# AN ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF CONTACT AREA STRESS DISTRIBUTION AND BUCKLING STRENGTH OF LIGHT GAUGE PUNCHED METAL HEEL PLATES FOR TIMBER TRUSSES

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This is to certify that the

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AN ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF CONTACT AREA STRESS DISTRIBUTION AND BUCKLING STRENGTH OF LIGHT GAUGE PUNCHED METAL HEEL PLATES FOR TIMBER TRUSSES

presented by

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# ABSTRACT

## AN ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF CONTACT AREA STRESS DISTRIBUTION AND BUCKLING STRENGTH OF LIGHT GAUGE PUNCHED METAL HEEL PLATES FOR TIMBER TRUSSES

By

Isaac Sheppard, Jr.

The purpose of this investigation was to develop a simple testing procedure and make a theoretical and experimental study of the contact area stresses and buckling stresses of light gauge metal heel plates used on wood trussed rafters.

A small, hand-operated hydraulic cylinder was mounted in a specially designed jig to apply a concentrated load at the peak of 8'-0" long triangular trusses. By mounting a dial gauge on the joint, load-deflection data was obtained.

A theoretical investigation developed the theory of contact area stresses in accordance with recent work on nailed joints and other analyses that combine direct stresses vectorially with eccentric, or rotational, stresses to get critical combined stresses. Methods of computing tensile stresses in heel plates, shear streses, and bending stresses on small elements, are presented.

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An initial comparison of six plate sizes, shapes, and orientations revealed that contact area stresses were not significantly different for any of the plates studied at 0.015" heel joint deflection. At ultimate load, however, those plates 2-3/4" to 3-3/4" wide, and lengths from two to three times their width were best, and were 20% to 50% stronger than the next three. These two strong joint types were more than twice as good as the worst group, 5"x7", placed the "wrong way."

A detailed study of surface strains using Stress-Coat brittle lacquer revealed that the shear stress in the steel is highest directly over the joint between members; that corner teeth are initially stressed quite highly; but that even at loads that cause buckling, large areas of wider plates are not stressed significantly. It was concluded that heel plates should be kept to a lesser width to better utilize contact area strength and prevent an erroneous feeling of confidence due to excessive width of the heel plates.

In a first preliminary comparison of 24 matched specimens (two repetitions each): 8'-0" vs. 24'-0"; Douglas fir vs. white fir; 3"x5", 3"x8", and 5"x5" heel plates; all evaluated at 0.015", 0.040", 0.080", and 0.150" heel deflection; it was found that:

1. The heel joints for 8'-0" specimens were 8% stronger than those on 24'-0" matched trusses.

2. The white fir heel joints were only 70% as strong as Douglas fir joints.

3. The 3"x5" and 3"x8" plates were almost identical, on a psi basis, but both were about 20% stronger than the 5"x5" plates.

4. Contact area stress was affected by several two-way interaction effects.

A second preliminary comparison verified these conclusions, plus showing there was no significant difference between 8'-0" specimens tested on the hand-operated jig and matched 8'-0" specimens tested on a Riehle mechanical testing machine.

A final analysis of variance comparison, performed with a least squares statistical routine on a Control Data Corp. 3600 computer, included the variables mentioned earlier, plus moisture content and specific gravity, along with their squares, as covariants, and was based on the load-deflection data from 56 different test specimens. This final comparison confirmed the earlier conclusions, plus finding that moisture content affects contact area stress significantly. Multiple correlation coefficients were computed that accounted for 91% of the variance and a contact area stress prediction equation was developed, with predicted stress being compared with measured stress for four deflection readings on each specimen.

A comparison of the theoretical results with the experimental tests showed that a simple axial stress calculation of contact stress, in the P/A manner, is a better predictor of test results than the theoretical method proposed. The experimental work led to recommendations for heel joint design that are also included.

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This will express appreciation to TrusWal Systems, Inc., Troy Steel Corp., and Duratile of Ohio for their truss plates, test specimens, and testing apparatus.

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# INTRODUCTION

The twenty year period, 1948-1968, has seen the use of wood trussed rafters grow from an almost infinitesimal beginning to a major market factor. Trussed rafters are now used on about half of all single family residential construction, as well as on a large share of agricultural, and a significant share of commercial and industrial construction. The trussed rafter has the advantages of greater strength, more uniformity, and lower cost as opposed to conventional joist-and-rafter construction. Greater spans without supports, faster construction and other benefits are provided by trussed rafters, too.

Trussed rafters, commonly called "trusses," may be built with any structurally suitable joint system to attach the wood framing members. Split-rings, nail-glued plywood gussets, bolts, nails, light gauge metal gusset plates, and other connector types have been used. The light gauge metal gusset plate has essentially taken over the market now, having displaced the other joint types due to its lower cost, faster fabrication, and easier shipment of completed trusses.

Many tests have been performed to insure that the truss plates have adequate tooth values or nail values and tensile strength. Other tests have been performed on completed trusses to show the over-all truss design to have adequate strength. While both these sets of tests have shown structural adequacy, there have been only minor attempts to analyze the shear stresses, buckling stresses, and eccentric forces that affect the heel joint, where the bottom chord and top chord meet. Since this joint is subject to a more complex set of forces and stresses than any of the other truss joints, and since it requires more steel than any other joint, a more elaborate study of it seems warranted. This project is intended to answer that need.

# CHAPTER I

## REVIEW OF LITERATURE

The design loads on trusses are usually specified by local building codes or nationally recognized building codes such as the "Basic Building Code" (1965), the "Uniform Building Code" (1967), the "Southern Standard Building Code" (1967), or the "National Building Code of Canada" (1966). Where no building code governs, the requirements of the Federal Housing Administration (1966), the United States of America Standards Institute, or, in the case of farm buildings, by the American Society of Agricultural Engineers (1967) may be used. Local climatological data is available for more detailed study from the Dept. of Commerce (1968).

The lumber used in trussed rafters has been standardized as to grades and strength by the official grading associations, Western Wood Products Association (1965) for west coast woods, and the Southern Pine Inspection Bureau (1968) for southern woods. These lumber allowable stresses, plus connector values for bolts, split-rings, nails, etc., are all published in one booklet by the National Forest Products Association (1968). The properties of individual species are given in separate reports by Littleford on Douglas fir (1967) and the Forest Products Laboratory on western hemlock (1965) and southern pine (1966). Strength and related properties of Canadian woods are summarized by Kennedy (1965). Probably the most important thing, the factor of safety, has been described in detail as a multi-valued characteristic by Wood (1958).

The background testing for the lumber grading rules and specifications has been performed under the American Society for Testing and Materials (A.S.T.M.) Designation D 245-67T (1967). The "strength ratio" related these tests of small, clear specimens to structural size by allowing for the reduction effect of knots, slope of grain, and other strength-reducing characteristics. The "strength ratio" is discussed by the Forest Products Laboratory in the "Wood Handbook" (1955).

Non-destructive testing of lumber has been described by McKean (1962, 1963), Bolger (1962), Miller (1962), Sunley (1962), Senft (1962), and Wood (1964). This non-destructive testing, commonly called "machine grading," permits more uniform strength standards for timber based on a statistical correlation of strength with flatwise stiffness.

Recent arguments of "green" (unseasoned) vs. "dry" (moisture content of 19% or less) lumber are being resolved through a set of "green" sizes and allowable stresses that match the existing size standard, but a set of equivalent "dry" sizes with smaller dimensions to account for shrinkage. The ratio of dry to green clear wood properties has been determined by A.S.T.M. in D-2555 (1967). These equivalent "dry" sizes were recommended by the Forest Products Laboratory (1964) on the basis of stiffness and shrinkage tests of green and dry joists.

The engineered use of nails for connections in wood structural members, particularly trusses, has been extensively reported by Stern (1952 through 1967). Nailed joint rigidity was studied by L. L. Boyd (1959) and rotational resistance of three-membered nailed joints was reported by Perkins (1962).

The use of nail-glued plywood gussets for wood trusses has been extensively investigated by Radcliffe (1954, 1956), J. S. Boyd (1955), Countryman (1954), Angleton (1960), and Suddarth (1961). A digital computer W-truss analysis program was developed by Suddarth (1964) for symmetric trusses with rigid joints (nail-glued plywood) or various combinations of rigid and pinned joints.

The design of light gauge metal connector plates with wood trussed rafters has been covered by the Truss Plate Institute's (T.P.I.) "Design Specifications for Light Metal Plate Connected Wood Trusses" in various editions (1962, 1965, 1966, 1968). These metal plates of every different manufacturer have been subjected to a large number of tensile tests, following either the T.P.I. procedure or the more recent A.S.T.M. procedure Designation D 1761-68 (1968). A tensile test has been proposed by Dudley, 1966, and A.S.T.M., 1968, to help evaluate the net tensile strength of steel, in addition to the strength of the truss plate teeth.

Deflection and creep characteristics of trussed rafters with metal plate fasteners were reported by Sliker (1965). The effect of three different types of metal plates, as compared to nail-glued plywood, as well as variations in moisture content, was reported by Radcliffe (1964). Moisture content cycling of trussed rafter joints was reported by Wilkinson (1966). An extensive series of Canadian trussed rafter tests to develop general performance criteria was reported by Hansen (1963). The effect of member stiffness and moisture content history on the deflection behavior of trusses fastened with metal plates was reported by Kawal (1965).

Suddarth (1963) reported on a detailed analytic study of W-trusses made with metal gusset plates, including the moment-rotation effect at the heel joint. This was his initial study, and reported that

> A workable formula for the rotational slippage-resisting moment relationship has been devised and tested for nailed joints with wood gussets by Perkins (1962). (He was referring to Perkins' conclusion that the torsion formula for the force on the extreme nail is suitable.) As yet, unpublished pilot experiments with short-tooth, long-tooth and nailed metal gusset plates have shown that the same fundamentals apply to the same degree. The rotation-moment formula is derived from the load-slip characteristics of a single fastener and considers the arrangement of the fasteners about their centroid.

Suddarth continued his study to analyze a 26'-8" span, 3/12 slope, 2"x4" W-truss as if it had rigid joints, then as if it had pinned joints but continuous chords and assumed that actual member moments in this metal plate connected truss lie between those obtained in these two cases.

A second report by Suddarth (1964) also concerned the fastener stresses, particularly the moment resisting capacity of metal plate joints. He reiterated his earlier conclusion (noted in the preceding paragraph). He also described a heel plate reduction ratio, $P_k/F_{ki}$, in which;

$P_k$ = unit nail, tooth, plug, or psi value of connector,

$F_{ki}$ = extreme force on an individual fastener due to moment being transferred at the joint.

Suddarth's reduction ratio for 24' trusses with short-tooth metal plates varied as follows:

| Pitch | Top Area | Bottom Area | Ave. |
|---|---|---|---|
| 2½/12 | .906 | .848 | .877 |
| 4/12 | 1.045 | .616 | .732 |
| 6/12 | 1.113 | .527 | .820 |

These percentages of allowable heel plate connector values were later adjusted to a uniform scale and adopted by the Truss Plate Institute (T.P.I.) as a practical engineering means of heel plate design to account for loss in heel strength due to moment transfer and eccentricity.

The Federal Housing Administration in its "Trussed Rafter Criteria" (1960) has always required a heel plate analysis based on the net vertical reaction, the distance from the intersection of member centerlines, and the polar section modulus of the heel plate. The FHA requirement is described in more detail under "Typical Calculations" and illustrated in Figure 8.

Misra (1966) studied the stress distribution in the punched metal plates at a straight tension joint and concluded that even for this type of joint the tensile stresses are not uniform. The maximum stress he calculated was 2.4 times the average, and was based on the distance from centerline of joint to tensile area being considered, much like rows of rivets at a riveted joint. He used a difference equation, as well as the principle of minimum complementary energy to predict stresses and got good agreement with experimental results.

Der-chun Lee (1965) did an experimental analysis of a king-post truss with semi-rigid joints, measuring the relative rotation of the top chord with respect to the bottom chord by means of the Moire Fringe effect. He assumed the rafter member is supported by a continuous elastic foundation, i.e., by equally spaced nails, which yielded analytical results reasonably close to those found experimentally.

Ivan Dah-Wu Chow (1965) worked along with Der-chun Lee on the analytical work and reported that the analytic results, using the assumption of semi-rigid joints, were closer to experimental results than the assumption of rigid joints.

# CHAPTER II

## PURPOSE

The purpose of this investigation was to develop a simple testing procedure and make a theoretical and experimental study of the contact shear stresses and the buckling stresses of light gauge metal heel plates used on wood trussed rafters. The specimens tested were fabricated with a variety of truss plate sizes from each of two manufacturers. Three different species of lumber were used.

# CHAPTER III

# THEORETICAL INVESTIGATION

The theoretical analysis of the heel joint was made by first describing the types of failure known to occur. These failure types are all caused by overstress. The next step, therefore, was an attempt to develop a rational design through prevention of premature failure by consideration of the types of overstresses that resulted in failure.

## Types of Heel Joint Failure

Assuming that the metal gusset plate is sufficiently strong to be properly impaled, there are four types of failure that can occur at the heel joint:

### Tensile Failure

Tensile failure can occur when the length of plate in tension (and consequently the number of teeth) exceed the "development length."

"Development length" refers to primary tensile joints and means the length of truss plate contact area necessary on each side of the joint to balance the net steel section in tension at the critical location.

The development length is similar to the minimum permissible anchorage for reinforcing bars in reinforced concrete

construction. Development length in that case refers to the bar length that must be used to develop the strength of the reinforcing bar. The concept has been described in detail by Ferguson (1958).

When the contact area exceeds the development length, as when a longer plate is used, no extra strength is gained because the plate will fail in tension. The extra length, beyond the "development length" may add to better appearance, but can not increase the strength because the net tensile strength limits the joint performance.

This concept of development length is a means of assuring that contact area and net tensile section are both considered as possible limitations on joint strength. When riveted joints are designed in steel construction, both shear area of the rivets, as well as bearing area on the connected parts, must be checked, with the more limiting factor governing design. In the case of punched metal truss plates, connecting timber tension joints, both contact area on the wood and net tensile section of steel must be considered and the design is limited by the smaller value. Development length is the minimum length required for the contact area to develop the tensile capacity.

Truss plate areas shorter than the development length will be limited by their contact area stress, whereas those truss plate areas longer than the development length will be limited by net tensile capacity. Development length, then, is a convenient expression of the maximum contact length that may be used without being limited by the net tensile strength of the steel.

The development length is affected by the truss plate's thickness, percentage of holes, and yield or ultimate tensile stress of the steel being used. In addition, since the tooth, nail, or plug value of the truss plate contact area is dependent on the density, specific gravity and species of lumber, these wood properties affect development length too. Development length is a property of both the truss plate and the lumber. The same connector plate will have a longer development length in balsa wood, due to its lesser nail holding power, than in white oak.

For a heel joint to fail in tension, the contact area of the plate provides more strength than the tensile cross-section. While this type of failure is much more common at true tensile joints (such as lower chord splice joints), it can be a factor in heel joints that are placed parallel to the bottom chord. The triangular contact areas on the top and bottom chord develop increasingly large tensile stresses in the small isthmus between teeth at the smallest end of the triangular area. See Figure 1.

Tensile failures can be prevented by providing more net section of steel, either by thicker or wider truss plates, or by reducing the percentage of holes in the truss plate surface, or by properly positioning the plate to prevent excessive tensile stresses.

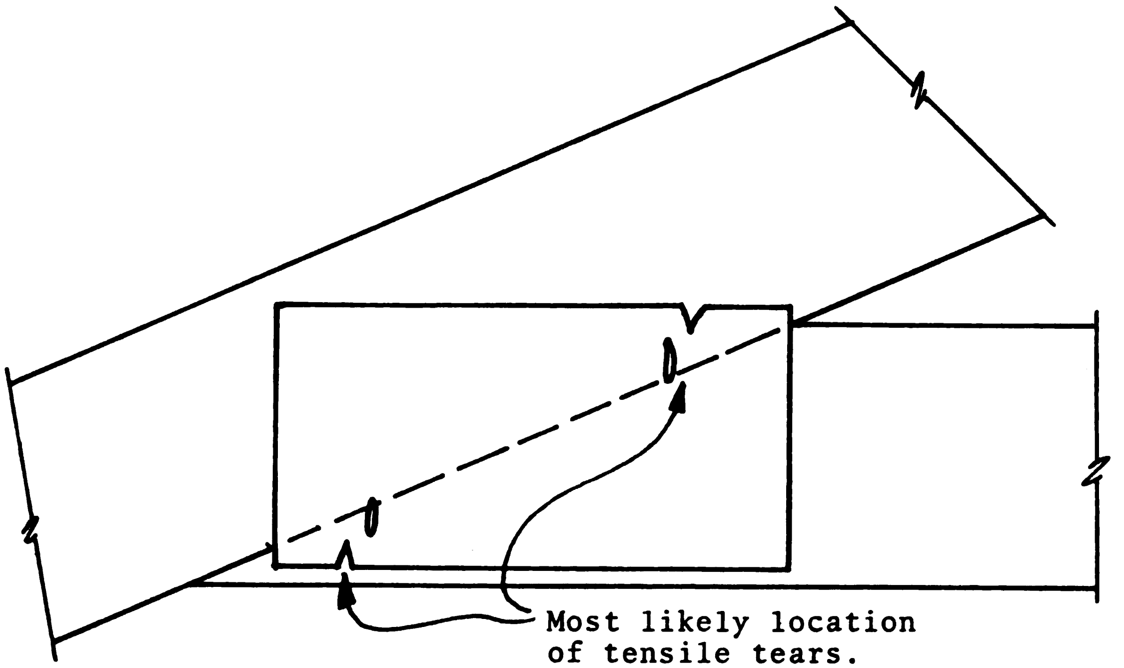



Figure 1. Tensile failure at heel plate.

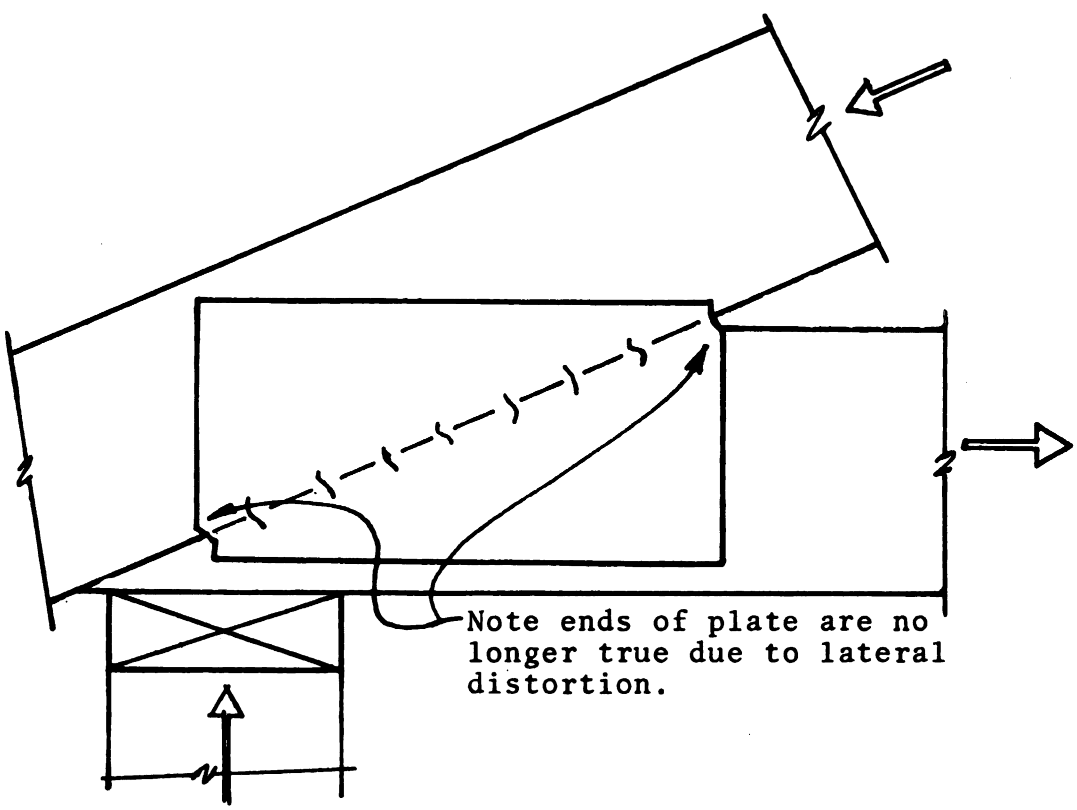



Figure 2. Plate buckling along shear line.

## Tooth Failure

Tooth failure refers to withdrawal of the teeth from the wood. Normally this occurs by progressive enlargement or elongation of the entrance area of the hole which the tooth makes in the wood during impalement. As this entrance area of the hole becomes more and more elongated (due to exceeding the bearing capacity of the wood) the tooth attempts to follow the slope of the hole by bending. The further the tooth bends, the more nearly it is loaded in withdrawal (as opposed to its typical shear loading). Eventually, the tooth is bent nearly $45^{\circ}$ back from vertical and pulls out of the hole entirely.

It has been found that teeth being bent back toward their original hole in the parent steel are more vulnerable, less rigid, and weaker than teeth which are being bent further away from their original plane (within the parent steel). However, that was outside the area of this research and was not investigated further.

## Wood Failure

Wood failure occurs when the truss plate teeth essentially retain their original shape and direction, yet tear through the wood fiber. Wood failure results from the tooth exceeding the bearing capacity, and/or the shear parallel to grain capacity, of the wood. It may be counteracted by either choosing a denser species or by increasing the size of the metal plate. Wood failure and tooth failure are inter-related.

Buckling Failure

Buckling failure occurs along the shear line (i.e., the crack between the top and bottom chords) and is related to truss plate thickness, size and shape of holes (or more precisely, the isthmus size, shape, and thickness between holes), orientation of holes to the shear line (i.e, parallel to it, perpendicular, or some angle in between) and size and shape of over-all truss plate contact area. See Figure 2.

## Description of Stresses in the Heel Plate

It has already been established by Misra in a straight tensile test that the stresses in the isthmus between holes in the surface of the plate vary approximately linearly with each row of teeth from the end of the plate to the tensile joint. This verifies the commonly held belief that each tooth provides equal value. However, this is only true where it is a straight tensile joint with no eccentric effect. Further, Misra showed that the teeth, holes, and metal between holes of a thin truss plate behaved exactly the same as the theory has always been for rivets making tensile joints, as for example, relatively thick boiler plate.

At a heel joint, there are both axial forces and eccentric forces, due to the type of joint. The description of these two types of forces, as they affect heel joints, follows:

## Axial Contact Area Stresses

Axial contact area stresses which result from the direct forces in the members must be contained and resisted by the joints. These so-called axial forces, then, must move toward the surface of the member in the vicinity of the truss plate. They may move considerably away from the axis of the member. It is possible to place a truss plate in such a position that it fits less than half way onto one of the members, thereby not even passing over the axis of the member. See Figure 3.

Since the members are mono-planar in a metal plate connected wood truss, the heel gusset plate can not occur at the intersection of center lines because the lower chord butts into the bottom edge of the upper chord. It is essential that the direct forces in the members be taken by the metal plate at this contact line between the members. By keeping the metal plate essentially centered over the crack, half the contact area will be on the top chord and half will be on the bottom chord. Then, making the usual assumption, there will be a uniform load on the teeth due to these axial forces.

## Eccentric Contact Area Stresses

Eccentric contact area stresses are caused by the eccentric force, or rotational moment, brought into play by the fact that the two contact areas (one on the top chord and the other on the bottom chord) each have their own distinct centroids and that these centroids are separated by a certain distance, e. See Figure 4.

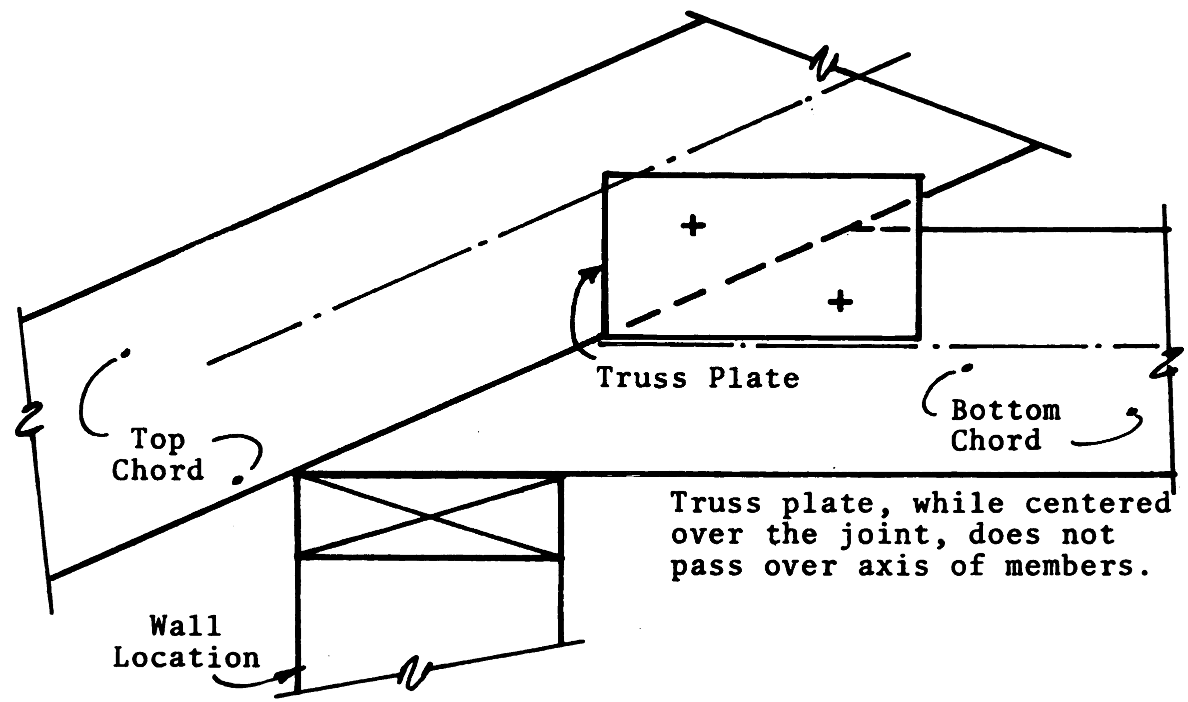



Figure 3. Heel plate not on member C.L.

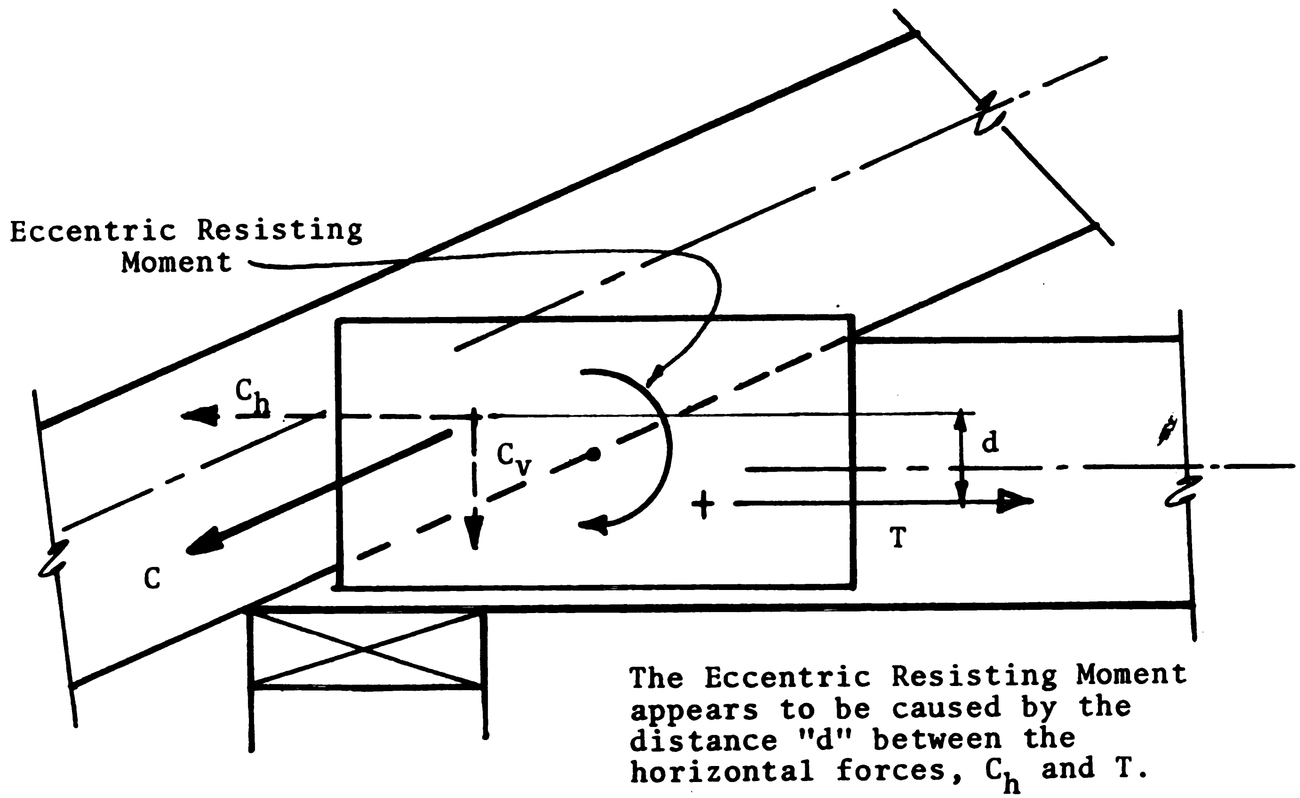



Figure 4. Eccentric Resisting Moment.

To determine the magnitude of this rotational moment, both the size and direction of the forces must be known, as well as the distance between centroids of their respective contact areas. It would first appear that the magnitude and direction of the axial forces could be used, but closer inspection shows that these are not in fact equal or opposite since the top chord is on a slope and has a larger force than does the bottom chord.

a. The horizontal torsion component results from the force in the bottom chord contact area. This force must be parallel to the chord since there is no vertical component (except when the top chord is birdsmouthed to bear on the support, letting the bottom chord hang in such manner that any ceiling load must be transmitted vertically into the top chord by the connector plate). This means that the force on the top chord contact area must be equal and opposite, rather than parallel to the slope of the top chord.

b. The vertical component of the top chord force must be transferred directly to the support from the top chord by crushing on the very small feather end of the scarf cut of the bottom chord. This is due to the tight fit between chord members at the heel joint. A tight fitting heel joint is the general rule since it is the simplest joint to cut, easy to clamp together in a jig, easy to inspect, and the wood-to-wood contact area is longer than other joints. See Figure 5.

c. The rotational moment is due to the vertical distance, e, between the centroids ($c.g._u$) of the upper chord contact area and the centroid ($c.g._b$) of the bottom chord. This concept is illustrated in Figure 6.

Shear Stress in the Steel

Shear stress exists in the steel, being a maximum directly over the crack, since the top chord area is in compression and the bottom chord in tension. The heel plate must resist the entire axial force of both member, causing these shear stresses. Since the members are very large and stiff, compared to the plate, which results in the shear stress being essentially uniform along the shear crack.

## Proposed Heel Joint Contact Stress Calculation Method

The direct stress, b, is found by dividing the axial force, c, by the "effective" contact area $A_{t.c.}$, ("effective" area means that the nails within 1/4" edge distance or 1/2" end distance, assumed too close to the crack to be useful, have not been counted).

The eccentric moment stress, c, is found by multiplying the force under consideration by the distance, e, to the opposite force, and dividing this quantity by the polar section modulus, $Z_p$.

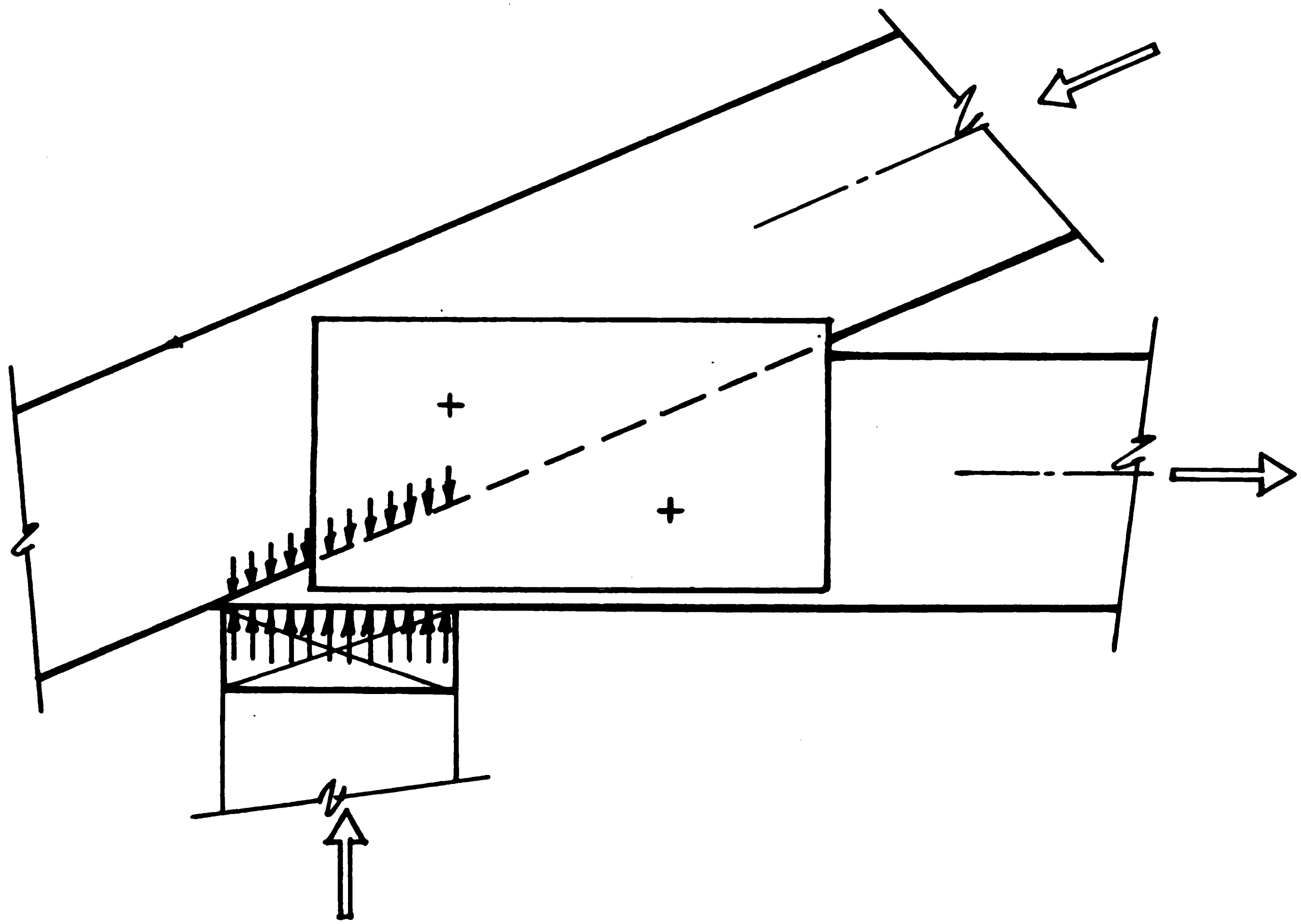


Figure 5. Vertical forces taken by wood-to-wood bearing.

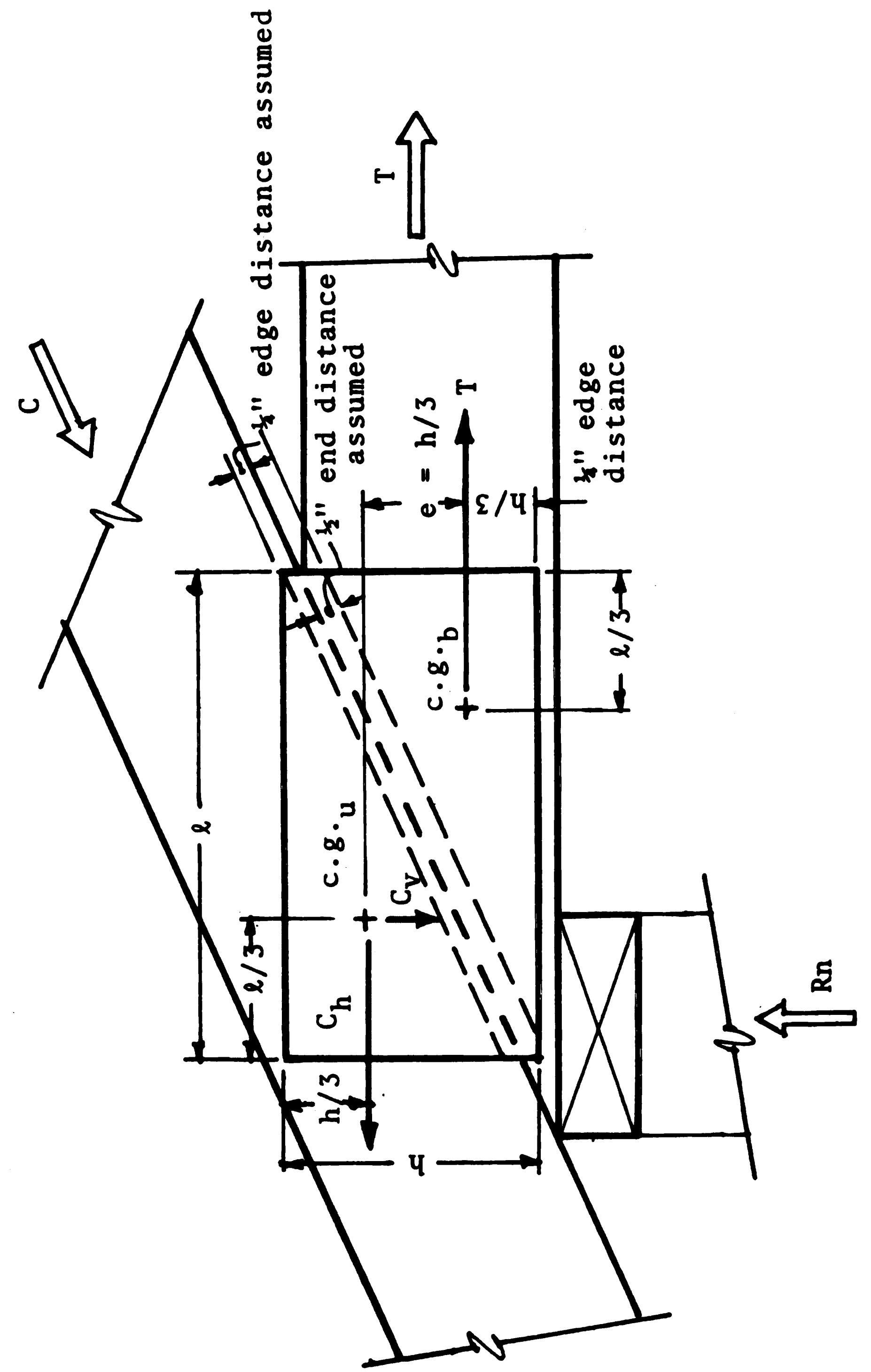



Figure 6. Rotational moment.

The direct stress, b, and the eccentric moment stress, c, must be added vectorially, $b \leftrightarrow c = a$. The resultant, a, therefore depends on the angle, A, between "b" and "c," as well as on their relative quantities. This vectorial addition may be performed by the use of the Cosine Law, $a^2 = b^2 + c^2 - 2bc \cos A$. By noting which direction the vectors "b" and "c" point with respect to each other at each corner, the critical corner can be located so the Cosine Law solution need be applied only once, instead of at all four corners. Normally, the critical corner will be the outermost top chord corner, due to its having the largest angle, A, between "b" and "c" because of the effect of the top chord slope. See Figure 7.

## Comparison of Existing Heel Joint Analysis Methods

There are several alternate procedures for determining heel joint contact shear stress, as described below:

### General Method

The general requirement of heel joint analysis is that the connections be designed to provide adequate capacity for the direct axial forces at the joint involved. Normally the effects of eccentricity would be neglected by most engineers not familiar with the FHA or TPI requirements mentioned in the Review of Literature.

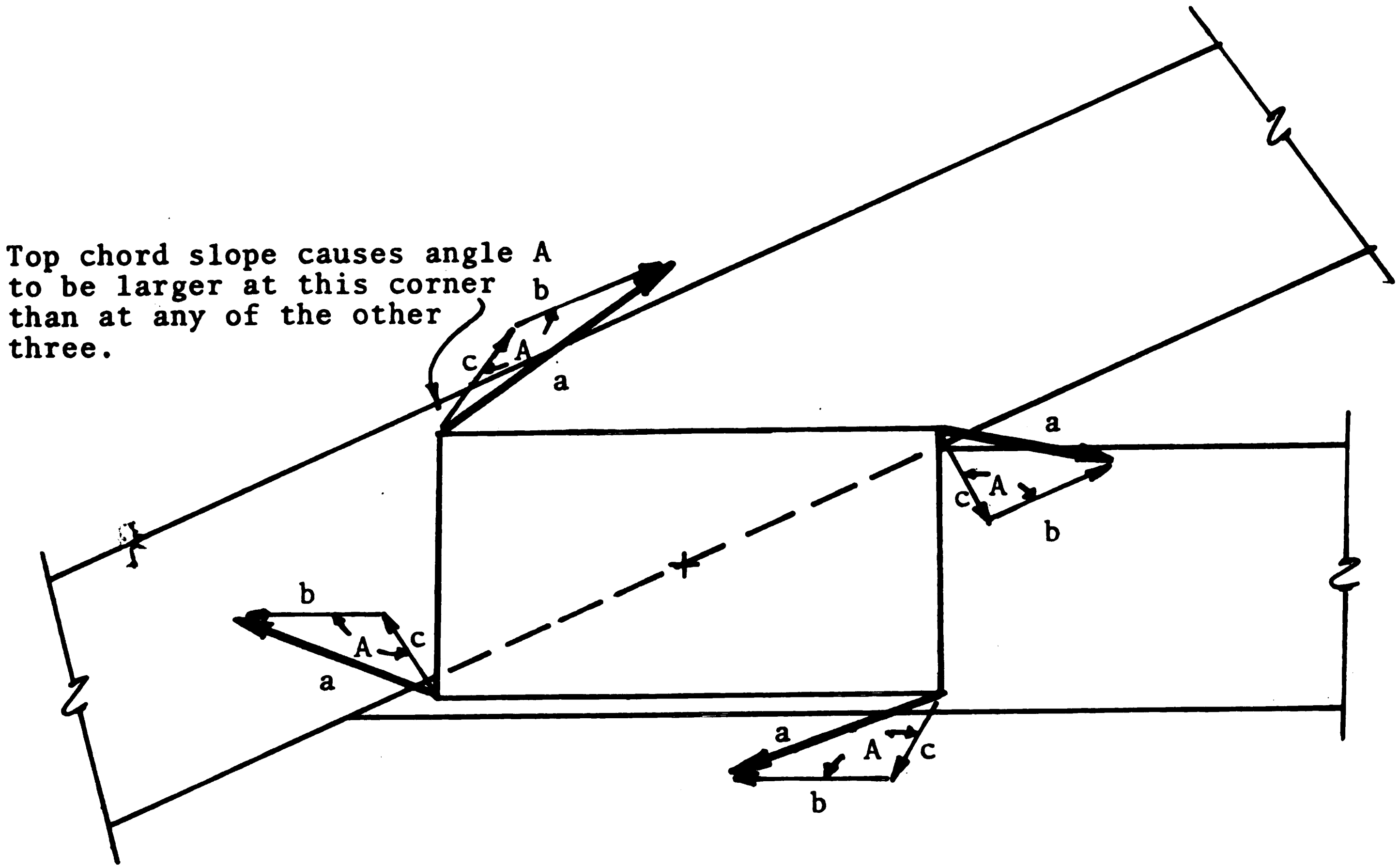



Figure 7. Vector addition for combined stress.

TPI Method

The Truss Plate Institute requires, in their specification, TPI-68 that:

> To allow for moment effects at the heel joint, design the heel plate to have sufficient capacity to withstand the direct axial stress of the top and bottom chords by their respective nail, tooth, or plug groups, with the following reductions in allowable nail, tooth, or plug load:
>
> | | |
> |---|---|
> | Under 3/12 slope | 85% of allowable |
> | 3/12 to less than 4/12 slope | 80% of allowable |
> | 4/12 to less than 5/12 slope | 75% of allowable |
> | 5/12 to and including 5½/12 slope | 70% of allowable |
> | Over 5½/12 slope | 65% of allowable |

FHA Method

FHA requires that the eccentric moment be found by multiplying the net reaction, $R_n$, at the support, by the distance, e, measured from the intersection of center-lines of the top and bottom chord to the centroid of the connector plate. Then eccentric moment stress is added vectorially to direct axial stress to determine the critical stress. See Figure 8.

Proposed Method

It is proposed that the eccentric moment be computed by using the bottom chord axial tension force, T, multiplied by the vertical distance, e, between the centroid, $c.g._b$, of the bottom chord contact area and the centroid, $c.g._u$, of the upper chord contact area. This eccentric moment results in an eccentric stress that must be added vectorially to the axial stress to obtain the critical stress.

