Modern Timber Connectors

for

Modern Timber Structures

by

Wm. V. Raser

A Thesis

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CONTENTS

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Bibliography; 18 pages; 8 illustrations.

Introduction

The oldest mechanical devices used for shear con-
nections in timber were wooden pins or dowels, succeeded by
nails and bolts. The major distinction is that nails are
inserted with considerable force and rely on friction for
proper action, whereas bolts are installed more or less
loosely into prebored holes, with friction playing no im-
portant part. Therefore, screws and drift bolts, which de-
pend on friction, fall into the same classification as nails.

The function of nails, screws, and drift bolts is
the same as that of rivets in steel construction; however,
they have a disadvantage in that their ratio of slenderness
is very high. For instance, whereas a 3/4" diameter rivet
is associated with an average plate thickness of 3/8", a 7/16"
diameter drift bolt may be used for a timber 3 and 1/2" in
thickness. In other words, while the ratio of plate thick-
ness to rivet diameter is of an average magnitude of 1/2,
the equivalent value for timbers and drift bolts may be 8.
For nails it may be as much as 12. This means that nails
and drift bolts are subject not only to shear but also to
bending, which causes a non-uniform bearing pressure.

This condition together with the effects of shrink-
age and checking has defied any pure theoretical attack, and
all safe-working loads have therefore been established by a
large number of tests, and the recommended safe values are
based on the proportional-limit load of the connection and
an appropriate safety factor. (1)

Factors Limiting the Efficiency of Bolts

Nails are ordinarily not accepted in this country for primary load-carrying connections. They are distrusted because the art of using them safely is little known and not well established in practice.

Of all connective devices for timbers, bolts have had the widest appeal. As a rule they are inserted into holes 1/16" larger than their own diameters. This increases the natural initial yield of timber structures by about 1/32" for every connection, and therefore a structure with a large number of bolted connections has a greater unelastic deflection than a nailed or drift-bolted structure. For this reason the timber designer always provides his bolted structures with ample cambers and limits the number of joints and splices to a minimum.

As mentioned before, nails, screws, and drift-bolts are stressed not only by shear but also in bending. This is true again for bolts. It will be observed from fig. 1 that because flexure is present the actual bearing is distributed over a comparatively small part of the length of the bolt, and even within this part the full bearing strength of the timber is utilized only at one point. Evidently the bolt would not carry more, even if the timbers were thicker. In fact its diameter D is already too small compared to the thickness of the center timber L. The ratio L/D in this case happens to be 14, whereas the bearing capacity of the bolt would be exhausted at a ratio of 6 or 7. In other words, in

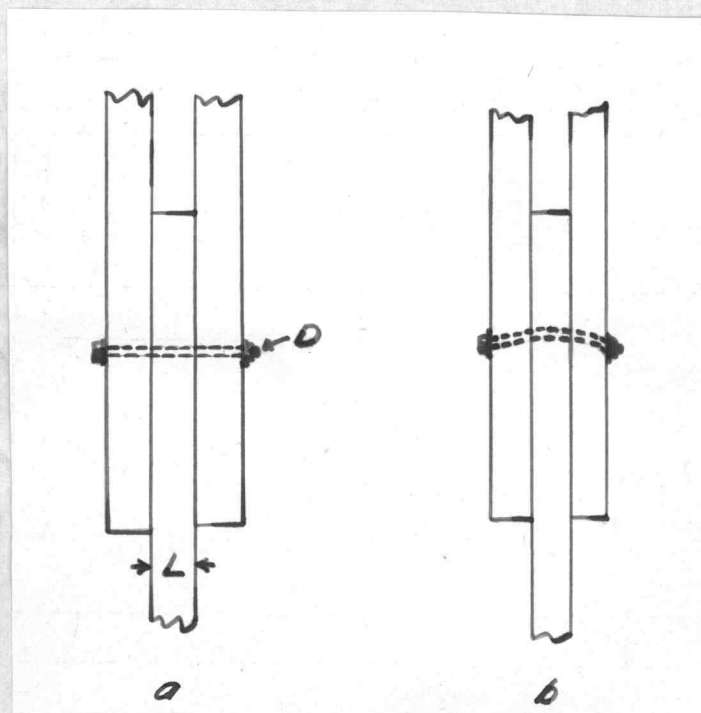Single Bolt

Bearing Parallel to Grain

Fig. 1- Bolt in "a" has taken
on maximum load without show-
any sign of deformation. Bolt
in "b" has taken on more than
its maximum load and shows
definite sign of deformation.

bearing parallel with the grain, a 1" bolt reaches its max-
imum safe load in a 6" timber and cannot be credited with
more load in an 8 or 10" timber. For the same reason the
strength of a 3/16" nail will be fully exploited in a plank
thickness L of seven times this diameter D, or 1 and 5/16".
Inasmuch as nails--to avoid splitting of the timber--must
never have an L/D ratio of less than 7, they are rated at
their maximum load. Bolts, on the other hand, should pref-
erably be designed with a bearing length smaller than the
critical one, and their safe load will therefore vary with
the L/D ratio.

