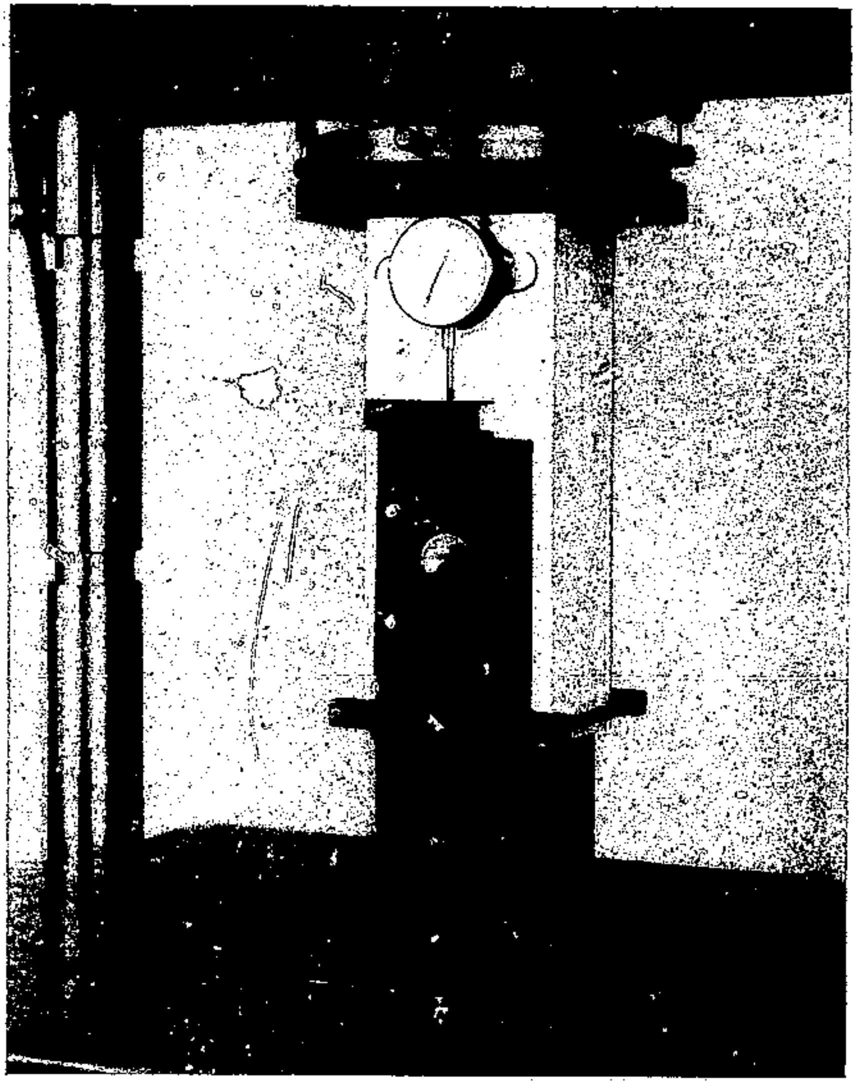

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FIGURE 31.—Method of conducting compression test of claw-plate connector joint with metal side plates; load applied parallel to the grain of the wood.

some splitting, crushing, and shear of the core. Small fractures in the metal at the hub were also evident in some of the connectors at a relatively large slip. In the denser species, crushing of the wood under the bolt and connectors was less severe, but the failure of the metal connector itself was more pronounced (fig. 33). Rupture or shear of the hubs was common, and in some tests buckling and fracture of the webs also took place. The slip of the joint at maximum load was usually less than in the lighter species.