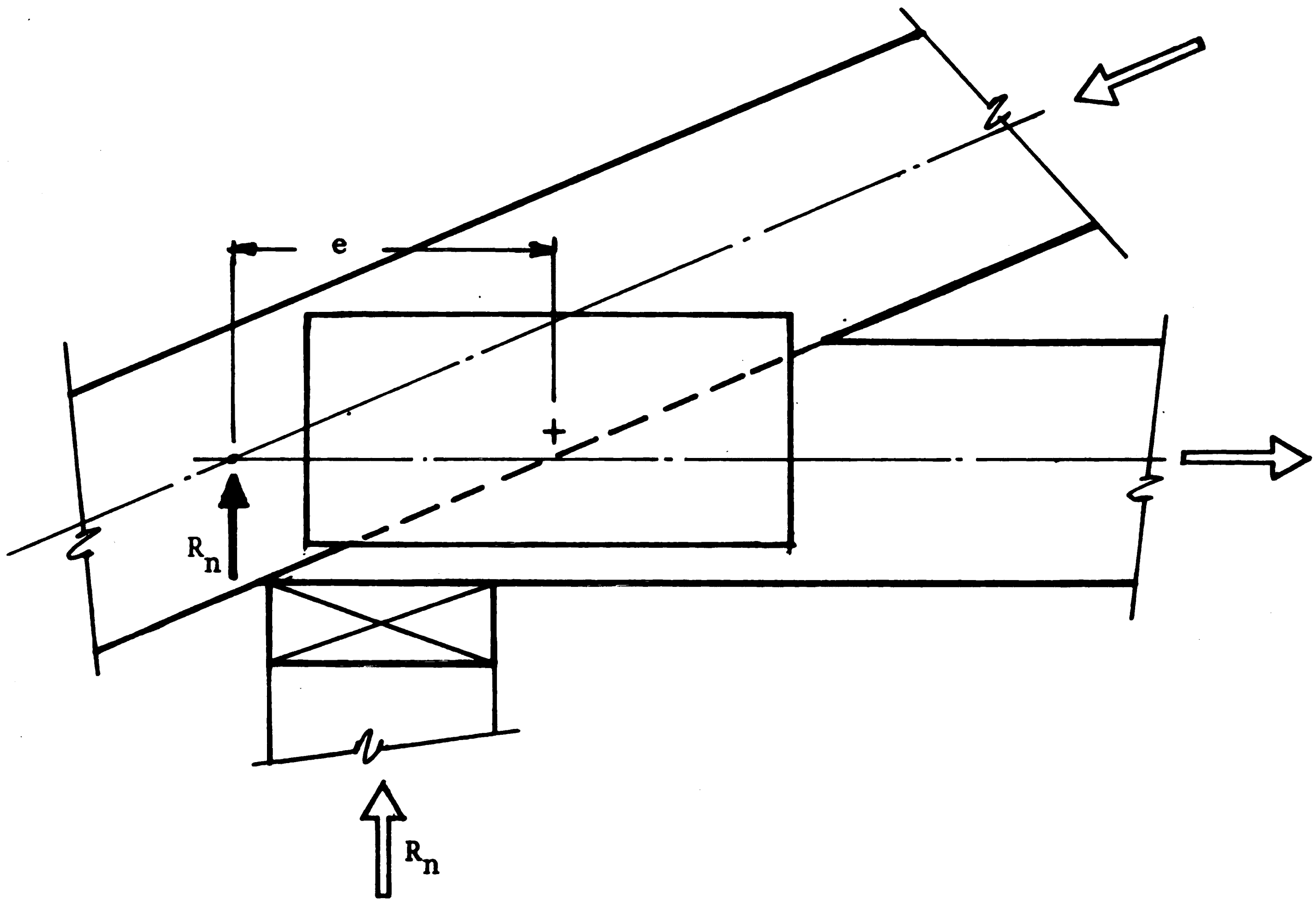



Figure 8. FHA eccentricity analysis.

The proposed method has several advantages:

a. It includes the effect of eccentricity; an improvement over the "general method."

b. It includes, as does the FHA method, the increase in rotational resistance of larger plates through their vastly increased polar section moduli; an improvement over the TPI method which has fixed percentage factors based entirely on slope, rather than plate size.

c. It considers an eccentric moment that is not affected by the size of the members, whereas the FHA method results in a much larger moment if the top chord is larger than the bottom chord, or a somewhat smaller moment if the bottom chord is larger than the top chord. Since the axial forces are dependent on pitch, span, configuration of webs, and loads, but are not affected by member size, it would seem that the eccentric moment should not be affected by differences in the top vs. bottom chord member size. For example, using the FHA analysis, assume a truss is designed with a 2"x6" top chord but a 2"x4" bottom chord and an appropriately selected heel plate size. If the design is changed to a 2"x6" bottom chord (usually a stronger, more expensive truss), the FHA analysis permits a smaller heel plate than with the 2"x4" bottom chord, due to the reduction in the distance from the plate centroid to the intersection of member center lines.

Typical Calculations

Typical heel joint calculations shown here are all for the same plate, 3-11/16" x 9", shown in Figure 9. They give a comparison of the different methods. A further comparison of 3"x5", 3"x8", and 5"x5" plates is given in Table 1.

General method:

$$b = \frac{C}{A_{t.c.}} = \frac{3{,}160 \text{ lbs.}}{2 \times 13.25 \text{ in.}^2} = 119 \text{ psi}$$

TPI method:

$$b = \frac{C}{A(\text{gross}) \times 75\%} = \frac{3{,}160 \text{ lbs.}}{33.2 \text{ in.}^2 \times 0.75} = 127 \text{ psi}$$

FHA method:

$$R_n = 1{,}000 \text{ lbs.} \qquad e = 6\tfrac{1}{4}"$$

$$b = \frac{3{,}160 \text{ lbs.}}{2 \times 16.6 \text{ in.}^2} = 95 \text{ psi}$$

$$c = \frac{R_n e}{2Z_p} = \frac{1{,}000 \text{ lbs.} \times 6.25 \text{ in.}}{2 \text{ plates} \times 54 \text{ in.}^3 \text{ each}} = 58 \text{ psi}$$

$$\angle A = 22.3^\circ \text{ (plate)} + 90^\circ + 18.4^\circ \text{ (4/12 slope)}$$

$$= 130.7^\circ$$

$$\cos A = \cos 130.7 = -\sin(130.7^\circ - 90^\circ) = -0.65$$

Cosine Law: $a^2 = b^2 + c^2 - 2bc \cos A$

$$= (95)^2 + (58)^2 - 2(95)(58)(-0.65)$$

$$= 19{,}570 \text{ (psi)}^2$$

$$a = 140.4 \text{ psi}$$

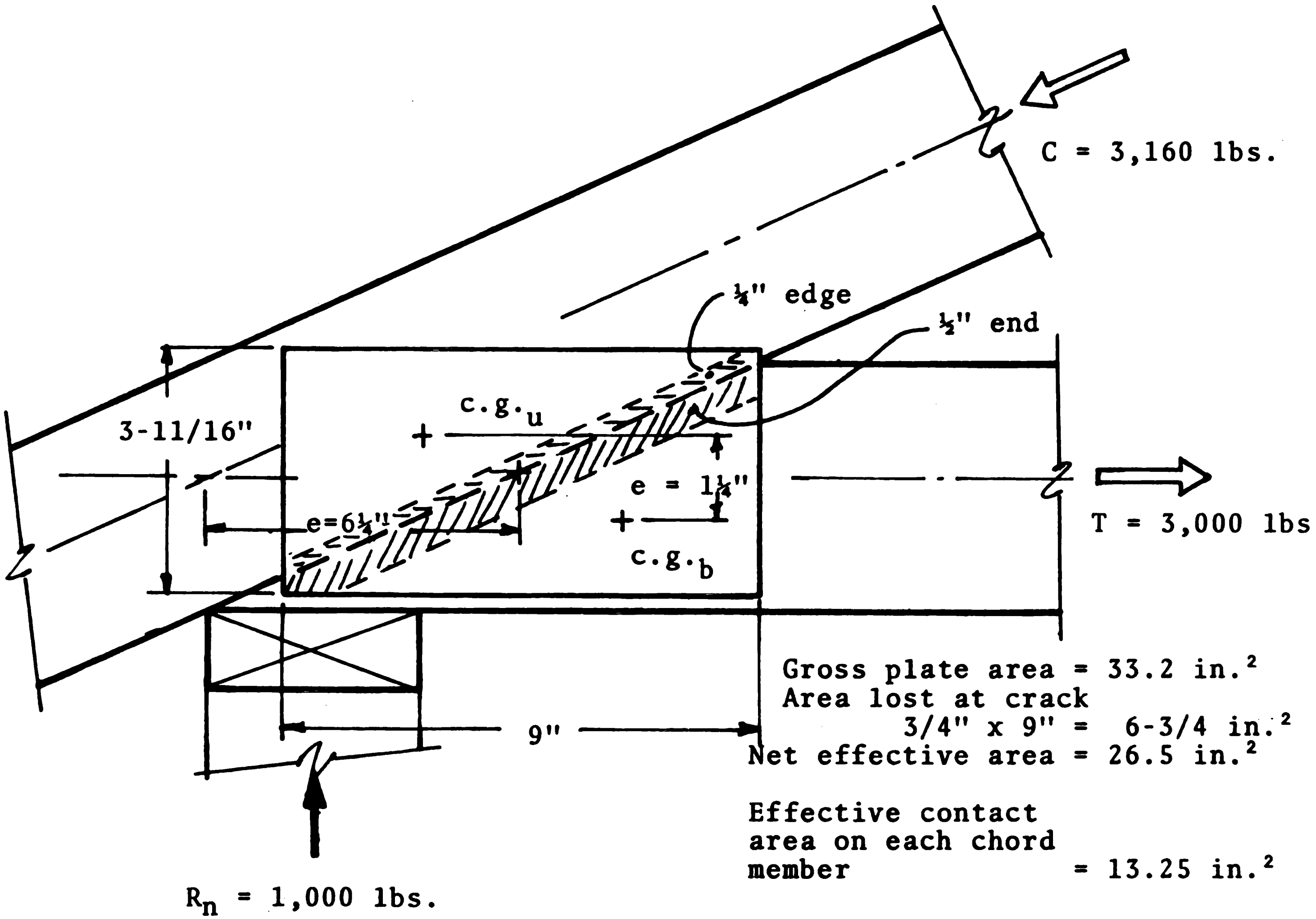
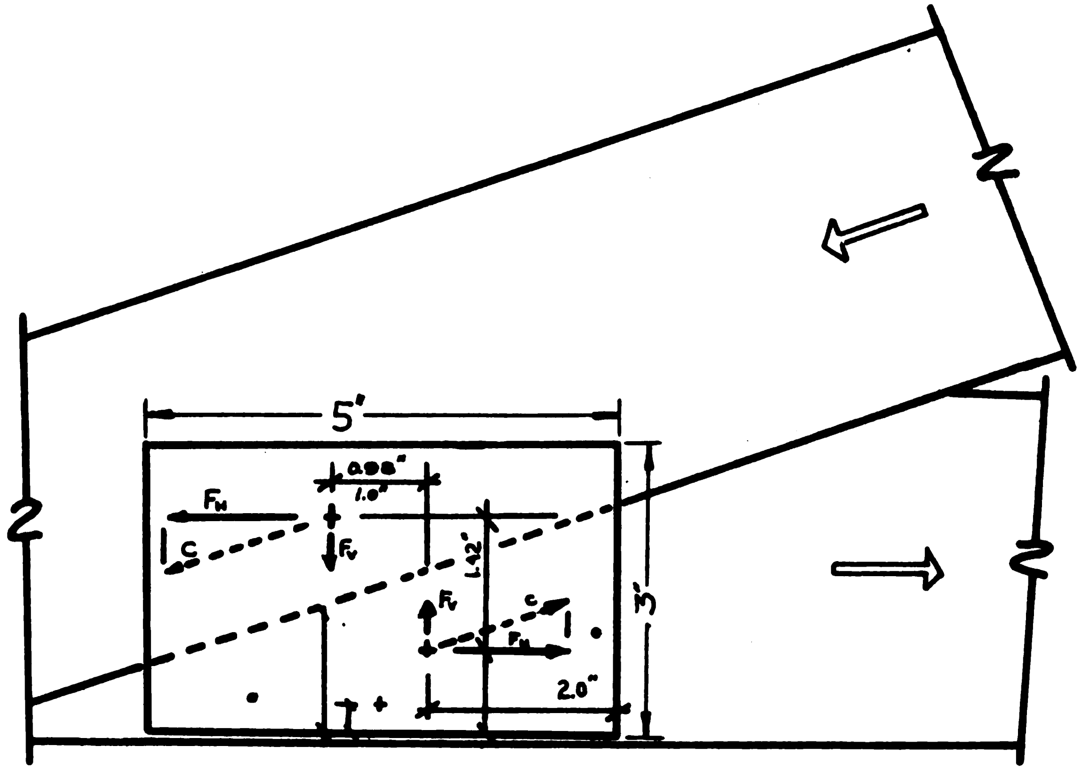



Figure 9(a). Typical Heel Plate Contact Stress Calculations for 3-11/16"x9" Plate.




Try C = 3,000 lbs. (top chord force)

$$M = \frac{3{,}000}{1.055} \times 1.42'' + \frac{3{,}000}{1.055} \times \frac{4}{12} \times 0.98''$$

$$M = 4040 + 930 = 4970 \text{ lb.in.}$$

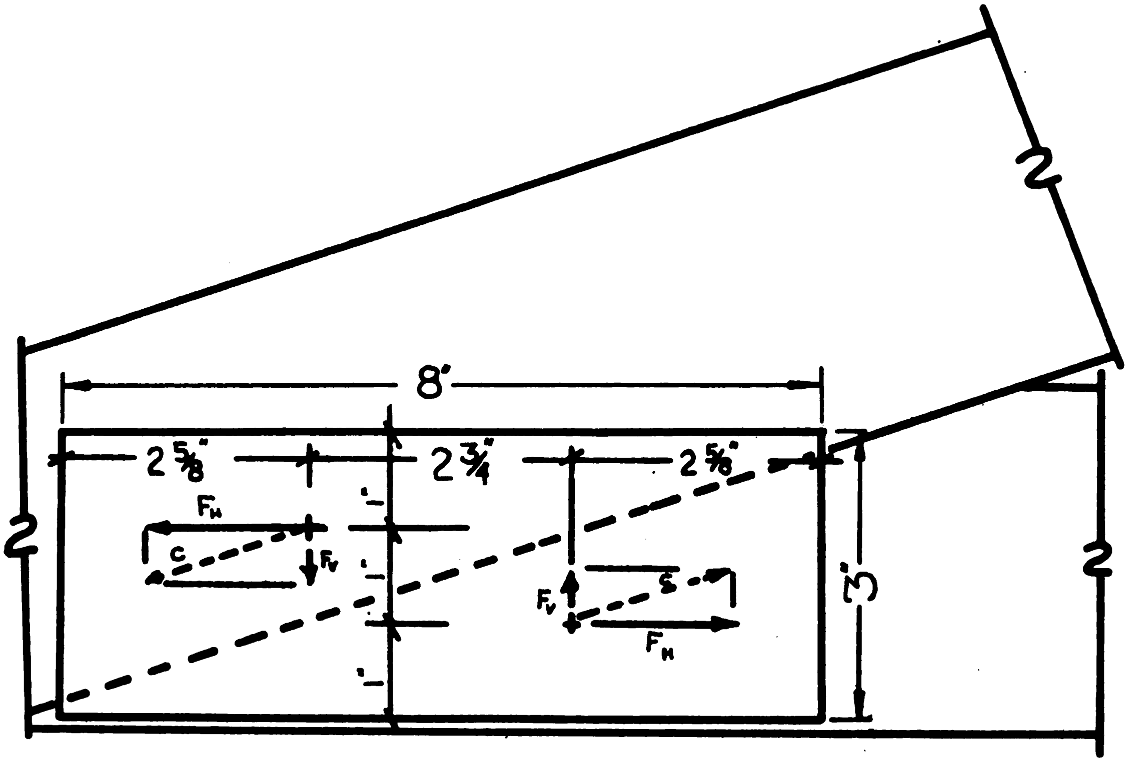
Combined stress equation (FHA)

$$\frac{P}{2A} + \frac{M}{2S} = \frac{3{,}000\#}{2 \times \frac{1}{2} \times 3 \times 5} + \frac{4040\#''}{2 \times 14.6 \text{ in.}^3} + \frac{930}{2 \times 14.6}$$

$$= 200 + 138 + 31.8 = 369.8 \text{ psi}$$

The direct stress is 200 psi and the torsional moment adds 85% to total 370 psi.

Figure 9(b). Typical Heel Plate Contact Stress Calculations for 3"x5" Plate.




Try C = 4,800 lbs. (top chord force)

$$M = \frac{4,800}{1.055} \times 1'' + \frac{4,800}{1.055} \times 4 \times 1.00''$$

$$M = 4,500 + 1,517 = 6,067 \text{ lb.in.}$$

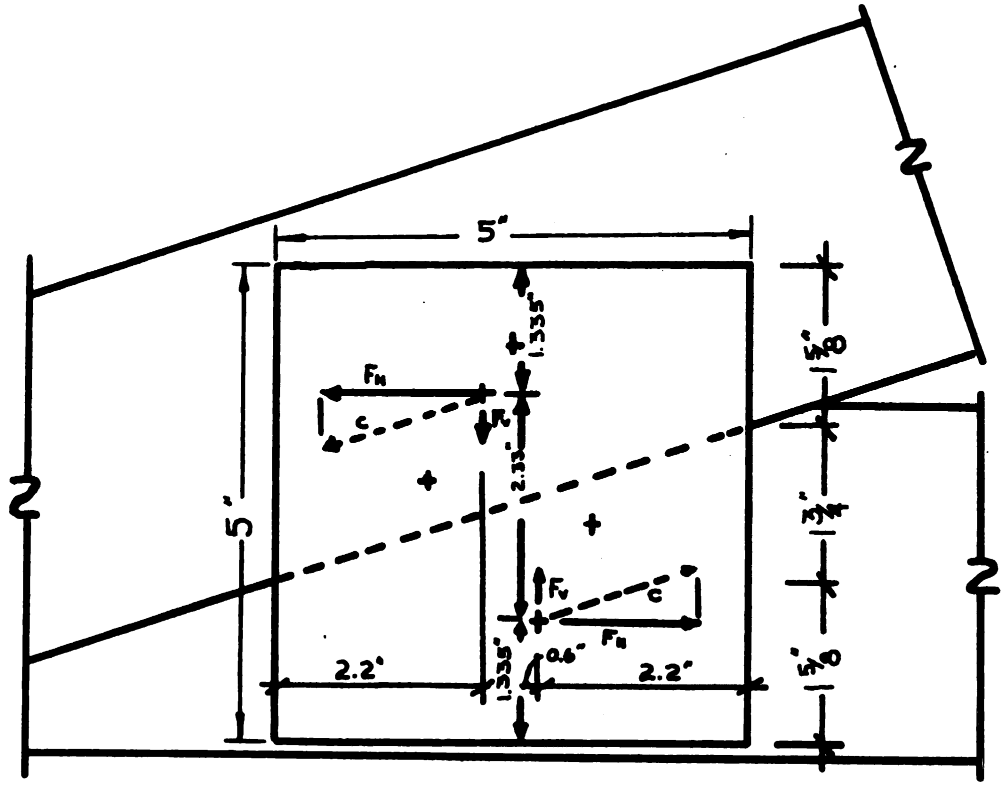
Combined stress

$$\frac{P}{2A} + \frac{M}{2S} = \frac{4,800 \text{ lbs.}}{2 \times \frac{1}{2} \times 3 \times 8} + \frac{4,550 \text{ lb.in.}}{2 \times 34.16 \text{ in.}^3} + \frac{1,517}{2 \times 34.16}$$

$$= 200 + 66.5 + 22.2 = 288.7 \text{ psi}$$

The direct stress is 200 psi and the torsional moment adds 44% to total 288 psi.

Figure 9(c). Typical Heel Plate Contact Stress Calculations for 3"x8" Plate.




$$S_p = \frac{bd}{6}\sqrt{b^2 + d^2} = 29.45 \text{ in.}^3$$

Try C = 5,000 lbs. (top chord force)

$$M = \frac{5{,}000}{1.055} \times 2.33'' + \frac{5{,}000}{1.055} \times \frac{4}{12} \times 0.6'' = 11{,}050 + 950$$

Combined stress:

$$\frac{P}{2A} + \frac{M}{2S} = \frac{5{,}000}{2 \times \frac{1}{2} \times 5 \times 5} + \frac{11{,}050}{2 \times 29.45} + \frac{950}{2 \times 29.45}$$

$$= 200 \text{ psi} + 188 + 16 = 404 \text{ psi}$$

The direct stress is 200 psi but the torsional moment adds 102% to total 404 psi.

Figure 9(d). Typical Heel Plate Contact Stress Calculations for 5"x5" Plate.

Proposed method:

$$b = \frac{C}{A_{net}} = \frac{3{,}160 \text{ lbs.}}{2 \times 13.25 \text{ in.}^2} = 119 \text{ psi}$$

$$c = \frac{3{,}000 \text{ lbs.} \times 1.25 \text{ in.}}{2 \times 54 \text{ in.}^3 \text{ each}} = 34.7 \text{ psi}$$

Cosine Law:

$$a^2 = (119)^2 + (34.7)^2 - 2(119)(34.7)(-0.65)$$

$$a = 143 \text{ psi}$$

Shear stress:

Assume the critical shear section is approximately

50% holes: $S_s = \dfrac{C}{\cancel{2}l_d t \cancel{50\%}}$

$$= \frac{3{,}160 \text{ lbs.}}{9'' \times \dfrac{\sqrt{(4)^2 + (12)^2}}{12} \times 0.035 \text{ in.}}$$

$$= 9{,}550 \text{ psi}$$

where $l_d$ = length of plate along shear line

$t$ = thickness of plate

A comparison of these four theoretical heel joint calculation methods for 3"x5", 3"x8", and 5"x5" heel plates (See Figures 9(b), 9(c), and 9(d)) yielded the results shown in Table 1. These three plate sizes were later studied experimentally, too.

## Calculation of Tensile Stresses within the Bottom Chord Contact Area

### Assumptions

It is assumed that the plate is positioned parallel to the bottom chord, with equal "effective" teeth into both

Table 1. Comparison of Heel Joint Calculation Methods for 3"x5", 3"x8", and 5"x5".

| | | Critical Contact Area Stress (psi) | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | FHA Method | | Proposed Method | |
| Heel Plate Size | Assumed Top Chord Force (lbs.) | General Method P/A | TPI P/.75A | Eccentric Moment (lb.in.) | Resultant Stress | Eccentric Moment (lb.in.) | Resultant Stress |
| 3"x5" | 3,000 | 200 | 266.7 | 4,990 | 348 | 4,040 | 323 |
| 3"x8" | 4,800 | 200 | 266.7 | 7,990 | 289 | 4,500 | 248 |
| 5"x5" | 5,000 | 200 | 266.7 | 13,050 | 411 | 11,050 | 378 |

top and bottom chords, allowing 1/4" edge distance at top chord and 1/2" end distance (measure perpendicular to crack) for bottom chord, as shown hatched in Figure 10. Further, it is assumed that area within the crack allowance does not carry its share of tensile stress, except as required by shear from the adjacent areas.

## Notation

The numbers and letters on Figure 10 denote the following:

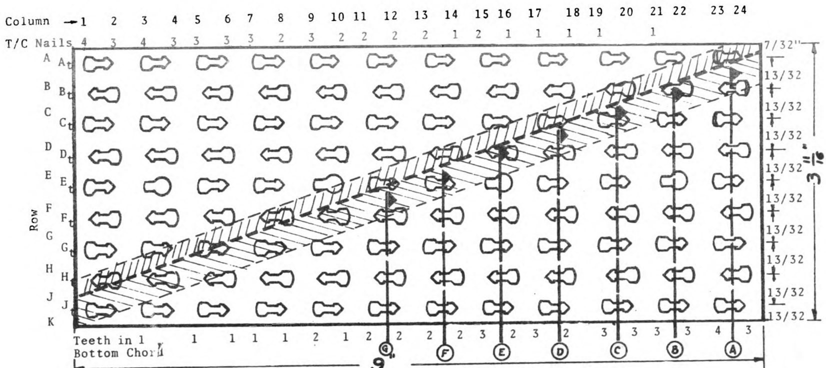
a. Numbers across top of the plate denote that column of teeth, the areas between columns being denoted 11-1/2 (for the group of isthmuses between 11 and 12), 14-1/2 (for the solid parent steel between 14 and 15), etc. Note: unless specifically noted, the numbers refer only to the top chord portion of the column, or bottom chord portion, rather than entire column.

b. Letters down the side mean the strips (or isthmus lines) between holes, and letters with the "T" subscript denote the rows of teeth.

## Shear Stress Calculations

The following steps were taken to arrive at shear stress:

a. Neglecting the effects of eccentricity, the direct force (3,000 lbs.) may be divided by the total number of teeth (2 sides x 44 teeth per side), 88, to get the axial load per tooth = 3000/88 = 34.1 lb.




Net tensile area per isthmus: 13/32" x 0.036" x 50% = 0.0073 in.$^2$

Net shear area per row: 3/8" x 0.036" = 0.0135 in.$^2$

Shear area converted to equivalent tensile area: 0.0135 in.$^2$ x 2/3 = 0.0090 in.$^2$

Figure 10. Typical Heel Plate for Tensile and Shear Calculations.

b. Assume uniform shear along the crack line; which is assumed further to have only 50% effective area (the other 50% holes). The shear per lineal inch will be $\frac{3{,}160 \text{ lbs.}}{9\frac{1}{2}'' \times 2 \text{ sides} \times 50\%} = 332$ lbs./in.

(166 lbs./in. = Gross Shear).

c. Assume 50% net tensile area at all sections with teeth cut out.

d. Assume allowable shear stress is 2/3 of allowable tension stress, and that the net shear area is 2/3 as effective, per inch, as the net tension area due to this 2/3 relationship.

e. Tension section A-A (3 effective teeth @ 34.1 lbs. per tooth,

$\{(7 \times 13/32'') + 6/32''\} \times 0.036'' \times 50\% = 0.054 \text{ in.}^2$

net section in tension, 3/16" net shear line length.

f. Section A-

$$\frac{3 \text{ teeth} \times 34.1 \text{ lb./each}}{(7\frac{1}{2} \text{ tensile strips @ } 0.0073 \text{ in.}^2) + 0.0045} =$$

$= 1{,}730$ psi

Section B-

$$\frac{10 \text{ teeth} \times 34.1 \text{ lb.}}{(6\frac{1}{2} \text{ strips} \times 0.0073) + (1\frac{1}{2} \times 0.009)} = 5{,}600 \text{ psi}$$

Section C-

$$\frac{16T \times 34.1 \text{ lb.}}{(6 \times 0.0073) \times (2\frac{1}{2} \times 0.009)} = 8{,}240 \text{ psi}$$

Section D-

$$\frac{21 \times 34.1}{(5\frac{1}{2} \times 0.0073) \times (3\frac{1}{2} \times 0.0009)} = 10{,}000 \text{ psi}$$

Section E-

$$\frac{26 \times 34.1}{(4\frac{1}{2} \times 0.0073) + (4\frac{1}{2} \times 0.009)} = 12{,}100 \text{ psi}$$

Section F-

$$\frac{30 \times 34.1}{(4 \times 0.0073) + (5\frac{1}{2} \times 0.009)} = 13{,}000 \text{ psi}$$

Section G-

$$\frac{34T \times 34.1}{(3\frac{1}{2} \times 0.0073) + (6\frac{1}{2} \times 0.009)} = 13{,}800 \text{ psi}$$

Improvements to Calculations

Since the "slip" is uniform along the shear line (crack between the top and bottom chord), the shear stress must also be uniform along the crack, rather than different in each section as indicated in the preceding set of computations. If the shear stress is in fact uniform, then the amount of shear force at each strip may be subtracted from the tooth value tensile force to determine the effective tensile force to be carried by net tensile section of the isthmuses between the holes. This concept is used in the following calculations for the same sections used before:

Shear force per strip = 332 lbs./in. (net x 3/8" strip)

= 125 lbs./strip

Section A-

$$\frac{3 \times 34.1 \text{ lb.} - \tfrac{1}{2} \times 125 \text{ lb.}}{7\tfrac{1}{2} \text{ strips} \times 0.0073 \text{ in.}^2} = 730 \text{ psi}$$

Section B-

$$\frac{341 \text{ lb.} - 1\tfrac{1}{2} \times 125 \text{ lb.}}{6\tfrac{1}{2} \times 0.0073 \text{ in.}^2} = 3{,}200 \text{ psi}$$

Section C-

$$\frac{545 \text{ lb.} - 2\tfrac{1}{2} \times 128}{6 \times 0.0073} = 5{,}300 \text{ psi}$$

Section D-

$$\frac{715 \text{ lb.} - 3\tfrac{1}{2} \times 125}{5\tfrac{1}{2} \times 0.0073} = 6{,}920 \text{ psi}$$

Section E-

$$\frac{886 \text{ lb.} - 4\tfrac{1}{2} \times 125}{0.0328} = 9{,}850 \text{ psi}$$

Section F-

$$\frac{1023 \text{ lb.} - 5\tfrac{1}{2} \times 125}{0.292} = 11{,}500 \text{ psi}$$

Section G-

$$\frac{1160 \text{ lb.} - 6\tfrac{1}{2} \times 125}{0.0256} = 13{,}550 \text{ psi}$$

## Buckling and Shear Stresses in the Steel

### Investigation of the Cause of Buckling

A small element centered over the shear line will be in a state of pure shear. The element may come from the area

$12\frac{1}{2}$ - $E_t$, or that vicinity, on the truss plate shown in Figure 10. Figure 11 is a blown-up view of this element.

Since pure shear can exist only in one particular plane through a two-dimensional element, there also exist tensile and compressive stresses on other planes through the point. The maximum and minimum normal (principal) stresses occur as shown in Figures 12(b) and 12(c) on planes that bisect the angles between the planes on which the given shearing stresses act, and these principal stresses are equal in magnitude to the shearing stresses. The shearing stresses on these $45^o$ (principal) planes are equal to zero.

The principal stresses at a point are used to compute the shearing stress as follows;

$$T_{max} = \frac{1}{2} (\sigma_{max} - \sigma_{min})$$

in which a principal stress is considered to be positive if it is a tensile stress and negative if a compressive stress. Furthermore, this maximum shearing stress occurs on each of the two planes that bisect the angles between the planes on which the maximum and minimum principal stresses occur.

Compressive buckling, applying this concept to the truss plate, is caused when the compressive stresses that result from the shear exceeds the Euler formula critical level. The direction of the buckling can be determined, prior to its occurrence, from the slope of the shear line, rotating $45^o$ to get to the maximum compressive stress.

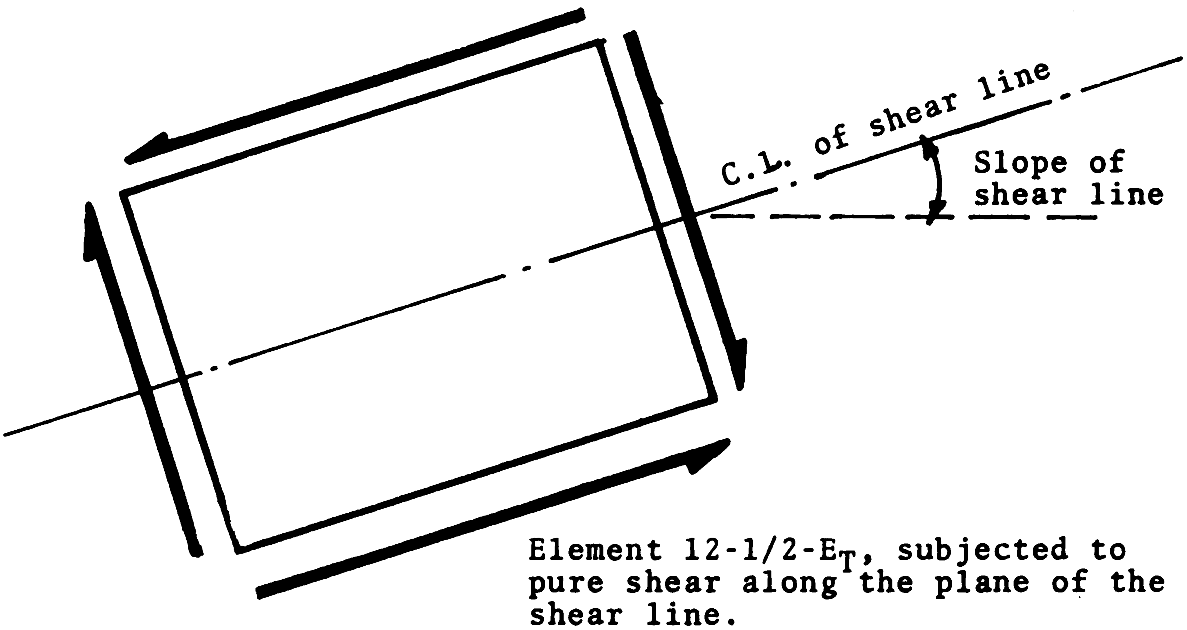
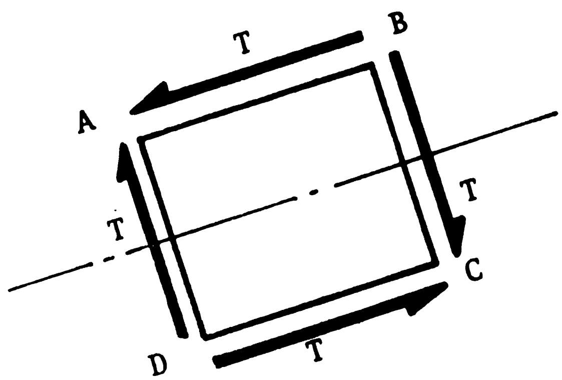
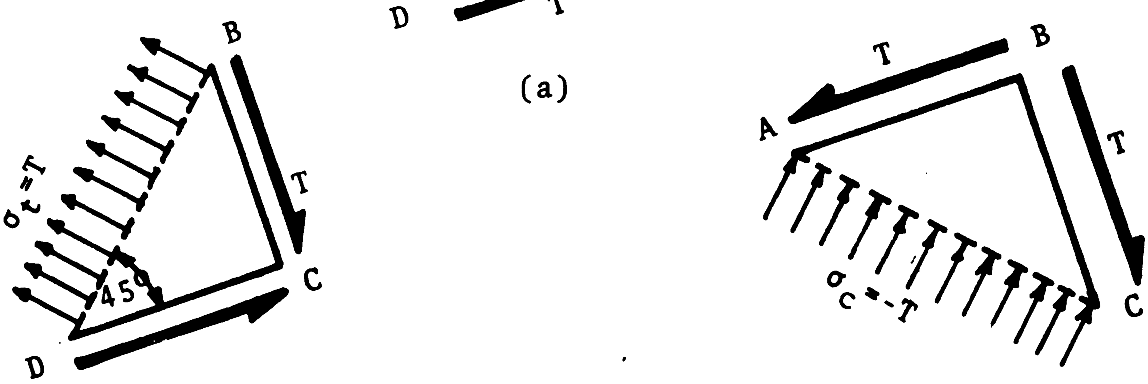



Figure 11. Element on shear line.




(a)




(b)

(c)

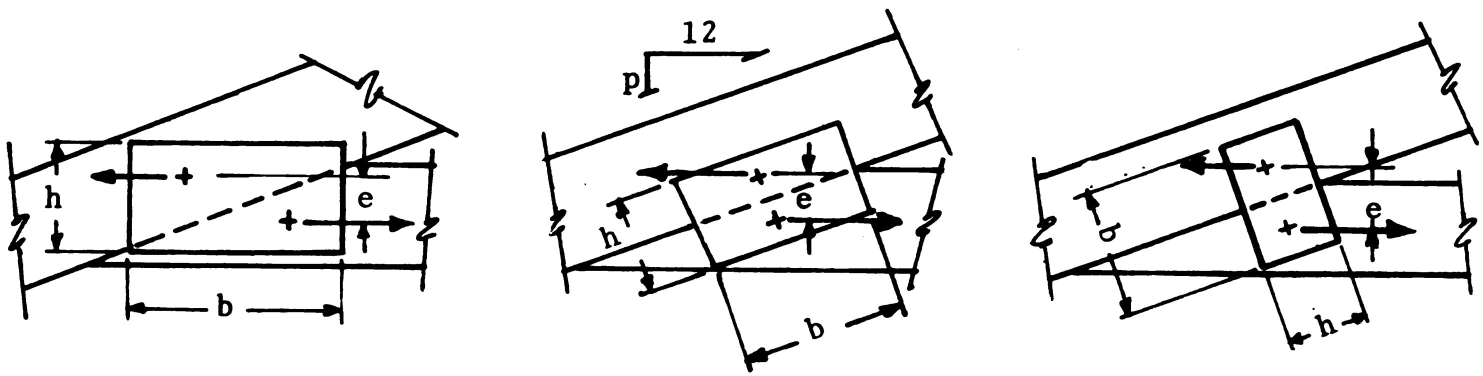
Figure 12. Free-body diagrams of shear element.

Discussion of Shear Stress in the Steel

The shear stress in the steel at the crack is uniform along the plate. If the truss plate is oriented parallel to the shear line and centered over it, the equal contact areas will provide an approximately equal number of effective teeth into each chord member. Since the "parallel to shear crack" orientation keeps the eccentricity of the two contact area centroids (see Figure 13) approximately the same as the "parallel to bottom chord" orientation, the effect of the eccentric moment will be minimized.

The "parallel to crack" orientation permits a more precise determination of cross-sectional area at the shear crack than does the "parallel to bottom chord" orientation. Since the tooth hole punch-outs are located in uniform rows (in one of the types of plates investigated), in line with each other, the net steel area parallel to either the "die direction" of the plate (b, which is always equal to some multiple of 2-1/4") or the "across die direction" (h, which is equal to 2-7/8", 3-11/16", or 5-5/16") is about 50% of surface area, at the critical section of that particular plate type.

For orientations of the plate other than "parallel to crack" or "perpendicular to crack," it is much more difficult to precisely compute effective net shear area, due to the unequal way the rows of teeth cross the shear line. This can be easily seen in Figure 10, which is shown for a 4 in 12 pitch.




$e = \frac{h}{3}$

Net shear area is over 50%

(a)

$e = \frac{h}{2} \frac{12}{\sqrt{p^2 + (12)^2}}$

Net shear area = 50%

(b)

$e = \frac{b}{2} \frac{12}{\sqrt{p^2 + (12)^2}}$

Net shear area = 50%

(c)

Figure 13. Eccentricity for alternate heel plate positions.

Since the net steel area exactly parallel or exactly perpendicular to the plate, measured along the critical line, is 50% (for this particular manufacturer's plates), no other plate orientation results in a shear line of less than 50%. For design purposes, it could be assumed that the net steel was 50% of the shear line length. This assumption is conservative.

Calculation of Shear Stress at Critical Section

The calculation of shear stress at the critical section uses the conventional formula:

$$S_s = \frac{C}{2(\text{plates})Lt\ 50\%(\text{net})} = \frac{C}{Lt}$$

where C = top chord compressive force (which acts parallel to the shear line)

L = length of plate along shear line

t = thickness of plate

From Figure 9:

$$S_s = \frac{3{,}160 \text{ lbs.}}{9'' \times \frac{\sqrt{(4)^2 + (12)^2}}{12} \times 0.035''} = 9{,}550 \text{ psi}$$

For a similar plate parallel to the crack:

$$S_s = \frac{3{,}160 \text{ lbs.}}{9'' \times 0.035''} = 10{,}050 \text{ psi}$$

This shear stress must be transferred through eleven full size steel sections, 0.375 in. x 0.035 in., and two half sections 0.1875 x 0.035 per plate. These sections are approximately 13/64 in. high (0.203 in.). See Figure 14.

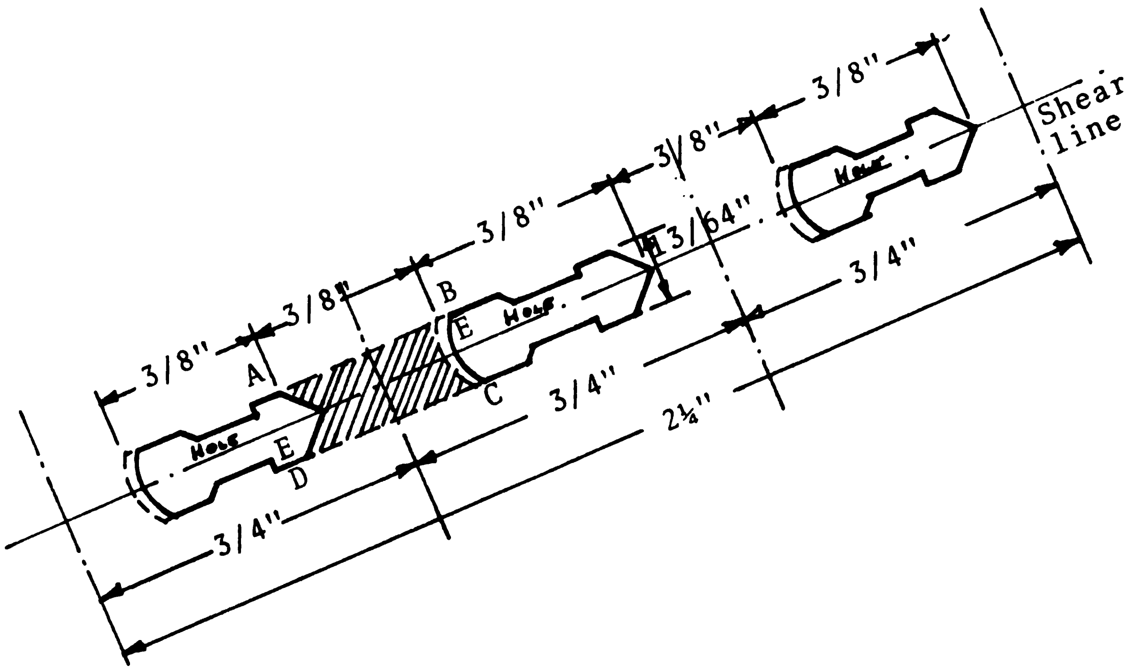



Figure 14. Critical shear stress (buckling) area.

$$S_s = \frac{P}{A} = \frac{131.8 \text{ lbs.}}{3/8'' \times 0.035''}$$

$$= 10{,}050 \text{ psi}$$

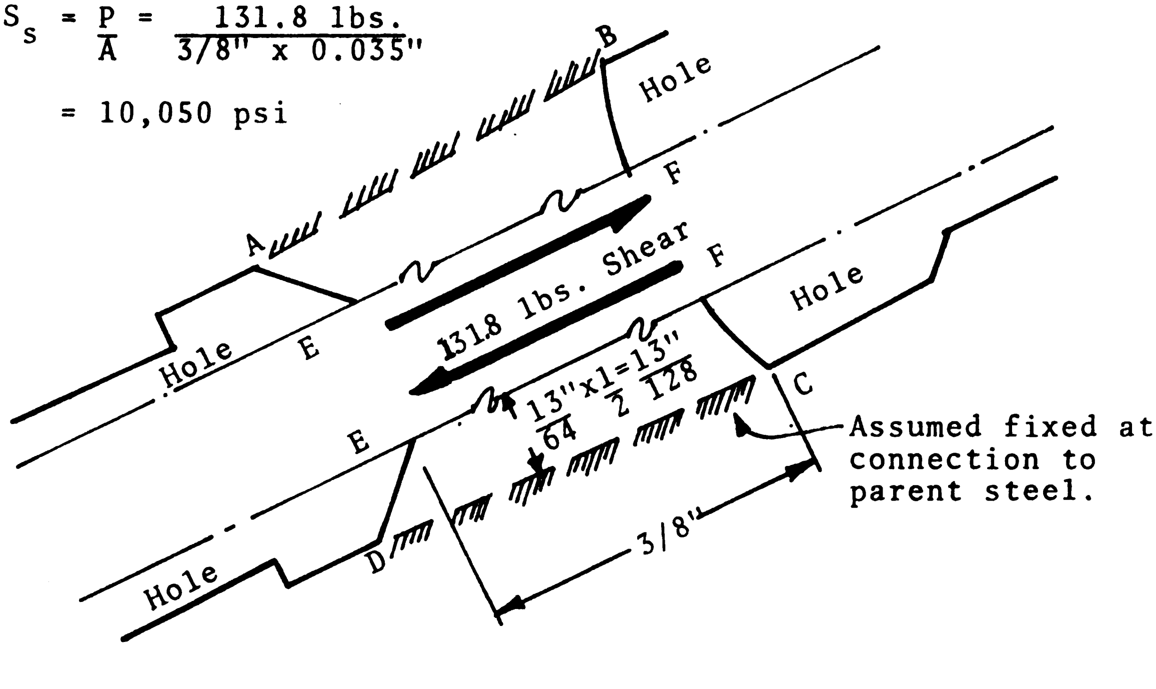



Figure 15. Free body diagram at shear line.