The same situation prevails in bearing perpendic-
ular to the fiber of the timbers with the exception that an
increase of L/D beyond 8 actually decreases the proportional
limit load of the connective device (though only slightly).
In other words, the safe load of a 1" bolt is somewhat high-
er in an 8" timber than in a 10" timber. There is also this
difference, that the proportional limit of the bearing stress
across grain increases as D decreases. For instance the safe
load of a 5/8" bolt in a 2 and 1/2" timber is 1500 lb. par-
allel to the fiber, but only 650 lb. perpendicular to it,
while for a 5/16" bolt it is in both cases 415 lb. Four 5/16"
bolts weigh the same as one 5/8" bolt, but they will carry in
any direction 1660 lb. This explains the relative efficiency
of nails and drift bolts within their limitations. It demon-
strates, on the other hand why, beyond these limitations, the
timber designer was handicapped by want of connective devices
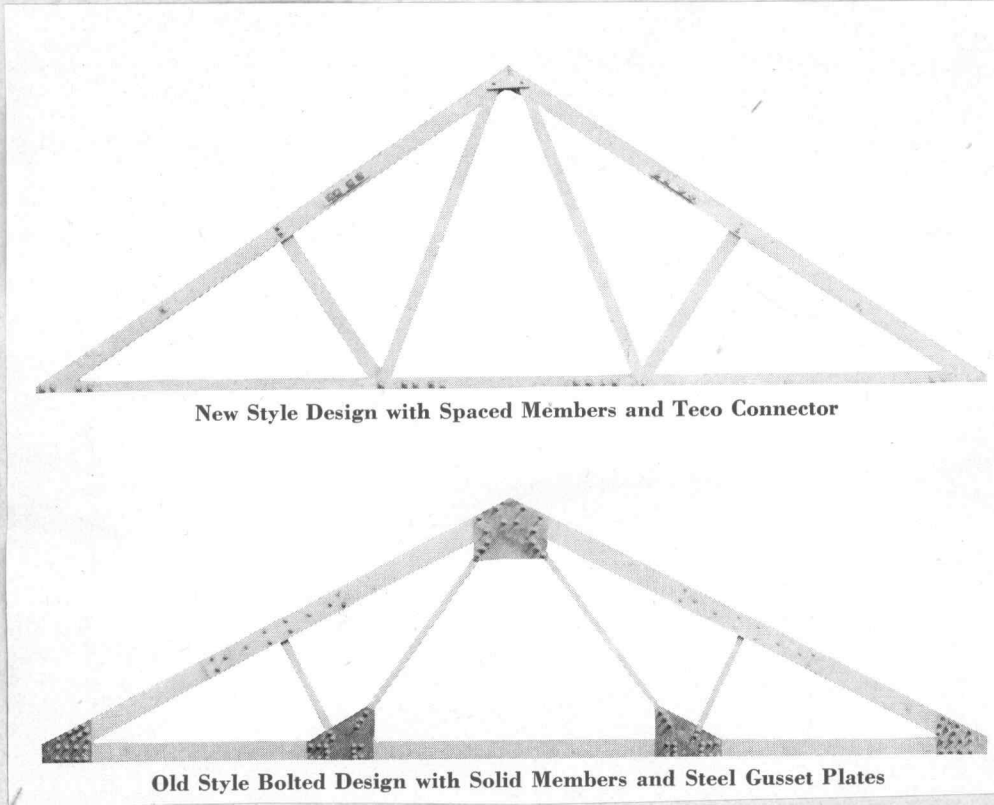
more efficient than bolts. (1)

Modern Timber Connectors

Modern methods in timber designing are the result of devices known as timber connectors which carry the loads in timber joints or in the joints of wood and metal. Timber connectors distribute the load over a larger area in a joint than do bolts alone, thereby making it feasible to pick up the loads in the members up to 100% of their capacity. Such a high percentage of load transfer heretofore with bolts alone has been either difficult or impossible.

Timber connectors profitably employ smaller structural sizes of lumber (Fig. 2), as well as increase the efficient use of larger sizes. In addition they also eliminate much of the complicated framing which accompanies the customary type of heavy timber structure. The combined advantages of this type of construction have resulted in timber designs which are practical and economical, as well as designs which previously have been thought of only in steel.

Four standard types of timber connectors in common use are (1) split ring, (2) toothed ring, (3) spiked grid connectors, used for transmitting load between timbers, and (4) shear plates, used for transmitting load from wood to metal (Fig. 3). The split ring connector requires a groove to be cut in the overlapped faces of the timbers to receive the ring; toothed rings and spiked grids are embedded into joint members by means of high-strength rods or

New Style Design with Spaced Members and Teco Connector

Old Style Bolted Design with Solid Members and Steel Gusset Plates

Designed for a 45-lb. Loading and a 16-ft. Spacing Built of No. 1 Structural Material

Old Design		New TECO Design
Bolted Design with Solid Members		Connector Design with Spaced Members

Old Design		New TECO Design #223
1–4″x6″x10′	Vertical	1–3″x8″x18′
1–4″x6″x12′	Diagonal	4–2″x6″x18′
	Splices	{ 2–2″x6″x14′
2–3″x12″x14′		{ 1–3″x6″x16′
4–6″x10″x14′	Bottom chord	5–3″x6″x16′
4–6″x12″x12′	Top chord	{ 4–3″x10″x18′
		{ 2–3″x10″x20′
Total 696 FBM @ $40/M = $27.84	**LUMBER**	Total 560 FBM @ $40/M = $22.40

Old Design		New TECO Design
538 # Gusset Plates and Angles @ 5c/# Cost $26.90	**STEEL**	None