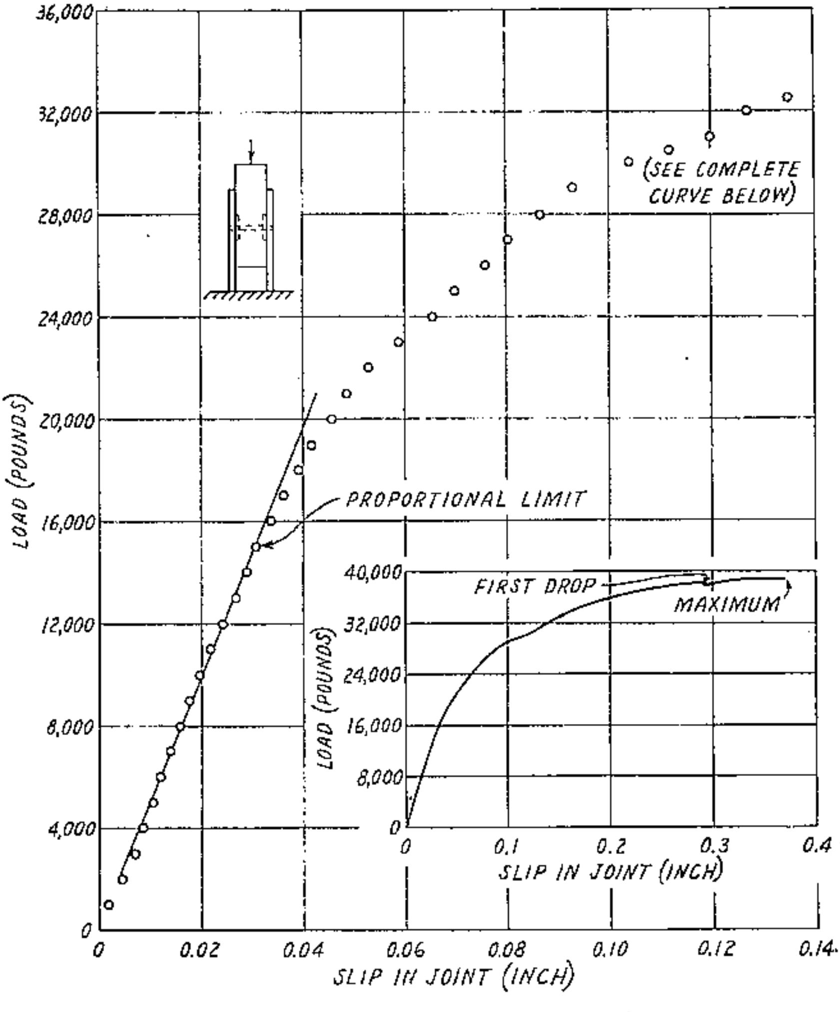

FIGURE 32.—Relation between load and slip in a claw-plate connector joint bearing parallel to the grain of air-dry wood; individual test specimen.

The results of the tests, with supplementary information, are given in table 27. In general, the load at proportional limit and the maximum load both increase directly with the specific gravity of the material until a density of wood is reached at which the strength of the joint is affected by failure of the metal connectors. When failure occurs in the connectors, the load for the joint obviously increases very little with a further increase in the specific gravity of the material (fig. 34). The ratios of maximum load to proportional limit load average about 2½ for the different sizes of connectors and species of wood.

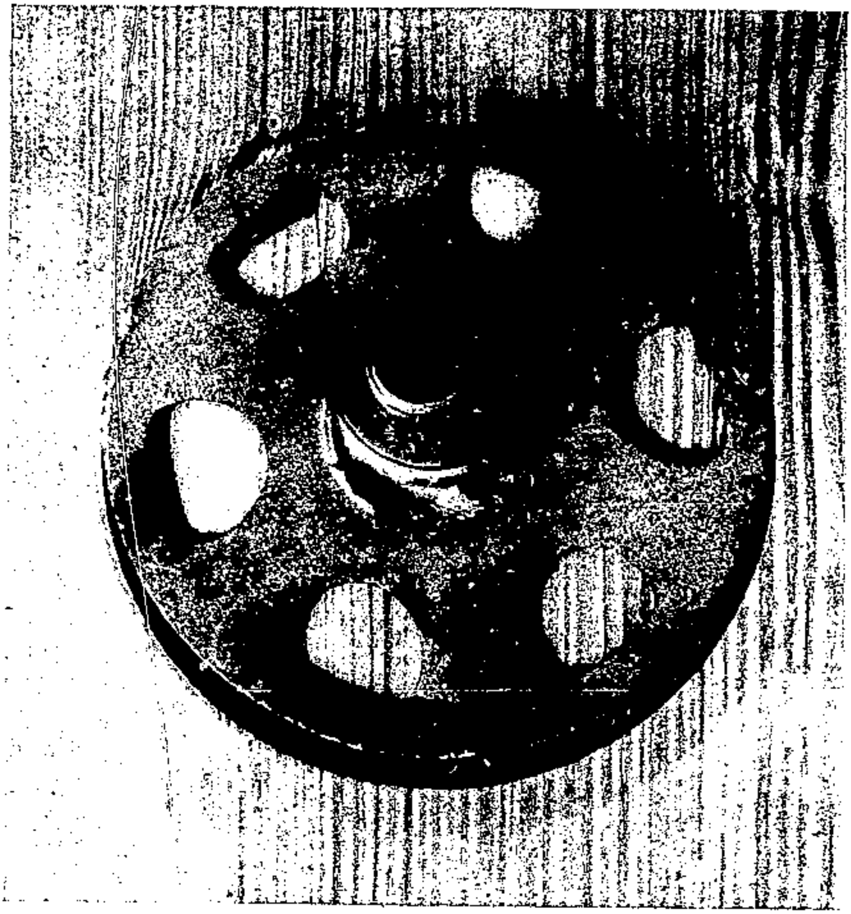
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FIGURE 33.—Failure of 4-inch claw-plate connector joint when bearing parallel to the grain of dense southern yellow pine.