Analysis of Section A-B-C-D (shown hatched in Figure 14).

a. Shear force on line E-F =

$$\frac{3{,}160 \text{ lbs.}}{22 \text{ full sections} + 4 \text{ half sections}} = \frac{3{,}160}{22 + 2}$$

131.8 lbs. per section

b. Shear stress on a full section, such as E-F =

$$S_s = \frac{P}{A} = \frac{131.8 \text{ lbs.}}{3/8'' \times 0.035''} = 10{,}050 \text{ psi}$$

(This checks with the general calculations on the preceding page.)

c. From Figure 15, the stress at the line C-D can be computed by assuming that C-D-E-F is a short canti-level beam, 3/8" deep, 13/128" long, 0.035" thick, with a concentrated load of 1,318 lbs. at the end.

d. Section Modulus, S, at section C-D =

$$\frac{bd^2}{6} = \frac{(0.035 \text{ in.})(.375 \text{ in.})^2}{6} = 0.00082 \text{ in.}^3$$

e. $$f = \frac{M}{S} = \frac{Pl}{S} = \frac{131.8 \text{ lbs.} \times 13/128 \text{ in.}}{0.00082 \text{ in.}^3} = 16{,}300 \text{ psi}$$

# CHAPTER IV

# EXPERIMENTAL ANALYSIS

## General

A variety of heel plate sizes and shapes were used to test the proposed heel joint analysis method. A small 8'-0" test specimen and corresponding jig were developed and used to permit a large number of different specimens to be tested quickly and cheaply. Each type of plate could have several repetitions very easily to confirm results. A second set of 8'-0" specimens was built and matched to 24'-0" trusses to correlate the load-deflection data with full scale trusses. Lastly, Stress-Coat brittle lacquer was used to determine location and direction of the principal stresses.

## Test Specimens

The initial set of test specimens were built using 20 ga. TroyTrus plates of various sizes of the type shown in Figure 10. The lumber was all 1500f Industrial Light Framing West Coast Hemlock. All the plates and lumber were supplied, and specimens fabricated, by Troy Steel Corp. using a press assembly similar to that shown in Figure 19. All the lumber was kiln dried, but no attempt was made to determine moisture content or specific gravity. See Table 2.

Table 2. List of Specimens Tested.

| No. | Size | Mfr. | Lg. | Pitch | Species | Grade | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | 3 x 10 | TW | 8' | 4/12 | Doug. | 1500f | |
| 2 | 3 x 8 | " | " | " | " | " | 18 |
| 3 | 3.7 x 6.7 | TR | " | " | Hem. | " | |
| 4 | 5 x 7 | TW | " | " | Doug. | " | |
| 5 | 5 x 5 | " | " | " | " | " | 18 |
| 6 | 2.9 x 6.8 | TR | " | 6/12 | Hem. | 1500f | (1) |
| 7 | 3.7 x 4.5 | " | " | " | " | " | |
| 8 | " " | " | " | " | " | " | (1) |
| 9 | 2.9 x 9 | " | " | " | " | " | |
| 10 | 3.7 x 2.2 | " | " | " | " | " | (1) (5) |
| 11 | 2.9 x 6.8 | " | " | " | " | " | |
| 12 | 2.9 x 2.2 | " | " | " | " | " | (6) |
| 13 | 5.3 x 4.5 | " | " | 4/12 | " | " | |
| 14 | 3.7 x 6.8 | " | " | " | " | " | |
| 15 | 2.9 x 9 | " | " | " | " | " | |
| 16 | 5.3 x 4.5 | " | " | " | " | " | (1) |
| 17 | " " | " | " | " | " | " | (2) |
| 18 | " " | " | " | " | " | " | (3) |
| 19 | 5.3 x 6.8 | " | " | " | " | " | |
| 20 | 2.9 x 9 | " | " | " | " | " | |
| 21 | 3.7 x 6.8 | " | " | " | " | " | |
| 22 | 3.4 x 5.1 | DU | " | " | " | " | (3) |
| 23 | 3.7 x 6.8 | TR | " | " | " | " | |
| 24 | 5.3 x 6.8 | " | " | " | " | " | (3) |
| 25 | 3.7 x 4.5 | " | " | " | " | " | (2) (5) |
| 26 | 5.3 x 4.5 | " | " | " | " | " | (2) |
| 27 | 5.3 x 6.8 | " | " | " | " | " | |
| 28 | " " | " | " | " | " | " | |
| 29 | 3.7 x 6.8 | " | " | " | " | " | (1) |
| 30 | 2.9 x 9 | " | " | " | " | " | |
| 31 | 5.3 x 4.5 | " | " | " | " | " | (2) |
| 32 | | | | | | | |
| 33 | 3.4 x 5.1 | DU | " | " | " | " | |
| 34 | 2.9 x 9 | TR | " | " | " | " | |
| 35 | 3.7 x 6.8 | " | " | " | " | " | |
| 36 | 3.4 x 7.6 | DU | " | " | " | " | |
| 37 | " " | " | " | " | " | " | (3) |
| 38 | 3 x 5 | TW | " | " | Doug. | Const. | |
| 39 | " " | " | " | " | " | " | |
| 40 | 3 x 8 | " | " | " | " | " | |
| 41 | " " | " | " | " | " | " | |
| 42 | 5 x 5 | " | " | " | " | " | (7) |
| 43 | " " | " | " | " | " | " | (7) |
| 44 | 3 x 5 | " | 24' | " | " | " | |
| 45 | " " | " | " | " | " | " | |
| 46 | 3 x 8 | " | " | " | " | " | |
| 47 | " " | " | " | " | " | " | |
| 48 | 5 x 5 | " | " | " | " | " | |

Table 2. (cont'd.)

| No. | Size | Mfr. | Lg. | Pitch | Species | Grade | Remarks |
|---|---|---|---|---|---|---|---|
| 49 | 5 x 5 | TW | 24' | 4/12 | Doug. | Const. | |
| 51 | 3 x 5 | " | 8' | " | Wh.Fir. | 1650f | |
| 52 | " " | " | " | " | " | " | |
| 53 | 3 x 8 | " | " | " | " | " | |
| 54 | " " | " | " | " | " | " | |
| 55 | 5 x 5 | " | " | " | " | " | |
| 56 | " " | " | " | " | " | " | |
| 57 | " " | " | " | " | Doug. | Stand. | |
| 58 | " " | " | " | " | " | " | |
| 59 | 3 x 5 | " | 24' | " | Wh.Fir. | | |
| 60 | " " | " | " | " | " | " | |
| 61 | 3 x 8 | " | " | " | " | " | |
| 62 | " " | " | " | " | " | " | |
| 63 | 5 x 5 | " | " | " | " | " | |
| 64 | " " | " | " | " | " | " | |
| 65 | 55/16x41/2 | TR | 8' | " | W.Hem. | " | (2) |
| 66 | 311/16x63/4 | " | " | " | " | " | |
| 67 | 311/16x41/2 | " | " | " | " | " | |
| 68 | " " | " | " | " | " | " | |
| 69 | 55/16x41/2 | " | " | " | " | " | (2) |
| 70 | " " | " | " | " | " | " | (2) |
| 71 | " " | " | " | " | " | " | (2) |
| 72 | 55/16x63/4 | " | " | " | " | " | (3) |
| 73 | " " | " | " | " | " | " | |
| 74 | " " | " | " | " | " | " | |
| 75 | " " | " | " | " | " | " | (1) |
| 76 | " " | " | " | " | " | 1500f | (1) |
| 77 | " " | " | " | " | " | " | (1) |
| 78 | 3 x 5 | TW | " | " | Doug. | 1500f | |
| 79 | " " | " | " | " | " | " | |
| 80 | " " | " | " | " | " | " | |
| 81 | " " | " | " | " | " | " | |
| 82 | " " | " | 24' | " | " | " | |
| 83 | " " | " | " | " | " | " | |
| 84 | " " | " | " | " | " | " | |
| 85 | " " | " | " | " | " | " | |
| 86 | 3 x 8 | " | 8' | " | " | " | (4) |
| 87 | " " | " | " | " | " | " | |
| 88 | " " | " | " | " | " | " | |
| 89 | " " | " | " | " | " | " | |
| 90 | 5 x 5 | " | " | " | " | " | |
| 91 | " " | " | " | " | " | " | |
| 92 | " " | " | " | " | " | " | |
| 93 | " " | " | " | " | " | " | |
| 94 | 3 x 8 | " | " | " | Wh.Fir. | 1500f | |
| 95 | " " | " | " | " | " | " | |
| 96 | " " | " | " | " | " | " | |
| 97 | " " | " | " | " | " | " | |
| 98 | 3 x 5 | " | " | " | Doug. | " | |

Table 2. (cont'd.)

| No. | Size | Mfr. | Lg. | Pitch | Species | Grade | Remarks |
|---|---|---|---|---|---|---|---|
| 99 | 3 x 5 | TW | 8' | 4/12 | Doug. | 1500f | |
| 100 | " " | " | " | " | " | " | |
| 101 | " " | " | " | " | " | " | (4) |
| 102 | " " | " | " | " | Wh.Fir. | " | |
| 103 | " " | " | " | " | " | " | |
| 104 | " " | " | " | " | " | " | |
| 105 | " " | " | " | " | " | " | |
| 106 | 5 x 5 | " | " | " | " | " | |
| 107 | " " | " | " | " | " | " | |
| 108 | " " | " | " | " | " | " | |
| 109 | " " | " | " | " | " | " | |

"Lg." in Table denotes length of test specimen.
"Mfr." in Table denotes manufacturer of truss plates as follows:

TW stands for TrusWal Systems
TR stands for Troy Steel Corporation
DU stands for Duratile.

Remarks"
(1) Plates parallel to crack
(2) Plates perpendicular to bottom chord
(3) Plates perpendicular to bottom crack
(4) Riehle testing machine
(5) Two plates each side
(6) Three plates each side
(7) Plates not impaled properly

The second set of test specimens, including 24'-0" trusses, were built using truss plates of 3"x5", 3"x8", and 5"x5" of a second type, shown in Figure 39. The lumber was of Coast Region Douglas Fir for one set, both 8'-0" specimens and matched 24'-0" trusses, and white fir for a second matched set, both 8'-0" and 24'-0". Truss plates of 20 gauge steel were applied without nails, using a roller press. Moisture content and specific gravity at time of test were determined for the top and bottom chords of each test specimen and are recorded in Table 3.

## Test Jigs

For the first series of tests, a small 8'-0" long test jig with single hand-pumped hydraulic cylinder (Blackhawk Mfg. Co., Milwaukee, Wis., 53227, Model R159 Porto-Power 10 ton capacity, 6" travel, 1.688" diameter ram with Model P76 pump) was built as shown in Figure 17. The actual jig is shown in Figure 20 with a test specimen in place.

For the second series of tests, a wall mounted full scale hydraulic test jig located in the Michigan Building Components plant on Decker Road, Walled Lake, Michigan, was used to test the 24'-0" trusses. It is shown in Figure 21.

For the third series of tests, an old Riehle Testing Machine located in the Forestry Building, Michigan State University, was used to test 8'-0" specimens. It is shown in Figure 22.

Table 3. Moisture Content and Specific Gravity.

| Spec. No. | Species | Test Wt. (g) | Oven Dry Wt. (g) | Water Displ. (cc) | Moisture Content (%) | Specific Gravity | Average Moisture Content (%) | Average Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| 38 B | Doug. | 78.12 | 64.26 | 132.5 | 21.6% | 0.485 | 20.15% | .5025 |
| 38 T | " | 80.28 | 67.65 | 130.0 | 18.7% | 0.520 | | |
| 39 B | " | 73.50 | 62.77 | 137.8 | 17.1% | 0.454 | 17.45% | .4415 |
| 39 T | " | 68.27 | 57.95 | 135.6 | 17.8% | 0.429 | | |
| 40 B | " | 86.66 | 73.18 | 132.0 | 18.4% | 0.553 | 18.45% | .5510 |
| 40 T | " | 80.08 | 67.61 | 123.3 | 18.5% | 0.549 | | |
| 41 B | " | 90.75 | 77.43 | 131.6 | 17.2% | 0.590 | 18.4 % | .567 |
| 41 T | " | 77.68 | 64.94 | 119.3 | 19.6% | 0.544 | | |
| 44 B | " | 78.61 | 67.16 | 133.7 | 17.1% | 0.502 | 17.30% | .4825 |
| 44 T | " | 79.68 | 67.78 | 146.4 | 17.5% | 0.463 | | |
| 45 B | " | 78.91 | 67.45 | 137.1 | 17.0% | 0.492 | 17.15% | .5110 |
| 45 T | " | 88.72 | 75.67 | 142.4 | 17.3% | 0.530 | | |
| 46 B | " | 91.03 | 78.00 | 145.2 | 16.7% | 0.538 | 19.35% | .605 |
| 46 T | " | 107.74 | 88.32 | 131.6 | 22.0% | 0.672 | | |
| 47 B | " | 67.35 | 58.08 | 132.2 | 15.9% | 0.440 | 16.70% | .458 |
| 47 T | " | 74.73 | 63.59 | 133.4 | 17.8% | 0.477 | | |
| 48 B | " | 72.43 | 61.72 | 125.5 | 17.4% | 0.492 | 17.8 % | .515 |
| 48 T | " | 95.32 | 80.70 | 150.0 | 18.1% | 0.538 | | |
| 49 B | " | 86.98 | 74.50 | 143.3 | 16.8% | 0.520 | 17.35% | .5475 |
| 49 T | " | 84.18 | 71.41 | 124.3 | 17.9% | 0.575 | | |
| 51 B | White | 72.95 | 61.61 | 133.8 | 18.4% | 0.461 | 19.0 % | .4165 |
| 51 T | " | 61.89 | 51.76 | 138.8 | 19.6% | 0.372 | | |
| 52 B | " | 69.52 | 59.94 | 142.7 | 16.0% | 0.420 | 16.9 % | .402 |
| 52 T | " | 62.07 | 52.71 | 137.4 | 17.8% | 0.384 | | |
| 53 B | " | 54.60 | 46.27 | 133.5 | 18.0% | 0.346 | 18.6 % | .405 |
| 53 T | " | 76.80 | 64.40 | 138.5 | 19.2% | 0.464 | | |
| 54 B | " | 63.37 | 54.55 | 148.3 | 16.2% | 0.367 | 16.2 % | .367 |
| 54 T | " | 69.83 | 60.20 | 137.8 | | | | |

Table 3. (cont'd.)

| Spec. No. | Species | Test Wt. (g) | Oven Dry Wt. (g) | Water Displ. (cc) | Moisture Content (%) | Specific Gravity | Average Moisture Content (%) | Average Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| 55 B | White | 63.57 | 54.37 | 135.8 | 16.9% | 0.401 | 18.2 % | 0.3795 |
| 55 T | " | 59.26 | 49.59 | 138.7 | 19.5% | 0.358 | | |
| 56 B | " | 57.22 | 49.41 | 143.7 | 15.8% | 0.346 | 16.95% | 0.392 |
| 56 T | " | 71.25 | 60.16 | 137.6 | 18.4% | 0.438 | | |
| 57 B | Doug. | 68.95 | 57.62 | 133.8 | 19.7% | 0.430 | 19.7 % | 0.484 |
| 57 T | " | | 67.80 | 132.4 | | 0.538 | | |
| 58 B | " | 80.76 | 67.00 | 132.7 | 20.5% | 0.504 | 20.6 % | 0.5135 |
| 58 T | " | 79.91 | 66.17 | 126.3 | 20.7% | 0.523 | | |
| 59 B | White | 76.39 | 62.90 | 179.4 | 21.5% | 0.351 | 20.15% | 0.3465 |
| 59 T | " | 65.24 | 54.90 | 160.1 | 18.8% | 0.342 | | |
| 60 B | " | 78.04 | 63.53 | 161.7 | 22.8% | 0.394 | 21.4 % | 0.380 |
| 60 T | " | 68.55 | 57.13 | 156.3 | 20.0% | 0.366 | | |
| 61 B | " | 87.01 | 72.16 | 181.8 | 20.5% | 0.398 | 19.55% | 0.406 |
| 61 T | " | 83.19 | 70.08 | 169.5 | 18.6% | 0.414 | | |
| 62 B | " | 86.01 | 70.27 | 166.5 | 22.4% | 0.422 | 20.2 % | 0.395 |
| 62 T | " | 63.73 | 53.72 | 184.2 | 18.7% | 0.368 | | |
| 63 B | " | 70.98 | 58.58 | 156.9 | 21.2% | 0.373 | 19.6 % | 0.405 |
| 63 T | " | 83.19 | 70.41 | 161.0 | 18.1% | 0.437 | | |
| 64 B | " | 77.45 | 63.82 | 168.2 | 21.4% | 0.379 | 19.6 % | 0.393 |
| 64 T | " | 74.50 | 63.20 | 155.1 | 17.8% | 0.407 | | |
| 78 B | Doug. | 104.05 | 85.12 | 167.5 | 22.2% | 0.508 | 19.8 % | 0.489 |
| 78 T | " | 94.10 | 80.21 | 170.7 | 17.5% | 0.470 | | |
| 79 B | " | 98.58 | 81.69 | 174.4 | 20.7% | 0.468 | 21.5 % | 0.533 |
| 79 T | " | 128.67 | 105.28 | 176.0 | 22.2% | 0.598 | | |
| 80 B | " | 80.51 | 68.80 | 171.5 | 17.2% | 0.401 | 23.3 % | 0.498 |
| 80 T | " | 129.51 | 100.15 | 168.2 | 29.3% | 0.595 | | |

Table 3. (cont'd.)

| Spec. No. | Species | Test Wt. (g) | Oven Dry Wt. (g) | Water Displ. (cc) | Moisture Content (%) | Specific Gravity | Average Moisture Content (%) | Average Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| 81 B | Doug. | 91.49 | 80.15 | 168.1 | 14.1% | 0.477 | 14.2 % | 0.502 |
| 81 T | " | 104.84 | 91.80 | 174.5 | 14.2% | 0.526 | | |
| 82 B | " | 70.87 | 61.42 | 129.0 | 15.4% | 0.476 | 15.0 % | 0.454 |
| 82 T | " | 65.72 | 57.40 | 132.8 | 14.5% | 0.432 | | |
| 83 B | " | 77.31 | 66.25 | 135.9 | 16.7% | 0.487 | 17.3 % | 0.519 |
| 83 T | " | 84.19 | 71.40 | 129.5 | 17.9% | 0.551 | | |
| 84 B | " | 78.97 | 66.74 | 125.6 | 18.3% | 0.531 | 18.2 % | 0.499 |
| 84 T | " | 73.77 | 62.51 | 133.8 | 18.0% | 0.467 | | |
| 85 B | " | 72.28 | 62.06 | 132.5 | 16.5% | 0.468 | 16.0 % | 0.479 |
| 85 T | " | 71.48 | 61.95 | 126.6 | 15.4% | 0.489 | | |
| 86 B | " | 76.22 | 62.52 | 114.8 | 21.9% | 0.545 | 22.8 % | 0.587 |
| 86 T | " | 93.01 | 75.21 | 119.8 | 23.7% | 0.628 | | |
| 87 B | " | 73.82 | 59.95 | 119.1 | 21.3% | 0.503 | 20.6 % | 0.504 |
| 87 T | " | 74.68 | 62.30 | 123.3 | 19.9% | 0.505 | | |
| 88 B | " | 72.81 | 59.06 | 127.4 | 23.3% | 0.464 | 22.3 % | 0.474 |
| 88 T | " | 77.23 | 63.68 | 131.6 | 21.3% | 0.484 | | |
| 89 B | " | 74.45 | 61.07 | 117.4 | 21.9% | 0.520 | 20.2 % | 0.543 |
| 89 T | " | 83.72 | 70.51 | 124.3 | 18.7% | 0.567 | | |
| 90 B | " | 73.79 | 60.28 | 122.2 | 22.4% | 0.493 | 19.8 % | 0.509 |
| 90 T | " | 81.42 | 69.39 | 132.2 | 17.3% | 0.525 | | |
| 91 B | " | 57.12 | 47.09 | 107.6 | 21.2% | 0.438 | 19.6 % | 0.462 |
| 91 T | " | 68.91 | 54.45 | 120.3 | 17.9% | 0.486 | | |
| 92 B | " | 59.51 | 49.40 | 103.6 | 20.4% | 0.477 | 18.0 % | 0.500 |
| 92 T | " | 70.73 | 61.18 | 116.9 | 15.6% | 0.523 | | |
| 93 B | " | 55.27 | 46.56 | 112.3 | 18.7% | 0.415 | 21.3 % | 0.440 |
| 93 T | " | 72.51 | 58.56 | 126.1 | 23.8% | 0.464 | | |
| 94 B | White | 62.10 | 54.68 | 135.1 | 13.5% | 0.405 | 13.5 % | 0.371 |
| 94 T | " | 48.32 | 42.59 | 126.3 | 13.5% | 0.337 | | |

Table 3. (cont'd.)

| Spec. No | Species | Test Wt. (g) | Oven Dry Wt. (g) | Water Displ. (cc) | Moisture Content (%) | Specific Gravity | Average Moisture Content (%) | Average Specific Gravity |
|---|---|---|---|---|---|---|---|---|
| 95 B | White | 63.63 | 55.43 | 126.9 | 14.8% | 0.437 | 14.7 % | 0.396 |
| 95 T | " | 51.22 | 44.70 | 125.4 | 14.6% | 0.356 | | |
| 96 B | " | 62.91 | 53.35 | 146.0 | 17.9% | 0.365 | 15.9 % | 0.355 |
| 96 T | " | 53.56 | 47.04 | 136.5 | 13.9% | 0.345 | | |
| 97 B | " | 57.10 | 48.59 | 125.8 | 17.5% | 0.386 | 15.4 % | 0.351 |
| 97 T | " | 42.97 | 37.92 | 120.1 | 13.3% | 0.316 | | |
| 98 B | Doug. | 85.89 | 65.04 | 131.6 | 32.1% | 0.494 | 27.8 % | 0.485 |
| 98 T | " | 77.97 | 63.12 | 132.5 | 23.5% | 0.476 | | |
| 99 B | " | 79.47 | 61.47 | 124.1 | 29.3% | 0.445 | 26.0 % | 0.453 |
| 99 T | " | 73.54 | 59.93 | 145.6 | 22.7% | 0.412 | | |
| 100 B | " | 103.00 | 77.91 | 142.2 | 32.2% | 0.548 | 29.1 % | 0.494 |
| 100 T | " | 68.28 | 54.20 | 123.0 | 26.0% | 0.441 | | |
| 101 B | " | 112.07 | 76.31 | 132.0 | 46.9% | 0.578 | 39.7 % | 0.571 |
| 101 T | " | 91.63 | 69.12 | 122.4 | 32.6% | 0.565 | | |
| 102 B | White | 61.01 | 53.21 | 132.5 | 14.7% | 0.402 | 16.9 % | 0.444 |
| 102 T | " | 70.32 | 59.06 | 121.5 | 19.1% | 0.486 | | |
| 103 B | " | 71.34 | 58.29 | 132.6 | 22.4% | 0.440 | 19.3 % | 0.38 |
| 103 T | " | 52.11 | 44.82 | 140.1 | 16.3% | 0.320 | | |
| 104 B | " | 61.18 | 54.15 | 153.4 | 13.0% | 0.353 | 13.2 % | 0.346 |
| 104 T | " | 56.09 | 49.47 | 145.8 | 13.4% | 0.339 | | |
| 105 B | " | 46.81 | 41.10 | 118.3 | 14.0% | 0.347 | 16.0 % | 0.359 |
| 105 T | " | 50.53 | 42.86 | 115.5 | 17.9% | 0.371 | | |
| 106 B | " | 54.40 | 47.92 | 145.9 | 13.5% | 0.328 | 14.7 % | 0.357 |
| 106 T | " | 58.68 | 50.69 | 131.3 | 15.8% | 0.386 | | |
| 107 B | " | 62.59 | 54.96 | 139.4 | 13.9% | 0.394 | 14.3 % | 0.398 |
| 107 T | " | 62.53 | 54.58 | 135.7 | 14.6% | 0.402 | | |
| 108 B | " | 50.73 | 44.92 | 132.5 | 12.9% | 0.339 | 14.7 % | 0.364 |
| 108 T | " | 57.63 | 49.50 | 127.3 | 16.4% | 0.389 | | |
| 109 B | White | 57.58 | 51.00 | 124.7 | 12.9% | 0.409 | 13.8 % | 0.400 |
| 109 T | " | 54.68 | 47.67 | 121.7 | 14.7% | 0.392 | | |

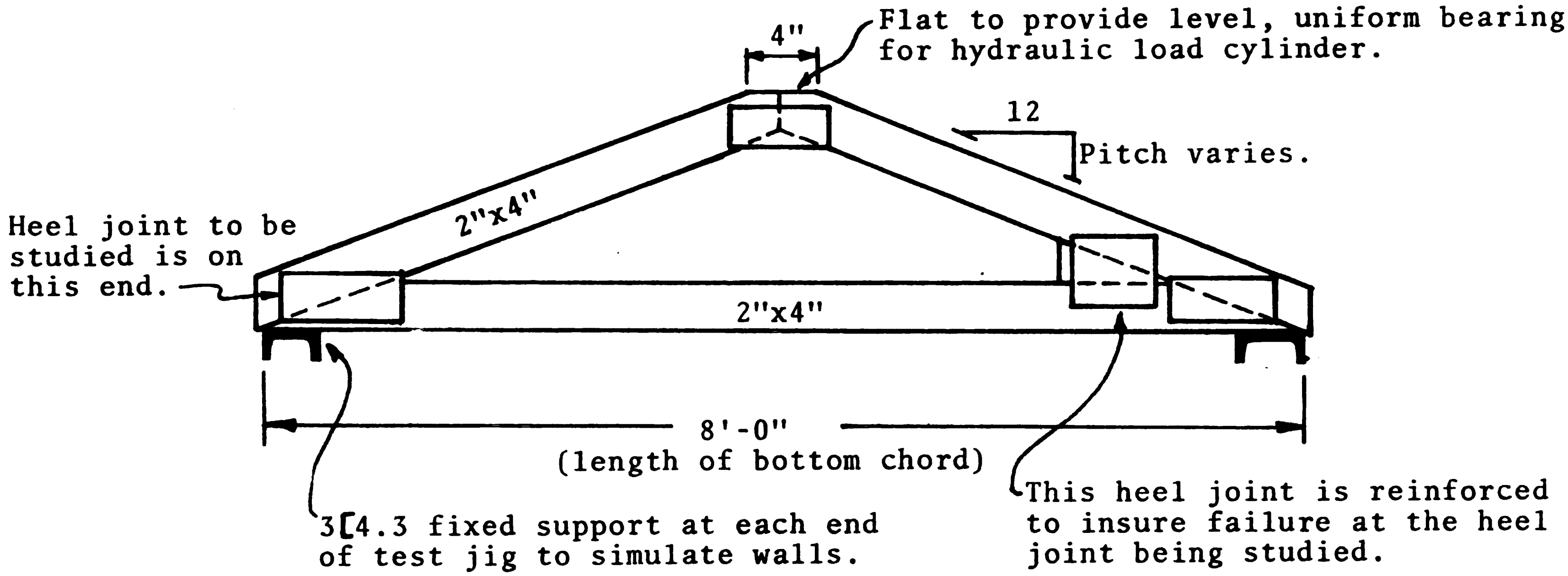



Figure 16. 8'-0" test specimen.

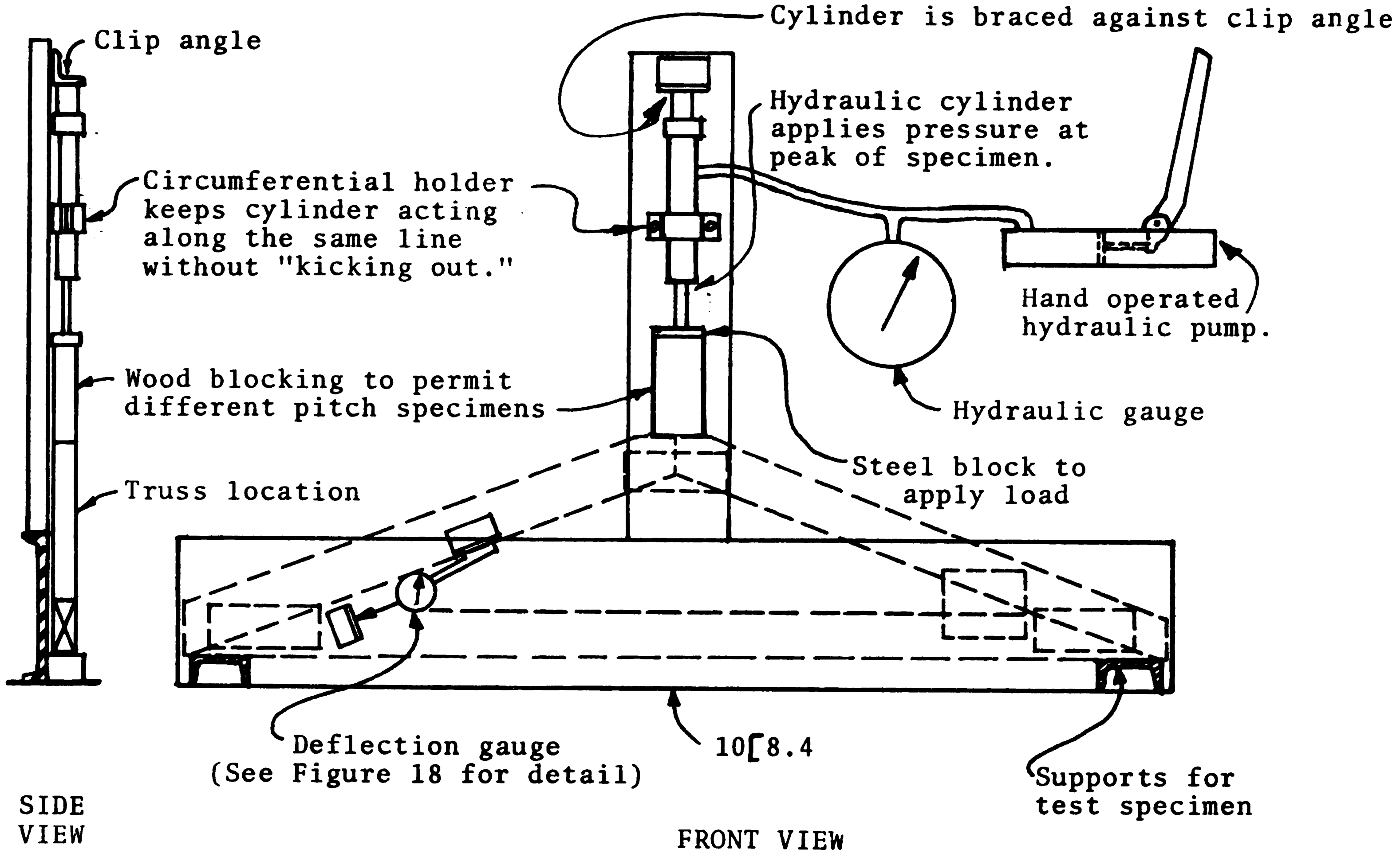



Figure 17. 8'-0" test jig.

## Instrumentation

A Starrett dial gauge, accurate to 0.001", was mounted at one heel joint as shown in Figure 18. It was mounted with screws on the centerline of the top chord. Its plunger was against a steel angle which was screwed symmetrically over the bottom chord center line.

A hydraulic gauge on the R159 Porto-Power was used to read the pressure on the peak of the initial 8'-0" specimen. The gauge had marks for every 400 psi and was read to 200 psi accuracy. This gauge was calibrated on the Instron machine at the Forestry Building, Michigan State University, and the calibration data is given in Table 4, page 64.

A hydraulic gauge on the wall-mounted full scale test jig was installed in the hydraulic line at the peak of the 24'-0" trusses as shown in Figure 21. It was marked in 25 psi increments and read in 10 psi increments. This gauge was also calibrated on the Michigan State University Forestry Department Instron machine. The calibration data is given in Table 5, page 65.

The Riehle testing machine used for the last series of 8'-0" specimens is mechanically operated and has a balance scale accurate to 5 lb. increments. The heel deflection was read every 200 lbs. of peak force, at the instant the balance arm hit the top. See Figure 22, page 63.

## Test Procedure

For the initial series of 8'-0" tests, on the hand-pumped hydraulic test jig, the heel deflection was read

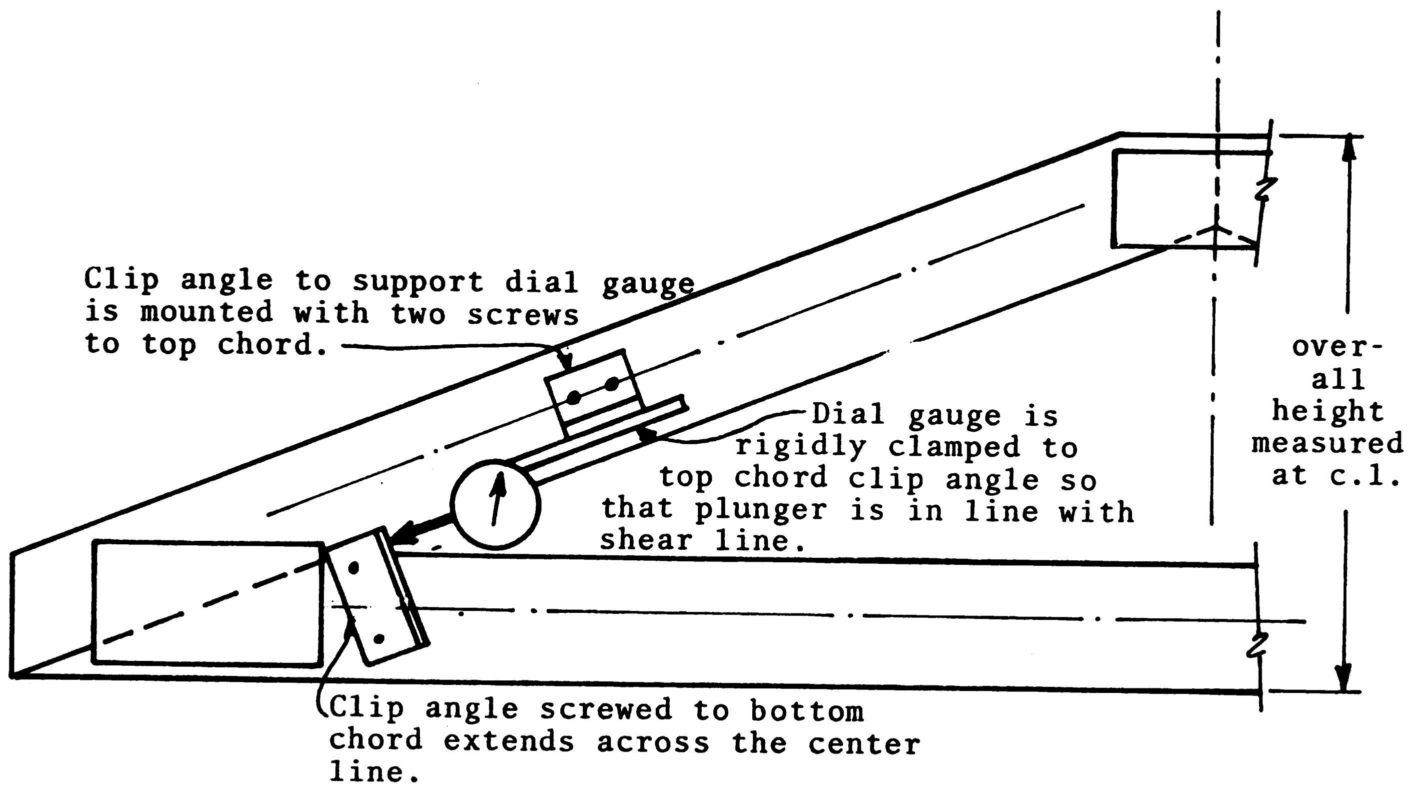
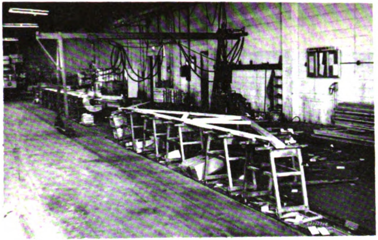
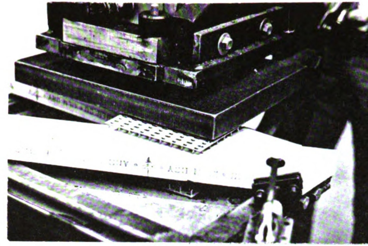


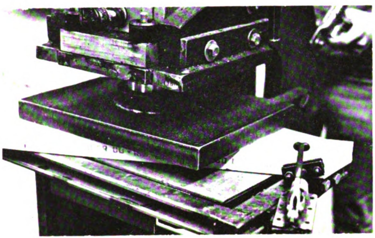

Figure 18. Dial gauge set-up.



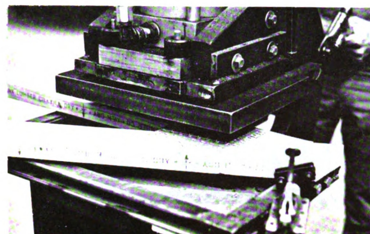
(a) Truss assembly jig.



(b) Ready to impale plate.

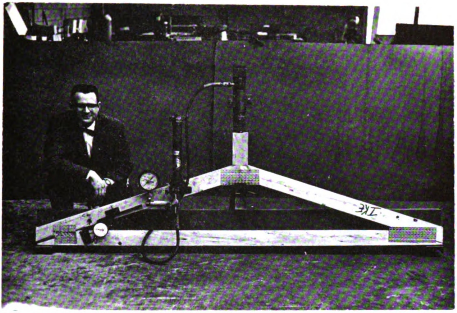


(c) During impalement.

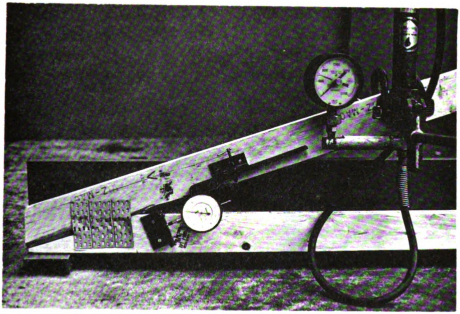


(d) After impalement.

Figure 19. Sequence of truss assembly photos.

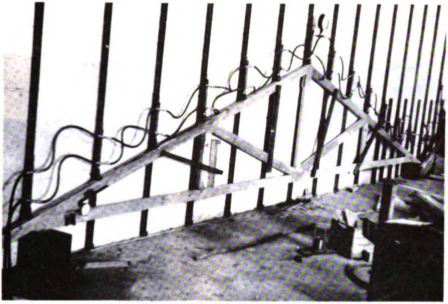


(a) Test apparatus for 8'-0" specimens.

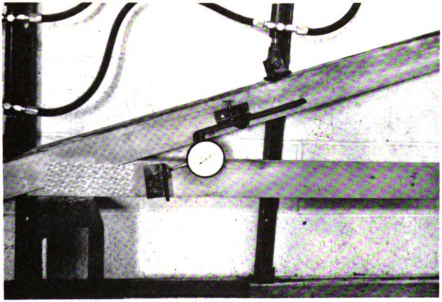


(b) Close-up of gauges.

Figure 20. Small test jig for 8'-0" specimens.

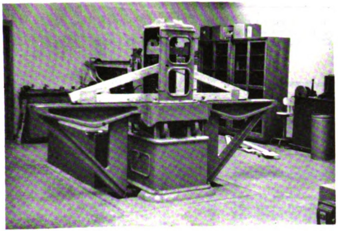


(a) Wall mounted hydraulic apparatus.

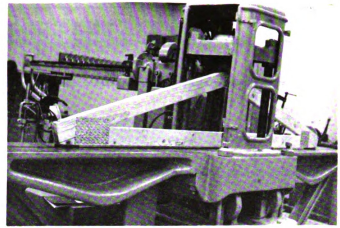


(b) Close-up of heel, showing gauge.

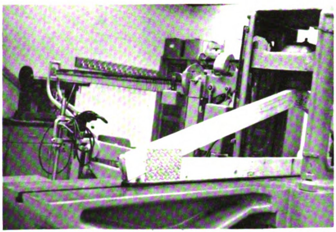
Figure 21. Test jig for 24'-0" trusses.



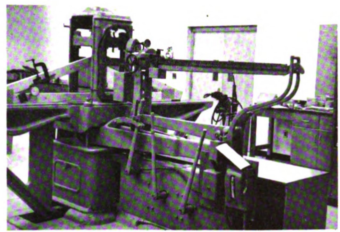
(a) Front view.



(b) Front close-up.



(c) Load application and specimen support.



(d) Rear view showing dial gauge and balance arm.

Figure 22. Riehle test machine for 8'-0" specimens.

Table 4. Calibration Data for Blackhawk Hydraulic Gauge.

| Act. Press. | Press. Read. | Instron Reading | | | | |
|---|---|---|---|---|---|---|
| | | #1 | #2 | #3 | #4 | Ave. |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 25 | 85 | 88 | 83 | 75 | 82.75 |
| 58.2 | 50 | 135 | 132 | 128 | 125 | 130.00 |
| 80.6 | 75 | 185 | 183 | 180 | 172 | 180.00 |
| 102.3 | 100 | 232 | 232 | 229 | 221 | 228.50 |
| 124.8 | 125 | 282 | 283 | 280 | 270 | 278.75 |
| 147.3 | 150 | 335 | 332 | 328 | 322 | 329.25 |
| 176.9 | 175 | 400 | 398 | 397 | 385 | 395.00 |
| 200 | 200 | 446 | 452 | 448 | 437 | 446.75 |
| 218.5 | 225 | 487 | 497 | 493 | 482 | 489.75 |
| 240.5 | 250 | 537 | 542 | 541 | 532 | 538.25 |
| 264 | 275 | 592 | 595 | 591 | 581 | 589.75 |
| 286 | 300 | 638 | 645 | 642 | 631 | 639.00 |
| 312 | 325 | 693 | 705 | 698 | 687 | 696.75 |
| 335 | 350 | 745 | 757 | 747 | 742 | 747.75 |
| 356 | 375 | 794 | 802 | 797 | 790 | 795.75 |
| 379 | 400 | 845 | 852 | 850 | 838 | 846.25 |
| 400 | 425 | 887 | 902 | 897 | 890 | 894.00 |
| 422 | 450 | 937 | 948 | 946 | 938 | 942.25 |
| 450 | 475 | 1007 | 1017 | 1013 | 1000 | 1009.25 |
| 472 | 500 | 1057 | missed | 1063 | 1053 | 1057.67 |
| 495 | 525 | 1109 | 1115 | 1110 | 1105 | 1109.75 |
| 518 | 550 | 1153 | 1163 | 1162 | 1155 | 1158.25 |
| 540 | 575 | 1202 | 1215 | 1212 | 1208 | 1209.25 |
| 562 | 600 | 1255 | 1263 | 1260 | 1262 | 1260.00 |

Blackhawk Porto-Power hand operated hydraulic pump
Model R159
Serial #A21233
Area: 2.2365 sq. in.
Oil capacity: 13.419 cu. in.
6" travel
1.688" diameter cylinder
8950 psi maximum pressure @ 103 lb. handle pressure

Table 5. Calibration Data for
Full Scale Test Jig.

| Hyd. Press. | Instron Reading | | | | | |
|---|---|---|---|---|---|---|
| | #1 | #2 | #3 | #4 | #5 | Ave. |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 500 | 510 | 575 | 575 | 535 | 560 | 551 |
| 1000 | 975 | 1065 | 1050 | 1040 | 1035 | 1033 |
| 1500 | 1485 | 1540 | 1540 | 1505 | 1530 | 1520 |
| 2000 | 1910 | 2025 | 2055 | 2000 | 1985 | 1995 |
| 2500 | 2440 | 2520 | 2530 | 2500 | 2490 | 2496 |
| 3000 | 2935 | 2970 | 2960 | 9240 | 2910 | 2943 |
| 3500 | 3410 | 3450 | 3430 | 3425 | 3400 | 3423 |
| 4000 | 2910 | 4065 | 3960 | 3920 | 3915 | 3956 |
| 4500 | 4455 | 4290 | | 4405 | 4410 | 4390 |
| 5000 | 4900 | 5000 | | 4950 | 4900 | 4938 |

approximately every 400 lbs. of peak pressure. This gave a minimum of five readings and a maximum of ten, depending on specimen type. It was necessary to use both hands to take the deflection data, which necessitated releasing the hydraulic pump handle. This in turn allowed a slight relaxation in the pressure, reducing the measured deflection. As a result, it was believed that the load-deflection data from these initial 8'-0" specimens indicated too much stiffness. To counteract this possibility, later tests were performed on the Riehle testing machine. Duration of tests varied from five to ten minutes for these tests and all tests were performed indoors at $60^{o}$ to $65^{o}$ F, on this hand jig.

The second set of tests, performed on the 24'-0" full-scale wall mounted hydraulic jig, took twenty to twenty-five minutes per test. Pressure was applied 24" o.c. using a motor driven pump which maintained constant pressure. The heel deflection gauge was allowed to stabilize before each reading, and readings were made about every 50 psi, for a minimum of six per test specimen. These tests, also inside, were performed at temperatures ranging from $65^{o}$ to $85^{o}$.