Old Design		New TECO Design	
Machine Bolts 72–1″x9″	$13.73	TECO Toothed Rings 12–2–5/8″	$1.08
" " 24–1″x12″	5.44	" " " 104–4″	10.93
" " 4–3/4″x14″	.58	Machine Bolts 6–3/4″x10″	.68
" " 2–3/4″x6″	.16	" " 26–3/4″x13″	3.53
O. G. Washers 48 for 1″ bolts	5.28	" " 2–3/4″x15″	.28
		Plate Washers 68 for 3/4″ bolts	4.08
Total	$25.19	Total	$20.58

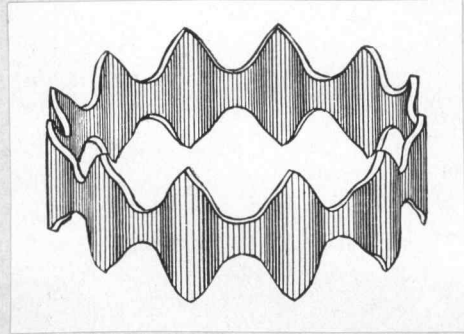| Old Design	New TECO Design
Total Cost of Materials = $80.93 (100%)	Total Cost of Materials = $42.96 (53.1%)

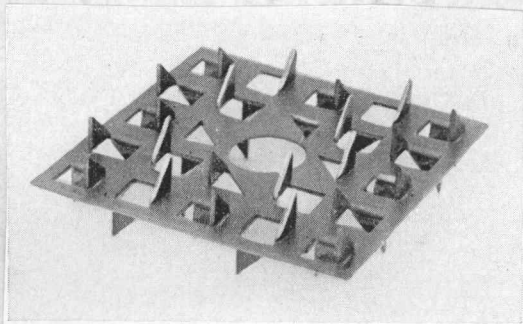Fig. 2

(Washington, D.C. prices used)
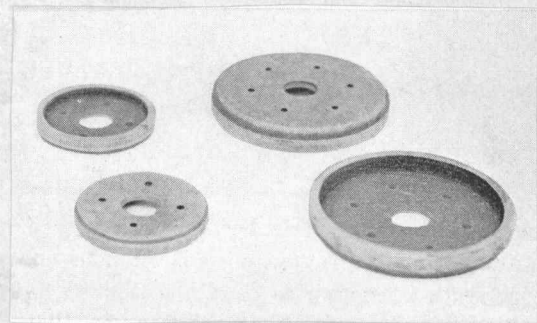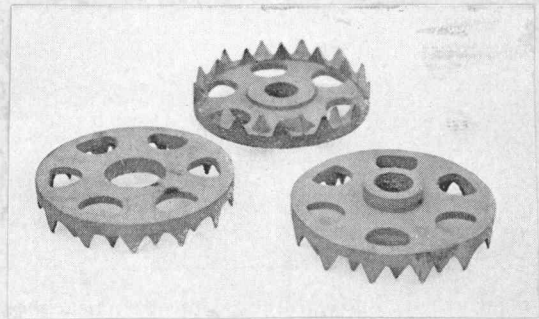
Standard Types of Connectors
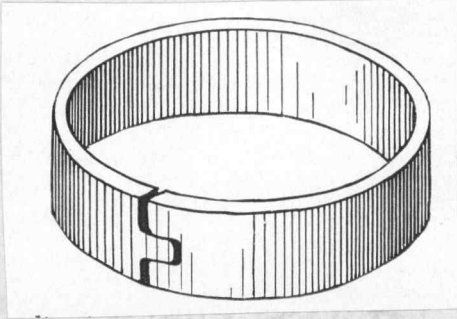
Split
Ring

Toothed
Ring

Spiked Grid

Shear Plate

Fig. 3

special presses; and shear plates are installed partially into a previously cut circular dap and the remainder of the way by means of driving or with a press.

Other connectors made on special order include: (1) clamping plates with projecting teeth on each face for use between bridge ties and guard rails or stringers, between caps and tops of piles, and at other points where lateral movement of one timber on another occurs, (2) claw-plates for use in wood-to-wood, or wood-to-steel connections. (These are similar to the toothed shear plates previously mentioned, but have sharper teeth), and (3) plain flanged shear plates for wood-to-wood connections where the timber framing is to be taken down and reassembled.

The specific type of connector to be used in a joint depends upon the size of the load and the kind of joint. Although no definite rules apply in choosing between a split or toothed ring connector, it is generally recognized that relatively heavy loads are best handled by split rings and lighter loads by toothed rings. Spiked grids of the single curve or double curve types are designed for pile joints and the flat grid is applicable to similar uses when sawn faces are encountered. Where it is required to transmit load from wood to metal for anchoring structures or making connections by metal straps or plates, shear plates or claw plates may be used. (2)

Old and Modern Methods of Timber Framing

Connections in timber framing customarily are made by lapping the ends of the several members over each other. Contact areas are thus obtained in which loads are transmitted from one member to another. In these areas of contact, it is possible to develop with bolts only from 40 to 60% of the allowable working load of the members.

By use of timber connectors a pound of good structural timber will do in general the same work that can be expected from a pound of steel. The greatly increased strength secured at crucial points is of such prime engineering importance as frequently to change both the methods of design and cost aspects of many structural types. Timber can now be used economically for types of structures for which it has not formerly been considered, and timber structures can now be designed for wider spans and heavier loads than before.