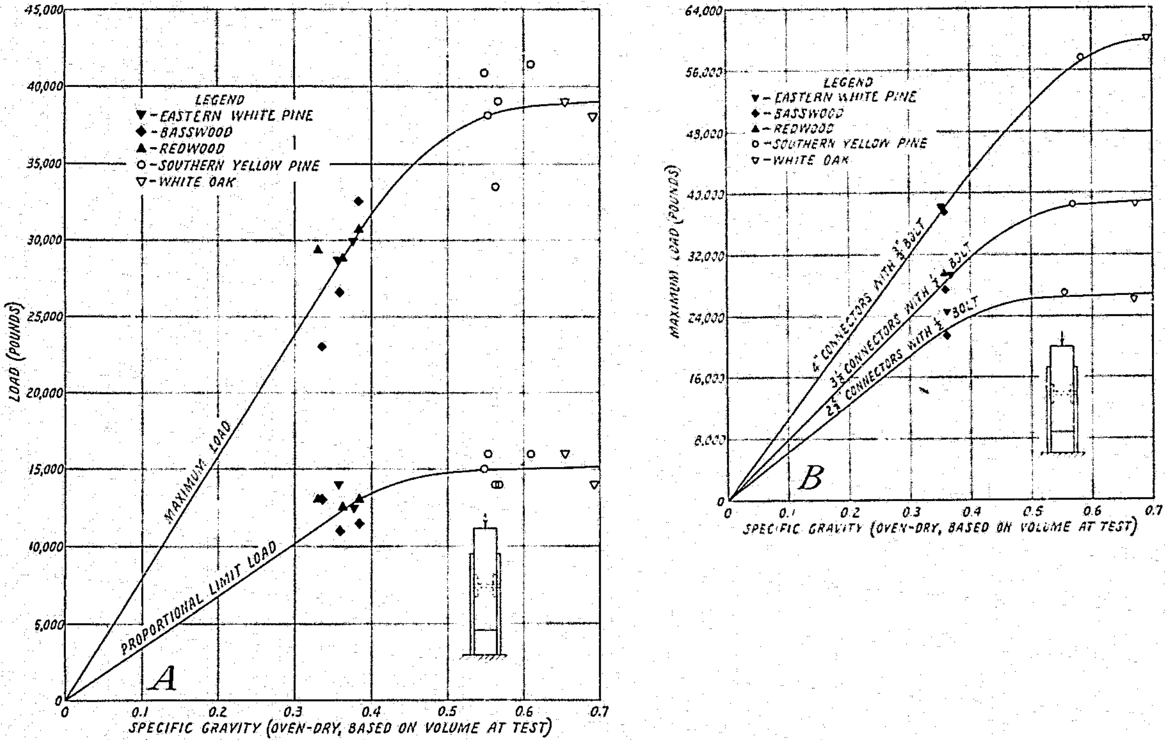

FIGURE 34.—*A*, Relation between load and specific gravity for a 3-member, claw-plate connector joint (3⅛-inch connector and ½-inch bolt); *B*, relation between maximum load and specific gravity for various connectors. Metal side plates and bearing parallel to grain of air-dry wood in both cases.

TABLE 27.—*Effect of wood species on strength of 3-member, claw-plate connector joints bearing either parallel or perpendicular to grain*[1]

LOADS ACTING PARALLEL TO GRAIN

Size of connector unit,[2] type of side plates, and species	Width of member [3]	Properties of specimens: Moisture content	Properties of specimens: Specific gravity [4]	Properties of specimens: Maximum compressive strength parallel to grain	Proportional limit: Load	Proportional limit: Slip	Load at 0.08-inch slip	First drop: Load	First drop: Slip	Maximim or load at 0.60-inch slip: Load	Maximim or load at 0.60-inch slip: Slip
	Inches	*Percent*		*Pound per square inch*	*Pounds*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*
2⅝-inch connectors; ½-inch bolt:											
Metal plates:											
White pine [5]	4½	9.4	0.362	5,660	9,500	0.042	16,450	24,435	0.48	24,610	0.55
Basswood [6]		9.0	.361	5,311	9,500	.055	13,050	20,610	.42	21,440	.57
Southern yellow pine		10.2	.555	9,124	11,000	.029	21,260	26,245	.25	27,175	.30
White oak [5]		8.4	.669	8,340	11,250	.038	21,200	25,980	.15	26,080	.17
Wood plates: Southern yellow pine	4½	10.2	.562	9,210	11,000	.039	18,220	27,925	.60	27,925	.60
3⅛-inch connectors; ½-inch bolt:											
Metal plates:											
White pine [5]	5	9.8	.368	5,620	13,250	.032	22,550	26,300	.15	29,300	.50
Basswood [6]		9.1	.360	5,399	11,830	.043	19,030	24,150	.17	27,380	.56
Redwood [6]		7.5	.359	5,529	12,830	.050	17,930	29,620	.60	29,620	.60
Southern yellow pine		10.1	.568	8,649	15,000	.028	27,670	37,720	.20	38,620	.36
White oak [5]		8.5	.672	8,474	15,000	.021	30,200	38,590	.25	38,590	.25
4-inch connectors; ¾-inch bolt:											
Metal plates:											
White pine [5]	5⅞	9.1	.351	5,217	16,000	.052	23,900	38,200	.32	38,200	.32
Basswood [6]		9.1	.357	5,192	15,730	.055	21,900	37,430	.26	37,500	.28
Southern yellow pine		10.3	.584	9,083	23,400	.041	35,500	57,560	.45	57,600	.47
White oak [5]		8.2	.692	9,025	23,000	.048	32,500	59,475	.36	60,025	.42
Wood plates: Southern yellow pine	5⅞	10.0	.554	9,010	20,670	.059	23,140	51,250	.60	51,250	.60

LOADS ACTING PERPENDICULAR TO GRAIN

Size of connector unit,[2] type of side plates, and species	Width of member [3]	Properties of specimens: Moisture content	Properties of specimens: Specific gravity [4]	Properties of specimens: Maximum compressive strength parallel to grain	Proportional limit: Load	Proportional limit: Slip	Load at 0.08-inch slip	First drop: Load	First drop: Slip	Maximim or load at 0.60-inch slip: Load	Maximim or load at 0.60-inch slip: Slip
2⅝-inch connectors; ½-inch bolt:											
Metal plates: Southern yellow pine	4½	10.7	0.526	----------	9,200	0.033	15,210	17,545	0.16	18,020	0.19
Wood plates: Southern yellow pine		10.8	.550	----------	9,200	.048	12,610	16,330	.21	16,545	.23
3⅛-inch connectors; ½-inch bolt:											
Metal plates:											
Redwood [6]	5	8.0	.329	----------	6,530	.030	10,860	11,440	.11	11,670	.13
Southern yellow pine		10.9	.542	----------	10,700	.025	20,530	22,255	.14	22,255	.14
4-inch connectors; ¾-inch bolt:											
Metal plates: Southern yellow pine	5⅞	10.3	.548	----------	12,600	.037	21,200	24,050	.12	24,050	.12
Wood plates: Southern yellow pine		10.2	.546	----------	12,600	.042	18,820	24,055	.16	24,055	.16

[1] Values are averages of 5 tests, except as noted.