The third set of tests, performed on Michigan State University Forestry Department's Reihle machine, involved readings at every 200 lbs. of peak loading. The load was mechanically applied at a uniform speed of 1/16" per minute and readings were made each time the balance arm hit the top. About twenty readings were made per test specimen.

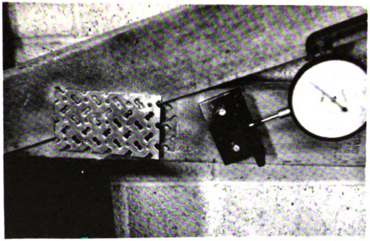
In all cases, the deflection gauge at the heel had to be removed when failure appeared imminent to prevent damage to the gauge. This meant that deflection data could not be taken in the neighborhood of ultimate load. Should further research by others be continued on this type of joint, the dial gauge should be mounted to read by extension rather than by compression, to eliminate the danger of damage and permit the full range of readings to be made.

## Test Results

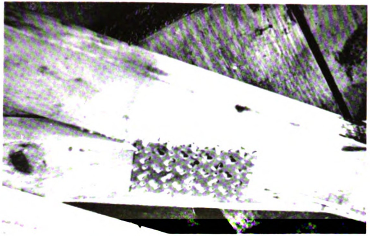
### Types of Failure of Experimental Specimens

During the testing program, all the types of failure described earlier were observed. A record of type of failure was made of most of the specimens, with the following results:

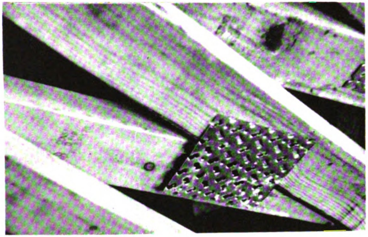
a. All 3"x5" and 3"x8" in both white fir and Douglas fir, and all 2-7/8"x9", 3-11/16"x4-1/2", and 3-11/16"x6-3/4" in western hemlock failed by the tooth withdrawal associated with the highest stresses. See Figure 23 for photographs of this type of failure. Very little rotation was noticed in the 3"x5" and 3-11/16"x4-1/2" sizes, and no rotation was seen in the three longer sizes. This amount of rotation, or lack of it, was in accordance with the proposed theoretical analysis which predicts less rotation in longer plates due to their higher polar section modulus (higher resistance to eccentric forces).



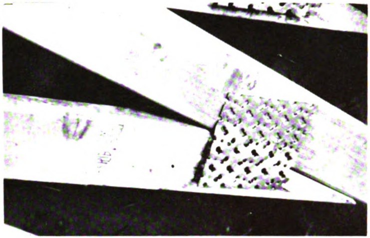
(a) 3" x 5" plate.



(b) 3" x 5" plate.



(c) 5" x 5" plate.



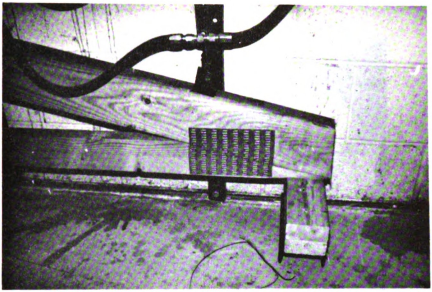
(d) 5" x 5" plate.

Figure 23. Typical wood and tooth failures (contact area).

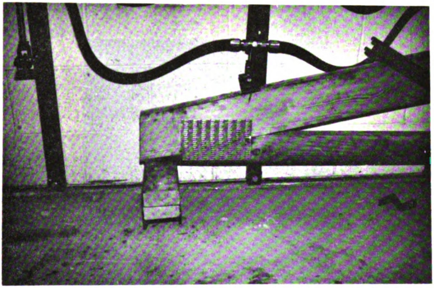
b. All the <u>5"x5"</u> plates (which had teeth oriented in all four directions, every 90$^{o}$) showed considerable rotation, as well as some S-shaped distortion, prior to failure. See Figure 24 for photographs of this S-shaped distortion, though of a different, heavier gauge plate. The rotation was less pronounced but somewhat similar to that shown for the nailed plate in Figure 25. Ultimate failure of these 5"x5" plates was the result of tooth withdrawal, which always started essentially simultaneously at the upper left and lower right corners as they lifted out of the wood first, due to that diagonal dimension of the plate stretching as the plate became S-shaped.

c. All the <u>5-5/16"x6-3/4"</u> plates which were equally applied on top and bottom chords failed by buckling, regardless of their orientation. Those placed perpendicular to the crack (see photo sequence in Figures 26 and 27) failed at lower loads than those placed parallel to the bottom chord (see photo sequence in Figures 29 and 30). This showed the higher shear value and greater buckling resistance when the long dimension of tooth holes is oriented approximately parallel to the crack.

d. All the <u>5-5/16"x4-1/2"</u> plates (which had teeth and holes pointed perpendicular to the bottom chord) showed both buckling and rotation, as seen in the

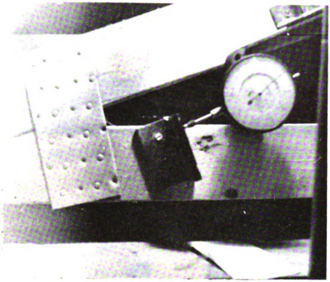


(a) Right-hand heel joint.
(Note S-shape of ends of plate.)

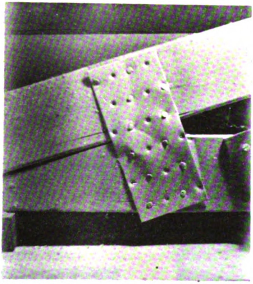


(b) Left-hand heel joint.

Figure 24. Distortion of 18 gauge heel plates.

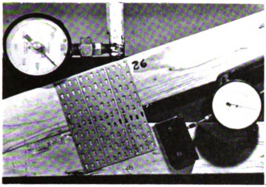


(a) Original location, showing deflection gauge.

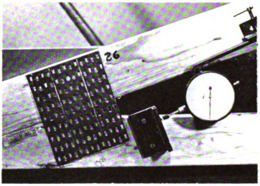


(b) Deflected position.

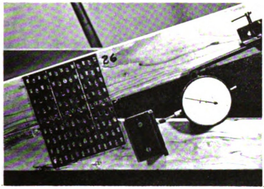
Figure 25. Photos of nailed plate distortion.



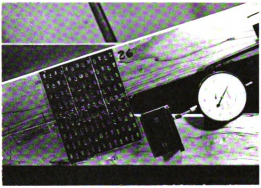
(a) Initial set-up.



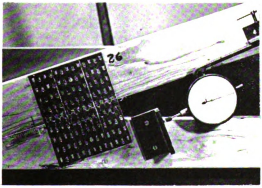
(b) 0.019" deflection.



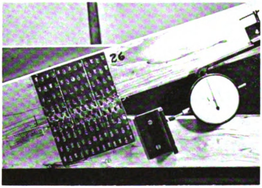
(c) 0.045" deflection. (Note initial buckling along shear line.)



(d) 0.075" deflection. (Initial buckling is more severe.)

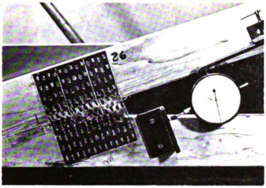


(e) 0.088" deflection.

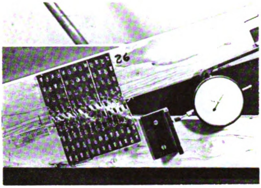


(f) 0.162" deflection.

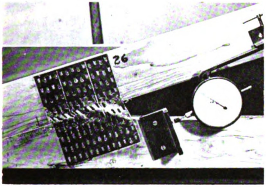
Figure 26. Initial buckling of Specimen 26.



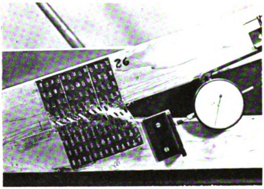

(a) 3/16" deflection.



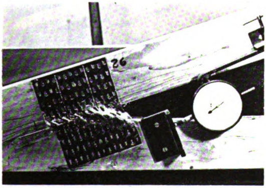

(b) 1/4" deflection.



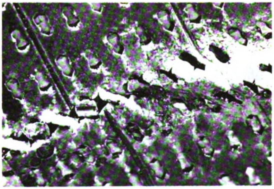

(c) 5/16" deflection.




(d) 7/16" deflection.

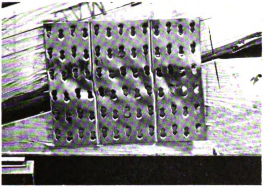



(e) 9/16" deflection. (No rotation. All buckling failure.)

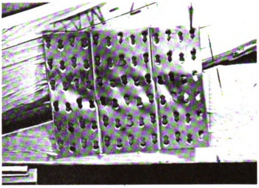


(f) 9/16" deflection. (Close-up.)

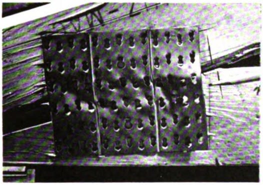
Figure 27. Progressive buckling of Specimen 26.



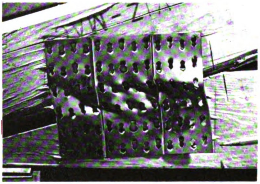
(a) 1/4" deflection.
(Note rotation of plate.)



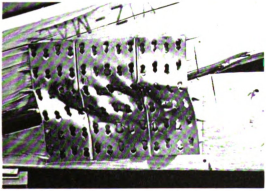
(b) 3/8" deflection.
(Hole enlargement at upper right.)



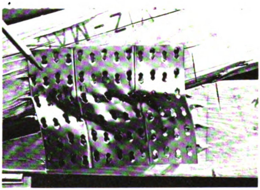
(c) 1/2" deflection.
(Pulling of teeth at pencil.)



(d) 5/8" deflection.
(Lifting of teeth at pencil.)



(e) 3/4" deflection.
(Buckling severely.)



(f) 1" deflection.
(Holes enlarged on adjacent corners, showing rotation.)

Figure 28. Buckling sequence of 5-5/16" x 4-1/2" plate.

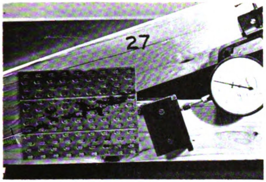
photo sequence in Figure 28, prior to ultimate failure by tooth withdrawal. Close inspection of the corner teeth in Figure 28 reveals the hole enlargement, especially at the upper right behind the tooth at the pencil, and at the lower left.

e. The 3"x10" plates on one of the earliest specimens tested failed in tension, rather than by either buckling or tooth withdrawal. The tensile joint had already been studied by Misra and was only of marginal interest to this study as an additional limiting factor, rather than a part of the main study of contact area stresses and buckling strength. As a result, it was not studied in more detail. Shorter heel plates were selected to prevent this type of failure in the main protion of the tests.

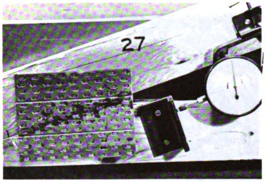
Stress-Coat Analysis

A Stress-Coat analysis was made of several sizes of plates, on both 8'-0" specimens and full size 24'-0" trusses. Both showed the same pattern of stress cracks.

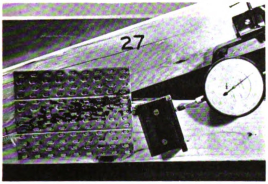
The Stress-Coat crack pattern development sequence has been photographed (Figure 29) for specimen 27, a 5-5/16"x 6-3/4" plate applied in the normal position. Since the cracks were too small to show up in the photos, red dye etchant was painted over the increasing area that had Stress-Coat cracks, for each new level of loading. By following the sequential photos, Figures 29(a) through 29(e), the spreading Stress-Coat pattern indicates that the strains are greatest



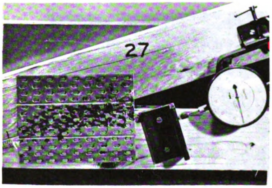

(a) 0.037" Deflection.
(Stress-Coat cracks painted.)



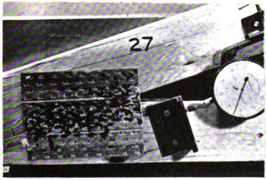

(b) 0.056" Deflection



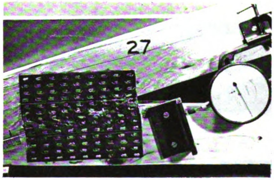

(c) 0.072" Deflection.




(d) 0.105" Deflection.




(e) 0.214" Deflection.
(Some areas still have no stress cracks.)



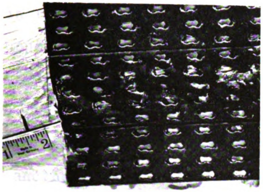

(f) 0.401" Deflection.
(Entire plate painted to show buckling.)

Figure 29. Photos of Stress-Coat cracks on Specimen 27.

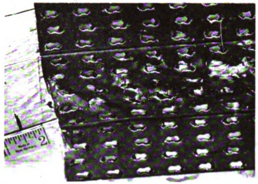
(a

(

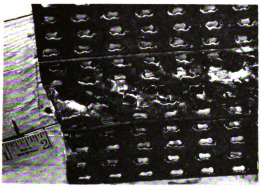
(



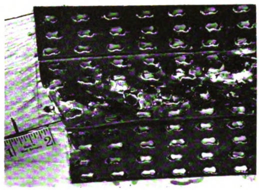
(a) 3/8" deflection.



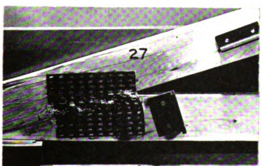
(b) 1/2" deflection.



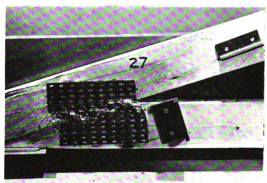
(c) 5/8" deflection.



(d) 3/4" deflection.




(e) 3/4" deflection.




(f) 1" deflection.

Figure 30. Progressive buckling of Specimen 27.

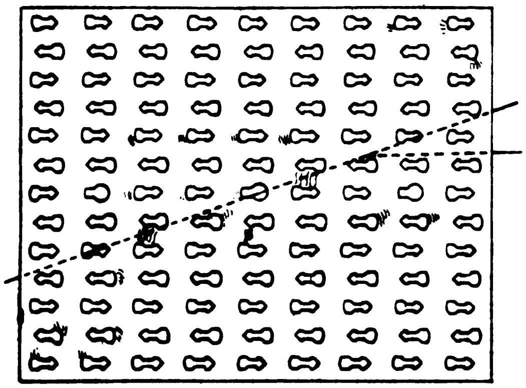
in the area of the shear crack, with just a few teeth at the upper right and lower left beginning to show high strains in Figure 29(d) at 0.105" deflection. Even in Figure 29(e), at 0.214" deflection, just prior to the start of buckling, the top three rows of teeth (about 1-1/4") and bottom three rows (another 1-1/4" strip of plate) still showed very few Stress-Coat cracks. This means that for a 5-5/16" wide plate, almost 2-1/2", or 50%, is not contributing its full value to joint strength. The joint apparently would have been just as strong, in terms of total top chord axial force, had a somewhat smaller heel plate been used.

The entire surface of the plate has been painted in Figure 29(f) to better illustrate the buckling sequence by showing the light reflection off the ripples.

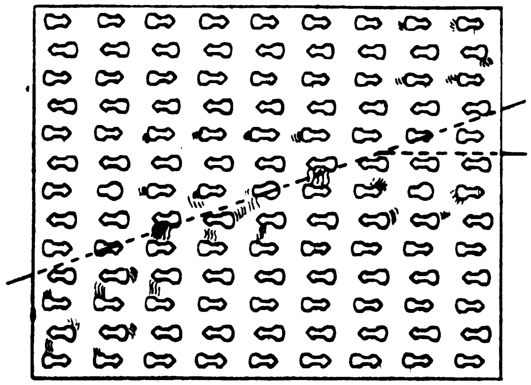
A small-scale sequence of crack pattern development on a 5-5/16"x6-3/4" plate is shown in Figure 31, followed by larger scale drawings in Figures 32, 33, and 34. It should be noticed in Figure 32 that the Stress-Coat cracks <u>between</u> teeth start in the vicinity of the shear crack between top and bottom chord members. At the same time, initial Stress-Coat cracks also occur at the <u>bases</u> of teeth located in the extreme upper right and lower left corners. This verifies two important predictions:

a. Shear stress in the steel is greatest along the joint between chords.

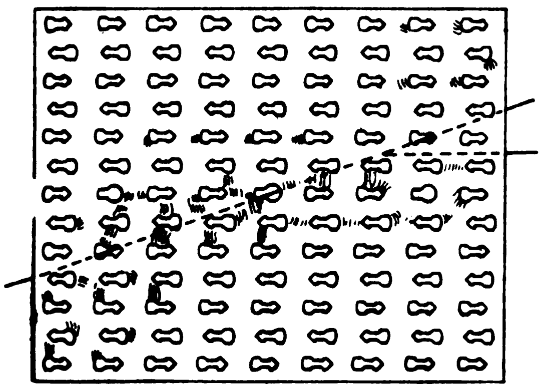
b. Tooth stresses are highest, initially, on corner teeth.



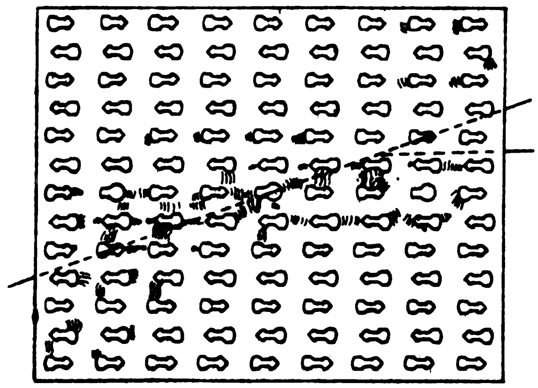
(a) 4,320 lbs.



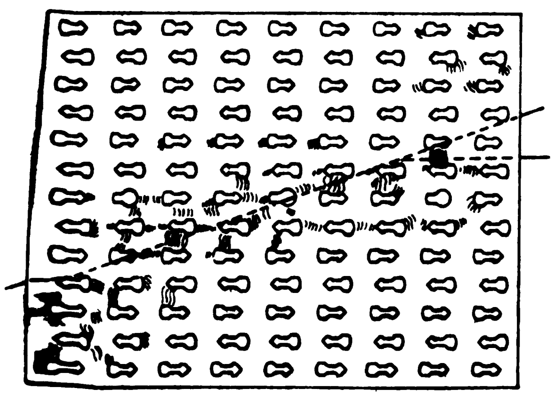
(b) 5,690 lbs.



(c) 6,320 lbs.



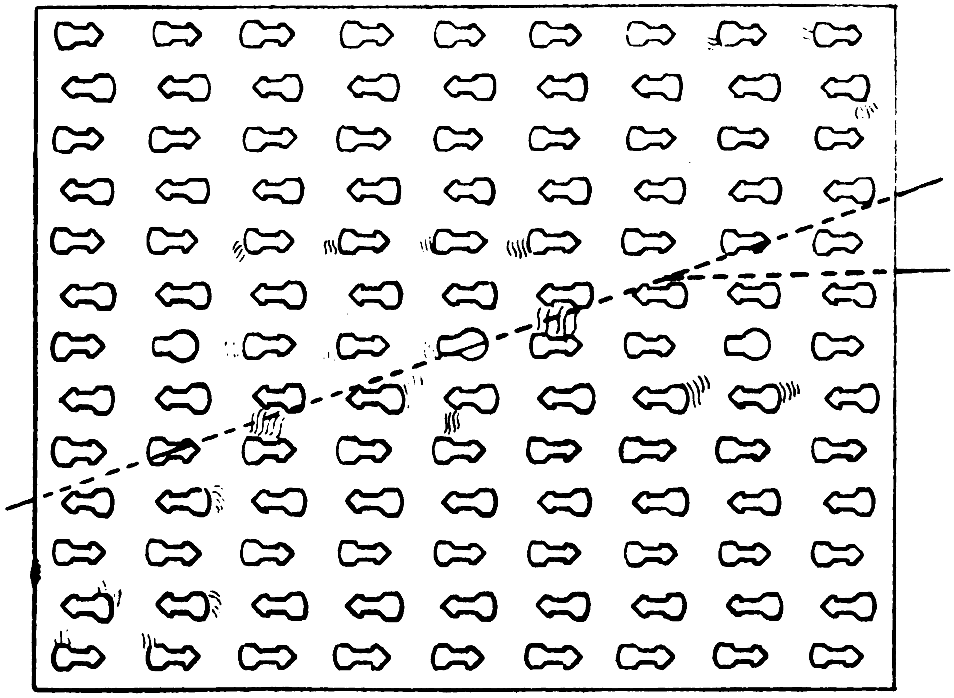
(d) 6,950 lbs.



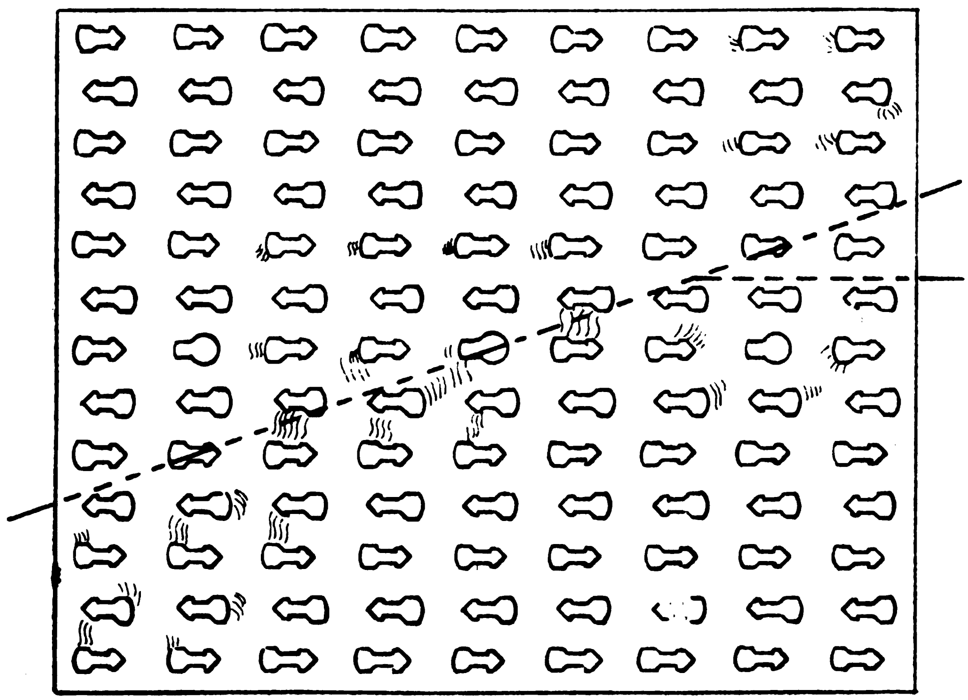
(e) 8,850 lbs.
Start of buckling.

Axial force in top chord is given below each drawing of progressive stress cracks.

Figure 31. Sequence drawing of Stress-Coat cracks on 5-5/16" x 6-3/4" plate.

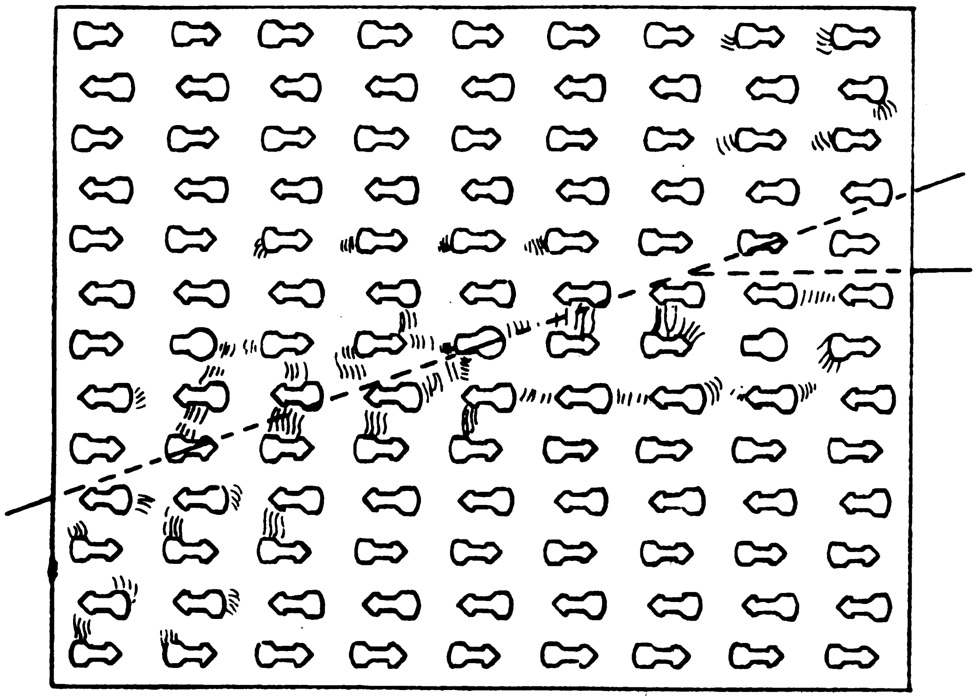


(a) 4,320 lbs. top chord force.

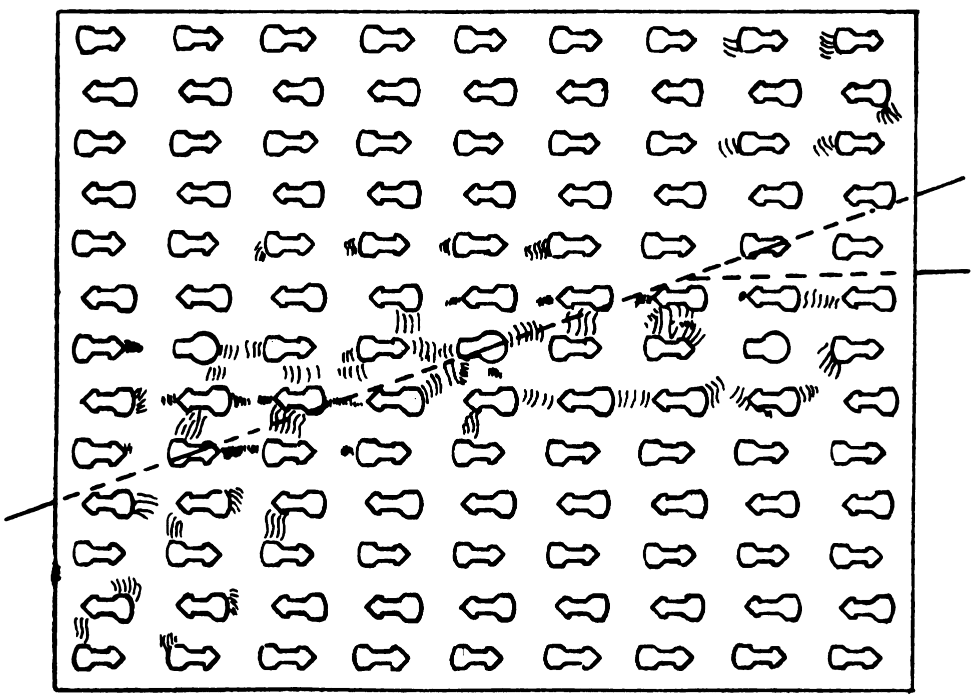


(b) 5,690 lbs. top chord force.

Figure 32. Large scale of initial Stress-Coat cracks on 5-5/16" x 6-3/4" plate.

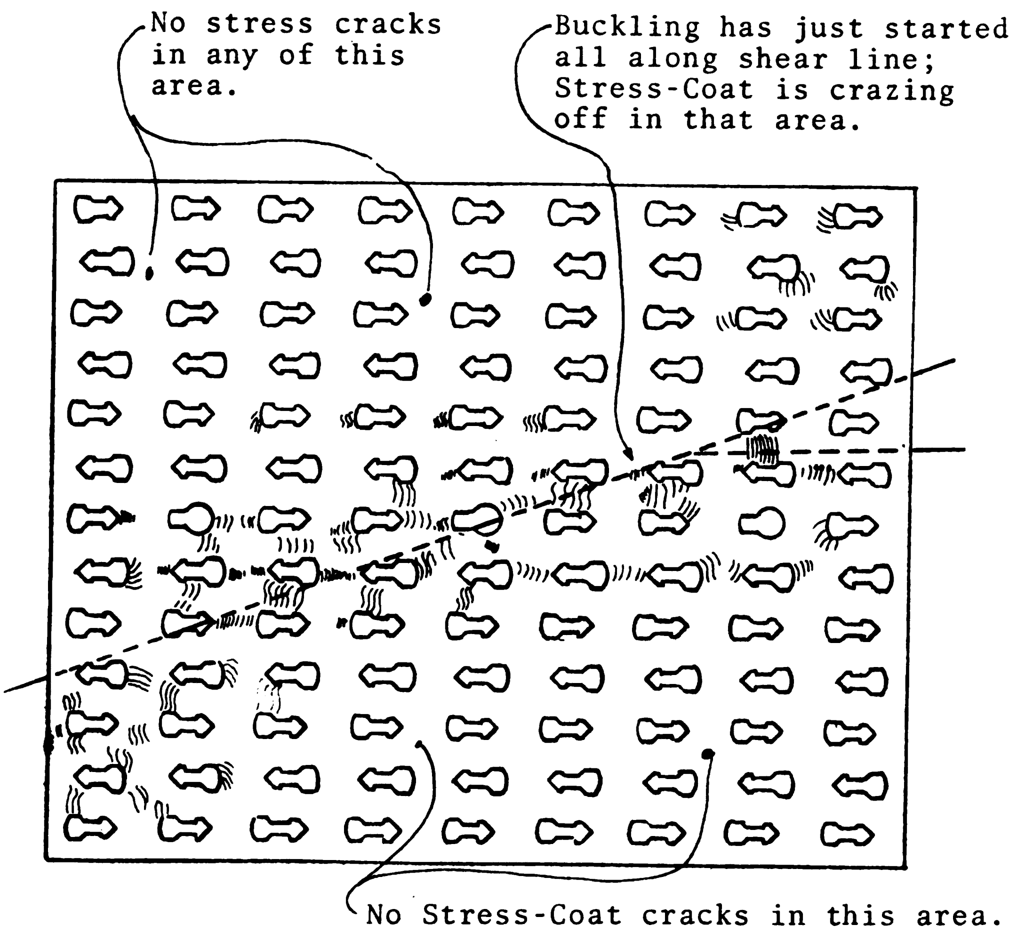


(a) 6,320 lbs. top chord force.



(b) 6,950 lbs. top chord force.

Figure 33. Large scale of later Stress-Coat cracks on 5-5/16" x 6-3/4" plate.




8,850 lbs. top chord force.

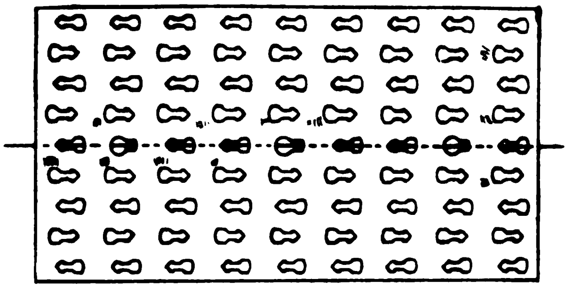
Figure 34. Large scale of Stress-Coat cracks at start of buckling of 5-5/16" x 6-3/4" plate.

Close inspection of Figure 33 reveals that stresses and strains are definitely increasing rapidly along the shear line, due to these increased top chord forces. There is very little indication of new Stress-Coat cracking at the upper right and lower left corner teeth, indicating that the plate, or teeth, is slightly distorted or undergoing relaxation, and tooth forces are being redistributed.

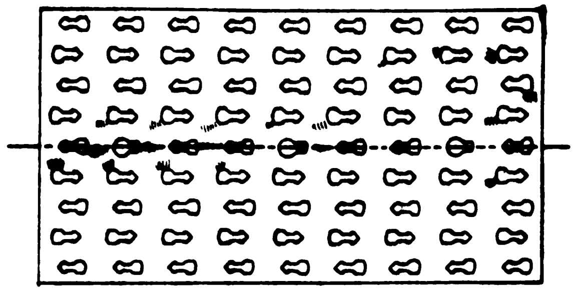
Figure 34 shows very dramatically that large areas of this 5-5/16" wide plate are not stressed highly enough to cause Stress-Coat cracking, despite forces high enough to initiate buckling along the shear line between top and bottom chords. Load-deflection data showed that the initiation of buckling precluded higher loadings. Large areas of the plate just weren't very highly stressed, even at ultimate load.

Figure 35 shows drawings of the Stress-Coat crack development for a 3-11/16"x6-3/4" plate applied with its centerline directly over the crack between top and bottom chords (the so-called "parallel to crack" orientation).

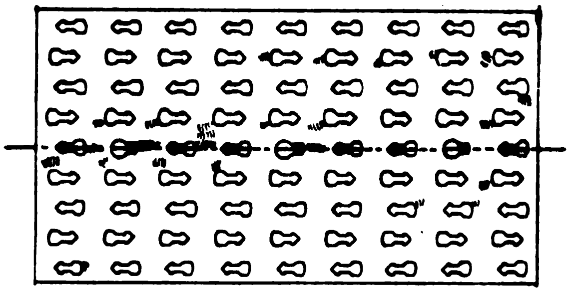
Figure 36(a) indicates that initial stresses at the base of the teeth are highest for teeth nearest the crack, and that one tooth at the upper right corner is also stressed about the same amount (apparently due to rotation, or attempted rotation, of the plate). Figures 36(b) and (c) show the progressive development of stress cracks at higher top chord forces, indicating the higher strains at the shear line, and one tooth base at the lower left corner. Since



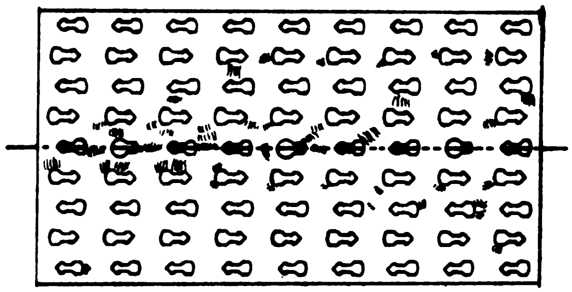
(a) 3,790 lbs.



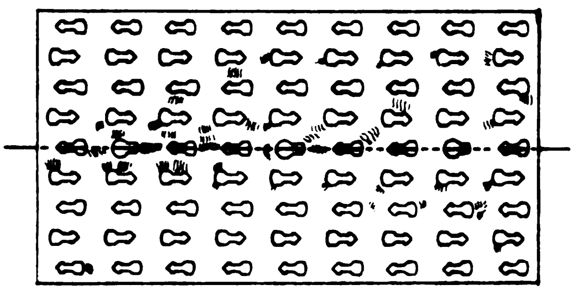
(b) 4,420 lbs.



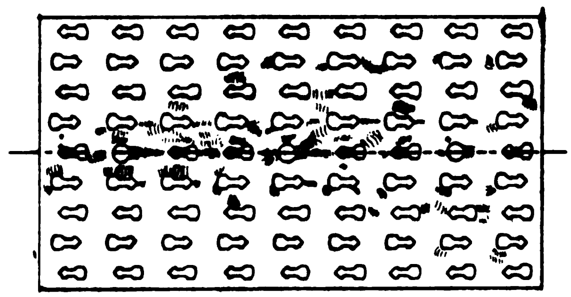
(c) 5,050 lbs.



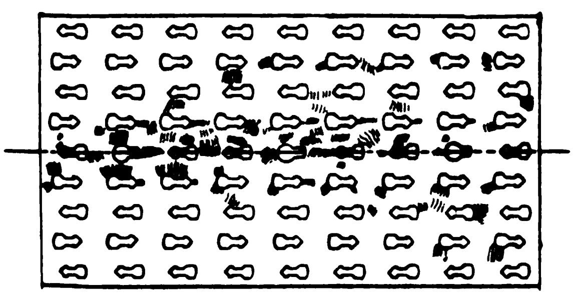
(d) 5,690 lbs.



(e) 6,320 lbs.



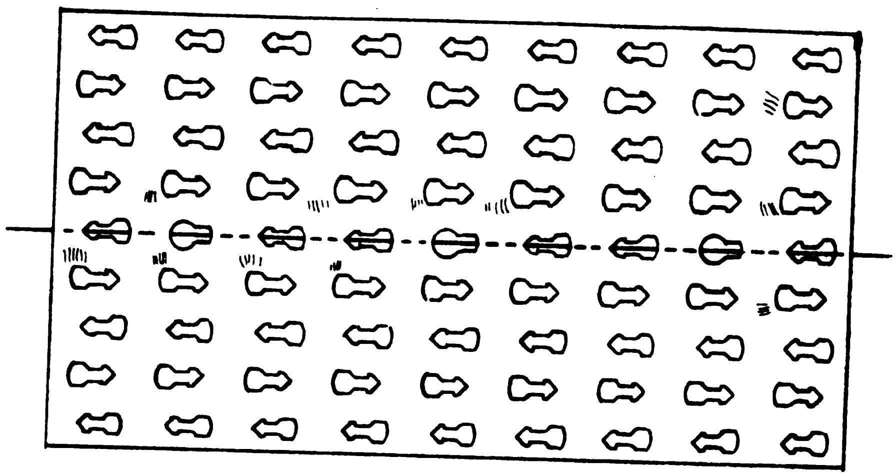
(f) 6,920 lbs.



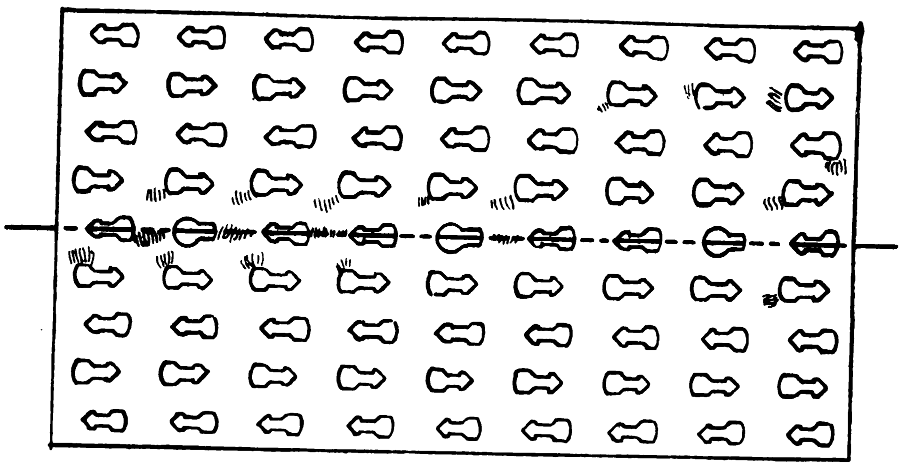
(g) 7,270 lbs.

Top chord axial force is given below each drawing.

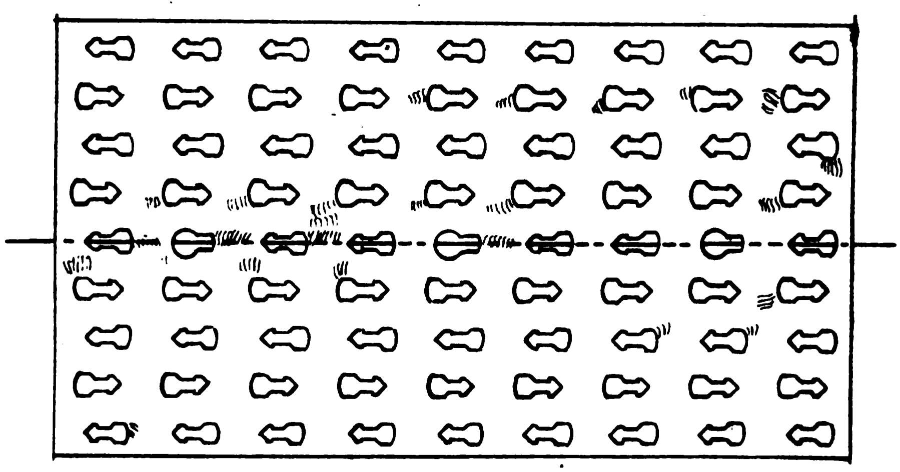
Figure 35. Sequence drawing of Stress-Coat cracks on 3-11/16" x 6-3/4" plate.



(a) 3,790 lbs. top chord force.

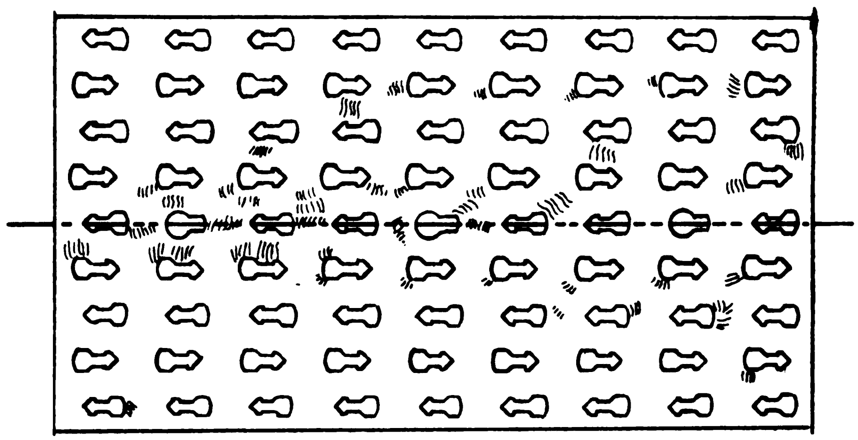


(b) 4,420 lbs. top chord force.

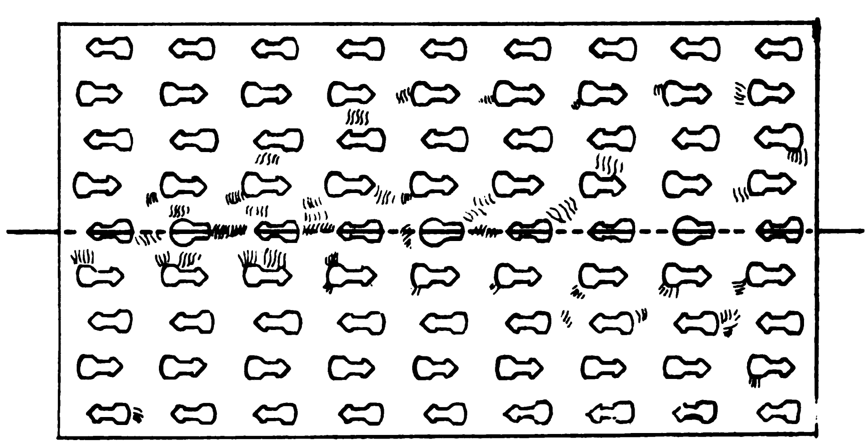


(c) 5,050 lbs. top chord force.

Figure 36. Large scale of initial Stress-Coat cracks on 3-11/16" x 6-3/4" plate.



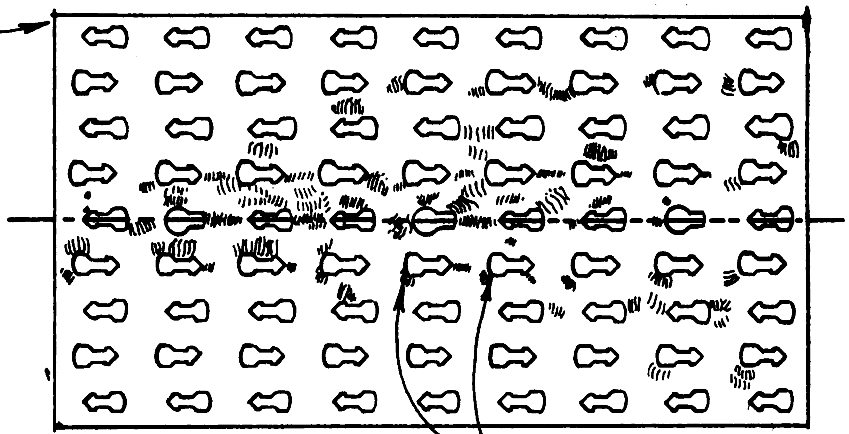
(a) 5,690 lbs. top chord force.



(b) 6,320 lbs. top chord force.

Figure 37. Large scale of later stress cracks on 3-11/16" x 6-3/4" plate.

This corner lifting. Holes considerably elongated.

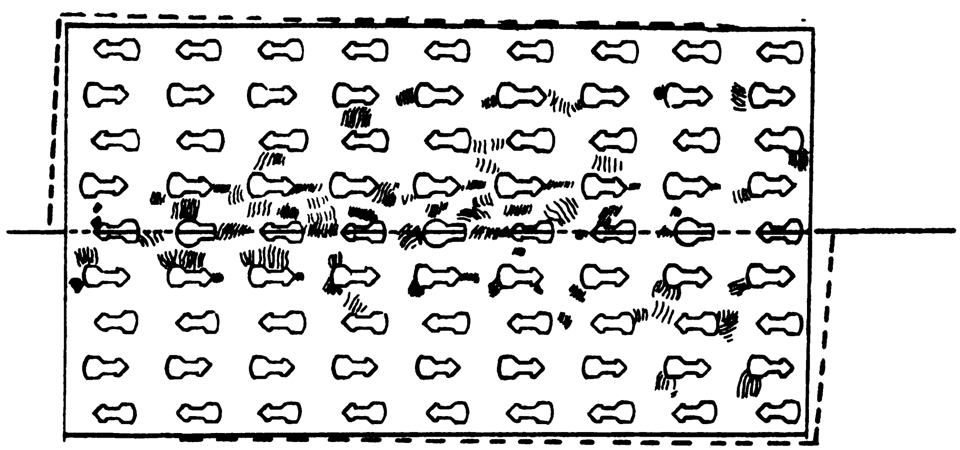


Dark areas are where Stress-Coat crazed off the plate.