As compared with the earlier types of notched or hand-fitted joints, timber connectors greatly reduce labor costs. As compared with joint details in which timbers are bolted to steel gussets, the connectors are lighter and cheaper, not only in weight of metal used, but also in the amount of timber required for a given load and in the assembly labor required. Design features are also greatly simplified because with the connectors the strength of joints can be quickly and accurately computed. (2)

The advantages of factory fabrication were soon realized; shops were equipped with modern power-driven saws, boring machines and other simple labor-saving devices, and today structural units in wood are prefabricated and shipped to construction jobs. All shaping, cutting, and boring is done in the shop so that expensive hand labor is supplanted almost entirely by modern mechanical devices.

Units may be shipped assembled or knocked down. When not assembled, each piece is marked for erection, the connectors may be inserted at the shop, and only the placing of the bolts in prebored holes is required at the job. This procedure, of course, is similar to erection methods with metal.

Costs have thus been reduced not only through more efficient fabrication methods, but also, as has been mentioned before, through a saving in the volume of wood required for a structure. These are obvious economies. In addition, however, are the opportunities for proper selection of species and grades at the fabricating shop, expert technical supervision, and elimination of waste material at the plant and consequent saving in freight charges.

For construction purposes where quick erection and dismantling are required, the modern connectors have proved especially valuable. In military as well as civilian operations they have been used in construction of barracks, bridges, trestles, and numerous other structures.

All the advantages mentioned have been demonstrated

in Europe, where in many respects conditions for the adoption of modern wood-construction methods seem much less favorable than in the United States. Here we have numerous soft pines, spruces, hemlocks, and true firs fully equal to the European species used in construction, and in addition such outstanding structural woods as southern yellow pine and Douglas fir, to say nothing of larch, redwood, the cedars, cypress, and oak. Because their superior strength properties are recognized, some American structural woods are imported by European countries, through special dispensation in some instances where the general economic policy has been to favor native species by actual prohibition of foreign lumber.

Certainly the conditions that lead to such importation are far less favorable than those in the United States. Also, as a result of exhaustive research by the Forest Products Laboratory, accurate and complete data are available as to strength properties of all commercial American species and grades. In Europe, engineers have been handicapped by a lack of complete data on their native woods. Yet, despite this, modern connectors have gained in popularity abroad. Moreover, in the United States, the ratio of cost of labor to cost of material on a construction job is far greater than in Europe and in consequence the possibilities of savings by increasing the efficiency of labor are correspondingly greater. Furthermore, local common labor may be employed in erection with modern timber connectors. (3)

Number and Size of Connectors

After the type of connector to use in the struc-
ture is decided upon, it remains, in the case of the split
rings and toothed rings, to determine the number and size of
the connectors which best apply. The choice of connector
size is based to a large extent on the following consider-
ations:

1. Load-carrying capacity of the connector as influ-
   enced by direction of load with reference to grain
   in the wood, grade of timber, and edge and end mar-
   gins;

2. Load to be carried;

3. Relative occurrence of similar types of joints in
   the structure;

4. Available overlapped surface area in the joints;

5. Number of rings in a single joint.

Safe working loads assigned to timber connectors
for the different conditions listed in No. 1 above, may be
read from the load charts in the "Manual of Timber Connector
Construction" (Fig. 4 a and b). The unit load per connec-
tor, divided into the total load, will give the number of
connectors required. The specific size or sizes of connec-
tors to employ in a timber design will be determined by the
types of joints. If the load in a large percentage of the
joints can be carried effectively by a single ring size on
one or more bolts, this factor will greatly influence the
size recommended for the remainder of the structure. A
single connector size, especially the split ring type, used
in a design, keeps the cost at a minimum, since it means