[2] The diameter of the bolt hole was 1/16 inch larger than the nominal diameter of bolt.

[3] Width of center member, which was 4 inches thick in all cases. Metal side plates were ½ inch in thickness and wood side plates 2 inches.

[4] Based on the weight of oven-dry wood and the volume at time of test.

[5] 2 tests.

[6] 3 tests.

WOOD SIDE MEMBERS BEARING PARALLEL TO GRAIN

The tests in which the claw-plate connectors were used in pairs with wood side plates were made with southern yellow pine specimens, using 2⅝- and 4-inch connectors (table 27). For the 2⅝-inch connectors the load at the proportional limit and the maximum load are about the same as those obtained in comparable tests with metal side plates, but for the 4-inch connectors with wood side plates they are about 10 percent lower. The type of failure, however, indicates that this difference is evident only in the denser species, where the strength of the connectors is the controlling factor. In the lighter species, where wood strength controls, the load at proportional limit and the maximum load would correspond more closely to those obtained with metal side plates. The slip of the joint is somewhat greater at a given load with wood than with metal side plates.

In developing safe working loads for wood side members, the same values were used as for metal side plates, with one exception: When the bearing is parallel to the grain of the wood, the loads for the 3⅛- and 4-inch claw-plate connectors used with group 2 woods are taken as 5 percent less than those for a joint with metal side members; with group 3 woods, 10 percent less; and with group 4 woods, 10 and 15 percent less, respectively.

DIRECTION OF GRAIN OF WOOD

BEARING PERPENDICULAR TO GRAIN

The tests of claw-plate connectors bearing perpendicular to the grain of the wood were made with 2⅝- and 4-inch connectors for southern yellow pine, using both metal and wood side plates, and with 3⅛-inch connectors, with metal side plates, for southern yellow pine and redwood specimens (table 27). The material was comparable in quality and of the same dimensions as that used with corresponding tests made parallel to the grain.

For comparable tests, the proportional limit and the maximum load are approximately the same for both metal and wood side plates. The slip of the joint for a given load, however, is greater with the wood than with the metal side plates. The failure at the maximum load usually consisted of splitting of the center member, accompanied in some joints by a slight fracture of the connector at the hub.

For metal side plates, the ratio of the load for connectors bearing perpendicular to the grain to that for connectors bearing parallel to the grain varied with the size of connector and averaged 78, 64, and 57 percent, respectively, for the 2⅝-, 3⅛-, and 4-inch connectors at the proportional limit and at given slips of the joint. These percentages are applicable for size of members tested and will be greater for wider members, as is subsequently shown (p. 100). In determining the safe loads for bearing perpendicular to the grain, consideration is given to the effect of width of member and to the failure of the wood, which is more pronounced than in the parallel-to-grain arrangement (table 3).

BEARING AT VARIOUS ANGLES TO GRAIN

The loads for claw-plate connectors bearing at an inclination to the grain are dependent on the loads parallel and perpendicular to the grain as well as on the degree of the angle (*5*). Tests made with the

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Siemens-Bauunion connectors (7), which are similar in design and which function approximately as do the claw-plate connectors used in this investigation, have demonstrated that the loads at various angles to the grain may be obtained by the formula

$$n=\frac{pq}{p\sin^2\theta+q\cos^2\theta}$$

in which

n=the load in a direction at inclination θ with the direction of the grain.
p=the load parallel to the grain.
q=the load perpendicular to the grain.

The ratio between the load perpendicular to the grain and that parallel to the grain is, however, not of sufficient magnitude to cause appreciable difference in the results when using a lineal relationship in lieu of the formula. For convenience, therefore, it is suggested that the loads for intervening angles be obtained by direct interpolation between the values at 0° and 90° with the grain.

THICKNESS OF MEMBER

The tests to determine the strength of claw-plate connector joints with different thicknesses of member were made with the 3⅛-inch connector in southern yellow pine specimens. The joints, which consisted of a center wood member, two metal side plates, two male connectors, and a bolt, were tested in tension parallel to the grain. The center wood members were 5 inches in width and ranged from 1¾ to 5⅝ inches in thickness. The specimens for each of the two series tested were taken from the same plank.

The results of the tension tests given in table 28 and figure 35 are erratic. In general, the averages for the various thicknesses tested showed no consistent difference. Previous tests have shown that the strength of a claw-plate connector joint with a relatively strong, dense species such as southern yellow pine is limited by the strength of the connector.

TABLE 28.—*Effect of thickness of members on strength of 3-member, claw-plate connector joints bearing in tension parallel to grain, southern yellow pine*[1]

[Connector, 3⅛ inch; bolt, ½ inch [2]; center member, 5 inches wide [3]]

Thickness of center member [3]	Proportional limit		Load at 0.08-inch slip	First drop		Maximum	
	Load	Slip		Load	Slip	Load	Slip
	Pounds	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*
1¾	11,000	0.020	23,700	29,880	0.15	30,170	0.19
2	11,750	.026	23,150	29,410	.23	29,440	.28
2½	11,750	.024	23,850	29,190	.18	30,960	.42
3	11,500	.037	19,150	28,080	.24	29,595	.49
3½	12,000	.029	21,050	31,850	.44	31,850	.44
4	11,750	.030	20,150	31,985	.54	31,985	.54
5	12,000	.028	21,600	28,310	.33	29,935	.54
5⅝	12,250	.026	22,950	29,795	.23	30,725	.47

[1] Values are averages of 2 tests. All specimens had moisture content of 12.3 percent; 0.556 specific gravity, based on the weight of oven-dry wood and the volume at time of test; and 7,804 pounds per square inch maximum compressive strength parallel to grain.