Holes somewhat elongated.

(a) 6,920 lbs. top chord force.

Original location of plate had moved about as shown dashed.



(b) 7,270 lbs. top chord force (ultimate load).

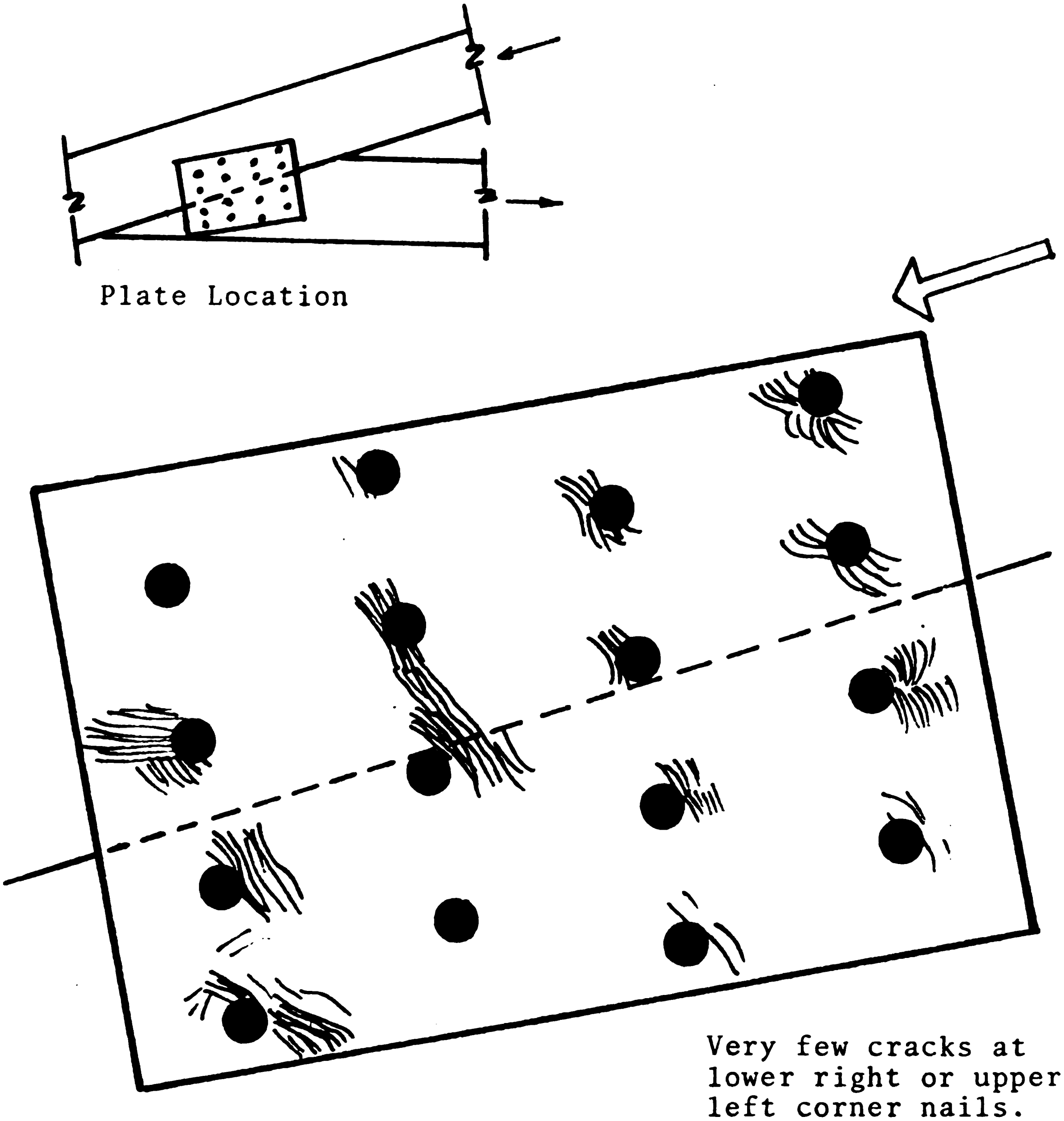
Figure 38. Large scale of Stress-Coat cracks at failure of 3-11/16" x 6-3/4" plate.

this plate has only nine rows of teeth, instead of thirteen, as in the 5-5/16" width, stress cracks would be expected to cover a larger percentage of total plate surface area.

Figures 37 and 38 follow the sequential increase in stress cracks at increasing loads on this same plate. They indicate, in Figure 38(a), that even at a top chord force of 6,920 lbs. (278 psi axial contact area stress), while the holes behind the teeth are considerably elongated and one corner of the plate is lifting, that there are still no stress cracks in the outermost row of teeth, either top or bottom of plate. This same observation is verified in Figure 38(b) even at ultimate load (7270 lbs. total, equivalent to 292 psi contact stress).

Figure 38(b) indicates the approximate distortion of the plate at ultimate load, and shows why the corners at the upper left and lower right lift up first and pull out their teeth. Those two corners are trying to become further apart, extending that diagonal dimension and pulling those teeth first. The other diagonal is shortening and imposing still higher forces on the upper right and lower left teeth, but not pulling them because they are being forced closer together, in the early stages of S-shaped distortion, or plate buckling.

Nailed plates were also subjected to the Stress-Coat analysis in an attempt to get a clearer picture of plate stresses. Figure 39 shows the Stress-Coat cracks that had occurred in a 3-3/8"x5-1/16", 20 gauge plate at 0.260"




This plate is 3-3/8"x5-1/16" - 20 ga., a flat, nailed plate shown full-size, with the Stress-Coat cracks that had occurred by 0.260 in. deflection.

Figure 39. Stress-Coat cracks in nailed plate specimen 44.

deflection. Note that very few cracks had occurred at the upper left and lower right extreme nails, verifying the earlier analytic and Stress-Coat work.

Figure 40 shows the stress pattern for a larger plate, 3-3/8" x 7-5/8" with 24 holes, half of which had 1-1/2" long, 8d, screw type nails located as shown. The stress cracks indicate the distribution of strains near each nail, in accordance with the nail's push against the plate, and its attempt to buckle the 20 ga. plate.

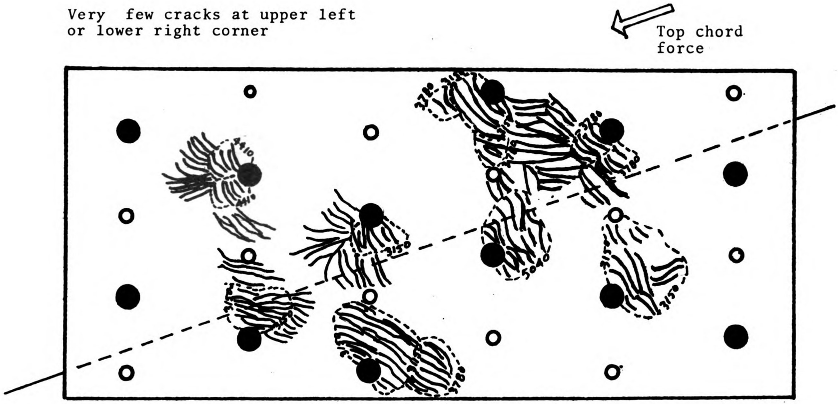
Figure 41 shows the same size plate as Figure 40, but oriented roughly at right angles to the crack. This drawing verifies that the stress cracks form at lower loads when a plate is oriented perpendicular to the crack than when its long dimension is parallel to the crack. Keeping the plate parallel to the crack (or parallel to the bottom chord in the standard orientation) reduces the eccentricity and increases the joint's over-all strength since a higher portion of the truss plate's capacity is available for axial load resistance.

Determination of Top Chord Axial Force

The top chord axial force was determined as follows:

a. The total load applied on the test specimen was computed, being corrected for the hydraulic gauge discrepancies noted in the calibration data, Table 4, page 64 and Table 5, page 65.


Very few cracks at upper left
or lower right corner
Top chord
force




This plate is 3-3/8"x7-5/8" with 24 holes, but only 12 nails, shown full size. Stress-Coat cracks were traced and labelled at 3150, 3780, and 5040 lbs. top chord force, which gave 0.184", 0.220", and 0.298" deflection respectively.

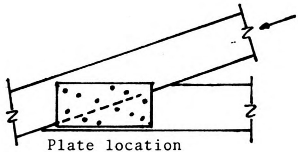
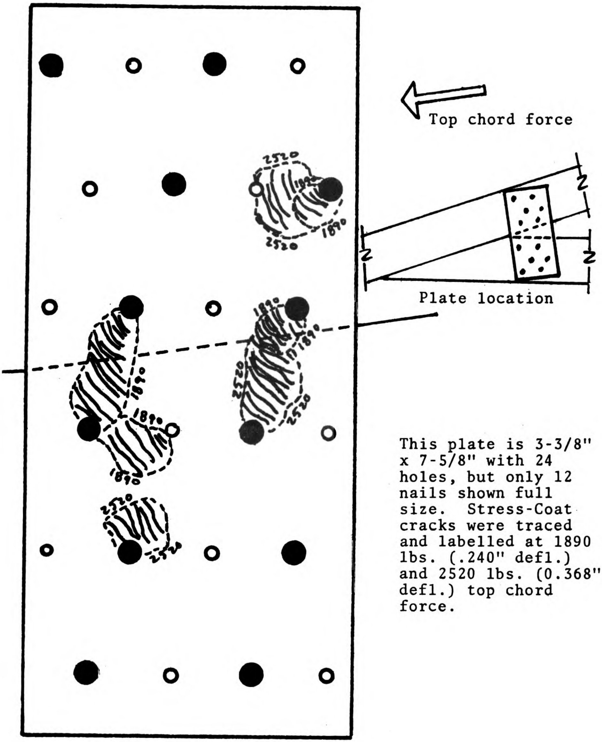



Figure 40. Stress-Coat cracks in nailed-plate specimen 36.




This plate is 3-3/8" x 7-5/8" with 24 holes, but only 12 nails shown full size. Stress-Coat cracks were traced and labelled at 1890 lbs. (.240" defl.) and 2520 lbs. (0.368" defl.) top chord force.

Figure 41. Stress-Coat cracks in nailed plate specimen 37.

b. The total load was divided by two to get the value of the two equal reactions. All loadings were applied symmetrically.

c. For the 24'-0" trusses, continuity was counted at the quarter panel points since the 2"x4" chords were continuous members across those joints. The peak, heel, and bottom chord splice joints were assumed as pin-connected. To account for the two-span continuity of the chords, 5/8 of the top chord load on each side was assumed to act at the quarter point (for a two-span continuous beam on unyielding supports) rather than 1/2 as in the case of pin-connected joints. The vertical heel panel load, then, was only 3/16 of the top chord load instead of 1/4 as for pin-connected designs. This analysis resulted in the net reaction being 13/16 of top chord load, rather than 3/4 for pin-connected, increasing the calculated axial force in the top chord by about 8-1/3% over a pin-connected analysis.

d. The 8'-0" specimens were assumed pin-connected throughout.

e. Top chord axial forces were computed using the geometrical relationship of forces at the heel joint after the net reaction had been computed.

Determination of Contact Stress and Shear Line Stress

The contact area stress was determined by dividing the top chord axial force by the area of the heel plate. The area of one plate equals one-half the area of the front and rear plates. This was a straight P/A stress calculation. No allowance was made for end distance or edge distance and none for eccentricity.

The shear line stress in the steel was computed by dividing the top chord axial force by the length of one truss plate measured along the shear line crack. To get the stress per inch on one plate, these values would have to be divided by two, for the front and rear plates.

Comparison of Six Plate Types

The load-deflection data for the initial series of 8'-0" test specimens are given in the Appendix in Tables 27 through 32. The results of repetitive tests on six different 20 ga. plates manufactured by Troy Steel Corp. were compared statistically using Duncan's New Multiple Range Test. Duncan's Test compares all possible pairs of means to determine whether the differences are significant.

The six truss plates used for this evaluation were all impaled in kiln-dried western hemlock (tsuga Heterophylla).

a. 3-11/16" x 4-1/2" - 2 specimens

b. 3-11/16" x 6-3/4" - 5 specimens

c. 2-7/8" x 9" - 5 specimens

d. 5-5/16" x 4-1/2" $\perp$ - 5 specimens

e. 5-5/16" x 6-3/4" - 3 specimens

f. 5-5/16" x 6-3/4" ⊥ - 4 specimens (perp. to crack)

The three 5-5/16" x 6-3/4" plates in group e were applied parallel to the crack, rather than parallel to the bottom chord (the usual position). They were applied off-center, and had only four rows of teeth (about 1.84 inches) instead of six rows (about 5.31"/2 = 2.65") as normally required. The contact area calculations were based on actual area, 1.84" x 6.75", rather than the expected area. This group, then, had actual contact area about equal to that of the 3-11/16" x 6-3/4" plates in group b.

The statistical comparison of these 8'-0" specimens, done in part on Michigan State University's CDC 3600 Computer using the AES Stat Series, Description 13, was performed using the cards and data given in Table 8. The output for each of four levels of deflection (0.015", 0.040", 0.080", 0.150") and ultimate load is given in Table 9 along with the Duncan Table of Mean Differences for each level.

Initial Comparison of 8'-0" vs. 24'-0" Test Specimens

The load-deflection data for the 8'-0" and 24'-0" matched specimens are given in Tables 33 through 38. The results of repetitive tests (two in each cell) were analyzed with the M.S.U. CDC 3600 Computer using AES Stat Description 14, Analysis of Variance with Equal Frequency in Each Cell, in two separate preliminary analyses as follows:

a. 8'-0" vs. 24'-0" specimens - See Table 6, next page.

b. 8'-0" small jig tests vs. 8'-0" Riehle tests - See Table 7, page 98.

These preliminary analyses indicated that the following factors had a significant effect on strength (stress level):

a. Species of lumber - Douglas fir was stronger than white fir.

b. Size of heel plate - The 3"x5" plates were strongest, 3"x8" next, and 5"x5" weakest, in terms of contact area stress.

c. Length of test specimen - The 8'-0" specimens were significantly stronger than the 24'-0" trusses, all other factors being equal.

d. Species and plate size had a significant interaction.

e. Species and deflection level had a significant interaction.

f. Plate size and deflection level had a significant interaction.

It was also found that the repetitions (whether the sample was No. 1 or No. 2 of a matched pair) were not significant in either preliminary analysis. The level of deflection had a highly significant effect on contact area stress, as would certainly be expected. The location of the test jig used, whether the small 8'-0" hand hydraulic jig used at home, or the Riehle mechanical testing machine at M.S.U., had no significant effect on results.

# Table 6. Preliminary Comparison of 8' vs. 24' Specimens.

ANALYSIS OF VARIANCE TABLE

DEPENDENT VARIABLE IS X( 6) STRESS

| SOURCE OF VARIANCE | SUM OF SQUARES | DEGS. OF FREEDOM | MEAN SQUARE | F STATISTIC | APPROX. SIGNIFICANCE PROBABILITY OF F STAT. | |
|---|---|---|---|---|---|---|
| E Repetitions (No. 1 or No. 2) | 145,04166666 | 1 | 145,04166666 | 0,76820 | 0,385 | 1. Reps. not sig. |
| A Specie (Doug. Fir or White Fir) | 78690,04166603 | 1 | 78690,04166603 | 413,59890 | <0,0005 | 2. Specie highly sig. |
| B Length (8'-0" or 24'-0") | 10500,16666651 | 1 | 10500,16666651 | 55,61346 | <0,0005 | 3. Length highly sig. |
| C Plate Size (3x5, 3x8, or 5x5) | 10750,14583325 | 2 | 5375,07291663 | 28,46873 | <0,0005 | 4. Plate size highly sig. |
| D Deflection (.015, .040, .080, .150) | 423396,16666412 | 3 | 141132,05555344 | 747,49689 | <0,0005 | 5. Defl. highly sig. |
| AB Specie-Length | 672,04166666 | 1 | 672,04166666 | 3,55943 | 0,065 | 6. No specie-length interaction |
| AC Specie-Plate Size | 8437,27083325 | 2 | 4218,63541663 | 22,34373 | <0,0005 | 7. Specie interacts with plate size |
| AD Specie-Deflection | 15785,79166675 | 3 | 5261,93055558 | 27,86948 | <0,0005 | 8. Specie interacts with defl. |
| BC Length-Plate Size | 4400,02083325 | 2 | 2200,01041663 | 11,65221 | <0,0005 | 9. Length interacts with plate size |
| BD Length-Deflection | 856,50000000 | 3 | 285,50000000 | 1,51213 | 0,222 | 10. No length interaction with defl. |
| CD Plate Size-Deflection | 7670,27083337 | 6 | 1278,37847221 | 6,77085 | <0,0005 | 11. Plate size interacts with defl. |
| ABC Specie-Length-Plate Size | 1715,14583331 | 2 | 857,57291666 | 4,54208 | 0,015 | 12. 3-way interaction here |
| BCD Length-Plate Size-Defl. | 1628,06250000 | 6 | 271,34375000 | 1,43715 | 0,218 | 13. No interaction here |
| ACD Specie-Plate Size-Defl. | 5438,64583325 | 6 | 906,44097221 | 4,80091 | 0,001 | 14. 3-way interaction here |
| ABD Specie-Length-Defl. | 539,79166666 | 3 | 179,93055555 | 0,95299 | 0,422 | 15. No interaction here |
| REMAINING ERROR | 10006,72921753 | 53 | 189,80621165 | | | |
| TOTAL | 580031,83337402 | 95 | | | | |

A IS CATEGORY VARIABLE X( 2) SPECIE
B IS CATEGORY VARIABLE X( 3) LENGTH
C IS CATEGORY VARIABLE X( 4) PL. SIZE
D IS CATEGORY VARIABLE X( 5) DEFL.
E IS CATEGORY VARIABLE X( 1) REP.

Table 7. Preliminary Comparison of 8' Small Jig vs. Riehle Machine.

Table 7. Preliminary Comparison of 8' Small Jig vs. Riehle Machine.

A N A L Y S I S   O F   V A R I A N C E   T A B L E

DEPENDENT VARIABLE IS X( 6) STRESS

| SOURCE OF VARIANCE | SUM OF SQUARES | DEGS. OF FREEDOM | MEAN SQUARE | F STATISTIC | APPROX. SIGNIFICANCE PROBABILITY OF F STAT. | |
|---|---|---|---|---|---|---|
| E Repetitions (No. 1 or No. 2) | 372.09375000 | 1 | 372.09375000 | 0.65411 | 0.422 | 1. Reps. not sig. |
| A Specie (Doug. Fir or White Fir) | 81142.51041603 | 1 | 81142.51041603 | 142.64286 | <0.0005 | 2. Specie highly sig. |
| B Location (Home or M.S.U. test) | 518.01041666 | 1 | 518.01041666 | 0.91063 | 0.344 | 3. No effect of location |
| C Plate Size (3x5, 3x8, 5x5) | 19858.27083302 | 2 | 9929.13541651 | 17.45473 | <0.0005 | 4. Plate size highly sig. |
| D Deflection (.015, .040, .080, .150) | 392006.61458588 | 3 | 130668.87152863 | 229.70675 | <0.0005 | 5. Level of defl. highly sig. |
| AB Specie-Location | 981.76041667 | 1 | 981.76041667 | 1.72587 | 0.195 | 6. No specie-location interaction |
| AC Specie-Plate Size | 9135.14583325 | 2 | 4567.57291663 | 8.02947 | 0.001 | 7. Specie interacts with plate size |
| AD Specie-Deflection | 12798.28125000 | 3 | 4266.09375000 | 7.49949 | <0.0005 | 8. Specie interacts with load |
| BC Location-Plate Size | 3291.02083331 | 2 | 1645.51041666 | 2.89269 | 0.064 | 9. No location-plate size interaction |
| BD Location-Deflection | 4023.28125000 | 3 | 1341.09375000 | 2.35755 | 0.082 | 10. No location-defl. interaction |
| CD Plate Size-Deflection | 14206.72916651 | 6 | 2367.78819442 | 4.16241 | 0.002 | 11. Plate size interacts with defl. |
| ABC 3-way Interactions | 1382.64583331 | 2 | 691.32291666 | 1.21530 | 0.305 | 12. No 3-way interaction!!! |
| BCD 3-way Interactions | 3296.31250000 | 6 | 549.38541666 | 0.96578 | 0.457 | 13. No 3-way interaction!!! |
| ACD 3-way Interactions | 3956.18750000 | 6 | 659.36458333 | 1.15912 | 0.342 | 14. No 3-way interaction!!! |
| ABD 3-way Interactions | 1063.03125000 | 3 | 354.34375000 | 0.62291 | 0.603 | 15. No 3-way interaction!!! |
| REMAINING ERROR | 30149.09367371 | 53 | 568.85082403 | | | |
| TOTAL | 578180.98950195 | 95 | | | | |

A IS CATEGORY VARIABLE X( 2) SPECIE
B IS CATEGORY VARIABLE X( 3) LOCATION
C IS CATEGORY VARIABLE X( 4) PL. SIZE
D IS CATEGORY VARIABLE X( 5) DEFL.
E IS CATEGORY VARIABLE X( 1) REP.

## Final Statistical Comparison of Matched 8' and 24' Specimens

A final statistical analysis was prepared, after the preliminary results were available as a guide to the inter-action effects, combining all the specimens, plus the extras that had been deleted earlier from the initial comparisons to make all the cells equal. This final statistical analysis used the M.S.U. AES Stat Series Description 18, Analysis of Covariance and Analysis of Variance with Unequal Frequencies Permitted in the Cells (Least Squares Routine).

This LS routine permitted the inclusion of moisture content and specific gravity as covariants along with the category variables of species, length of test specimen, plate size, and deflection level. It required the creation of twenty "indicator variables" as described in Description 18 for all these categories and the two-way inter-actions mentioned previously. The transformation instructions for the creation of those indicator variables are given near the beginning of Table 17 followed by the data cards. Two additional covariants were created, (a) the square of the moisture content and (b) the square of the specific gravity, as variables nos. 29 and 30, with the transformation sub-deck.

The computer output from this analysis is reprinted, after slight abridgement to reduce unnecessary material, as

Table 18. Statistics on Transformed Variable.

Table 19. Analysis of Variance for Over-All Regression.

Table 20. Simple Correlation Coefficients.

Table 21. Measured Stress vs. Predicted Stress.

# CHAPTER V

# DISCUSSION OF RESULTS

## General

This section presents load-deflection curves of each set of plates evaluated experimentally to permit quick, convenient visual comparison of the data. These load-deflection curves are grouped according to their purpose, and include a small drawing of the plate size, orientation, and other pertinent data. These load-deflection curves can be compared in terms of top chord axial force (Graph A for each figure), contact area stress in lbs. per sq. in. (Graph B for each figure), or shear on the joint in lbs. per lineal inch (Graph C for each figure).

The statistical analysis of the experimental results is presented in more detail in this chapter for each comparison studied. The raw data input, the computer statistical output, other comparison calculations, and a discussion of the significance of the findings is included.

A prediction equation for the contact area stress is presented, along with a table comparing the predicted contact stress with the experimentally measured contact stress. Finally, the results of the theoretical and experimental analyses are compared.

## Initial Study of Effect of Size, Shape, and Orientation on Contact Area Strength

### Description

Six different types of heel joints, using 20 ga. truss plates manufactured by Troy Steel Corporation impaled in western hemlock were compared. The plate sizes, orientation, and load-deflection curves are shown in Figures 43 through 47. The raw data for these plates is in the Appendix, Tables 27 through 32.

### Statistical Comparison

This data was prepared as the computer input given in Table 8, for comparison of the contact area stress at 0.015", 0.040", 0.080", 0.150", and ultimate load. The results, including Duncan's Multiple Range Comparison of Mean Differences, are given in Table 9 (a) through (e).

### Analysis of Results

An analysis of Tables 9 (a) through (e) yields the following:

a. From Table 9(a), for 0.015" deflection, there are no significant differences between the plates tested. This is reassuring since truss plate design values are based on strength at 0.015" deflection, as well as on ultimate. Any plate size, shape, and orientation can be used at the same relative efficiency for this low level of load.

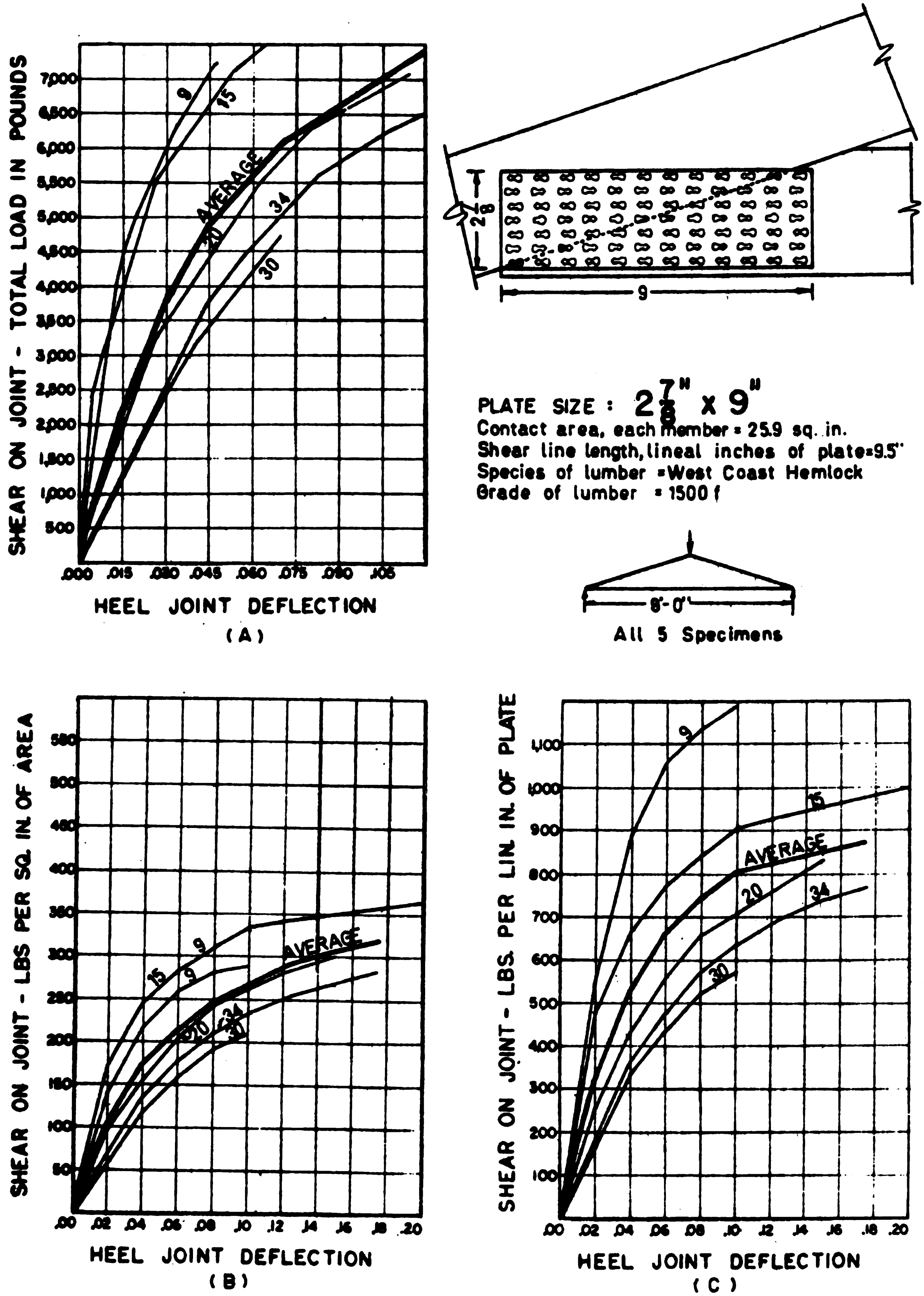
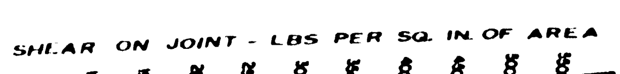
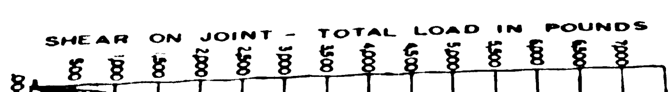



Figure 42. Load-Deflection Curves for 2-7/8"x9" Plates.


SHEAR ON JOINT - LBS PER SQ. IN. OF AREA


SHEAR ON JOINT - TOTAL LOAD IN POUNDS
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
6,500
7,000

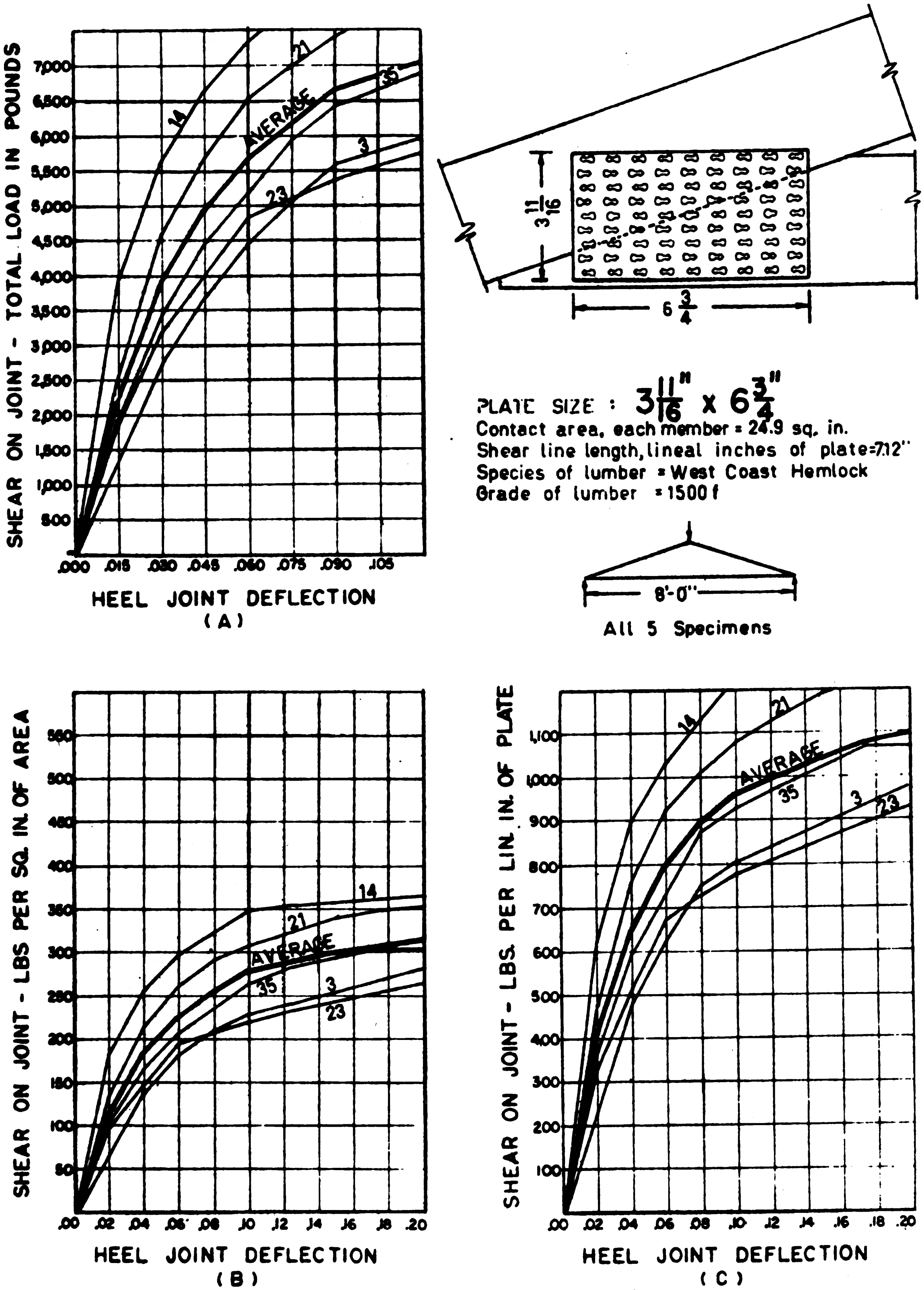



Figure 43. Load-Deflection Curves for
3-11/16"x6-3/4" Plates.

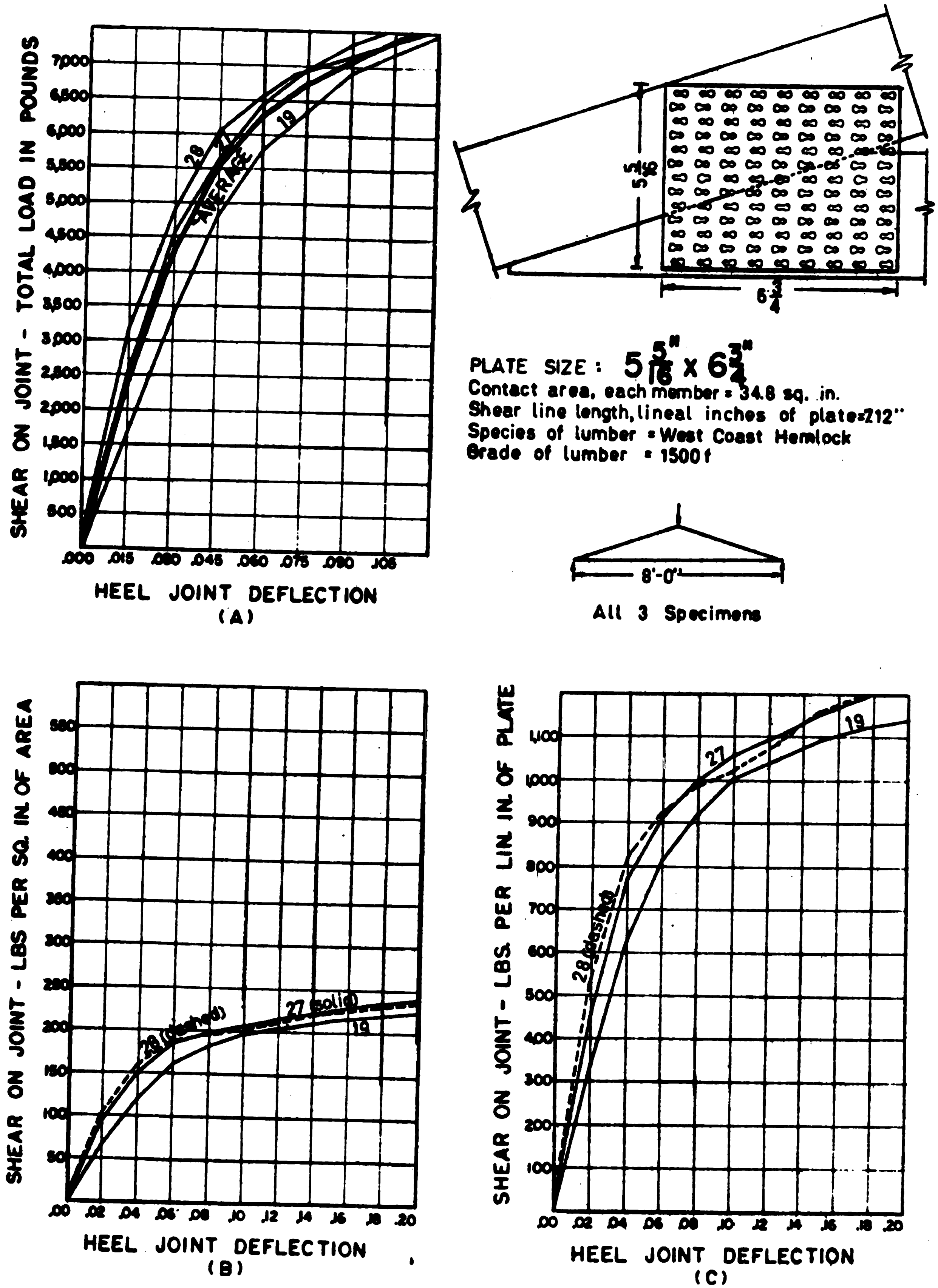
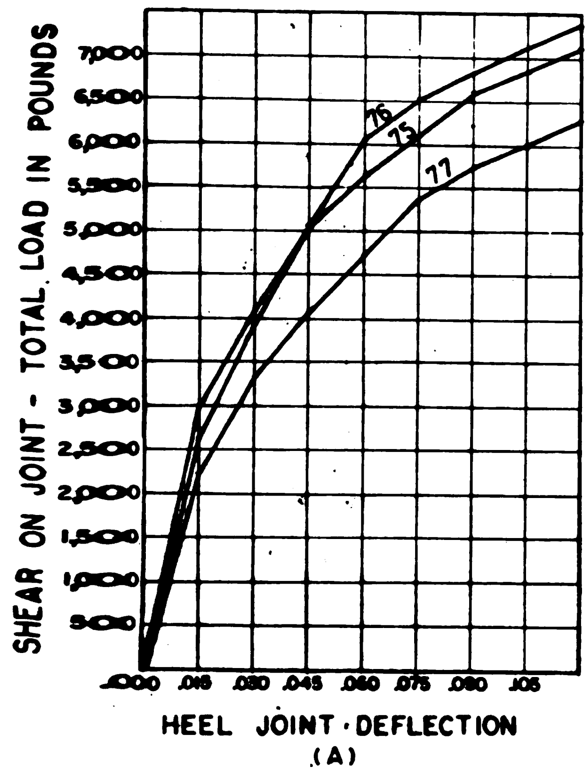



Figure 44. Load-Deflection Curves for 5-5/16"x6-3/4" Plates.



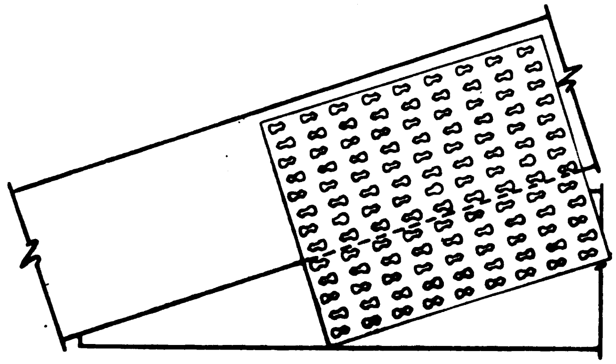
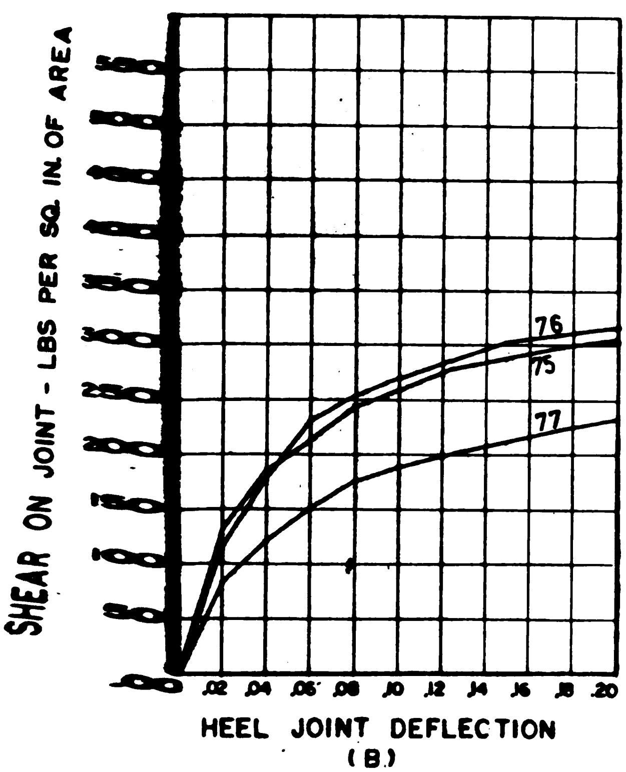



PLATE SIZE $5\frac{5}{16}'' \times 6\frac{3}{4}''$
Contact area, each member = 34.8 sq. in.
Shear line length, lineal inches of plate = 7.12"
Species of lumber = West Coast Hemlock
Grade of lumber = 1500 f

SPECIAL NOTE:
These plates were not positioned equally on the members. There were only 24.9 sq.in. on the bottom chord, as shown, instead of 35.8. Contact stress is based on 24.9, giving values 10.9/24.9=44% higher than expected if 35.8 were used.



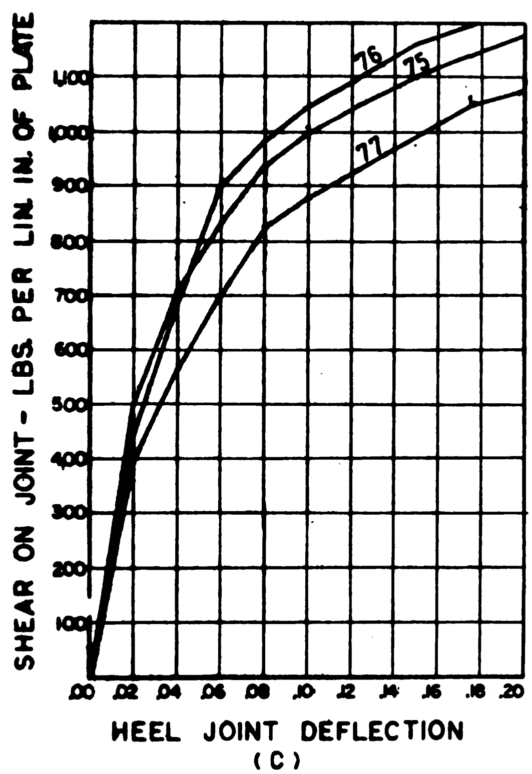




Figure 45. Load-Deflection Curves for 5-5/16"x6-3/4" Plates (Parallel to Crack).

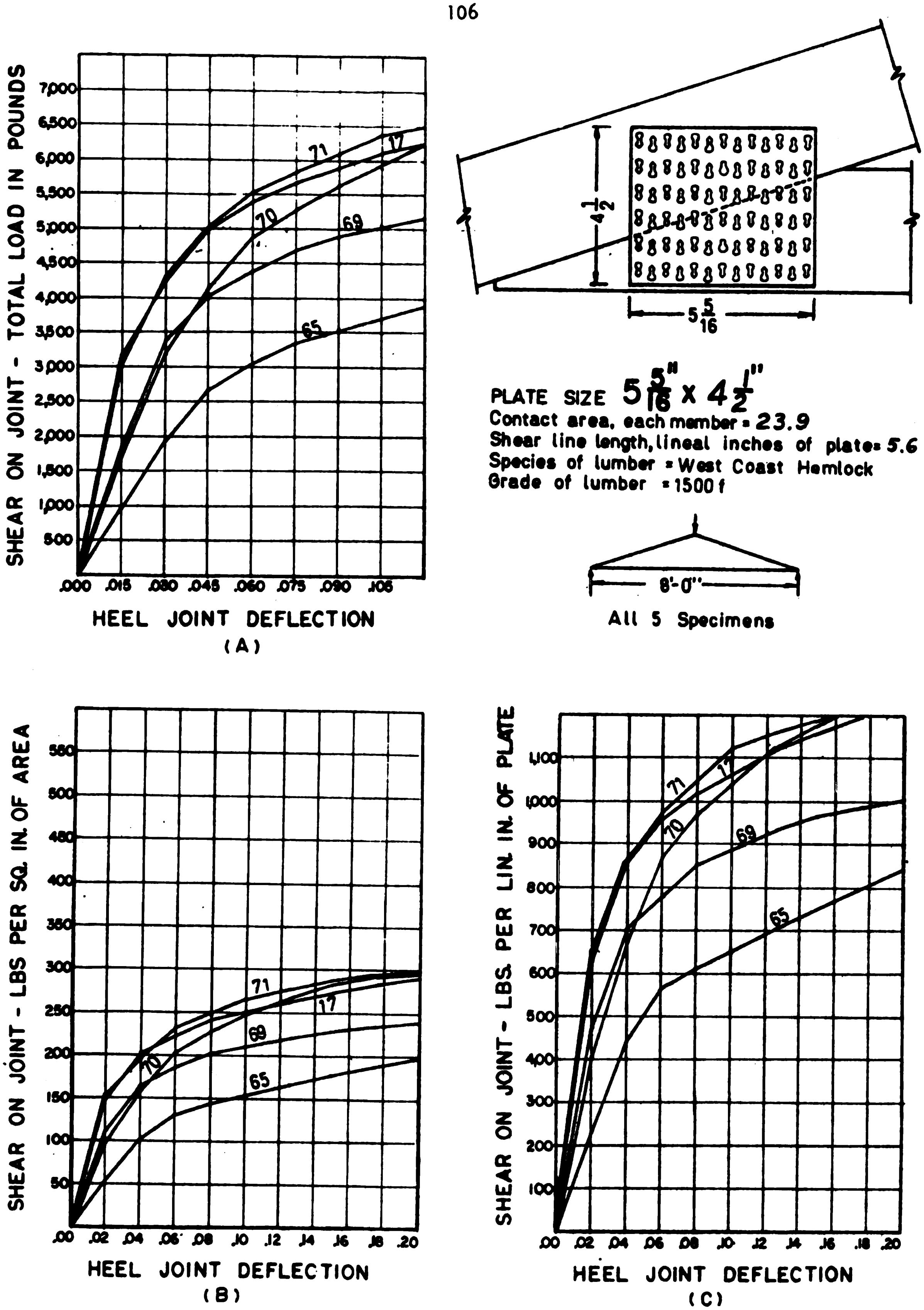



Figure 46. Load-Deflection Curves for 5-5/16"x4-1/2" Plates (⊥ to Bottom Chord).