Safe Working Loads for

One TECO Split Ring and Bolt in

Single Shear in Structural Grades of

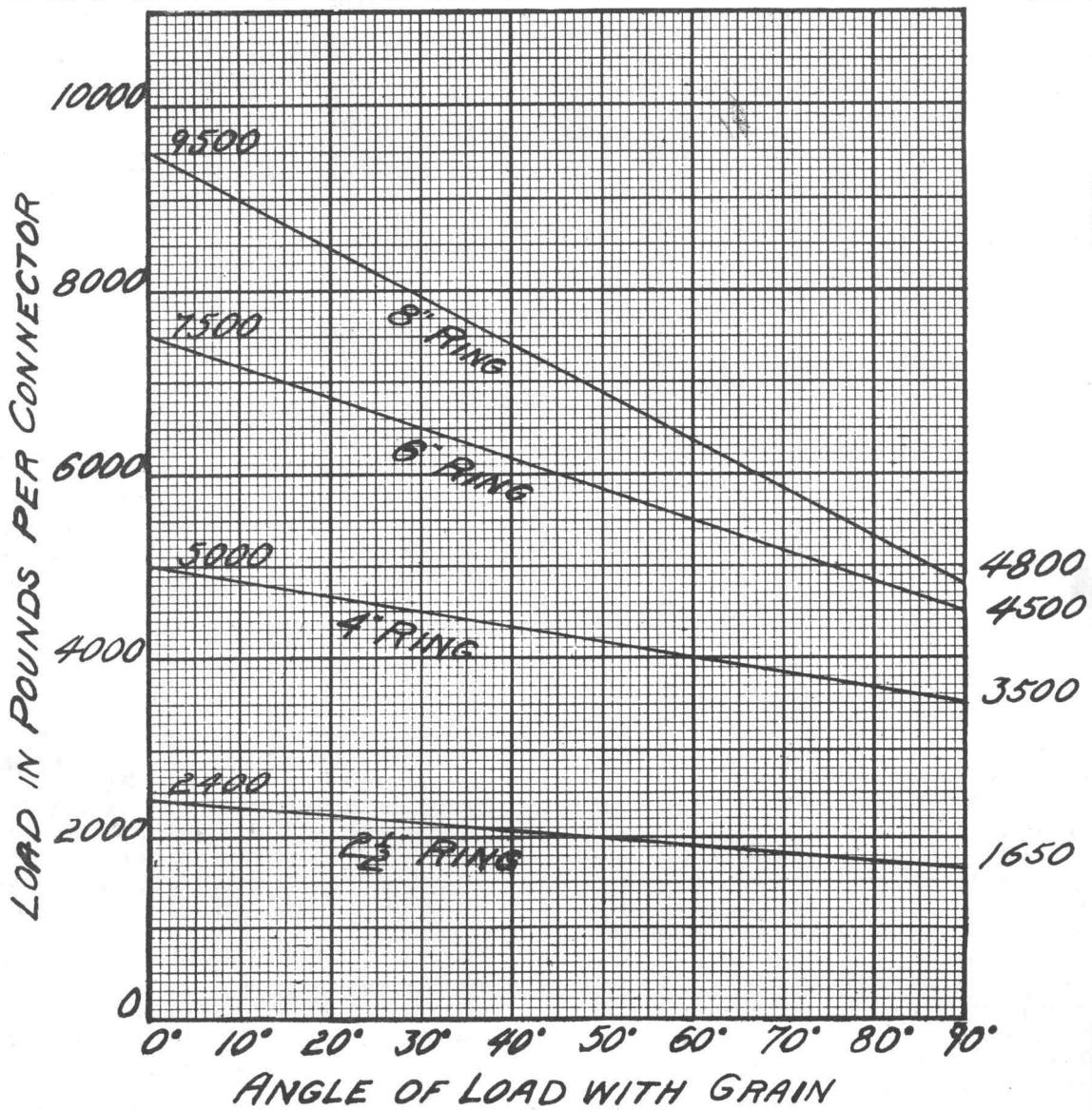Tidewater Red Cypress and California Redwood

Fig. 4-a

Safe Working Loads
For One TECO Split Ring and Bolt in Single Shear in
Dense and Non-Dense Structural Grades of
Douglas Fir, Western Larch,
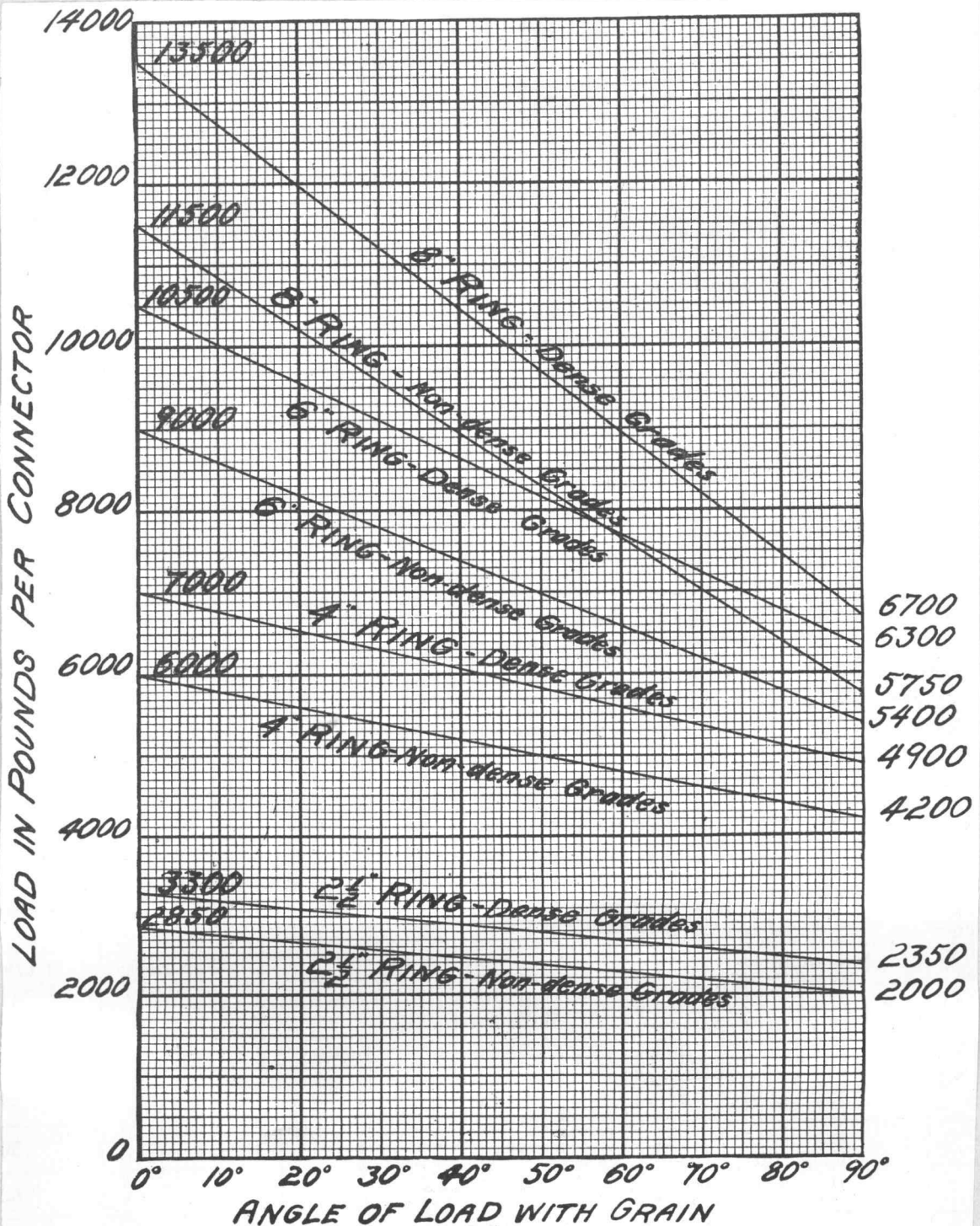### Southern Yellow Pine, and Tamarack