[2] The diameter of the bolt hole was 1/16 inch larger than the nominal diameter of bolt.

[3] Side members were ½-inch metal plates.

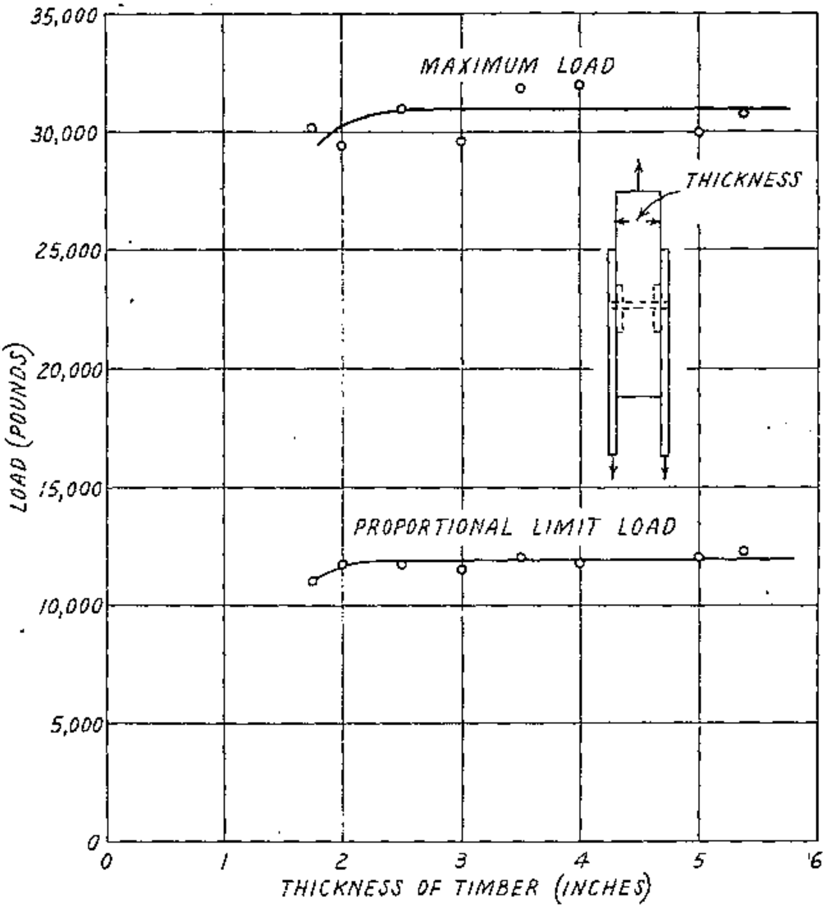

FIGURE 35.—Relation between load and thickness of timber for a claw-plate connector joint with metal side plates, bearing parallel to the grain of air-dry southern yellow pine in tension joints (3⅛-inch connectors and a ½-inch bolt).

EDGE MARGIN

BEARING PERPENDICULAR TO GRAIN

Tests of the influence of edge margin on the strength of claw-plate connector joints were made with the 2⅝- and 4-inch connectors in southern yellow pine specimens. The joints consisted of a center wood member attached to metal side members with two male connectors and a bolt. The wood member was 4 inches in thickness for all tests, 4½ inches wide for the 2⅝-inch connector, and 5⅞ inches wide for the 4-inch connector. The specimens were matched end to end for the different edge margins tested with each size of connector.

The edge margin, measured from the center of the connector to the edge of the timber toward which the load was acting, was varied by small increments from 1⁵⁄₁₆ inches (rim of connector flush with outside edge of timber) to 3³⁄₁₆ inches (connector flush with the opposite edge of timber) with the 2⅝-inch connector, and similarly from 2 to 3⅞ inches with the 4-inch connector.

The results (table 29 and figure 36) show that, within the limits of the tests, the load increases uniformly with an increase in edge margin. The average increase in load for the two sizes of connectors at the proportional limit, at maximum, and at given slips of the joint is approximately 20 percent for each 1-inch increase in edge margin.

TABLE 29.—*Effect of edge margin on strength of 3-member, claw-plate connector joints, bearing perpendicular to grain, southern yellow pine* [1]

2⅝-INCH CONNECTORS; ½-INCH BOLT [2]

[Member dimensions (inches): Width, 4½; thickness, 4 [3]]

Edge [4] margin (inches)	Properties of specimens		Proportional limit		Load at 0.08-inch slip	Maximum [6]	
	Moisture content	Specific gravity [5]	Load	Slip		Load	Slip
	Percent		*Pounds*	*Inch*	*Pounds*	*Pounds*	*Inch*
1³⁄₁₆	13.2	0.509	6,270	0.044	9,480	11,280	0.18
1¹¹⁄₁₆	12.9	.514	6,670	.037	10,850	12,250	.17
2³⁄₁₆	13.0	.516	7,730	.038	12,350	15,190	.21
2¹¹⁄₁₆	12.8	.507	8,130	.038	13,070	17,370	.32
3³⁄₁₆	13.1	.488	8,130	.038	12,620	17,880	.40

4-INCH CONNECTORS; ¾-INCH BOLT [2]

[Member dimensions (inches): Width, 5½; thickness, 4 [3]]

Edge [4] margin (inches)	Moisture content	Specific gravity [5]	Proportional limit load	Proportional limit slip	Load at 0.08-inch slip	Maximum load [6]	Maximum slip [6]
2	13.5	0.570	9,000	0.042	14,390	20,330	0.17
2⅜	13.7	.554	9,670	.039	16,475	21,430	.15
2⅞	13.6	.532	11,170	.045	17,830	24,570	.17
3⅜	14.0	.528	11,000	.034	19,830	27,980	.19
3⅞	13.4	.532	12,330	.037	21,500	31,230	.23

[1] Values are averages of 3 tests.
[2] The diameter of the bolt hole was 1/16 inch larger than the nominal diameter of bolt.
[3] Dimensions of center timber. Side members were ½-inch metal plates.
[4] Distance from edge of timber toward which load is acting to center of bolt hole.
[5] Based on the weight of oven-dry wood and the volume at time of test.
[6] The load and slip at first drop were approximately the same as that at the maximum.