SHEAR ON JOINT, LBS PER SQ IN OF AREA

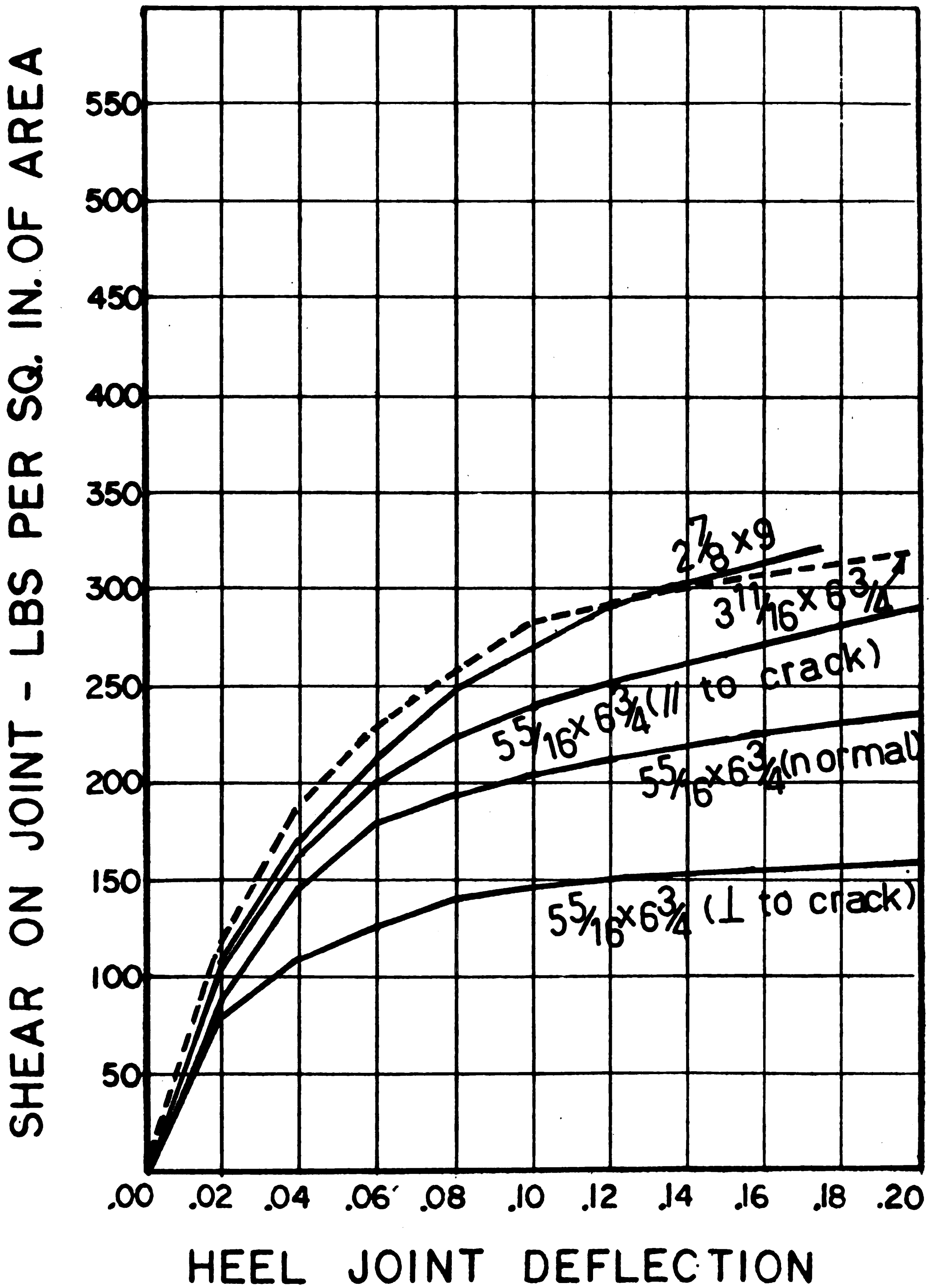



Figure 47. Load-Deflection Curves for Comparison of Six Plates.

b. From Table 9(b), both 2-7/8"x9" and 3-11/16"x6-3/4" heel plates are significantly stronger than 5-5/16"x 6-3/4" plates applied perpendicular to the top chord, at 0.040" deflection.

c. From Table 9(c), 2-7/8"x9", 3-11/16"x6-3/4", 5-5/16"x6-3/4" (parallel to the crack), and 5-5/16"x 4-1/2" plates perpendicular to the bottom chord are all highly significantly (at 0.01 level) stronger than the weakest ones, 5-5/16"x6-3/4" plates applied perpendicular to the crack. It might be noted that these range from 55% to 88% stronger than the weakest ones.

d. From Table 9(d), at 0.150" deflection, the same results as in c above, plus the fact that both 2-7/8"x9" and 3-11/16"x6-3/4" plates are significantly stronger than the 3-11/16"x4-1/2" plates.

e. From Table 9(e), at ultimate load, all plates were significantly stronger than the 5-5/16"x6-3/4" applied perpendicular to the crack. Also, the 2-7/8"x9" and 3-11/16"x6-3/4" were the strongest, and were significantly better than all the others. (The 5-5/16"x6-3/4" plates applied parallel to the top chord were not positioned uniformly over the two members, which made their results, based on the lesser contact area, appear better than normal.)

```
'EQUIP,20=MT(STAT)
'ROUTINE,UNEO1
' RUN, 0.44, 1000, 2
U TROY STEEL TRUSS PLATE COMPARISON (UNEO1)
D,6,24
LX(1) =0.015,0.040,0.080,0.150,ULTIMATE,TABLE NO
X(1)...X(5)=AOV(X(6))*
FORMAT(8X,5F3.0,F2.0)
401   75 11418524328631513
402   76 10118225530432513
403   77  7212225521123113
404   17 132203240274291  3
405   65  39104144177213  3
406   69  77166202228239  3
407   70  71161228279305  3
408   71 128200246281305  3
409   24  6610813815516612
410   72  7111214016117612
411   73  5810313515515912
412   74  6911213314115012
413    9 112218279300317  2
414   15 146245308349364  2
415   20  75156240303345  2
416   30  35122191308335  2
417   34  48134209270315  2
418   14 159256322357367  4
419   21 103216288330355  4
420   23  72147208243329  4
421   35  76160249291304  4
422    3  45138214254292  4
423   67  77147199229229  5
424   68  62125156187209  5
END OF RUN
```

Table 8. Computer Input for Comparison of Six Plate Sizes.

Table 9(a) Duncan's Multiple Range Comparison of Six Plate Sizes at 0.015" Deflection Level

| | SUM | FREQ | MEAN | MEAN INCREMENT | SUM OF SQUARES | STANDARD DEVIATION | SUM OF SQUARED DEVIATIONS FROM THE MEANS |
|---|---|---|---|---|---|---|---|
| (OVERALL) | 2008.000000 | 24 | 83.66666667 | | 193864.000000 | 33.532161 | 25861.333336 |
| CATEGORY | | | | | | | |
| 2-7/8" x 9" | 416.000000 | 5 | 83.20000000 | -0.466667 | 43014.000000 | 45.833394 | 8402.800000 |
| 5-5/16" x 4-1/2" ⊥ | 447.000000 | 5 | 89.40000000 | 5.733333 | 46299.000000 | 39.803266 | 6337.200000 |
| 3-11/16" x 6-3/4" | 455.000000 | 5 | 91.00000000 | 7.333333 | 48875.000000 | 43.214581 | 7470.000000 |
| 3-11/16" x 4-1/2" | 139.000000 | 2 | 69.50000000 | -14.166667 | 9773.000000 | 10.606602 | 112.500000 |
| 5-5/16" x 6-3/4" ⊥ | 264.000000 | 4 | 66.00000000 | -17.666667 | 17522.000000 | 5.715476 | 98.000000 |
| 5-5/16" x 6-3/4" | 287.000000 | 3 | 95.66666667 | 12.000000 | 28381.000000 | 21.901938 | 924.666667 |

Table of Mean Differences

| Rank | Size | Freq. | Mean | P=2 | P=3 | P=4 | P=5 | P=6 |
|---|---|---|---|---|---|---|---|---|
| 1. | 5-5/16" x 6-3/4" | 3 | 95.67 psi | 4.7 | 6.3 | 12.5 | 26.2 | 29.7 |
| 2. | 3-11/16" x 6-3/4" | 5 | 91.00 psi | 1.6 | 7.8 | 21.5 | 25.0 | |
| 3. | 5-5/16" x 4-1/2" ⊥ | 5 | 89.40 psi | 6.2 | 19.9 | 23.4 | | |
| 4. | 2-7/8" x 9" | 5 | 83.20 psi | 13.7 | 17.2 | | | |
| 5. | 3-11/16" x 4-1/2" | 2 | 69.50 psi | 3.5 | | | | |
| 6. | 5-5/16" x 6-3/4" ⊥ | 4 | 66.00 | | | | | |

No significant differences.

Table 9(b). Duncan's Multiple Range Comparison of Six Plate Sizes at 0.040" Deflection Level

| | SUM | FREQ | MEAN | MEAN INCREMENT | SUM OF SQUARES | STANDARD DEVIATION | SUM OF SQUARED DEVIATIONS FROM THE MEANS |
|---|---|---|---|---|---|---|---|
| (OVERALL) | 3831.000000 | 24 | 159.62500000 | | 658461.000000 | 45.174841 | 46937.625000 |
| CATEGORY | | | | | | | |
| 2-7/8" x 9" | 875.000000 | 5 | 175.00000000 | 15.375000 | 164725.000000 | 53.851648 | 11608.000000 |
| 5-5/16" x 4-1/2" ⊥ | 834.000000 | 5 | 166.80000000 | 7.175000 | 145502.000000 | 39.971240 | 6390.799999 |
| 3-11/16" x 6-3/4" | 926.000000 | 5 | 185.20000000 | 25.575000 | 181406.000000 | 49.776500 | 9910.799999 |
| 3-11/16" x 4-1/2" | 272.000000 | 2 | 136.00000000 | -23.625000 | 37234.000000 | 15.556349 | 242.000000 |
| 5-5/16" x 6-3/4" ⊥ | 435.000000 | 4 | 108.75000000 | -50.875000 | 47361.000000 | 4.272002 | 54.750000 |
| 5-5/16" x 6-3/4" | 489.000000 | 3 | 163.00000000 | 3.375000 | 82233.000000 | 35.538711 | 2526.000000 |

Table of Mean Differences

| Rank | Size | Freq. | Mean | P=2 | P=3 | P=4 | P=5 | P=6 |
|---|---|---|---|---|---|---|---|---|
| 1. | 3-11/16" x 6-3/4" | 5 | 185.2 psi | 10.2 | 18.4 | 22.2 | 49.2 | 76.4* |
| 2. | 2-7/8" x 9" | 5 | 175.0 psi | 8.2 | 12.0 | 39.0 | 66.3* | |
| 3. | 5-5/16" x 4-1/2" ⊥ | 5 | 166.8 psi | 3.8 | 30.8 | 58.1 | | |
| 4. | 5-5/16" x 6-3/4" | 3 | 163.0 psi | 27.0 | 54.3 | | | |
| 5. | 3-11/16" x 4-1/2" | 2 | 136.0 psi | 27.25 | | | | |
| 6. | 5-5/16" x 6-3/4" ⊥ | 4 | 108.75 psi | | | | | |

* Denotes statistical significance at 0.05 level.

Table 3(C). Duncan's Multiple Range Comparisons

Table 9(c). Duncan's Multiple Range Comparison of Six Plate Sizes at 0.080" Deflection Level

| | SUM | FREQ | MEAN | MEAN INCREMENT | SUM OF SQUARES | STANDARD DEVIATION | SUM OF SQUARED DEVIATIONS FROM THE MEANS |
|---|---|---|---|---|---|---|---|
| (OVERALL) | 5222.000000 | 24 | 217.58333333 | | 1207390.000000 | 55.626797 | 71169.833344 |
| CATEGORY | | | | | | | |
| 2-7/8" x 9" | 1227.000000 | 5 | 245.40000000 | 27.816667 | 310467.000000 | 48.876647 | 9361.200005 |
| 5-5/16" x 4-1/2" ⊥ | 1060.000000 | 5 | 212.00000000 | -5.583333 | 231640.000000 | 41.593269 | 6920.000000 |
| 3-11/16" x 6-3/4" | 1281.000000 | 5 | 256.20000000 | 38.616667 | 337689.000000 | 48.725763 | 9496.800003 |
| 3-11/16" x 4-1/2" | 355.000000 | 2 | 177.50000000 | -40.083333 | 63937.000000 | 30.405592 | 924.500000 |
| 5-5/16" x 6-3/4" ⊥ | 546.000000 | 4 | 136.50000000 | -81.083333 | 74558.000000 | 3.109126 | 29.000000 |
| 5-5/16" x 6-3/4" | 753.000000 | 3 | 251.00000000 | 33.416667 | 189099.000000 | 6.928203 | 96.000000 |

Table of Mean Differences

| Rank | Size | Freq. | Mean | P=2 | P=3 | P=4 | P=5 | P=6 |
|---|---|---|---|---|---|---|---|---|
| 1. | 3-11/16" x 6-3/4" | 5 | 256.2 psi | 5.2 | 10.8 | 44.2 | 78.7* | 119.7** |
| 2. | 5-5/16" x 6-3/4" | 3 | 251.0 psi | 5.6 | 39.0 | 73.5 | 114.5** | |
| 3. | 2-7/8" x 9" | 5 | 245.4 psi | 33.4 | 67.9 | 108.9** | | |
| 4. | 5-5/16" x 4-1/2" ⊥ | 5 | 212.0 psi | 34.5 | 75.5** | | | |
| 5. | 3-11/16" x 4-1/2" | 2 | 177.5 psi | 41.0 | | | | |
| 6. | 5-5/16" x 6-3/4" ⊥ | 4 | 136.5 psi | | | | | |

* Denotes statistical significance at 0.05 level.
** Denotes statistical significance at 0.01 level.

Table 9(d). Duncan's Multiple Range Comparison of Six Plate Sizes at 0.150" Deflection Level

| | SUM | FREQ | MEAN | MEAN INCREMENT | SUM OF SQUARES | STANDARD DEVIATION | SUM OF SQUARED DEVIATIONS FROM THE MEANS |
|---|---|---|---|---|---|---|---|
| (OVERALL) | 6082.000001 | 24 | 253.41666667 | | 1637176.000000 | 64.578768 | 95095.833313 |
| CATEGORY | | | | | | | |
| 2-7/8" x 9" | 1530.000000 | 5 | 306.00000000 | 52.583333 | 471374.000000 | 28.257742 | 3194.000000 |
| 5-5/16" x 4-1/2" ⊥ | 1239.000000 | 5 | 247.80000000 | -5.616667 | 315191.000000 | 45.185175 | 8166.800003 |
| 3-11/16" x 6-3/4" | 1484.000000 | 5 | 296.80000000 | 43.383333 | 450616.000000 | 50.418336 | 10164.800003 |
| 3-11/16" x 4-1/2" | 416.000000 | 2 | 208.00000000 | -45.416667 | 87410.000000 | 29.698485 | 882.000000 |
| 5-5/16" x 6-3/4" ⊥ | 612.000000 | 4 | 153.00000000 | -100.416667 | 93852.000000 | 8.485281 | 216.000000 |
| 5-5/16" x 6-3/4" | 801.000000 | 3 | 267.00000000 | 13.583333 | 218733.000000 | 49.325450 | 4866.000000 |

Table of Mean Differences

| Rank | Size | Freq. | Mean | P=2 | P=3 | P=4 | P=5 | P=6 |
|---|---|---|---|---|---|---|---|---|
| 1. | 2-7/8" x 9" | 5 | 306.0 psi | 9.2 | 39.0 | 58.2 | 98.0* | 153.0** |
| 2. | 3-11/16" x 6-3/4" | 5 | 296.8 psi | 29.8 | 49.0 | 88.8* | 143.8** | |
| 3. | 5-5/16" x 6-3/4" | 3 | 267.0 psi | 19.2 | 59.0 | 114.0** | | |
| 4. | 5-5/16" x 4-1/2" ⊥ | 5 | 247.8 psi | 39.8 | 94.8** | | | |
| 5. | 3-11/16" x 4-1/2" | 2 | 208.0 psi | 55.0 | | | | |
| 6. | 5-5/16" x 6-3/4" ⊥ | 4 | 153.0 psi | | | | | |

* Denotes statistical significance at 0.05 level.
** Denotes statistical significance at 0.01 level.

Table 9(e). Duncan's Multiple Range Comparison of Six Plate Sizes at Ultimate Load

| | SUM | FREQ | MEAN | MEAN INCREMENT | SUM OF SQUARES | STANDARD DEVIATION | SUM OF SQUARED DEVIATIONS FROM THE MEANS |
|---|---|---|---|---|---|---|---|
| (OVERALL) | 6636.000000 | 24 | 276.50000000 | | 1943962.000000 | 68.875439 | 189108.000000 |
| CATEGORY | | | | | | | |
| 2-7/8" x 9" | 1676.000000 | 5 | 335.20000000 | 58.[illegible] | 563460.000000 | 20.408980 | 1664.800003 |
| 5-5/16" x 4-1/2" ⊥ | 1353.000000 | 5 | 270.60000000 | -5.90[illegible] | 373221.000000 | 42.128375 | 7099.200005 |
| 3-11/16" x 6-3/4" | 1647.000000 | 5 | 329.40000000 | 52.900000 | 546635.000000 | 32.067117 | 4113.199997 |
| 3-11/16" x 4-1/2" | 438.000000 | 2 | 219.00000000 | -57.500000 | 96122.000000 | 14.142136 | 200.000000 |
| 5-5/16" x 6-3/4" ⊥ | 651.000000 | 4 | 162.75000000 | -113.750000 | 1[illegible]6313.000000 | 10.996211 | 362.750000 |
| 5-5/16" x 6-3/4" | 871.000000 | 3 | 290.33333333 | 13.833333 | 258211.000000 | 51.626866 | 5330.666668 |

Table of Mean Differences

| Rank | Size | Freq. | Mean | P=2 | P=3 | P=4 | P=5 | P=6 |
|---|---|---|---|---|---|---|---|---|
| 1. | 2-7/8" x 9" | 5 | 335.2 psi | 5.8 | 44.9 | 64.5** | 116.2** | 172.45** |
| 2. | 3-11/16" x 6-3/4" | 5 | 329.4 psi | 39.1 | 58.8* | 110.4** | 166.65** | |
| 3. | 5-5/16" x 6-3/4" | 3 | 290.3 psi | 19.7 | 71.3* | 127.6** | | |
| 4. | 5-5/16" x 4-1/2" ⊥ | 5 | 270.6 psi | 51.6 | 107.9** | | | |
| 5. | 3-11/16" x 4-1/2" | 2 | 219.0 psi | 56.3* | | | | |
| 6. | 5-5/16" x 6-3/4" ⊥ | 4 | 162.75 psi | | | | | |

* Denotes statistical significance at 0.05 level.
** Denotes statistical significance at 0.01 level.

Summary

The over-all conclusions from this series of tests and statistical comparisons of six plate sizes and orientations were that:

a. At 0.015" deflection, any plate size may be used.

b. At high levels of deflection (and high loads), plates ranging in width from 2-3/4" to about 4" and in length from two to three times their width are the most efficient, being about twice as strong as the nearly square plates applied in the weakest possible direction.

c. The comparison of load-deflection curves is shown in Figure 47 for the average values of these six plate sizes, shapes, and orientations.

## Comparison of Matched Specimens

Description

Fifty-six specimens were tested to evaluate the effect of each of the following factors on contact area stress:

a. Size of truss plate (3"x5", 3"x8", or 5"x5").

b. Length of test specimens (8'-0" or 24'-0").

c. Species of lumber (Douglas fir or white fir).

d. Level of deflection (0.015", 0.040", 0.080", 0.150").

e. Moisture content.

f. Specific gravity.

f. Location of 8'-0" tests (at home on small jig, or at M.S.U. on Forestry Dept.'s Riehle Testing Machine).

The plate size, specimen length, species, load-deflection curve, and other pertinent data for each group of specimens is given in Figures 48 through 59. The raw data is given in the Appendix, in Tables 33 through 46.

Comparison of 8'-0" vs. 24'-0" Specimen Length

The results of an initial comparison of 24 matched specimens was reported in "Test Results" of the chapter on "Experimental Analysis." Load-deflection curves comparing 8'-0" specimens with full-scale 24'-0" trusses are given in Figures 48 through 53.

The load-deflection curves for the 24'-0" trusses are shown with solid lines, while the 8'-0" specimens and curves are shown dashed. The 8'-0" specimens had higher values than the 24'-0" trusses for all cases except the 3"x5" plates in Douglas fir (Figure 48). However, by taking the average ultimate contact stress from the data Tables 33 through 38 in the Appendix, the comparison in Table 10 can be made:

Table 10. 8'-0" vs. 24'-0" Specimens at Ultimate Load.

| Description | | Average Ultimate Contact Stress | | |
|---|---|---|---|---|
| Plate Size | Species | 8'-0" | 24'-0" | 8'/24' Ratio |
| 3"x5" | D. fir | 301 | 322 | 93½% |
| 3"x8" | " " | 317 | 422 | 75 |
| 5"x5" | " " | 287 | 290 | 99 |
| 3"x5" | Wh. fir | 232 | 233 | 100 |
| 3"x8" | " " | 225 | 193 | 116½ |
| 5"x5" | " " | 220 | 202 | 109 |
| | | | | 6)593 % |

8' average = 99% of 24'

This means the 8'-0" specimen average was almost identical to the 24'-0" average at ultimate load. Ultimate load data was not included in the statistical analysis.

A similar comparison at the other loads is given in Table 11.

Table 11. 8'-0" vs. 24'-0" Specimens at Four Deflection Levels.

| Deflection | Comparison |
|---|---|
| 0.015" | 8'-0" specimen is 8½% stronger than 24'-0" |
| 0.040" | 8'-0" " " 21 % " " 24'-0" |
| 0.080" | 8'-0" " " 9 % " " 24'-0" |
| 0.150" | 8'-0" " " 4 % " " 24'-0" |
| Ultimate | 8'-0" " " 1 % weaker " 24'-0" |
| Over-all | 8'-0" specimen is 8 % stronger than 24'-0" |

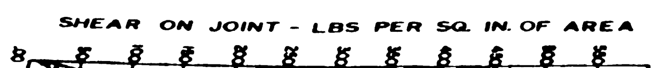
Comparison of Small 8'-0" Jig Results with Riehle Machine Results

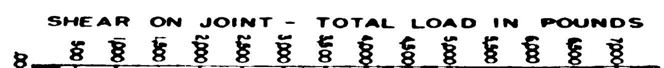
As a result of concern over the data from the 8'-0" specimens tested on the small hand operated hydraulic test jig, an additional set of 24 specimens 8'-0" long was built, listed in Table 12.

Table 12. Riehle Machine 8'-0" Test Specimens

| Group | Quan. | Heel Plate | Species |
|---|---|---|---|
| 1 | 4 | 3"x5" | D. fir |
| 2 | 4 | 3"x8" | " " |
| 3 | 4 | 5"x5" | " " |
| 4 | 4 | 3"x5" | Wh. fir |
| 5 | 4 | 3"x8" | " " |
| 6 | 4 | 5"x5" | " " |

Two samples, the first two tested, were selected from each group and matched in a Preliminary Analysis of Variance to compare the effect of test location. The results are


SHEAR ON JOINT - LBS PER SQ. IN. OF AREA
.00
50
100
150
200
250
300
350
400
450
500
550


SHEAR ON JOINT - TOTAL LOAD IN POUNDS
.00
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
5,500
6,000
6,500
7,000

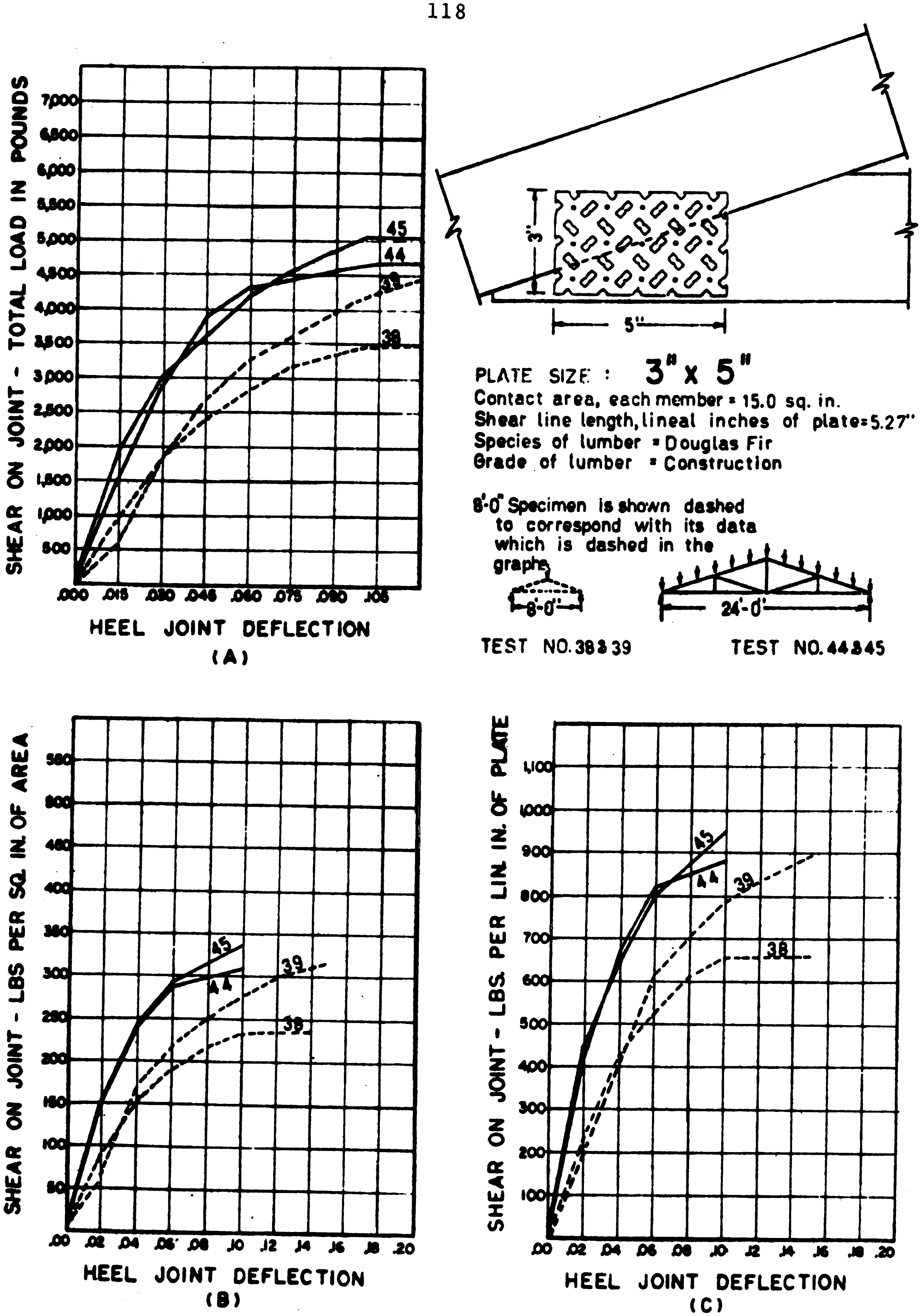



Figure 48. Load-Deflection Curves for 8' vs. 24' - 3"x5" - Douglas Fir.

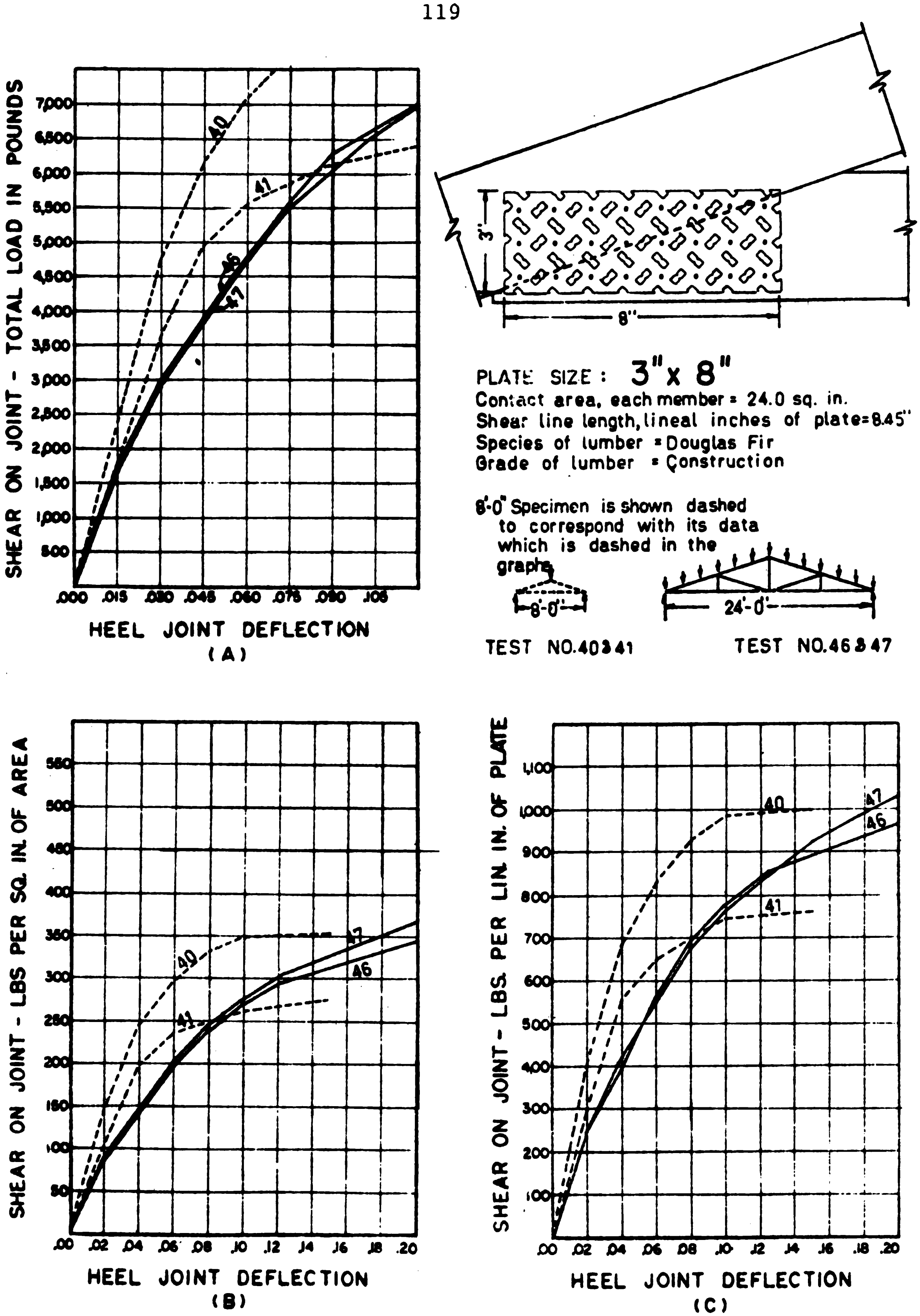



Figure 49. Load-Deflection Curves for 8' vs. 24' - 3"x8" - Douglas Fir.

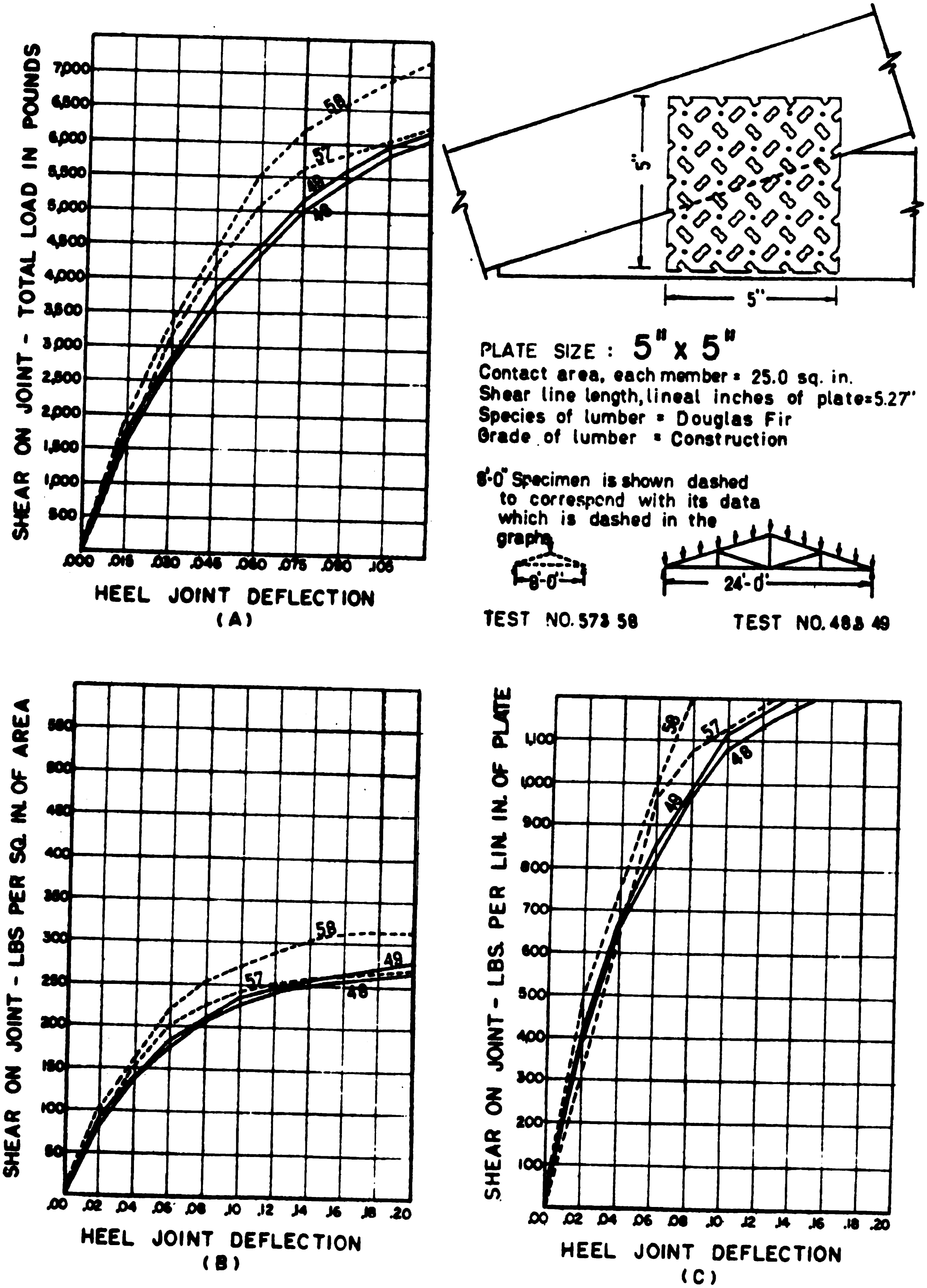



Figure 50. Load-Deflection Curves for 8' vs. 24' - 5"x5" - Douglas Fir.

SHEAR ON JOINT - LBS PER SQ. IN. OF AREA

SHEAR ON JOINT - TOTAL LOAD IN POUNDS

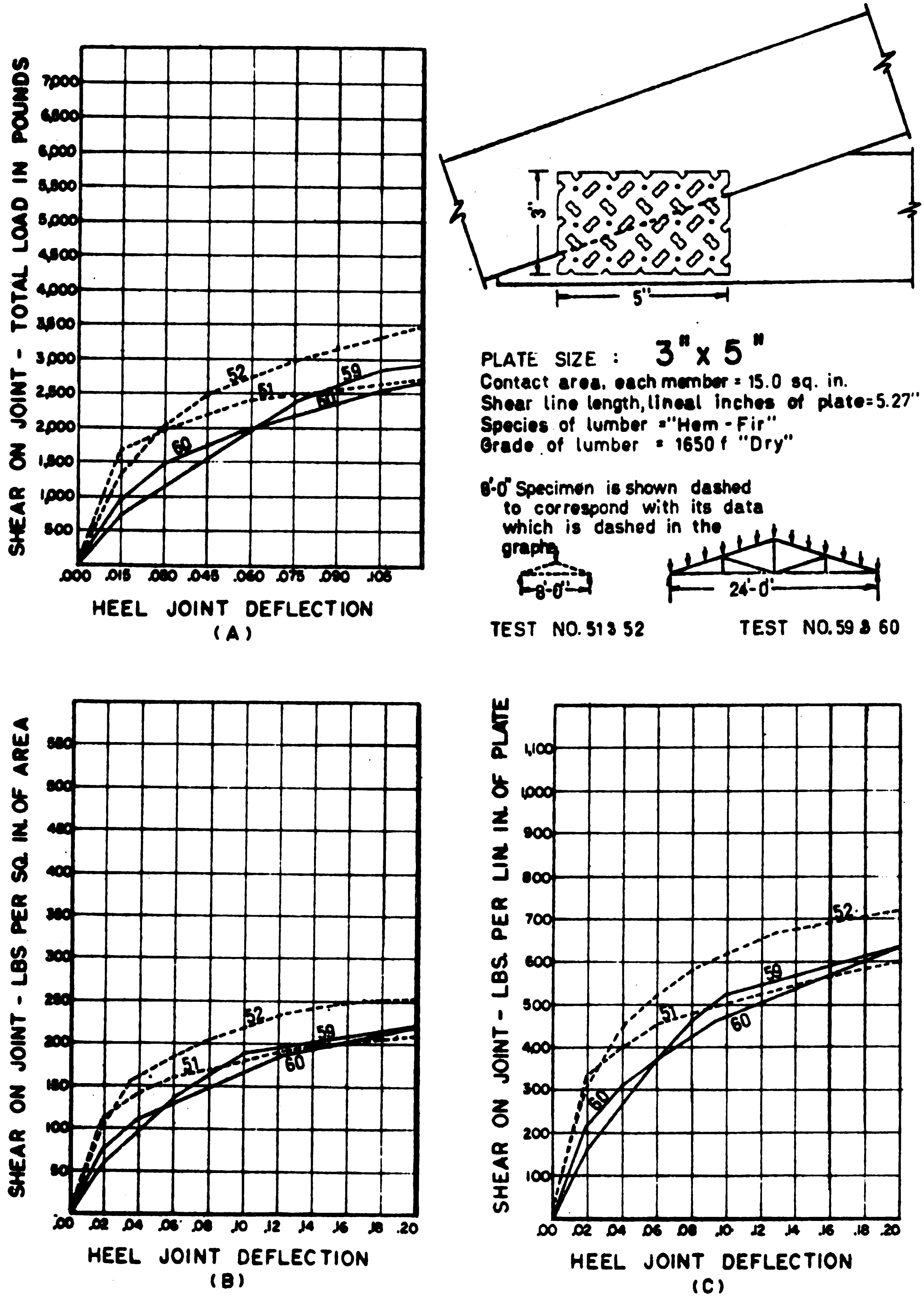



Figure 51. Load-Deflection Curves for 8' vs. 24' - 3"x5" - White Fir.

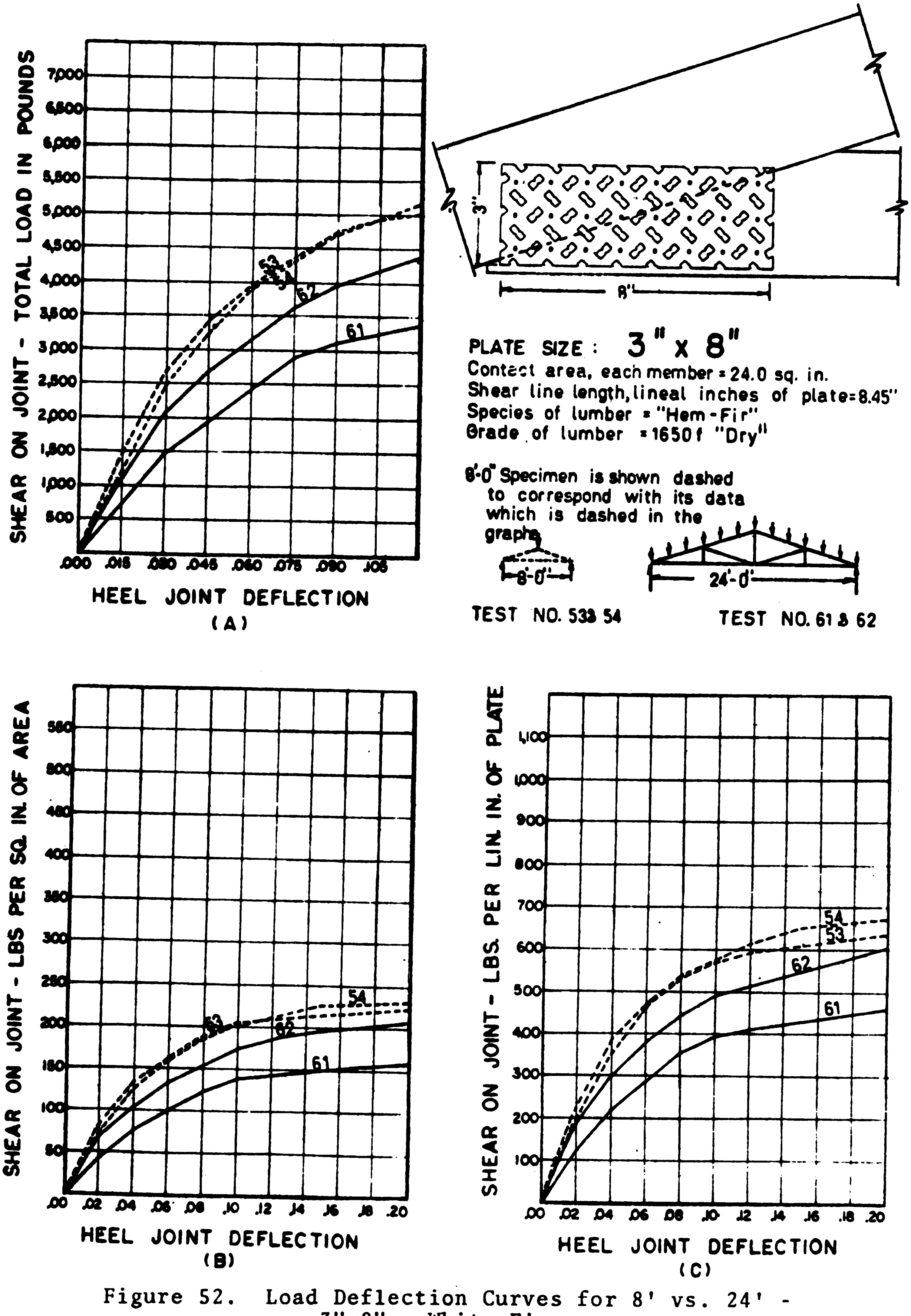



Figure 52. Load Deflection Curves for 8' vs. 24' - 3"x8" - White Fir.