Fig. 4-b

fewer tools to buy and fewer to handle during fabrication.
Different sizes of rings in a structure, on the other hand,
are sometimes quite advantageous for large trusses or for a
large job where parts are shop fabricated with plenty of
equipment available and their use need not be ruled out un-
less it is evident that a single size will serve effectively.

The overlapped area in timber joints may also in-
fluence connector size by permitting sufficient end and edge
margins for a single bolt with a large ring, but not pro-
viding proper spacing for two or more bolts with smaller rings
or conversely may provide adequate margins and spacings for
multiple small rings but not for the larger ones. It should
be noted in this connection that a connectored joint with a
single bolt plus connectors is the easiest type to fabricate
and to assemble. The use of a large number of bolts and small
connectors in a joint is generally not recommended due to the
more complicated joint. However, it may be necessary at times
to avoid the necessity of increasing the size of the structur-
al member in order to provide the required margins, end and
side, for the larger ring. The relative economy of the lar-
ger size ring in the larger timber in such a case should be
weighed against that of the smaller timber and greater number
of rings. (2)

Diagonals Between Vertical and Chord Members

In certain types of construction, such as Pratt or
Howe trusses, where the diagonal web members are highly
stressed and overlapped area is at a premium, it frequently

happens that by placing the diagonals between the vertical
and horizontal members that ample space is provided for con-
nectors. Other advantages gained from this type of joint
are that (1) the bottom chord which is in tension does not
need to be the same thickness as the top chord; (it may be
thinner and wider to afford more space for the connectors),
(2) a smooth exterior is presented by the truss chords; and
(3) the load per connector in the vertical is increased be-
cause the angle to the grain is now less than 90° with the
diagonal to which it is connected. The following descrip-
tion demonstrates this type of joint (Fig. 5).

      Conditions: Flat top Pratt Truss Span 60'
                    Panel spacing 16'-0" c. to c.
                    Total live and dead loads 40 lbs./sq. ft.
                    Joint in lower chord

      The feature of this joint is that the diagonals
which must transmit the greatest load in the joint are placed
between the vertical and horizontal members, thereby present-
ing two faces into which connectors may be placed instead of
one face each, if the diagonals were placed outside the
chords. The load to be transmitted between the diagonals to
the vertical is 9,100 lbs. The allowable connector load for
a 4" split ring acting at an angle of 42° with the grain is
5,150 lbs. Therefore, two connectors, one each side of the
vertical, will more than carry the 9,100 lbs. required.

      In the lower chord which is continuous through the
joint, it is necessary only to eliminate the difference be-
tween the stresses on opposite sides of the joint. There-

Diagonals Between Vertical
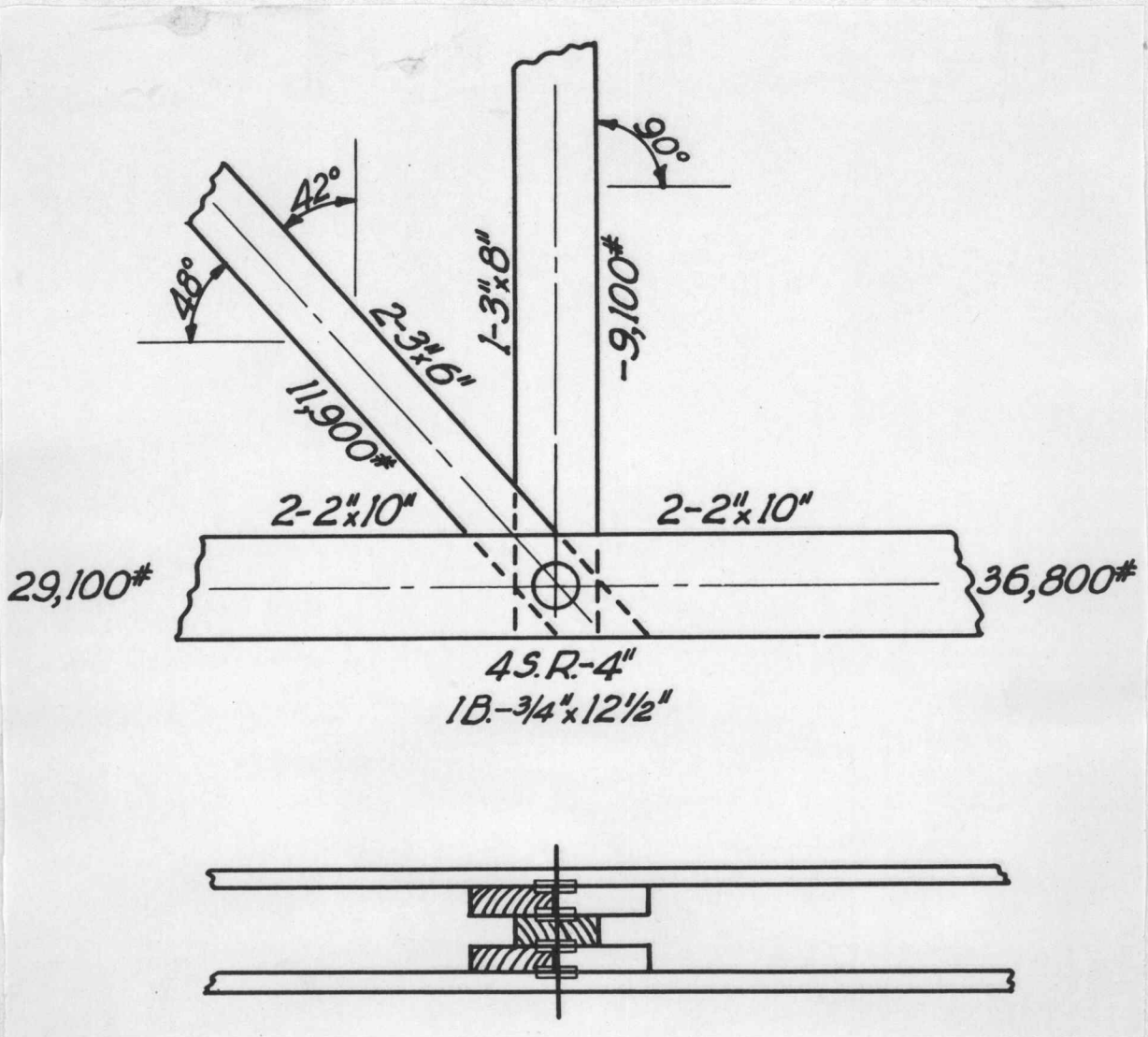
and Horizontal Members