The minimum widths of members recommended for use with the 2⅝-, 3⅛-, and 4-inch claw-plate connectors bearing perpendicular to grain are 3⅝, 4⅝, and 5½ inches, respectively. The connectors should be centered in such members, the minimum edge margins in either direction then being half these widths. Increasing this edge margin in the direction toward which the load is acting increases the load at the rate of 20 percent per inch up to an edge margin equal to the diameter of the connector; or, if the connector is centered in the member, at the rate of 10 percent per inch increase in width of the member over the minimum, up to a width equal to twice the diameter of the connector.

BEARING PARALLEL TO GRAIN

When bearing parallel to the grain, the minimum widths of member which should be used with the above claw-plate connectors are the same as for perpendicular bearing, but, as with the split-ring connectors, no increase in load accompanies an increase in width over these minimums (p. 54). For intermediate angles the load for various edge margins or widths of member is a function of the load for comparable edge margins or widths of member parallel and perpendicular to the grain (table 3).

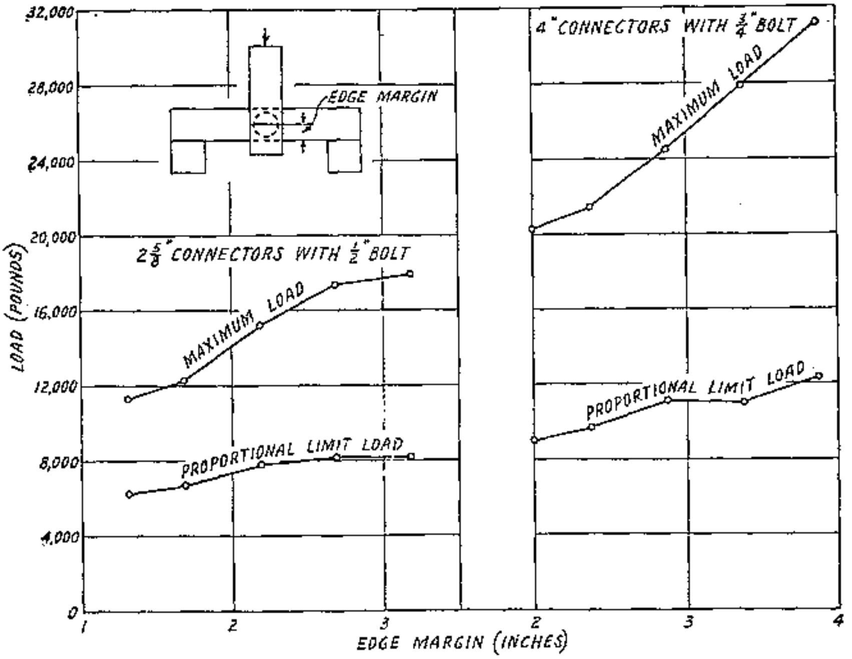

FIGURE 36.—Relation between load and edge margin for 3-member, claw-plate connector joints with metal side plates bearing perpendicular to the grain of air-dry southern yellow pine.

END MARGIN

BEARING PARALLEL TO GRAIN

The behavior of 3⅛-inch claw-plate connectors bearing parallel to the grain and placed at distances from the end of the member varying by 1-inch increments from 1 9/16 to 7 9/16 inches was investigated in southern yellow pine specimens. The joints, consisting of a center wood member, two metal side plates, two connectors, and a bolt, were tested in tension. The wood members were 5 inches wide and 4 inches thick and were matched end to end for the seven different end margins tested.

The proportional limit load was found to increase with an increase in end margin from the smallest tested to a constant value at margins of more than 4½ inches (table 30 and fig. 37). The maximum load also increased but was somewhat erratic with the larger end margins and did not reach a definite constant value within the limits of the test. With the smaller end margins, the failure consisted primarily of shear and splitting of the member; but, as the end margin increased, the failure in the wood members was less apparent and that of the metal connectors more pronounced.

Analyses of the stresses in the joint and comparison of the failures and load with those obtained with other tests on connectors indicate that the end margins required to sustain the full load in tension are approximately equal to the diameter of the connector plus 3 inches. The minimum end margins should not be less than one-half of the