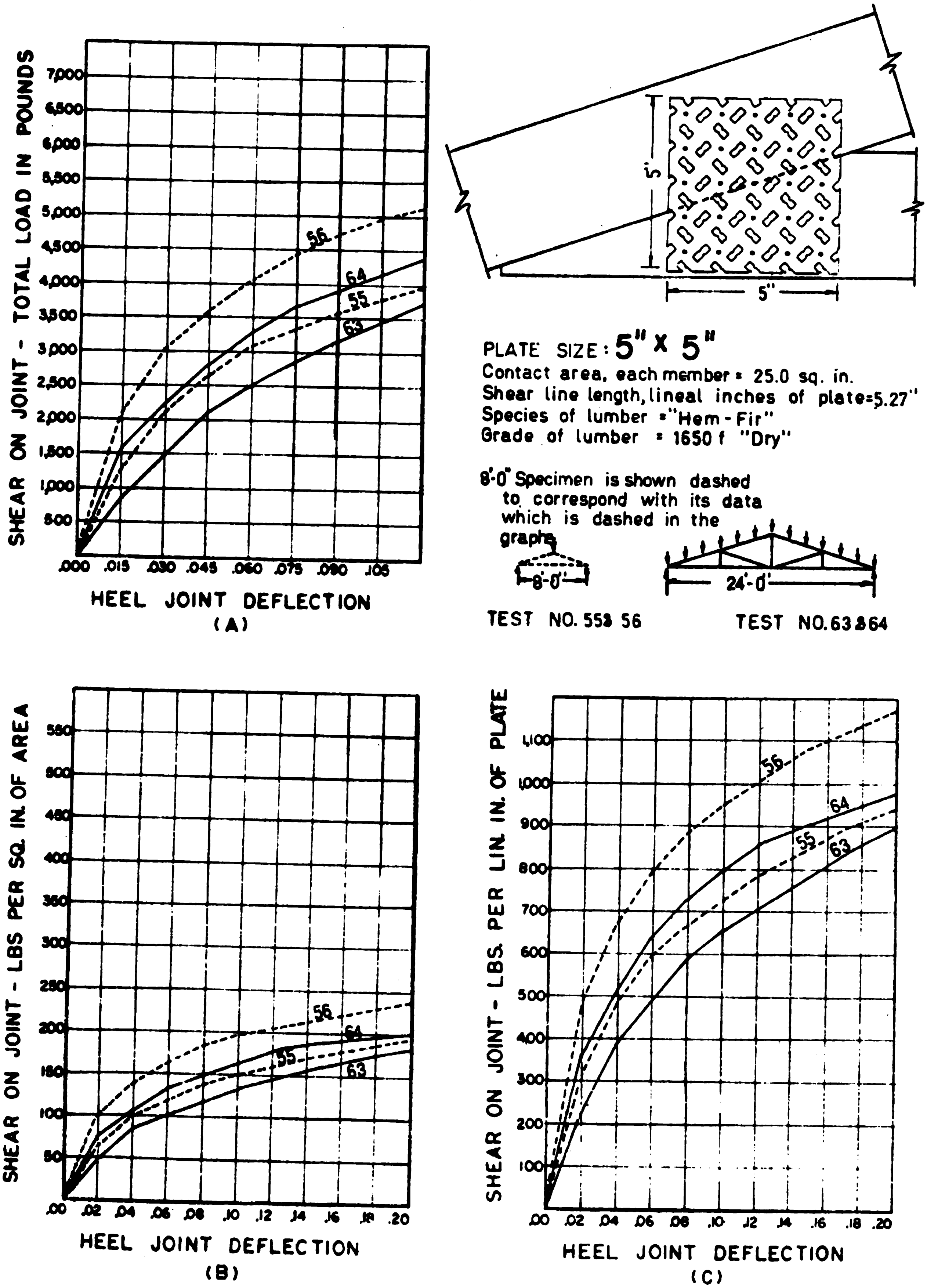



Figure 53. Load Deflection Curves for 8' vs. 24' - 5"x5" - White Fir.

shown in Table 7 which showed there was no significant effect due to location. The tests performed on the small 8'-0" hand-operated jig were just as valid, and essentially the same, as the tests performed on the Riehle testing machine.

## Comparison of Douglas Fir vs. White Fir

The same specimens were compared for the difference in species, and the load-deflection curves are shown in Figures 54 through 59. The Douglas fir trusses are shown with solid lines, while the white fir specimen curves are shown dashed. The Douglas fir specimens had higher values than the white fir in all cases. By making the comparison of average ultimate contact stress from the data Tables 33 through 38 in the Appendix, the species comparison in Table 13 can be made:

Table 13. White Fir vs. Douglas Fir at Ultimate Load.

| Description | | Average Ultimate Contact Stress | | |
|---|---|---|---|---|
| Plate Size | Length | White Fir | Doug. Fir | White/Doug. Ratio |
| 3"x5" | 8' | 232 | 301 | 77 % |
| 3"x8" | 8' | 225 | 317 | 71 |
| 5"x5" | 8' | 220 | 287 | 76½ |
| 3"x5" | 24' | 233 | 322 | 72½ |
| 3"x8" | 24' | 193 | 422 | 45½ |
| 5"x5" | 24' | 202 | 290 | 69½ |
| | | | | 6)412 % |
| | | | | 69 % |

White fir averaged 69% of the ultimate value of Douglas fir.

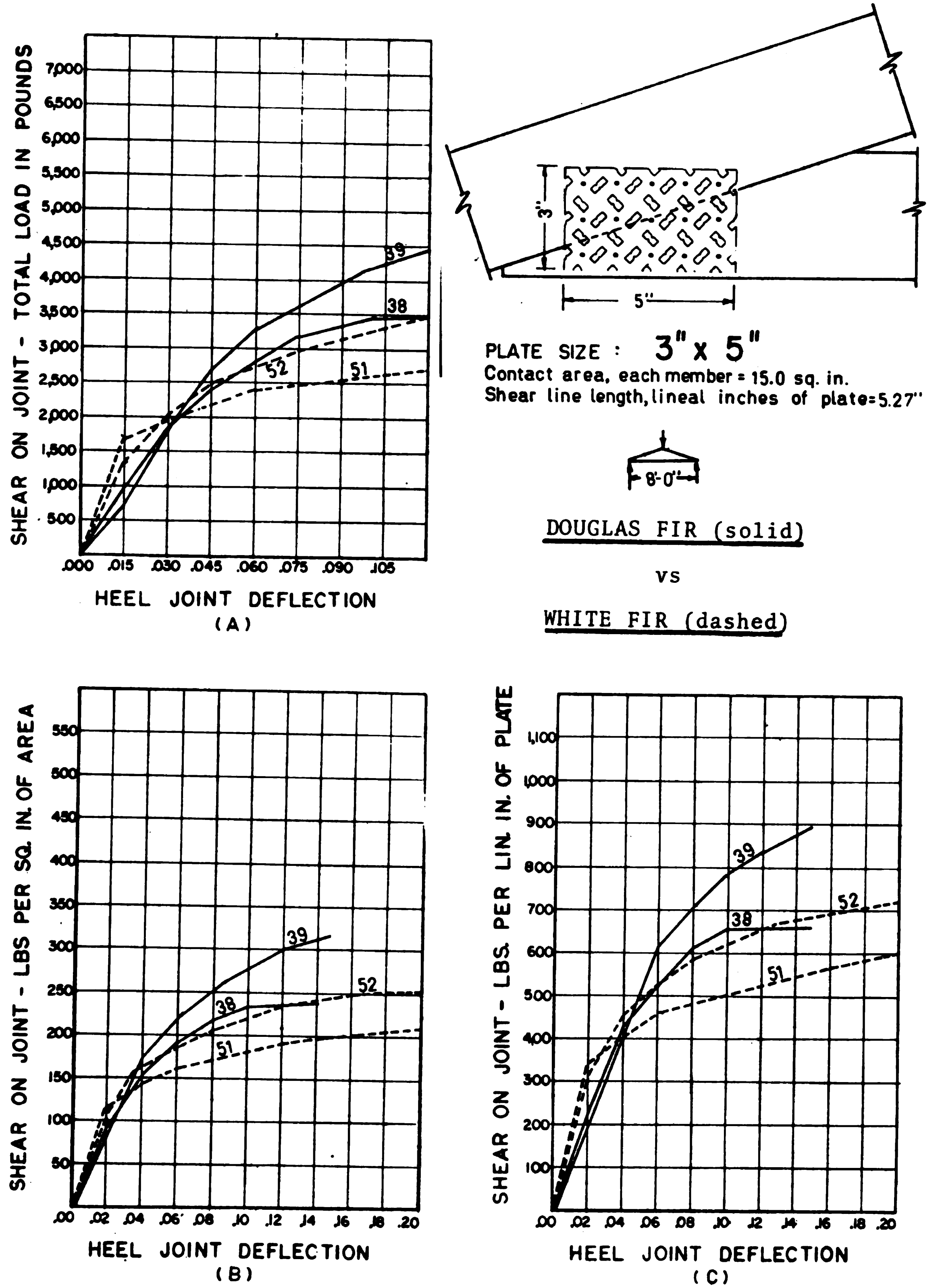



Figure 54. Load-Deflection Curves for Douglas vs. White Fir - 3"x5" - 8'.

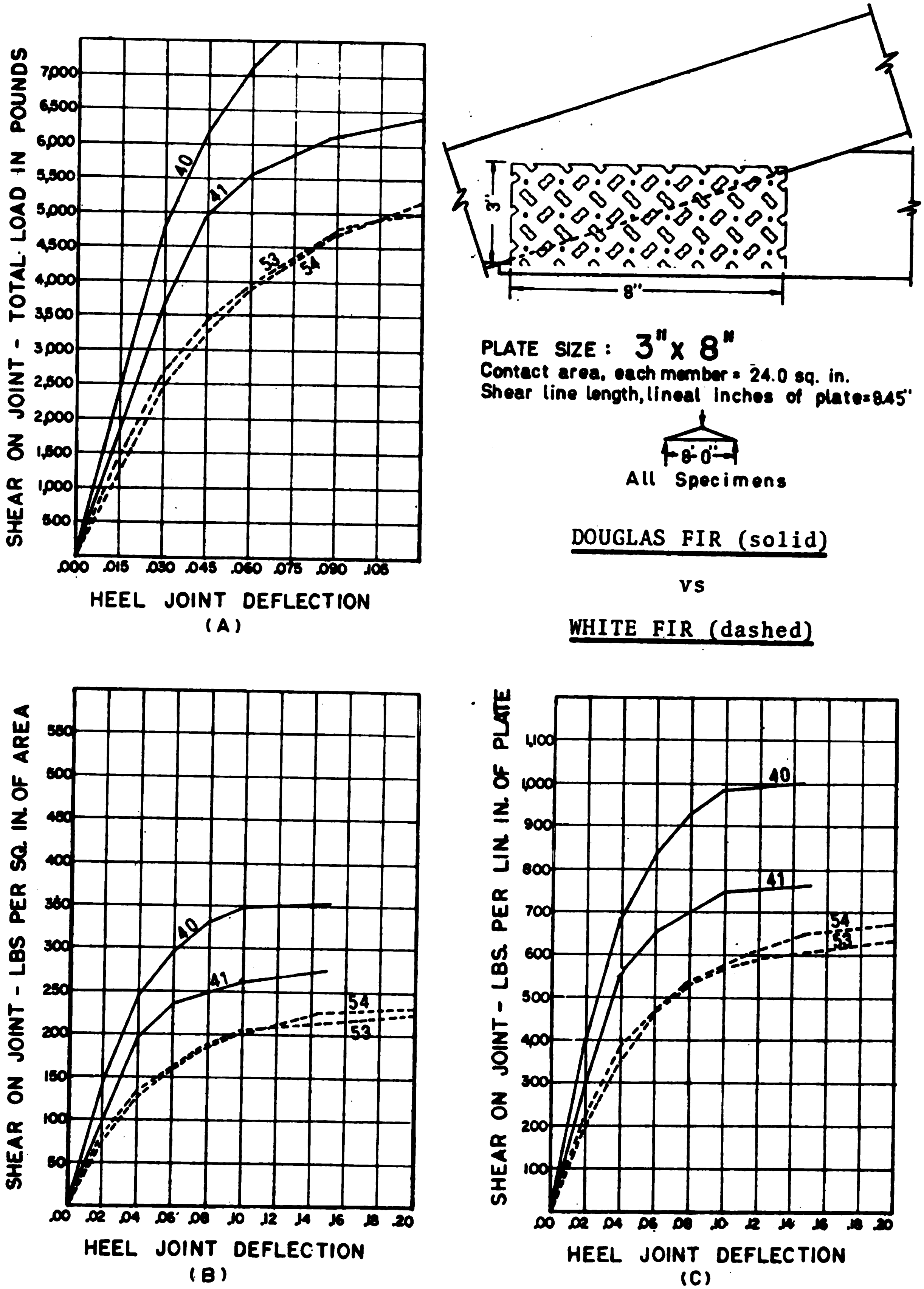



Figure 55. Load-Deflection Curves for Douglas vs. White Fir - 3"x8" - 8'.

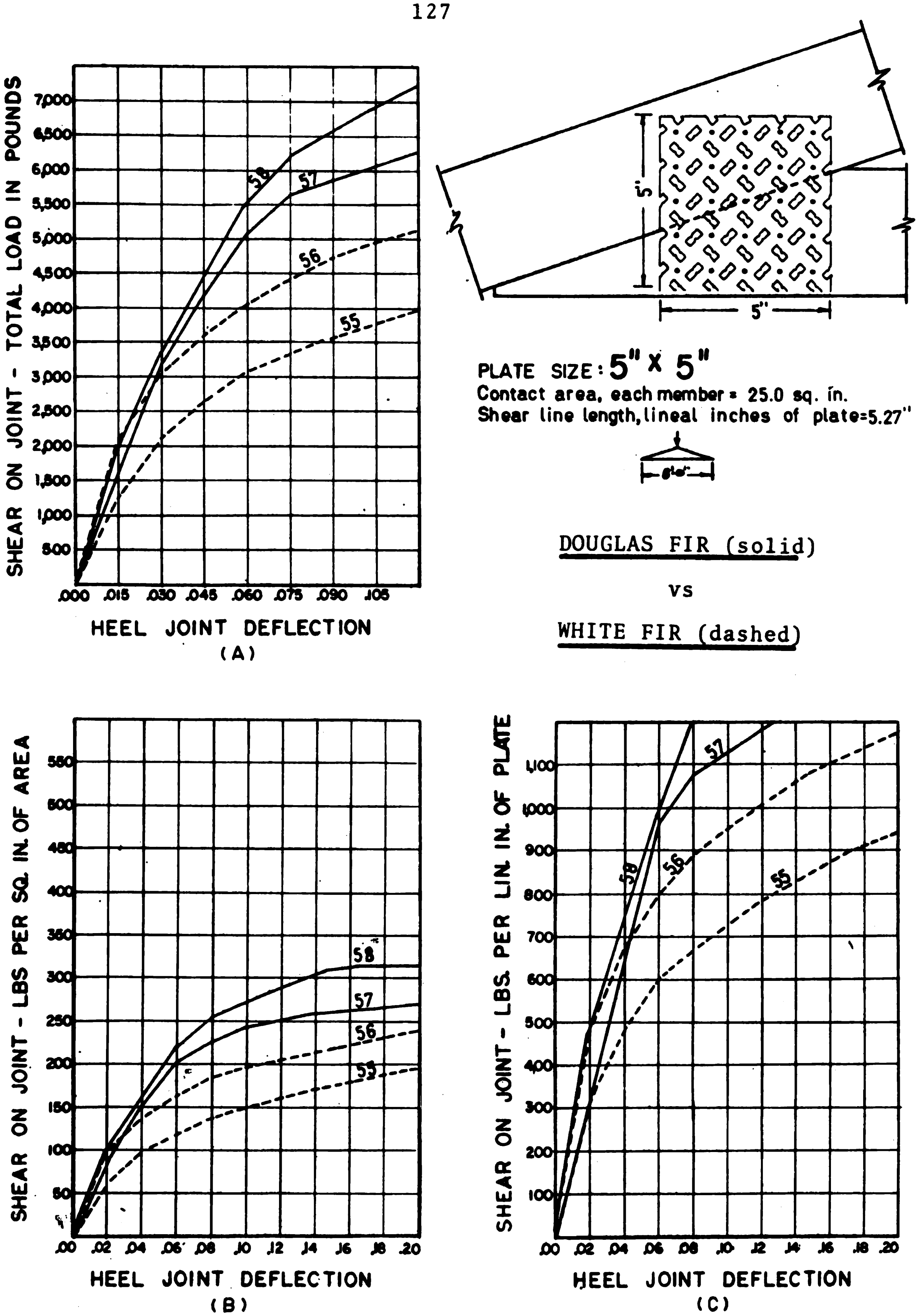



Figure 56. Load-Deflection Curves for Douglas vs. White Fir - 5"x5" - 8'.

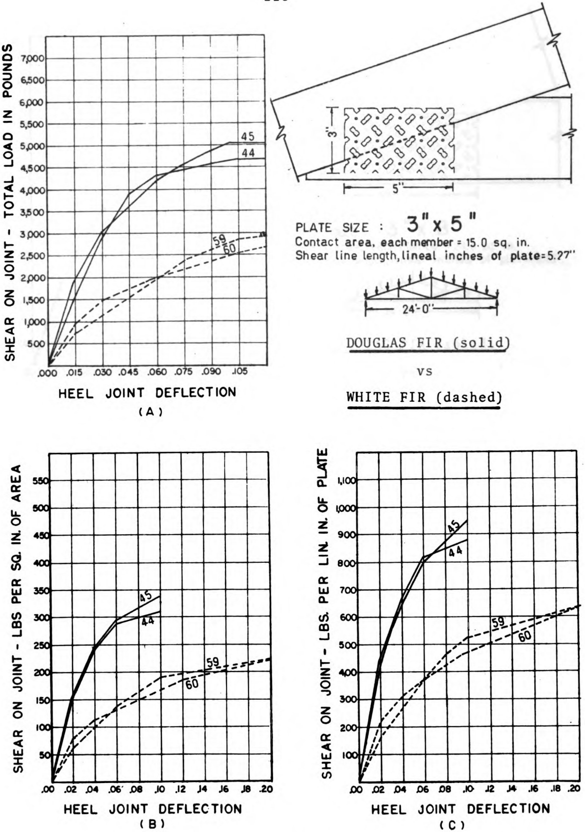



Figure 57. Load-Deflection Curves for
Douglas vs. White Fir - 3"x5" - 24'.

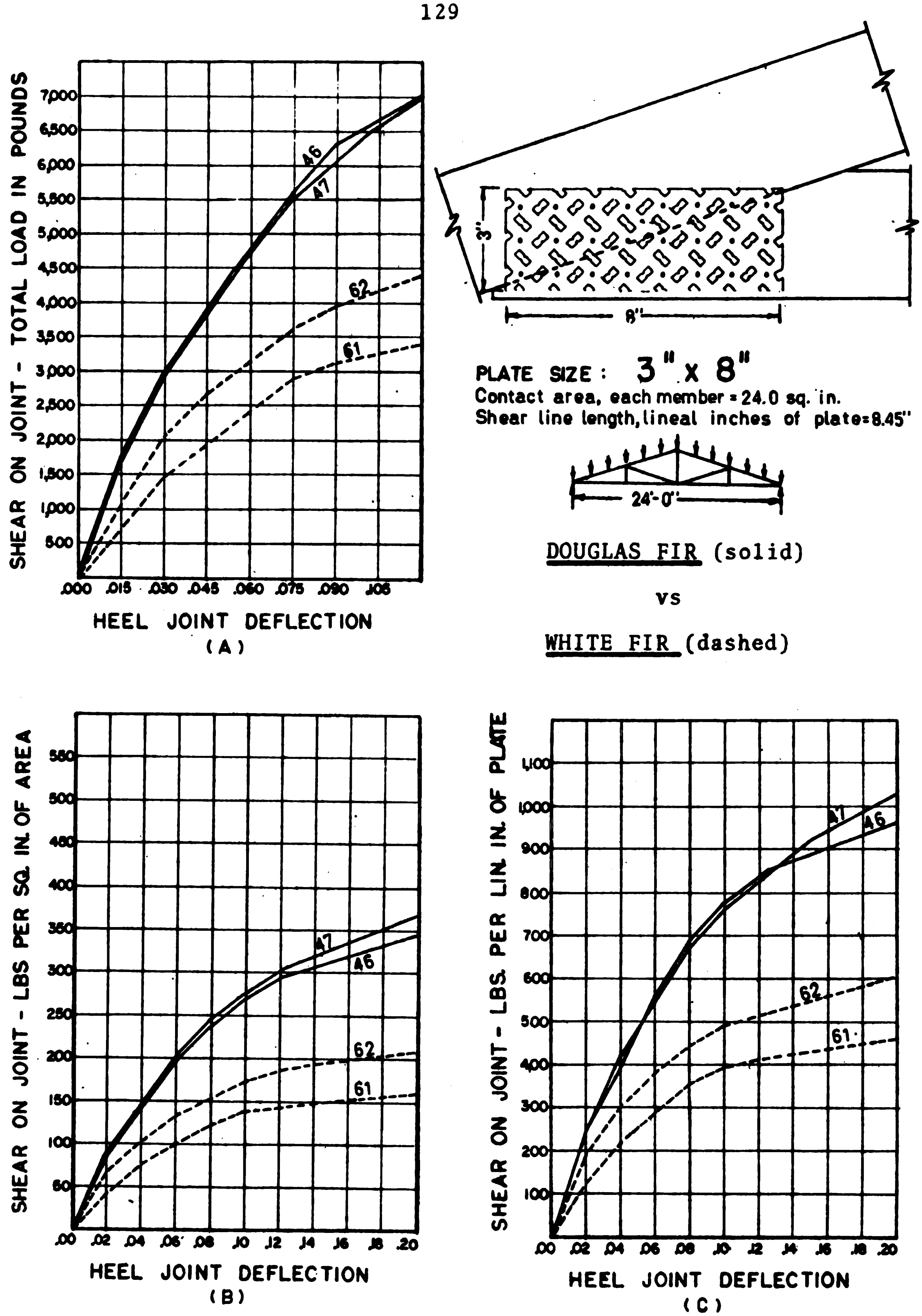



Figure 58. Load-Deflection Curves for Douglas vs. White Fir - 3"x8" - 24'.

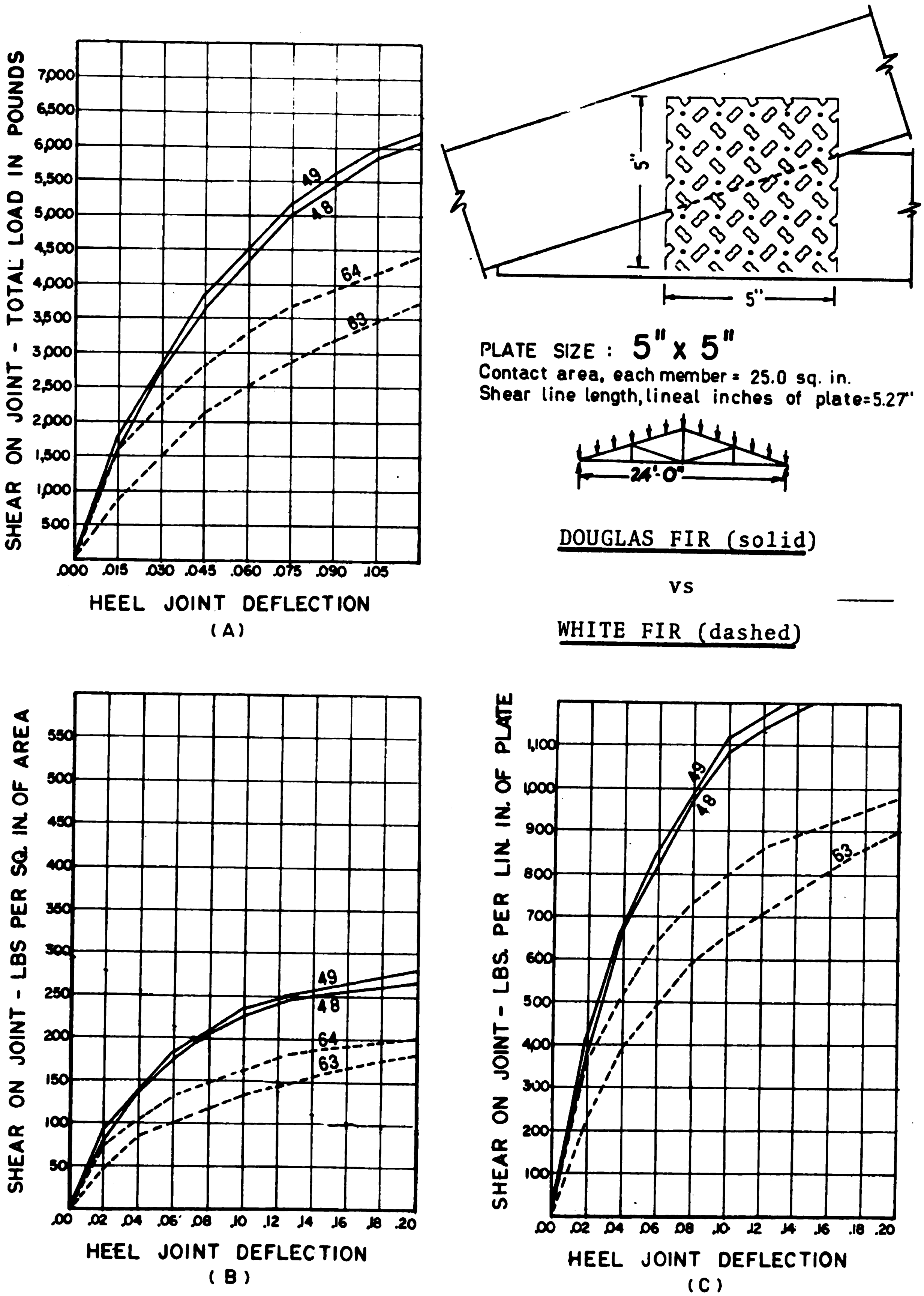



Figure 59. Load-Deflection Curves for Douglas vs. White Fir - 5"x5" - 24'.

A similar comparison of the other loads is given in Table 14.

Table 14. White Fir vs. Douglas Fir at Four Deflection Levels.

| Deflection | Comparison |
|---|---|
| 0.015" | White fir averages 72% of Douglas fir |
| 0.040" | " " " 70% " " " |
| 0.080" | " " " 62% " " " |
| 0.150" | " " " 69% " " " |
| Ultimate | " " " 69% " " " |

Over-all White fir averages 68% of Douglas fir

Comparison of 3"x5", 3"x8", and 5"x5" Plates

Using the same data, the average ultimate loads, based on plate sizes are shown in Table 15.

Table 15. 3"x5", 3"x8", and 5"x5" Plates Compared at Ultimate Load.

| | Average Ultimate Contact Stress | | |
|---|---|---|---|
| Length Specie | 3"x5" | 3"x8" | 5"x5" |
| 8'-0" Doug. fir | 301 | 317 | 287 |
| 8'-0" White fir | 232 | 225 | 220 |
| 24'-0" Doug. fir | 322 | 422 | 290 |
| 24'-0" White fir | 233 | 193 | 202 |
| | 4)1088 | 4)1157 | 4) 999 |
| | 272 | 289 | 250 |

The 3"x5" plates fail at 94% of the ultimate stress of 3"x8".

The 5"x5" plates fail at 86½% of the ultimate stress of 3"x8".

Similar comparisons were made and the results given in Table 16.

Table 16. 3"x5", 3"x8", and 5"x5" Plates Compared at Four Deflection Levels.

| | Average Contact Stress | | | | | |
|---|---|---|---|---|---|---|
| | 3"x5" | | 3"x8" | | 5"x5" | |
| | psi | % | psi | % | psi | % |
| 0.015" | 82 | 124 | 66 | 100 | 67 | 101 |
| 0.040" | 163 | 110 | 148 | 100 | 130 | 88 |
| 0.080" | 223 | 104 | 215 | 100 | 187 | 87 |
| 0.150" | 256 | 100 | 257 | 100 | 229 | 89 |
| Ultimate | 272 | 94 | 289 | 100 | 250 | 86½ |

Ave. % of 3"x8" value = 106% 100% 90%

## Final (4-way) Comparison, including Moisture Content and Specific Gravity

Description

A final comparison of contact area stress, involving all fifty-six specimens, was made on a lest squares statistical routine on the M.S.U. CDC 3600 Computer using A.E.S. Stat Description 18, "Analysis of Covariance and Analysis of Variance with Unequal Frequencies Permitted in the Cells." This comparison was more complete than the preliminary comparison of 8'-0" vs. 24'-0" (Table 6), or the comparison of the 8'-0" jig vs. the Riehle testing machine (Table 7), since it included all the specimens, plus evaluating the effect of moisture content and specific gravity. It was not necessary to delete specimens just to keep all cells equal. It was possible to include moisture content and specific gravity as covariants, and even to include the square of moisture content and specific gravity.

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Data

The load-deflection data from Tables 33 through 46 in the Appendix was used, for 0.015", 0.040", 0.080", and 0.150" deflection. The actual data input for the computer program is given in Table 17. A part of that program is the transformation sub-deck described further under the sections on "Creation of Indicator Variables."

Results

The computer output from this program, after slight abridgement, is included in Tables 18, 19, 20, 21, and 22. It should be noted in Table 19, that for the 224 observations, $R^2 = .9104$, which means that this set of variables accounted for 91% of the variance, a relatively high percentage for this type of research.

Summary of Final Analysis of Variance Comparison

By construction of an analysis of variance table from the data output, Table 22, the following conclusions could be drawn:

a. Species had a highly significant effect on strength with Douglas fir being about 59% stronger than white fir. This is a crucial factor since equivalent grades of the two species are often used interchangeably. That is a dangerous practice unless appropriately reduced tooth values (i.e., larger plates) are used.

**Table 17.** Data Input for Final Analysis of Variance.

```
!DEMAND,MT
      SUBROUTINE TRANS1(X)
      COMMON/A/NP,NT,IS,IDP,JP  $  DIMENSION X(200)
      DOUBLE PRECISION X
      IF(X(2).EQ.1.)X(9)=1.
      IF(X(2).EQ.2.)X(9)=-1.
      IF(X(3).EQ.1.)X(10)=1.
      IF(X(3).EQ.2.)X(10)=-1.
      X(12)=X(11)=2.0-X(4)
      IF(X(11).NE.-1.)X(12)=1.-X(11)
      X(13)=X(14)=X(15)=0.0
      IF(X(5).EQ.4)X(13)=X(14)=X(15)=-1.0
      K=X(5)
      IF(X(5).LT.4)X(12+K)=1.0
      X(16)=X(9)*X(11)
      X(17)=X(9)*X(12)
      X(18)=X(9)*X(13)
      X(19)=X(9)*X(14)
      X(20)=X(9)*X(15)
      X(21)=X(11)*X(13)
      X(22)=X(11)*X(14)
      X(23)=X(11)*X(15)
      X(24)=X(12)*X(13)
      X(25)=X(12)*X(14)
      X(26)=X(12)*X(15)
      X(27)=X(10)*X(11)
      X(28)=X(10)*X(12)
      X(29)=X(7)*X(7)
      X(30)=X(8)*X(8)
      RETURN
      END
!ROUTINE,LS
!RUN,1,30,2100,2
9,8,224
SSCP(X(6)...X(30)0X(5))TRANS1,RES*
FORMAT(8X,5F1.0,F3.0,F3.1,F3.3)
  1   98 11111101278485
  2   98 11112187278485
  3   98 11113223278485
  4   98 11114305278485
  5   99 21111 98260485
  6   99 21112173260485
  7   99 21113232260485
  8   99 21114276260453
  9  100 31111 84291494
 10  100 31112169291494
 11  100 31113238291494
 12  100 31114299291494
 13  101 41111109397571
 14  101 41112195397571
 15  101 41113232397571
 16  101 41114296397572
 17  102 12111 93169444
 18  102 12112150169444
 19  102 12113189169444
 20  102 12114210169444
 21  103 22111 72193380
 22  103 22112137193380
 23  103 22113177193360
 24  103 22114221193380
 25  104 32111 76132346
 26  104 32112134132346
 27  104 32113195132346
 28  104 32114220132346
 29  105 42111 68160359
 30  105 42112121160359
 31  105 42113113160359
 32  105 42114223160359
 33   86 11121 66228587
 34   86 11122203228587
 35   86 11123306228587
 36   86 11124386228587
 37   87 21121 97206504
 38   87 21122196206504
 39   87 21123303206504
 40   87 21124363206504
 41   88 31121 73223474
 42   88 31122160223474
 43   88 31123263223474
 44   88 31124350223474
 45   89 41121 96202543
 46   89 41122186202543
 47   89 41123279202543
 48   89 41124345202543
 49   94 12121 72135371
 50   94 12122118135371
 51   94 12123189135371
 52   94 12124237135371
 53   95 22121 71147306
 54   95 22122125147306
 55   95 22123172147306
 56   95 22124231147306
 57   96 32121 83159355
 58   96 32122163159355
 59   96 32123276159355
 60   96 32124264159355
 61   97 42121 60154351
 62   97 42122118154351
 63   97 42123180154351
 64   97 42124226154351
 65   90 11131 76198500
 66   90 11132143198500
 67   90 11133199198500
 68   90 11134230198500
 69   91 21131 84196462
 70   91 21132162196462
 71   91 21133216196462
 72   91 21134244196462
 73   92 31131114180500
 74   92 31132179180500
 75   92 31133216180500
 76   92 31134228180500
 77   93 41131 93213440
 78   93 41132166213440
 79   93 41133215213440
 80   93 41134240213440
 81  106 12131 70147357
 82  106 12132128147357
 83  106 12133180147357
 84  106 12134223147357
 85  107 22131 57143308
 86  107 22132110143308
 87  107 22133173143308
 88  107 22134217143308
 89  108 32131 66147364
 90  108 32132125147364
 91  108 32133182147364
 92  108 32134224147364
 93  109 42131 69138400
 94  109 42132126138400
 95  109 42133177138400
 96  109 42134237138400
 97   82 11211 83150454
 98   82 11212160154454
 99   82 11213241150454
100   82 11214209150454
101   83 21211112173519
102   83 21212140173520
103   83 21213232173519
104   83 21214260173519
105   84 31211 86182400
106   84 31212171182400
107   84 31213261182400
```

# Table 17. (cont'd.)

```
108  84 31214318182499
109  85 41211 83160479
110  85 41212170160479
111  85 41213242160479
112  85 41214318160479
113  59 12211 60202347
114  59 12212100202347
115  59 12213175202347
116  59 12214215202347
117  60 22211 74214380
118  60 22212110214380
119  60 22213161214380
120  60 22214206214380
129  46 11221 72194605
130  46 11222136194605
131  46 11223245194605
132  46 11224316194605
133  47 21221 77167458
134  47 21222148167458
135  47 21223239167458
136  47 21224325167458
145  62 12221 53202395
146  62 12222114202395
147  62 12223163202395
148  62 12224200202395
149  61 22221 37196406
150  61 22222 83196406
151  61 22223130196406
152  61 22224157196406
161  49 11231 75174548
162  49 11232145174548
163  49 11233213174548
164  49 11234267174548
165  48 21231 72178515
166  48 21232142178515
167  48 21233211178515
168  48 21234259178515
181  63 22231 40196405
182  63 22232 87196435
183  63 22233126166405
184  63 22234167196435
185  64 32231 70196393
186  64 32232112196393
187  64 32233157196393
188  64 32234192196393
193  78 11111120198489
194  78 11112224198489
195  78 11113271198489
196  78 11114295198489
197  79 21111177215533
198  79 21112264215533
199  79 21113278215533
200  79 21114202215533
201  80 31111 95233498
202  80 31112187233498
203  80 31113246233498
204  80 31114278233498
205  81 41111147142502
206  81 41112250142502
207  81 41113311142502
208  81 41114334142502
209  51 12111113190417
210  51 12112144190417
211  51 12113169190417
212  51 12114197190417
213  52 22111 90169402
214  52 22112163169402
215  52 22113207169402
216  52 22114241169432
225  40 11121 99185551
226  40 11122243185551
227  40 11123329185551
228  40 11124354185551
229  41 21121 73184567
230  41 21122198184567
231  41 21123248184567
232  41 21124272184567
241  54 12121 52162367
242  54 12122127162367
243  54 12123181162367
244  54 12124226162367
245  53 22121 63186405
246  53 22122136186405
247  53 22123182186435
248  53 22124210186405
257  58 11131 79206514
258  58 11132163206514
259  58 11133252206514
260  58 11134305206514
261  57 21131 59197484
262  57 21132153197484
263  57 21133222197484
264  57 21134254197484
273  55 12131 55182380
274  55 12132101182380
275  55 12133137182380
276  55 12134173182380
277  56 22131 86170392
278  56 22132138170392
279  56 22133177170392
280  56 22134217170392
293  38 11111 63202503
294  38 11112148202503
295  38 11113215202503
296  38 11114232202503
297  39 21111 40175442
298  39 21112164175442
299  39 21113246175442
300  39 211114316175442
301  44 11211102173483
302  44 11212236173483
303  44 11213298173483
304  44 11214310173483
305  45 21211127172511
306  45 21212228172511
307  45 21213313172511
308  45 21214335172511
X(6)=P(X(7)...X(30))RES,NRS*
RZ(X(9))RLO*
RZ(X(10))RLO*
RZ(X(11),X(12))RLO*
RZ(X(13)...X(15))RLO*
RZ(X(16),X(17))RLO*
RZ(X(18)...X(20))RLO*
RZ(X(21)...X(26))RLO*
RZ(X(27),X(28))RLO*
RZ(X(7))RLO*
RZ(X(8))RLO*
RZ(X(7),X(8))RLO*
END OF RUN
```

b. The length of test specimen (whether 8'-0" or 24'-0" long) also had a highly significant effect on strength with the 8'-0" specimens generally about 15% better test values than the 24'-0" trusses in the 0.015" to 0.150" range. Despite numerous re-tests, calibration of gauges, and careful re-evaluation of the test procedure, this difference could not be explained. Strengths of 8' and 24' specimens were essentially identical at ultimate load. Ultimate load was not included in the statistical analysis to premit study of interactions with deflection.

c. The heel plate size had a highly significant effect on strength with the 3"x5" and 3"x8" plates being approximately 45% and 39% respectively, stronger than the 5"x5" (based on axial contact area stress, psi).

d. Level of deflection had a highly significant effect on stress level, as would certainly be expected. Higher levels of deflection result from higher loads, which certainly cause higher stresses.

e. Plate size interacts significantly with species. The 3"x8" plates tested almost 90% better in Douglas fir, whereas the 3"x5" plates were 40% better and the 5"x5" plates only 25% better. This can be explained by the theory that it takes a wider "development width" in white fir to balance the buckling strength of the steel plate; i.e., a 5" wide plate which almost always buckles in Douglas fir will come closer to that same strength in white fir where buckling distortion is not a problem, than will 3" wide plates which never buckle in Douglas fir.

f. Plate size interacts with deflection. See Table 23 for values. The 3"x5" plates performed significantly better in the lower ranges, but the larger plates did better at the higher deflection levels.

g. Moisture content had a significant effect on strength with the lower moisture content lumber giving better heel plate test results, as would be expected.

h. Specific gravity did not have a significant effect on contact area strength, in the range included in the study.

## Stress Prediction Equation

### General

The use of M.S.U. A.E.S. Stat Description 18, Analysis of Covariance and Analysis of Variance with Unequal Frequencies Permitted in the Cells (Least Squares Routine), resulted in the computer developing a regression equation of best fit to accommodate the data from all the 56 specimens tested.

Table 18. Final (4-way) Comparison - Statistics on Transformed Variables.

| LABEL | VAR NO | MEAN | STANDARD DEVIATION | SUM | SUM OF SQUARES | SUM OF SQUARED DEVIATIONS FROM THE MEAN |
|---|---|---|---|---|---|---|
| Strength | 6 | 179.41964285 | 81.40918497 | 40190.00000000 | 8688798.00000000 | 1477922.55355835 |
| Moist. Cont. | 7 | 19.15178571 | 5.15121967 | 4289.99999988 | 88878.47999954 | 5917.31928563 |
| Spec. Grav. | 8 | 0.45470089 | 0.06984406 | 101.85300000 | 47.46048700 | 1.08783696 |
| Specie | 9 | 0.14285714 | 0.99195999 | 32.00000000 | 224.00000000 | 219.42857143 |
| Length | 10 | 0.42857143 | 0.90553144 | 96.00000000 | 224.00000000 | 182.85714285 |
| 3x5 Plate | 11 | 0.14285714 | 0.83485874 | 32.00000000 | 160.00000000 | 155.42857143 |
| 3x8 Plate | 12 | 0.00000000 | 0.75762196 | 0.00000000 | 128.00000000 | 128.00000000 |
| .015" Defl. | 13 | 0.00892857 | 0.70863395 | 2.00000000 | 112.00000000 | 111.98214286 |
| .040" Defl. | 14 | 0.00446429 | 0.70550537 | 1.00000000 | 111.00000000 | 110.99553571 |
| .080" Defl. | 15 | 0.00446429 | 0.70550537 | 1.00000000 | 111.00000000 | 110.99553571 |
| 3x5 Fir | 16 | 0.14285714 | 0.83485874 | 32.00000000 | 160.00000000 | 155.42857143 |
| 3x8 Fir | 17 | 0.00000000 | 0.75762196 | 0.00000000 | 128.00000000 | 128.00000000 |
| .015 Fir | 18 | 0.00892857 | 0.70863395 | 2.00000000 | 112.00000000 | 111.98214286 |
| .040 Fir | 19 | 0.00446429 | 0.70550537 | 1.00000000 | 111.00000000 | 110.99553571 |
| .080 Fir | 20 | 0.00446429 | 0.70550537 | 1.00000000 | 111.00000000 | 110.99553571 |
| 3x5 Pl. .015" | 21 | 0.00892857 | 0.59888590 | 2.00000000 | 80.00000000 | 79.98214286 |
| 3x5 Pl. .040" | 22 | 0.00446429 | 0.59518070 | 1.00000000 | 79.00000000 | 78.99553571 |
| 3x5 Pl. .080" | 23 | 0.00446429 | 0.59518070 | 1.00000000 | 79.00000000 | 78.99553571 |
| 3x8 Pl. .015" | 24 | 0.00000000 | 0.53571962 | 0.00000000 | 64.00000000 | 64.00000000 |
| 3x8 Pl. .040" | 25 | 0.00000000 | 0.53571962 | 0.00000000 | 64.00000000 | 64.00000000 |
| 3x8 Pl. .080" | 26 | 0.00000000 | 0.53571962 | 0.00000000 | 64.00000000 | 64.00000000 |
| 8' x 3x5 Pl. | 27 | 0.00000000 | 0.84704710 | 0.00000000 | 160.00000000 | 160.00000000 |
| 8' x 3x8 Pl. | 28 | 0.00000000 | 0.75762196 | 0.00000000 | 128.00000000 | 128.00000000 |
| (Moist. Cont.)$^2$ | 29 | 393.20750000 | 309.86495864 | 88078.47999954 | 56044752.17285156 | 21411631.24853516 |
| (Specific Grav.)$^2$ | 30 | 0.21160932 | 0.06424036 | 47.40048700 | 10.95066644 | 0.92028176 |
| CONSTANT | 0 | 1.00000000 | 0.00000000 | 224.00000000 | 224.00000000 | 0.00000000 |
| | 5 | 2.48660714 | 1.12045759 | 557.00000000 | 1665.00000000 | 279.95982143 |

Table 19. Final (4-way) Comparison - AOV for Over-all Regression and Regression Coefficients.