Fig. 5

fore, the stress to be absorbed at the joint is 7,700 lbs.
(36,000 lbs. minus 29,100 lbs.). The allowable safe load
capacity for a 4" connector bearing at an angle of 48° to
the grain in non-dense material is 5,000 lbs. Two connec-
tors therefore between the diagonals and chord members are
sufficient. Then, since the stress in the vertical is equal
to the vertical component of the diagonals and the differ-
ence between the two chords' stresses is equal to the hor-
izontal component of the diagonals, and since both the ver-
tical and chord members are directly connected to the diag-
onals, it follows that the connectors specified must develop
the stress in the diagonals. (2)

Connector Designed Roof Trusses

Timber construction is used exclusively in the
shipyard recently completed at Tacoma, Wash., for the
Seattle-Tacoma Shipbuilding Corporation which has a con-
tract to build five 6,800-ton freighters for the U.S. Mar-
atime commission. The covered area includes 103,200 sq. ft.
in a group of shop buildings adjoining two shipways that
lead from the plant into Puget Sound.

In the shops are 72 timber trusses with spans of
50 ft. or more; 12 have spans of 130 ft. Fabrication of
trusses began November 1, 1940, was completed December 21
and their erection was finished the first week in January,
1941. The buildings include a two-story, 130x260-ft. mold
loft; an 84x350-ft. assembly shop; two plate shops each 50x

150-ft.; a slab shop and a blacksmith shop, each 50x150-ft.; and a 50x200-ft. layout shop.

For the most part, truss spacings are 20 to 25-ft.; roofs are designed for a live load of 20 lbs./sq. ft. The roofing proper consists of 2-in. tongue and groove planks on 6x12 or 6x14-in. purlins spaced 8-ft. on centers. Joints in Howe trusses are made with split ring connectors, and in the bowstring trusses all heel plates and metal fastenings are attached with flush type shear plates. For all top and bottom chords, select structural Douglas fir was specified and for smaller diagonal web members the grade was select merch. (4)

Examples of Recent Timber Bridge Construction

One of the most difficult problems currently facing highway officials is that of providing bridges with a capacity commensurate with that of the connecting roadways at a cost that is not prohibitive. Several highway departments have pointed toward at least a partial solution of this problem by building adequate but relatively low cost wood structures.

Modern developments such as the stress grading of lumber, improved methods of drying to eliminate seasoning defects, the treatment of portions subject to unusual decay hazards and the many efficient modern types of joint connections provide greater flexibility in design than has been possible in wood design of the past.

Johnson Creek Bridge. A well designed example of

a garden variety of highway bridges is that on the Deardorff
Road over Johnson Creek in Multnomah County, Oregon (Fig. 6).
This is a five-panel pony truss without outriggers. The span
is 60 ft., with a 20-ft. clear roadway width between the
wheel guards. It is designed for an H-15 loading. The abut-
ments which also served the old structure are of rubble ma-
sonry.

All of the Douglas fir timber in the structure, in-
cluding the hand rails, was prefabricated and treated with
creosote under pressure. Split ring connectors were used to
transfer the load at all joints, as well as for fastening
floor beams and lateral bracing to the truss. A laminated
wood deck, in which the laminations were cut to form a 2-in.
pavement crown, was placed over the timber stringers and a
wearing surface of 2-in. asphaltic concrete applied.

All materials, including the treated lumber, hard-
ware, shims, and asphaltic concrete, were delivered to the
site for $1,968.95. Multnomah County erected the bridge with
WPA labor at a labor cost of $405. The total cost, exclusive
of foundation, was $39.58 per lineal foot of bridge.