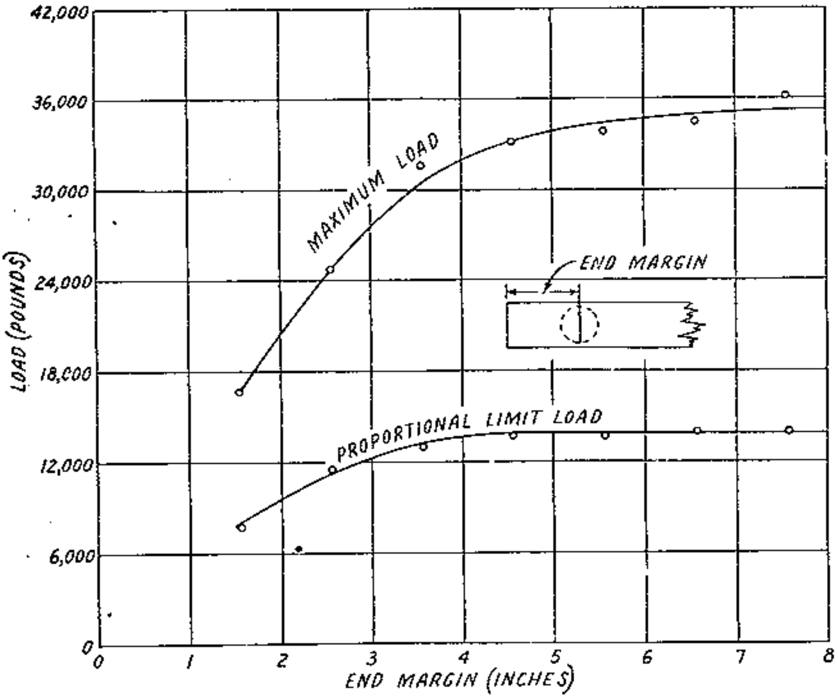

FIGURE 37.—Relation between load and end margin for a three-member, claw-plate connector joint, with metal side plates, bearing in tension parallel to the grain of air-dry southern yellow pine (3⅛-inch connectors and ½-inch bolt).

optimum margins, and the load at these minimum end margins is five-eighths of that at the optimum. For intervening margins the load may be obtained by direct interpolation.

In compression the end margins can be somewhat less than in tension, as shown in table 6, but at no time should the end margin be less than half the diameter of the connector plus 1½ inches.

TABLE 30.—*Effect of end margin on strength of 3-member, claw-plate connector joints, bearing parallel to grain, southern yellow pine* [1]

[3⅛-inch connectors; ½-inch bolt; bolt hole 9/16 inch. Center members 5 inches wide, 4 inches thick; side members, ¼-inch metal plates]

End margin [2] (inches)	Properties of specimens			Proportional limit			Maximum [4]	
	Moisture content	Specific [3] gravity	Maximum compressive strength parallel to grain	Load	Slip	Load at 0.08-inch slip	Load	Slip
	Percent		*Pounds per square inch*	*Pounds*	*Inch*	*Pounds*	*Pounds*	*Inch*
$1\frac{9}{16}$	11.9	0.557	7,784	7,750	0.026	15,225	16,720	0.40
$2\frac{9}{16}$	11.9	.557	7,784	11,500	.025	22,075	24,850	.13
$3\frac{9}{16}$	11.9	.557	7,784	13,000	.034	23,550	31,620	.16
$4\frac{9}{16}$	11.9	.557	7,784	13,750	.030	24,000	33,240	.19
$5\frac{9}{16}$	11.9	.557	7,784	13,750	.028	23,950	33,950	.32
$6\frac{9}{16}$	11.9	.557	7,784	14,000	.030	24,950	34,500	.33
$7\frac{9}{16}$	11.9	.557	7,784	14,000	.025	26,050	36,285	.47

[1] Values are averages of 2 tests.

[2] Distance from end of timber to center of bolt hole.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] The load and slip at first drop were approximately the same as that at the maximum.

SPACING OF MULTIPLE CONNECTORS (BEARING PARALLEL TO GRAIN)

The determination of the effect of the spacing of claw-plate connectors along the length of a member when bearing parallel to the grain was not included in this investigation. It may be observed, however, that the stresses induced in the member by the claw-plate connectors conform closely to those for the split-ring connectors, and the spacing requirements would therefore be expected to be somewhat similar.

These requirements are that the optimum center-to-center spacing between connectors should be at least 3 inches, plus 1½ times the diameter of the connectors. When the spacing is less than this, the load is also less, dropping off uniformly to 50 percent at a spacing equal to the diameter plus three-eighths inch for the 2⅝- and 3⅛-inch connectors, or one-half inch for the 4-inch connector (p. 63 and table 6).

For other details pertaining to the placement of claw-plate connectors in multiple joints, it is suggested that for equivalent loads and sizes of connectors the recommendations established for split-ring connectors be used.

SIZE OF BOLT HOLE

The diameter of the bolt hole in all tests made with the claw-plate connectors was one-sixteenth inch larger than that of the accompanying bolt. Tests to determine the effect of an oversized bolt hole on the strength of the joint were made with the 3⅛-inch claw-plate and a ½-inch bolt bearing parallel to the grain of southern yellow pine specimens. The bolt-hole diameter in half of the six specimens tested was one-half inch; and in the other half, nine-sixteenths inch.

The results of the tests are given in table 31, and the ratio between the loads at various slips for the joints with ⁹⁄₁₆- and ½-inch bolt holes are shown graphically in figure 38. It may be observed from the results that the difference in load between the two types of joints is not great. The greatest difference occurs at 0.02-inch slip, where the