Interesting features of this structure were the
elimination of outrigger bracing and uninterrupted traffic
flow over the bridge during its construction.

Dinky Creek Bridge. A typical wood bridge somewhat
larger than the 60-ft. Johnson Creek bridge is the 90-ft.
structure erected over Dinky Creek, about 60 miles northeast
of Fresno, Calif. The location is some 12 to 14 miles east

of the main highway to Huntington Lake, a popular recreational area at a 5,900-ft. elevation.

The bridge is a factory fabricated through truss structure designed for an H-15 loading. It has a 20-ft. roadway and required 38,888 ft. of Douglas fir in its construction. All timbers, except stringers and decking, had been treated with an 8-lb. creosote and petroleum oil treatment and timber connectors were employed in the truss connections. The contract price for lumber, prefabrication, creosoting, and hardware delivered to the site was $3,201.86, making the cost per lineal foot of roadway without erection $35.56.

Dolan Creek Bridge. It being increasingly realized by builders that timber with modern developments in connection lends itself well to the arch type of construction. An excellent example of this type of bridge is the Dolan Creek Arch, built of redwood and located on State Route 57. This structure, about 50 miles south of Monterey, Calif., is a three-hinged timber arch and is but one of the 20 wood bridges on this coast highway.

Dolan Creek bridge (Fig. 7), with an over-all length of 514 ft., has a roadway width of 24 ft. and is made up of a three-hinge arch span of 180 ft. (60-ft. rise), four 38-ft. timber girder spans and nine 19-ft. timber trestle bent approach spans. One end of the structure is on a curve which has been compensated by super-elevation and the roadway has a grade of 0.567 percent.

An interesting factor in connection with the construction of this bridge is that it was designed to serve under a 40-ton moving load. This is twice the loading normally assumed in California bridge design, but was required because of the frequent movements of 40-ton shovels along this coast route.

Split ring connectors up to 8 in. in diameter were used in assembling the arch ribs and the 38-ft. built-up girders. The successful bid for the whole 514-ft. Dolan Creek bridge, including excavation, foundations and piers, was $67,871.00, or $132.00 per linear foot.

North Umpqua, Oregon, Bridge. Another typical arch of somewhat different lines and shorter span is that bridging the North Umpqua River, in the heart of an important recreational area about 45 miles east of Roseburg (Fig. 8).

This 135-ft. arch, which is designed for an H-15 loading, is characterized by simplicity of design and detail and harmonizes with the natural environment. The arch is 30 ft. in depth at the springing lines and 6 ft. 3 in. at the crown, with a horizontal top chord and parabolic bottom chord. The top chord has a camber of 3 in. The top and bottom chords and vertical members were connected with modern timber connectors.
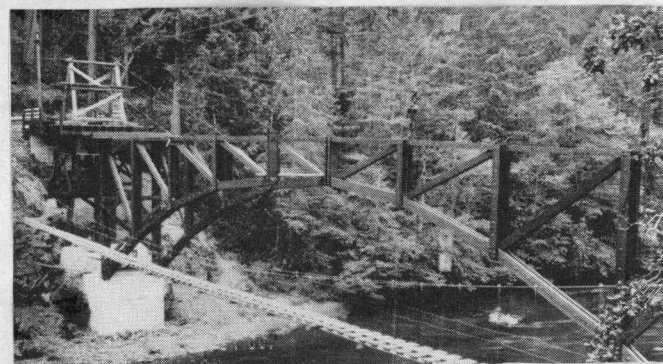
The top chord consists of two 2-in. x 8-in. side pieces and a 5-in. x 6-in. filler. The bottom chord is made of two 5-in. x 16-in. side pieces, with a 5-in. x 16-in. filler. The vertical web members consist of two 4-in. x 14-in.

Fig. 7 - Dolan Creek
Arch Bridge

Fig. 6 - Johnson Creek Bridge

Fig. 8 - North Umpqua River
Arch Bridge

side pieces and one 4-in. x 14-in. filler placed so that the
vertical web members could be fastened to the outside of the
chord members. The diagonals are one-piece members which fit
into the space between the two pieces forming the chord mem-
bers.

The deck is composed of laminated 2x4s and is car-
ried by eight 6-in. x 16-in. stringers. These in turn rest
on 12-in. x 20-in. floor beams which carry the load into the
arch trusses at each panel point.

Due to the erection conditions at the site, all
members were fully shop detailed and in addition each truss
was shop framed and bolt holes bored while assembled in the
shop. After fabrication the Douglas fir timber was given an
8-lb. empty cell treatment, using a mixture of 50 percent
petroleum and 50 percent creosote. Materials used in the
approaches and arch span were as follows: Creosoted timber,
73 M bd. ft.; untreated timber, 8.3 M bd. ft.; hardware,
7,300 lb.; and cast steel hinges, 600 lb. (5)

Trends in Timber Design

In the remote past, improvements in wood construc-
tion have depended largely upon the ingenuity of skilled
workmen, rather than the application of technical infor-
mation obtained through research and applied by the design-
ing engineer. This condition is changing rapidly today.
Capable progressive engineers, with their superior tech-
nical training, are studying the correct use of wood in eng-

ineering structures and modern development in wood design.

This healthy trend would seem to indicate that, in the future, as more scientific knowledge of wood is accumulated, and the engineering data on timber become more widely disseminated, wood will more nearly approach the much wider usage which its inherent merits as a construction material justify. (6)

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                      section in text of thesis corresponds
                      to bibliography number below)

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