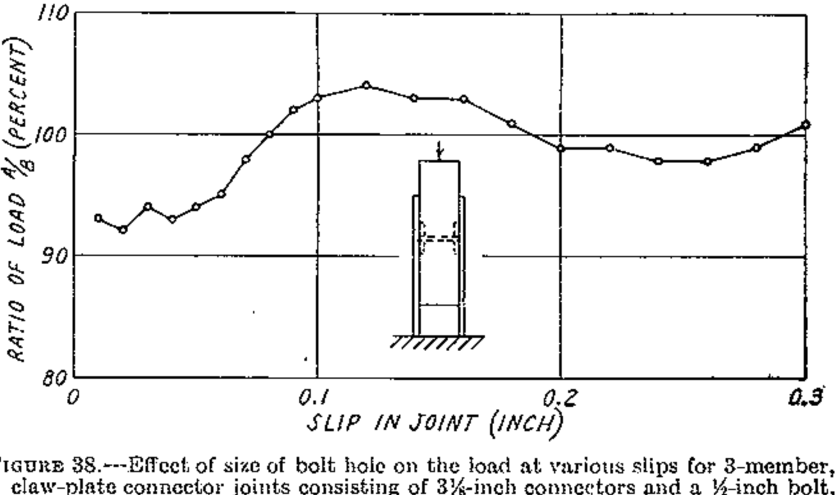

FIGURE 38.—Effect of size of bolt hole on the load at various slips for 3-member, claw-plate connector joints consisting of 3⅛-inch connectors and a ½-inch bolt, metal side plates, bearing parallel to the grain of air-dry southern yellow pine. Joint *A*, bolt hole ¹⁄₁₆-inch larger than bolt; joint *B*, bolt hole exact size of bolt.

load for the joint with an oversized bolt hole is 92 percent of the load for a joint with a bolt hole equal in size to the bolt. The maximum loads for the two types of joints are very nearly equal, although the slip at maximum load is somewhat greater when the oversized bolt hole is used.

TABLE 31.—*Effect of 1/16-inch oversized bolt hole on strength of 3-member, claw-plate connector joints, bearing parallel to grain, southern yellow pine* [1]

Item	½-inch bolt hole (0.492 inch bolt)	9/16-inch bolt hole (0.488 inch bolt)
Properties of specimens:		
Moisture content .... percent..	12.1	11.9
Specific gravity [2]	.540	.513
Maximum compressive strength parallel to grain ..pounds per square inch..	7,511	8,131
Results of tests:		
Proportional limit:		
Load .... pounds..	12,670	12,670
Slip .... inches..	0.026	0.028
Load at 0.08 inch slip .... pounds..	24,730	24,620
Maximum:		
Load .... do....	33,990	34,210
Slip .... inches..	0.40	0.51

[1] Values are averages of 3 tests of 3⅛-inch connectors. Size of center members (inches): Width, 5; thickness, 4. Side members were ½-inch metal plates.

[2] Based on the weight of oven-dry wood and the volume at time of test.

The ratio between the slip of the joints with and without an oversized bolt hole is about 110 percent at loads from 4,000 to 9,000 pounds, but the magnitude of the difference in slip is small.

MOISTURE CONDITION OF THE WOOD

Tests to provide information on the strength of claw-plate connector joints as affected by the moisture condition of the material were made with the 3⅛-inch connectors in redwood specimens.[15] Each joint consisted of a center wood member and two steel side plates. The tests were made parallel and perpendicular to the grain of matched green and dry specimens.

The joints made of dry material were tested immediately after assembly. Those made of green material were divided into two groups, one of which was tested immediately after assembly and the other after the material had been seasoned to an air-dry condition.

The results of the tests given in table 32 show that for redwood there is no appreciable difference in loads for the different conditions tested. The shrinkage and the ratio between the strength properties of green and dry redwood are less, however, than for most other structural species, and the results may, therefore, be somewhat different for other woods.

NET SECTION OF MEMBER

The net section requirements for the claw-plate connectors conform, in general, to those established for split-ring connectors (p. 73). The projected area used for the claw-plate connectors is equivalent to that for a cylinder extending to the points of the teeth.

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[15] See footnote, p. 73.

TABLE 32.—*Effect of moisture condition of members on strength of 3-member, claw-plate connector joints, bearing either parallel or perpendicular to grain, redwood* [1]

LOADS ACTING PARALLEL TO GRAIN

Size of connector	Condition [2] of specimens		Dimensions of specimens		Properties of specimens when tested			Proportional limit		Load at 0.08-inch slip	First drop		Maximum or load at 0.60-inch slip	
	When assembled	When tested	Width	Thickness	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	Load	Slip		Load	Slip	Load	Slip
			Inches	*Inches*	*Percent*		*Pounds per square inch*	*Pounds*	*Inch*	*Pounds*	*Pounds*	*Inch*	*Pounds*	*Inch*
3⅛-inch connector; ½-inch bolt [4]	Air-dry	Air-dry	5	4	7.5	0.359	5,529	12,670	0.049	17,930	29,620	0.60	29,620	0.60
	Green	do	5	4	11.6	.355	4,770	10,830	.032	19,070	26,670	.32	28,930	.60
	do	Green	5	4	139.2	.355	3,647	12,170	.039	18,370	24,830	.44	26,470	.60

LOADS ACTING PERPENDICULAR TO GRAIN

Size of connector	When assembled	When tested	Width	Thickness	Moisture content	Specific gravity [3]	Maximum compressive strength parallel to grain	Load	Slip	Load at 0.08-inch slip	First drop Load	First drop Slip	Maximum Load	Maximum Slip
3⅛-inch connector; ½-inch bolt [4]	Air-dry	Air-dry	5	4	8.0	0.329	----------	6,530	0.030	10,860	11,440	0.11	11,670	0.13
	Green	do	5	4	11.8	.358	----------	6,530	.030	10,890	11,640	.11	11,640	.11
	do	Green	5	4	152.0	.344	----------	6,000	.030	10,030	11,720	.14	11,720	.14

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[1] Values are averages of 3 tests.

[2] When the specimens were assembled and tested in the same condition the tests were made immediately after assembly; all others were made 17 months after assembly. Center timbers were 5 inches wide and 4 inches thick; side members were ½-inch metal plates.

[3] Based on the weight of oven-dry wood and the volume at time of test.

[4] The diameter of the bolt hole was 1/16 inch larger than the nominal diameter of bolt.

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