(LINES 1 AND 3 MAY BE INAPPROPRIATE IF NO OVERALL CONSTANT.)

| | SUM OF SQUARES | DEG OF FREEDOM | MEAN SQUARE | F | SIG |
|---|---|---|---|---|---|
| REGRESSION (ABOUT MEAN) | 1346201.77249146 | 24 | 56091.74852048 | 84.7418 | <0.0005 |
| ERROR | 131720.78106308 | 199 | 661.91357270 | | |
| TOTAL (ABOUT MEAN) | 1477922.55355835 | 223 | | | |

| OBSERVATIONS | MULTIPLE CORR COEFS R2 | R | R BAR 2 | R BAR | S STANDARD ERROR OF ESTIMATE |
|---|---|---|---|---|---|
| 224 | 0.9109 | 0.9544 | 0.9001 | 0.9487 | 25.72767912 |

| | VAR | REGRESSION COEFFICIENTS | STD. ERRORS OF COEFFICIENTS | BETA WEIGHTS | STD. ERRORS OF BETAS | TB | FB | SIG | PARTIAL CORR COEFS | R2 DELETES |
|---|---|---|---|---|---|---|---|---|---|---|
| CONSTANT | 0 | 112.69088422 | 103.71181690 | 0.00000 | 0.00000 | 1.0866 | 1.1806 | 0.279 | 0.07680 | 0.91035 |
| Moist. Cont. | 7 | -12.43535238 | 1.33145735 | -0.78686 | 0.08425 | -9.3397 | 87.2292 | <0.0005 | -0.55204 | 0.87181 |
| Spec. Grav. | 8 | 793.39420706 | 436.85750145 | 0.68068 | 0.37480 | 1.8161 | 3.2984 | 0.071 | 0.12769 | 0.90040 |
| Specie | 9 | 25.66863379 | 4.30887471 | 0.31277 | 0.05250 | 5.9572 | 35.4877 | <0.0005 | 0.38903 | 0.89498 |
| Length | 10 | 7.85040559 | 2.02555206 | 0.08732 | 0.02253 | 3.8757 | 15.0209 | <0.0005 | 0.26492 | 0.90415 |
| 3x5 Plate | 11 | 11.21429423 | 2.76005090 | 0.11500 | 0.02830 | 4.0631 | 16.5086 | <0.0005 | 0.27677 | 0.90348 |
| 3x8 Plate | 12 | 5.93477567 | 3.09963485 | 0.05525 | 0.02885 | 1.9153 | 3.6684 | 0.057 | 0.13454 | 0.90023 |
| .015" Defl. | 13 | -94.66283142 | 3.05096380 | -0.82408 | 0.02656 | -31.0272 | 962.6865 | <0.0005 | -0.91033 | 0.47072 |
| .040" Defl. | 14 | -22.73611972 | 3.05205440 | -0.19703 | 0.02645 | -7.4494 | 55.4943 | <0.0005 | -0.46697 | 0.88602 |
| .080" Defl. | 15 | 37.34254573 | 3.05215659 | 0.32362 | 0.02645 | 12.2348 | 149.6905 | <0.0005 | 0.65528 | 0.84383 |
| 3x5 Fir | 16 | -2.73093943 | 2.52791222 | -0.02802 | 0.02592 | -1.0803 | 1.1671 | 0.281 | -0.07638 | 0.91035 |
| 3x8 Fir | 17 | 9.69289224 | 2.78444304 | 0.09028 | 0.02591 | 3.4811 | 12.1180 | 0.001 | 0.23958 | 0.90545 |
| .015 Fir | 18 | -18.90844998 | 3.05132629 | -0.16450 | 0.02656 | -6.1968 | 38.4003 | <0.0005 | -0.40219 | 0.89368 |
| .040 Fir | 19 | -2.02269755 | 3.05201979 | -0.01753 | 0.02645 | -0.6627 | 0.4392 | 0.508 | -0.04693 | 0.91068 |
| .080 Fir | 20 | 9.90807182 | 3.05235545 | 0.08584 | 0.02645 | 3.2450 | 10.5303 | 0.001 | 0.22410 | 0.90616 |
| 3x5 Pl. .015" | 21 | 6.40459123 | 4.06831815 | 0.04712 | 0.02993 | 1.5743 | 2.4783 | 0.117 | 0.11091 | 0.90976 |
| 3x5 Pl. .040" | 22 | 5.25907573 | 4.07108602 | 0.03845 | 0.02976 | 1.2918 | 1.6688 | 0.198 | 0.09119 | 0.91013 |
| 3x5 Pl. .080" | 23 | -3.38279295 | 4.07246919 | -0.02473 | 0.02977 | -0.8306 | 0.6900 | 0.407 | -0.05878 | 0.91057 |
| 3x8 Pl. .015" | 24 | -16.61815330 | 4.43276288 | -0.10936 | 0.02917 | -3.7489 | 14.0545 | <0.0005 | -0.25684 | 0.90458 |
| 3x8 Pl. .040" | 25 | -6.66986501 | 4.43387516 | -0.04389 | 0.02918 | -1.5043 | 2.2629 | 0.134 | -0.10604 | 0.91006 |
| 3x8 Pl. .080" | 26 | 7.25040845 | 4.43576789 | 0.04771 | 0.02919 | 1.6345 | 2.6717 | 0.104 | 0.11510 | 0.90968 |
| 8' x 3x5 Pl. | 27 | -8.04692820 | 2.75271738 | -0.08373 | 0.02864 | -2.9233 | 8.5455 | 0.004 | -0.20292 | 0.90705 |
| 8' x 3x8 Pl. | 28 | 8.51004162 | 2.95508831 | 0.07928 | 0.02750 | 2.8798 | 8.2932 | 0.004 | 0.20002 | 0.90716 |
| (Moist. Cont.)$^2$ | 29 | 0.24026934 | 0.02136613 | 0.91453 | 0.08133 | 11.2453 | 126.4576 | <0.0005 | 0.62334 | 0.85424 |
| (Specific Grav.)$^2$ | 30 | -745.43050633 | 451.62240716 | -0.58822 | 0.35638 | -1.6506 | 2.7244 | 0.100 | -0.11621 | 0.90965 |

**Table 20.** Final (4-way) Comparison - Simple Correlation Coefficients.

SIMPLE CORRELATIONS

| | | 6 STR | 7 MC | 8 SG | 9 SP | 10 LG | 11 35 | 12 38 | 13 15 | 14 40 | 15 80 | 16 5F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strength | 6 | 1.00000 | | | | | | | | | | |
| Moist. Cont. | 7 | 0.20606 | 1.00000 | | | | | | | | | |
| Spec. Grav. | 8 | 0.35301 | 0.41914 | 1.00000 | | | | | | | | |
| Specie | 9 | 0.36975 | 0.36152 | 0.86877 | 1.00000 | | | | | | | |
| Length | 10 | 0.04780 | 0.10904 | -0.07901 | -0.06847 | 1.00000 | | | | | | |
| 3x5 Plate | 11 | 0.17033 | 0.23184 | 0.10187 | 0.14852 | -0.08135 | 1.00000 | | | | | |
| 3x8 Plate | 12 | 0.11786 | 0.03516 | 0.09034 | 0.00000 | 0.00000 | 0.45374 | 1.00000 | | | | |
| .015" Defl. | 13 | -0.74497 | 0.05024 | 0.00431 | 0.01094 | 0.00799 | 0.01299 | 0.00000 | 1.00000 | | | |
| .040" Defl. | 14 | -0.44078 | -0.00154 | -0.00015 | 0.00549 | 0.00401 | 0.00653 | 0.00000 | 0.49325 | 1.00000 | | |
| .080" Defl. | 15 | -0.17539 | -0.00574 | -0.00288 | 0.00549 | 0.00401 | 0.00653 | 0.00000 | 0.49325 | 0.49540 | 1.00000 | |
| 3x5 Fir | 16 | 0.11464 | 0.13383 | 0.11817 | 0.14852 | -0.08135 | 0.17647 | 0.00000 | 0.01299 | 0.00653 | 0.00653 | 1.00000 |
| 3x8 Fir | 17 | 0.08121 | 0.00804 | 0.12457 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.45374 |
| .015 Fir | 18 | -0.20318 | 0.05024 | 0.01518 | 0.01094 | 0.00799 | 0.01299 | 0.00000 | 0.14272 | 0.06271 | 0.06271 | 0.01299 |
| .040 Fir | 19 | -0.10364 | -0.00154 | 0.00531 | 0.00549 | 0.00401 | 0.00653 | 0.00000 | 0.06271 | 0.13510 | 0.06303 | 0.00653 |
| .080 Fir | 20 | -0.01971 | 0.00166 | 0.00622 | 0.00549 | 0.00401 | 0.00653 | 0.00000 | 0.06271 | 0.06303 | 0.13510 | 0.00653 |
| 3x5 Pl. .015" | 21 | -0.11404 | 0.05945 | 0.01154 | 0.01294 | 0.00945 | 0.01538 | 0.00000 | 0.16887 | 0.07420 | 0.07420 | 0.01538 |
| 3x5 Pl. .040" | 22 | -0.05936 | -0.00183 | -0.00018 | 0.00651 | 0.00475 | 0.00774 | 0.00000 | 0.07433 | 0.16014 | 0.07471 | 0.00774 |
| 3x5 Pl. .080" | 23 | -0.01827 | 0.00197 | -0.00018 | 0.00651 | 0.00475 | 0.00774 | 0.00000 | 0.07433 | 0.07471 | 0.16014 | 0.00774 |
| 3x8 Pl. .015" | 24 | -0.08277 | 0.00000 | 0.00360 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 3x8 Pl. .040" | 25 | -0.05244 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 3x8 Pl. .080" | 26 | -0.02098 | 0.00487 | 0.00719 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 8' x 3x5 Pl. | 27 | 0.03043 | 0.29064 | 0.11271 | 0.00000 | 0.18708 | 0.40584 | 0.22361 | 0.01494 | 0.00750 | 0.00750 | 0.00000 |
| 8' x 3x8 Pl. | 28 | 0.09474 | 0.01448 | 0.09847 | 0.00000 | 0.00000 | 0.22687 | 0.50000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| (Moist. Cont.)$^2$ | 29 | 0.22180 | 0.95937 | 0.33566 | 0.27528 | 0.11601 | 0.21152 | 0.02292 | 0.06794 | -0.00158 | -0.00401 | 0.15432 |
| (Specific Grav.)$^2$ | 30 | 0.34979 | 0.41924 | 0.99730 | 0.84929 | -0.07602 | 0.09817 | 0.11092 | 0.00460 | -0.00819 | -0.00269 | 0.10786 |
| CONSTANT | 0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| | 5 | 0.79029 | -0.14898 | -0.00495 | -0.01037 | -0.00758 | -0.01233 | 0.00000 | -0.94868 | -0.62677 | -0.30989 | -0.01233 |

# Table 20. (cont'd.)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3x8 Fir | 17 | 1.00000 | | | | | | | | | | |
| .015 Fir | 18 | 0.00000 | 1.00000 | | | | | | | | | |
| .040 Fir | 19 | 0.00000 | 0.49325 | 1.00000 | | | | | | | | |
| .080 Fir | 20 | 0.00000 | 0.49325 | 0.49548 | 1.00000 | | | | | | | |
| 3x5 Pl. .015" | 21 | 0.00000 | 0.16887 | 0.07420 | 0.07420 | 1.00000 | | | | | | |
| 3x5 Pl. .040" | 22 | 0.00000 | 0.07433 | 0.16014 | 0.07471 | 0.49053 | 1.00000 | | | | | |
| 3x5 Pl. .080" | 23 | 0.00000 | 0.07433 | 0.07471 | 0.16014 | 0.49053 | 0.49364 | 1.00000 | | | | |
| 3x8 Pl. .015" | 24 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.44726 | 0.22502 | 0.22502 | 1.00000 | | | |
| 3x8 Pl. .040" | 25 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.22363 | 0.45005 | 0.22502 | 0.50000 | 1.00000 | | |
| 3x8 Pl. .080" | 26 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.22363 | 0.22502 | 0.45005 | 0.50000 | 0.50000 | 1.00000 | |
| 8' x 3x5 Pl. | 27 | 0.00000 | 0.01494 | 0.00750 | 0.00750 | 0.01768 | 0.00889 | 0.00889 | 0.00000 | 0.00000 | 0.00000 | 1.00000 |
| 8' x 3x8 Pl. | 28 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.44721 |
| (Moist. Cont.)$^2$ | 29 | 0.00758 | 0.06794 | -0.00153 | 0.00044 | 0.08039 | -0.00182 | 0.00053 | 0.00000 | 0.00000 | 0.00293 | 0.25739 |
| (Specific Grav.)$^2$ | 30 | 0.13887 | 0.01450 | 0.00476 | 0.00519 | 0.01132 | -0.00022 | -0.00023 | 0.00528 | 0.00000 | 0.00657 | 0.11474 |
| CONSTANT | 0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| | 5 | 0.00000 | -0.13540 | -0.08218 | -0.03680 | -0.16021 | -0.09741 | -0.04362 | 0.00000 | 0.00000 | 0.00000 | -0.01417 |
| | | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| | | [illegible] | 15F | 40F | 80F | 51 | 54 | 58 | 81 | 84 | 8A | 85 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8' x 3x8 Pl. | 28 | 1.00000 | | | | |
| (Moist. Cont.)$^2$ | 29 | 0.00968 | 1.00000 | | | |
| (Specific Grav.)$^2$ | 30 | 0.11088 | 0.33919 | 1.00000 | | |
| CONSTANT | 0 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | |
| | 5 | 0.00000 | -0.06523 | -0.00515 | 0.00000 | 1.00000 |
| | | 28 | 29 | 30 | 0 | 5 |
| | | 88* | | | CONSTANT | |

Table 21. Final (4-way) Comparison
- Measured Stress vs. Predicted Stress.
(224 Data Points)

RESIDUALS

| | | | OB | STR Y = Y( 6) | ESTIMATED Y | Y - ESTIMATED Y |
|---|---|---|---|---|---|---|
| 1 | 98 | 1 | 1 | 101.00000000 | 88.91892031 | 12.08107969 |
| 2 | 98 | 2 | 2 | 187.00000000 | 176.58586897 | 10.41413103 |
| 3 | 98 | 3 | 3 | 223.00000000 | 239.95038510 | -16.95038510 |
| 4 | 98 | 4 | 4 | 305.00000000 | 278.88726760 | 26.11273240 |
| 5 | 99 | 1 | 5 | 98.00000000 | 88.03487169 | 9.96512831 |
| 6 | 99 | 2 | 6 | 173.00000000 | 175.70182034 | -2.70182034 |
| 7 | 99 | 3 | 7 | 232.00000000 | 239.06633647 | -7.06633647 |
| 8 | 99 | 4 | 8 | 276.00000000 | 274.98944642 | 1.01055357 |
| 9 | 100 | 1 | 9 | 84.00000000 | 91.09824499 | -7.09824499 |
| 10 | 100 | 2 | 10 | 169.00000000 | 178.76519364 | -9.76519365 |
| 11 | 100 | 3 | 11 | 238.00000000 | 242.12970978 | -4.12970978 |
| 12 | 100 | 4 | 12 | 299.00000000 | 281.06659228 | 17.93340772 |
| 13 | 101 | 1 | 13 | 109.00000000 | 134.46945952 | -25.46945952 |
| 14 | 101 | 2 | 14 | 185.00000000 | 222.13640817 | -37.13640817 |
| 15 | 101 | 3 | 15 | 232.00000000 | 285.50092430 | -53.50092430 |
| 16 | 101 | 4 | 16 | 296.00000000 | 324.37917394 | -28.37917395 |
| 17 | 102 | 1 | 17 | 93.00000000 | 95.20288192 | -2.20288192 |
| 18 | 102 | 2 | 18 | 150.00000000 | 149.09832570 | 0.90167430 |
| 19 | 102 | 3 | 19 | 189.00000000 | 188.60740309 | 0.39259691 |
| 20 | 102 | 4 | 20 | 210.00000000 | 225.30207783 | -15.30207783 |
| 21 | 103 | 1 | 21 | 72.00000000 | 74.76643042 | -2.76643042 |
| 22 | 103 | 2 | 22 | 133.00000000 | 128.66187420 | 4.33812580 |
| 23 | 103 | 3 | 23 | 177.00000000 | 163.33543894 | 13.66456105 |
| 24 | 103 | 4 | 24 | 221.00000000 | 204.86562633 | 16.13437367 |
| 25 | 104 | 1 | 25 | 76.00000000 | 94.41348681 | -18.41348681 |
| 26 | 104 | 2 | 26 | 134.00000000 | 148.30893059 | -14.30893059 |
| 27 | 104 | 3 | 27 | 195.00000000 | 187.81800799 | 7.18199201 |
| 28 | 104 | 4 | 28 | 220.00000000 | 224.51268272 | -4.51268273 |
| 29 | 105 | 1 | 29 | 68.00000000 | 82.72117551 | -14.72117551 |
| 30 | 105 | 2 | 30 | 121.00000000 | 136.61661929 | -15.61661929 |
| 31 | 105 | 3 | 31 | 113.00000000 | 176.12569668 | -63.12569668 |
| 32 | 105 | 4 | 32 | 223.00000000 | 212.82037142 | 10.17962858 |
| 33 | 86 | 1 | 33 | 66.00000000 | 90.40593336 | -24.40593336 |
| 34 | 86 | 2 | 34 | 203.00000000 | 189.16668580 | 13.83331420 |
| 35 | 86 | 3 | 35 | 306.00000000 | 275.09334408 | 30.90665592 |
| 36 | 86 | 4 | 36 | 386.00000000 | 327.71550905 | 58.28449095 |
| 37 | 87 | 1 | 37 | 97.00000000 | 96.47204144 | 0.52795855 |
| 38 | 87 | 2 | 38 | 196.00000000 | 195.23279388 | 0.76720612 |
| 39 | 87 | 3 | 39 | 303.00000000 | 281.15945216 | 21.84054784 |
| 40 | 87 | 4 | 40 | 363.00000000 | 333.78161713 | 29.21838287 |
| 41 | 88 | 1 | 41 | 73.00000000 | 90.92389023 | -17.92389023 |
| 42 | 88 | 2 | 42 | 160.00000000 | 189.68464267 | -29.68464267 |
| 43 | 88 | 3 | 43 | 263.00000000 | 275.61130094 | -12.61130094 |
| 44 | 88 | 4 | 44 | 350.00000000 | 328.23346591 | 21.76653408 |
| 45 | 89 | 1 | 45 | 96.00000000 | 98.02919697 | -2.02919698 |
| 46 | 89 | 2 | 46 | 186.00000000 | 196.78994941 | -10.78994941 |
| 47 | 89 | 3 | 47 | 278.00000000 | 282.71660768 | -4.71660769 |
| 48 | 89 | 4 | 48 | 345.00000000 | 335.33877266 | 9.66122734 |
| 49 | 94 | 1 | 49 | 72.00000000 | 74.91332691 | -2.91332691 |
| 50 | 94 | 2 | 50 | 118.00000000 | 139.90257448 | -21.90257448 |
| 51 | 94 | 3 | 51 | 189.00000000 | 201.97379402 | -12.97379402 |
| 52 | 94 | 4 | 52 | 237.00000000 | 252.35375122 | -15.35375123 |
| 53 | 95 | 1 | 53 | 71.00000000 | 73.66284375 | -2.66284375 |
| 54 | 95 | 2 | 54 | 125.00000000 | 138.65209131 | -13.65209131 |

Table 21. (cont'd.)

| | | | | | | |
|---|---|---|---|---|---|---|
| 55 | 95 | 3 | 55 | 172.00000000 | 200.72331085 | -28.72331085 |
| 56 | 95 | 4 | 56 | 231.00000000 | 251.10326806 | -20.10326806 |
| 57 | 96 | 1 | 57 | 83.00000000 | 57.98649930 | 25.01350070 |
| 58 | 96 | 2 | 58 | 163.00000000 | 122.97574686 | 40.02425314 |
| 59 | 96 | 3 | 59 | 236.00000000 | 185.04696640 | 50.95303360 |
| 60 | 96 | 4 | 60 | 264.00000000 | 235.42692361 | 28.57307639 |
| 61 | 97 | 1 | 61 | 60.00000000 | 59.37547923 | 0.62452077 |
| 62 | 97 | 2 | 62 | 118.00000000 | 124.36472680 | -6.36472680 |
| 63 | 97 | 3 | 63 | 180.00000000 | 186.43594634 | -6.43594634 |
| 64 | 97 | 4 | 64 | 226.00000000 | 236.81590354 | -10.81590355 |
| 65 | 90 | 1 | 65 | 76.00000000 | 76.96205353 | -0.96205353 |
| 66 | 90 | 2 | 66 | 143.00000000 | 156.97174487 | -13.97174487 |
| 67 | 90 | 3 | 67 | 199.00000000 | 223.69972491 | -24.69972491 |
| 68 | 90 | 4 | 68 | 230.00000000 | 263.64556812 | -33.64556812 |
| 69 | 91 | 1 | 69 | 84.00000000 | 74.28548589 | 9.71451411 |
| 70 | 91 | 2 | 70 | 162.00000000 | 154.29517723 | 7.70482276 |
| 71 | 91 | 3 | 71 | 216.00000000 | 221.02315727 | -5.02315727 |
| 72 | 91 | 4 | 72 | 244.00000000 | 260.96900048 | -16.96900049 |
| 73 | 92 | 1 | 73 | 114.00000000 | 82.62646846 | 31.37353153 |
| 74 | 92 | 2 | 74 | 178.00000000 | 162.63615981 | 15.36384019 |
| 75 | 92 | 3 | 75 | 216.00000000 | 229.36413984 | -13.36413985 |
| 76 | 92 | 4 | 76 | 228.00000000 | 269.30998306 | -41.30998306 |
| 77 | 93 | 1 | 77 | 93.00000000 | 67.18896448 | 25.81103552 |
| 78 | 93 | 2 | 78 | 166.00000000 | 147.19865583 | 18.80134417 |
| 79 | 93 | 3 | 79 | 215.00000000 | 213.92663586 | 1.07336414 |
| 80 | 93 | 4 | 80 | 240.00000000 | 253.87247908 | -13.87247908 |
| 81 | 106 | 1 | 81 | 70.00000000 | 76.03708719 | -6.03708719 |
| 82 | 106 | 2 | 82 | 128.00000000 | 122.27527366 | 5.72472634 |
| 83 | 106 | 3 | 83 | 189.00000000 | 165.14781496 | 23.85218504 |
| 84 | 106 | 4 | 84 | 223.00000000 | 202.85145041 | 20.14854959 |
| 85 | 107 | 1 | 85 | 57.00000000 | 87.67846496 | -30.67846496 |
| 86 | 107 | 2 | 86 | 110.00000000 | 133.91665143 | -23.91665143 |
| 87 | 107 | 3 | 87 | 173.00000000 | 176.78919273 | -3.78919273 |
| 88 | 107 | 4 | 88 | 217.00000000 | 214.49282818 | 2.50717182 |
| 89 | 108 | 1 | 89 | 66.00000000 | 77.82865887 | -11.82865887 |
| 90 | 108 | 2 | 90 | 125.00000000 | 124.06684534 | 0.93315465 |
| 91 | 108 | 3 | 91 | 182.00000000 | 166.93938664 | 15.06061336 |
| 92 | 108 | 4 | 92 | 224.00000000 | 204.64302209 | 19.35697791 |
| 93 | 109 | 1 | 93 | 68.00000000 | 90.91743824 | -22.91743824 |
| 94 | 109 | 2 | 94 | 126.00000000 | 137.15562472 | -11.15562472 |
| 95 | 109 | 3 | 95 | 177.00000000 | 180.02816601 | -3.02816602 |
| 96 | 109 | 4 | 96 | 237.00000000 | 217.73180147 | 19.26819853 |
| 97 | 82 | 1 | 97 | 83.00000000 | 113.95883684 | -30.95883684 |
| 98 | 82 | 2 | 98 | 169.00000000 | 199.57331971 | -30.57331972 |
| 99 | 82 | 3 | 99 | 241.00000000 | 264.99030162 | -23.99030162 |
| 100 | 82 | 4 | 100 | 298.00000000 | 303.92718412 | -5.92718413 |
| 101 | 83 | 1 | 101 | 112.00000000 | 107.63300673 | 4.36699326 |
| 102 | 83 | 2 | 102 | 149.00000000 | 195.42178575 | -46.42178575 |
| 103 | 83 | 3 | 103 | 232.00000000 | 258.66447151 | -26.66447152 |
| 104 | 83 | 4 | 104 | 269.00000000 | 297.60135402 | -28.60135402 |
| 105 | 84 | 1 | 105 | 86.00000000 | 103.42687598 | -17.42687598 |
| 106 | 84 | 2 | 106 | 171.00000000 | 191.09382464 | -20.09382464 |
| 107 | 84 | 3 | 107 | 261.00000000 | 254.45834076 | 6.54165923 |
| 108 | 84 | 4 | 108 | 318.00000000 | 293.39522327 | 24.60477673 |
| 109 | 85 | 1 | 109 | 83.00000000 | 111.41952262 | -28.41952262 |
| 110 | 85 | 2 | 110 | 170.00000000 | 199.08647127 | -29.08647128 |
| 111 | 85 | 3 | 111 | 242.00000000 | 262.45098740 | -20.45098741 |
| 112 | 85 | 4 | 112 | 318.00000000 | 301.38786991 | 16.61213009 |
| 113 | 59 | 1 | 113 | 60.00000000 | 64.21084801 | -4.21084801 |
| 114 | 59 | 2 | 114 | 100.00000000 | 118.10629179 | -18.10629179 |
| 115 | 59 | 3 | 115 | 175.00000000 | 157.61536918 | 17.38463082 |

Table 21. (cont'd.)

| | | | | | | |
|---|---|---|---|---|---|---|
| 116 | 59 | 4 | 116 | 215.00000000 | 194.31004392 | 20.68995608 |
| 117 | 60 | 1 | 117 | 74.00000000 | 69.58105617 | 4.41894383 |
| 118 | 60 | 2 | 118 | 119.00000000 | 123.47649995 | -4.47649995 |
| 119 | 60 | 3 | 119 | 161.00000000 | 162.98557734 | -1.98557735 |
| 120 | 60 | 4 | 120 | 206.00000000 | 199.68025208 | 6.31974791 |
| 129 | 46 | 1 | 121 | 72.00000000 | 63.77853090 | 8.22146910 |
| 130 | 46 | 2 | 122 | 136.00000000 | 162.53928333 | -26.53928333 |
| 131 | 46 | 3 | 123 | 245.00000000 | 248.46594161 | -3.46594161 |
| 132 | 46 | 4 | 124 | 316.00000000 | 301.08810658 | 14.91189342 |
| 133 | 47 | 1 | 125 | 77.00000000 | 73.78769764 | 3.21230236 |
| 134 | 47 | 2 | 126 | 148.00000000 | 172.54845008 | -24.54845008 |
| 135 | 47 | 3 | 127 | 238.00000000 | 258.47510836 | -20.47510836 |
| 136 | 47 | 4 | 128 | 325.00000000 | 311.09727333 | 13.90272667 |
| 145 | 62 | 1 | 129 | 53.00000000 | 18.46345244 | 34.53654756 |
| 146 | 62 | 2 | 130 | 114.00000000 | 83.45270000 | 30.54730000 |
| 147 | 62 | 3 | 131 | 163.00000000 | 145.52391955 | 17.47608045 |
| 148 | 62 | 4 | 132 | 200.00000000 | 195.90387675 | 4.09612325 |
| 149 | 61 | 1 | 133 | 37.00000000 | 22.34638011 | 14.65361989 |
| 150 | 61 | 2 | 134 | 83.00000000 | 87.33562767 | -4.33562767 |
| 151 | 61 | 3 | 135 | 130.00000000 | 149.40684721 | -19.40684721 |
| 152 | 61 | 4 | 136 | 157.00000000 | 199.78680442 | -42.78680442 |
| 161 | 49 | 1 | 137 | 75.00000000 | 70.79456051 | 4.20543949 |
| 162 | 49 | 2 | 138 | 145.00000000 | 150.80425185 | -5.80425185 |
| 163 | 49 | 3 | 139 | 213.00000000 | 217.53223189 | -4.53223189 |
| 164 | 49 | 4 | 140 | 267.00000000 | 257.47807510 | 9.52192490 |
| 165 | 48 | 1 | 141 | 72.00000000 | 69.17035976 | 2.82964023 |
| 166 | 48 | 2 | 142 | 142.00000000 | 149.18005111 | -7.18005111 |
| 167 | 48 | 3 | 143 | 211.00000000 | 215.90803114 | -4.90803115 |
| 168 | 48 | 4 | 144 | 259.00000000 | 255.85387436 | 3.14612564 |
| 181 | 63 | 1 | 145 | 40.00000000 | 51.52939993 | -11.52939993 |
| 182 | 63 | 2 | 146 | 87.00000000 | 102.78456386 | -15.78456386 |
| 183 | 63 | 3 | 147 | 126.00000000 | 151.85293449 | -25.85293449 |
| 184 | 63 | 4 | 148 | 167.00000000 | 183.36074061 | -16.36074061 |
| 185 | 64 | 1 | 149 | 70.00000000 | 49.14691198 | 20.85308802 |
| 186 | 64 | 2 | 150 | 112.00000000 | 95.38509845 | 16.61490155 |
| 187 | 64 | 3 | 151 | 157.00000000 | 138.25763975 | 18.74236025 |
| 188 | 64 | 4 | 152 | 192.00000000 | 175.96127520 | 16.03872480 |
| 193 | 78 | 1 | 153 | 120.00000000 | 97.17655415 | 22.82344584 |
| 194 | 78 | 2 | 154 | 224.00000000 | 184.84350281 | 39.15649719 |
| 195 | 78 | 3 | 155 | 271.00000000 | 248.20801894 | 22.79198106 |
| 196 | 78 | 4 | 156 | 295.00000000 | 287.14490144 | 7.85509856 |
| 197 | 79 | 1 | 157 | 177.00000000 | 94.29459159 | 82.70540841 |
| 198 | 79 | 2 | 158 | 264.00000000 | 181.96154024 | 82.03845975 |
| 199 | 79 | 3 | 159 | 278.00000000 | 245.32605637 | 32.67394362 |
| 200 | 79 | 4 | 160 | 202.00000000 | 284.26293887 | -82.26293888 |
| 201 | 80 | 1 | 161 | 95.00000000 | 90.41633948 | 4.58366052 |
| 202 | 80 | 2 | 162 | 187.00000000 | 178.08328813 | 8.91671187 |
| 203 | 80 | 3 | 163 | 246.00000000 | 241.44780426 | 4.55219574 |
| 204 | 80 | 4 | 164 | 278.00000000 | 280.38468677 | -2.38468677 |
| 205 | 81 | 1 | 165 | 147.00000000 | 121.77798858 | 25.22201142 |
| 206 | 81 | 2 | 166 | 250.00000000 | 209.44493723 | 40.55506277 |
| 207 | 81 | 3 | 167 | 311.00000000 | 272.80945336 | 38.19054663 |
| 208 | 81 | 4 | 168 | 334.00000000 | 311.74633586 | 22.25366413 |
| 209 | 51 | 1 | 169 | 113.00000000 | 83.10992687 | 29.89007313 |
| 210 | 51 | 2 | 170 | 144.00000000 | 137.00537065 | 6.99462935 |
| 211 | 51 | 3 | 171 | 169.00000000 | 176.51444805 | -7.51444805 |
| 212 | 51 | 4 | 172 | 197.00000000 | 213.20912278 | -16.20912279 |
| 213 | 52 | 1 | 173 | 90.00000000 | 88.36696197 | 1.63303803 |
| 214 | 52 | 2 | 174 | 163.00000000 | 142.26240575 | 20.73759424 |
| 215 | 52 | 3 | 175 | 207.00000000 | 181.77148315 | 25.22851685 |
| 216 | 52 | 4 | 176 | 241.00000000 | 223.61731283 | 17.38268717 |

Table 21. (cont'd.)

| | | | | | | |
|---|---|---|---|---|---|---|
| 225 | 40 | 1 | 177 | 99.00000000 | 103.18512199 | -4.18512199 |
| 226 | 40 | 2 | 178 | 243.00000000 | 201.94587443 | 41.05412557 |
| 227 | 40 | 3 | 179 | 329.00000000 | 287.87253270 | 41.12746729 |
| 228 | 40 | 4 | 180 | 354.00000000 | 340.49469768 | 13.50530232 |
| 229 | 41 | 1 | 181 | 73.00000000 | 102.90210978 | -29.90210978 |
| 230 | 41 | 2 | 182 | 198.00000000 | 201.66286221 | -3.66286222 |
| 231 | 41 | 3 | 183 | 248.00000000 | 287.58952049 | -39.58952049 |
| 232 | 41 | 4 | 184 | 272.00000000 | 340.21168546 | -68.21168546 |
| 241 | 54 | 1 | 185 | 52.00000000 | 59.63200791 | -7.63200791 |
| 242 | 54 | 2 | 186 | 127.00000000 | 124.62125547 | 2.37874453 |
| 243 | 54 | 3 | 187 | 181.00000000 | 186.69247501 | -5.69247501 |
| 244 | 54 | 4 | 188 | 226.00000000 | 237.07243222 | -11.07243222 |
| 245 | 53 | 1 | 189 | 63.00000000 | 58.13548803 | 4.86451197 |
| 246 | 53 | 2 | 190 | 136.00000000 | 123.12473559 | 12.87526441 |
| 247 | 53 | 3 | 191 | 182.00000000 | 190.21293258 | -8.21293258 |
| 248 | 53 | 4 | 192 | 210.00000000 | 235.57591234 | -25.57591234 |
| 257 | 58 | 1 | 193 | 79.00000000 | 74.93337070 | 4.06662930 |
| 258 | 58 | 2 | 194 | 163.00000000 | 154.94306204 | 8.05693796 |
| 259 | 58 | 3 | 195 | 252.00000000 | 221.67104208 | 30.32895792 |
| 260 | 58 | 4 | 196 | 305.00000000 | 261.61688529 | 43.38311471 |
| 261 | 57 | 1 | 197 | 59.00000000 | 75.92698202 | -16.92698202 |
| 262 | 57 | 2 | 198 | 153.00000000 | 155.93667336 | -2.93667336 |
| 263 | 57 | 3 | 199 | 222.00000000 | 222.66465339 | -0.66465340 |
| 264 | 57 | 4 | 200 | 254.00000000 | 262.61049661 | -8.61049661 |
| 273 | 55 | 1 | 201 | 55.00000000 | 65.79264264 | -10.79264264 |
| 274 | 55 | 2 | 202 | 101.00000000 | 112.03082911 | -11.03082911 |
| 275 | 55 | 3 | 203 | 137.00000000 | 154.90337041 | -17.90337041 |
| 276 | 55 | 4 | 204 | 173.00000000 | 192.60700586 | -19.60700586 |
| 277 | 56 | 1 | 205 | 86.00000000 | 73.18115083 | 12.81884917 |
| 278 | 56 | 2 | 206 | 138.00000000 | 119.41933731 | 18.58066269 |
| 279 | 56 | 3 | 207 | 177.00000000 | 162.29187860 | 14.70812139 |
| 280 | 56 | 4 | 208 | 217.00000000 | 199.99551405 | 17.00448594 |
| 293 | 38 | 1 | 209 | 63.00000000 | 96.80170267 | -33.80170267 |
| 294 | 38 | 2 | 210 | 148.00000000 | 184.46865133 | -36.46865133 |
| 295 | 38 | 3 | 211 | 215.00000000 | 247.83316746 | -32.83316746 |
| 296 | 38 | 4 | 212 | 232.00000000 | 286.77004996 | -54.77004996 |
| 297 | 39 | 1 | 213 | 40.00000000 | 100.49343286 | -60.49343286 |
| 298 | 39 | 2 | 214 | 164.00000000 | 188.16038151 | -24.16038152 |
| 299 | 39 | 3 | 215 | 246.00000000 | 251.52489765 | -5.52489765 |
| 300 | 39 | 1 | 216 | 431.00000000 | 397.90409330 | 33.09590670 |
| 301 | 44 | 1 | 217 | 102.00000000 | 105.95998451 | -3.95998451 |
| 302 | 44 | 2 | 218 | 236.00000000 | 193.62693316 | 42.37306684 |
| 303 | 44 | 3 | 219 | 298.00000000 | 256.99144929 | 41.00855071 |
| 304 | 44 | 4 | 220 | 310.00000000 | 295.92833179 | 14.07166821 |
| 305 | 45 | 1 | 221 | 127.00000000 | 107.84280646 | 19.15719353 |
| 306 | 45 | 2 | 222 | 228.00000000 | 195.50975512 | 32.49024488 |
| 307 | 45 | 3 | 223 | 313.00000000 | 258.87427124 | 54.12572875 |
| 308 | 45 | 4 | 224 | 335.00000000 | 297.81115375 | 37.18884625 |

| SUM Y | | SUM RES |
|---|---|---|
| 40190.00000000 | | 0.00000000 |
| SSY | SS(Y - MEAN Y) | SS RES |
| 8688798.00000000 | 1477922.55355835 | 131720.78106308 |
| R2 | D.W. STAT | SS(R - PREV R) |
| 0.91087437 | 1.07256554 | 141279.17008209 |

Table 22. Final (4-way) Comparison - Analysis of Variance for 4 Factors, 2 Cofactors and Interactions.

DEPENDENT VARIABLE--X( 6) STR

| Source of Variance | SUM OF SQUARES | DEG OF FREEDOM | MEAN SQUARE | F | SIG |
|---|---|---|---|---|---|
| 1. Species | 23489.78259087 | 1 | 23489.78259087 | 35.4877 | <0.0005 |
| 2. Length | 9942.56848645 | 1 | 9942.56848645 | 15.0209 | <0.0005 |
| 3. Plate Size | 23735.13164091 | 2 | 11867.56582046 | 17.9292 | <0.0005 |
| 4. Deflection | 919086.46629333 | 3 | 306362.15543365 | 462.8432 | <0.0005 |
| 5. Plate & Species Interaction | 8476.01282763 | 2 | 4238.00641382 | 6.4027 | 0.002 |
| 6. Defl. & Species Interaction | 30956.88358498 | 3 | 10318.96119499 | 15.5896 | <0.0005 |
| 7. Plate Size & Defl. Interaction | 16224.21447253 | 6 | 2704.03574538 | 4.0852 | 0.001 |
| 8. Length & Plate Size | 7737.47006333 | 2 | 3868.73503166 | 5.8448 | 0.003 |
| 9. Moisture Content | 57738.15421009 | 1 | 57738.15421009 | 87.2292 | <0.0005 |
| 10. Specific Gravity | 2183.23093355 | 1 | 2183.23093355 | 3.2984 | 0.071 |
| 11. Moist. Cont. & Spec. Gravity | 57998.76101494 | 2 | 28999.38050747 | 43.8114 | <0.0005 |

Table 23. Interaction of Plate Size and Deflection.

| | | Deflection | | | |
|---|---|---|---|---|---|
| | | 0.015" | 0.040" | 0.080" | 0.150" |
| Plate Size | 3"x5" | 101.5 | 172.3 | 223.7 | 261.5 |
| | 3"x8" | 73.2 | 155.1 | 229.1 | 280.6 |
| | 5"x5" | 76.9 | 140.1 | 194.9 | 233.7 |

All other variables and covariates are held constant at their means.

## Categories Studied

In order to describe the regression equation more detail, the data used in the analysis must be more completely explained. In punching the original cards for the Stat Description 14, Analysis of Variance, preliminary analysis for Tables 6 and 7, the following categories were used:

| Category | Description | Value |
|---|---|---|
| A ($X_2$) | Species | Doug. fir = 1<br>White fir = 2 |
| B ($X_3$) | Length | 8'-0" = 1<br>24'-0" = 2 |
| C ($X_4$) | Plate Size | 3"x5" = 1<br>3"x8" = 2<br>5"x5" = 3 |
| D ($X_5$) | Level of Defl. | 0.015" = 1<br>0.040" = 2<br>0.080" = 3<br>0.150" = 4 |
| E ($X_1$) | Repetitions | Spec. #1 = 1<br>Spec. #2 = 2<br>Spec. #3 = 3<br>Spec. #4 = 4 |

By using equal number in the cells, that is, the same number of repetitions and all factors matched, the following number of data points must be used:

Species (2) x Length (2) x Plate Size (3) x

Deflection (4) x Repetitions (2) = 96

So 96 separate data cards must be used so that each point may be unique.

## Creation of Indicator Variables for Categories

To use the Unequal Frequencies (Least Squares Routine) to perform an Analysis of Variance, the distinct category variables described above must be converted to Indicator Variables, denoted I.V., by use of a matrix, where each I.V. may have a value of 1, o, or -1.

For example, if the category has just two possibilities, (such as either Douglas fir or white fir), then just one I.V. is required, as follows:

| Value of | $X_9$ (I.V. for Species) |
|---|---|
| Douglas fir | 1 |
| White fir | -1 |

Similarly, $X_{10}$ (I.V. for test specimen length) = 1 for 8'-0" specimens and -1 for 24'-0" specimens. If the category contains three possibilities, such as 3"x5", 3"x8", or 5"x5" plate sizes, two I.V.s are required in a matrix as follows:

| Plate Size | $X_{11}$ | $X_{12}$ |
|---|---|---|
| 3"x5" | 1 | 0 |
| 3"x8" | 0 | 1 |
| 5"x5" | -1 | -1 |

This same type matrix may be used for the levels of deflection (4 choices in the category) by using three I.V.s;

| Level of Deflection | $X_{13}$ | $X_{14}$ | $X_{15}$ |
|---|---|---|---|
| 0.015" | 1 | 0 | 0 |
| 0.040" | 0 | 1 | 0 |
| 0.080" | 0 | 0 | 1 |
| 0.150" | -1 | -1 | -1 |

Creation of Indicator Variables for Interactions

To accommodate interactions, such as plate size (2 I.V.s) with level of deflection (which has 3 I.V.s), 2 x 3 = 6 new I.V.s must be created as follows:

| I.V. for Level of Deflection | I.V. for Plate Size $X_{11}$ | $X_{12}$ |
|---|---|---|
| $X_{13}$ | $X_{21}$ | $X_{24}$ |
| $X_{14}$ | $X_{22}$ | $X_{25}$ |
| $X_{15}$ | $X_{23}$ | $X_{26}$ |

Each of these Level of Deflection - Plate Size interaction indicator variables will have values as shown in the matrix following:

| Description | Plate Deflection Interaction Indicator Variables $X_{21}$ | $X_{22}$ | $X_{23}$ | $X_{24}$ | $X_{25}$ | $X_{26}$ |
|---|---|---|---|---|---|---|
| 3"x5" @ 0.015" defl. | 1 | 0 | 0 | 0 | 0 | 0 |
| 3"x5" @ 0.040" defl. | 0 | 1 | 0 | 0 | 0 | 0 |
| 3"x5" @ 0.080" defl. | 0 | 0 | 1 | 0 | 0 | 0 |
| 3"x8" @ 0.015" defl. | 0 | 0 | 0 | 1 | 0 | 0 |
| 3"x8" @ 0.040" defl. | 0 | 0 | 0 | 0 | 1 | 0 |
| 3"x8" @ 0.080" defl. | 0 | 0 | 0 | 0 | 0 | 1 |

It is not necessary to include the third plate size (5"x5") or the fourth level of deflection (0.150") since these are handled with the -1 values.

The Indicator Variables described in this section were created by the computer by use of a transformation sub-deck.

## Regression Equation

After creation of the appropriate indicator variables, (indicator variables must be used not only for all the main categories to be studied, but also for all the interactions which are of interest), the Least Squares Prediction Equation for stress can be written in terms of these indicator variables (along with the continuous variables used as co-variants), by using the regression coefficients given in Table 19.

Y(stress) = 112.69 - 12.43 x Moist. Cont. + 793.29 x Spec. Grav. + 25.67 x Species (Indicator Variable) + 7.85 x Length (I.V.) + 11.21 x 3"x5" Plate (I.V.) + 5.94 x 3"x8" Plate (I.V.) - 94.66 x 0.015" Defl. (I.V.) - 22.74 x 0.040" Defl. (I.V.) + 37.34 x 0.080" Defl. (I.V.) - 2.73 x 3"x5" - Fir Interaction Indicator Variable (I.I.V.) + 9.69 x 3"x8" - Fir (I.I.V.) - 18.90 x 0.015" - Fir (I.I.V.) - 2.02 x 0.040" Fir (I.I.V.) + 9.90 x 0.080" - Fir (I.I.V.) + 6.40 x 3"x5" - 0.015" (I.I.V.) + 5.26 x 3"x5" - 0.040" (I.I.V.) - 3.38 x 3"x5" - 0.080" (I.I.V.) - 16.62 x 3"x8" - 0.015" (I.I.V.) - 6.67 x 3"x8" - 0.040" (I.I.V.) + 7.25 x 3"x8" - 0.080" (I.I.V.) - 8.05 x 8' - 3"x5" (I.I.V.) + 8.51 x 8' x 3"x8" (I.I.V.) - 0.24 x (Moist. Cont.)$^2$ - 745.43 (Spec. Grav.)$^2$.

The predicted stress of the particular sample can be computed by just putting in the appropriate values for moisture content, specific gravity, and a +1, 0, or -1 as required for each of the Indicator Variable (I.V.) and Interaction Indicator Variable (I.I.V.) terms. The computer has already done this for all the data used in the analysis and compares the measured stress ($Y = X_6$) with the estimated stress, plus giving the differences (residuals, which equal measured stress minus predicted stress). See Table 21.

# Theoretical vs. Experimental Analysis

General

The contact area stresses derived in the theoretical section were based, in the main, on a standard engineering analysis of eccentricity, with just two modifications; (a) teeth closest to the crack were not counted due to edge or end distance, and (b) the vertical component of top chord axial force was neglected in the eccentricity calculations since it is believed to act directly on the support through crushing of the feather end of the bottom chord, without being transferred by the heel plate.

The theoretical contact area stress, for each of the three sizes studied most closely in the experimental phase is given in Table 24.

Table 24. Theoretical Contact Stress for 3"x5", 3"x8", and 5"x5" Plates

| Plate Size | Axial Stress | +→ | Eccentric Stress | = | Total | Proportion |
|---|---|---|---|---|---|---|
| 3"x5" | 200 | +→ | 138 | = | 323 | 130.2% |
| 3"x8" | 200 | +→ | 66 | = | 248 | 100 % |
| 5"x5" | 200 | +→ | 188 | = | 378 | 152.5% |

Theoretical vs. Experimental Results at 0.150" Deflection

Comparing these results with those contained in Table 23 (using stress at 0.150" deflection as the reference level), and assuming that the 3"x8" plates are equal experimentally and theoretically, the percentage comparison values are in Table 25.

Table 25. Comparison of Theoretical vs. Experimental Results @ 0.150" Deflection.

| Plate Size | Experimental | Theoretical | Difference |
|---|---|---|---|
| 3"x5" | 107.3% | 130.2% | 21.3% |
| 3"x8" | 100.0% | 100.0% | - |
| 5"x5" | 121.0% | 152.5% | 26 % |

If the theoretical results are exactly right for the 3"x8" size, then they are 21.3% and 26% too conservative for the 3"x5" and 5"x5" plates, respectively. The experimental stresses for both the 3"x5" and 5"x5" plates were much closer to the simple axial stress computation (no eccentricity considered) than either the proposed method of heel plate analysis or the FHA method.

When comparing experimental results at 0.150" deflection, the simple axial stress method is more accurate, especially for plates of the same width, than the more elaborate methods.

Theoretical vs. Experimental Results at 0.015" Deflection.

If the experimental results at 0.015" deflection (which is the design deflection) from Table 23, are compared with the theoretical values, Table 26 results:

Table 26. Comparison of Theoretical vs. Experimental Results @ 0.015" Deflection.

| Plate Size | Experimental | Theoretical | Difference |
|---|---|---|---|
| 3"x5" | 72.0% | 130.2% | 80.7% |
| 3"x8" | 100.0% | 100.0% | - |
| 5"x5" | 95.0% | 152.5% | 60.5% |

## Summary

This means that at the lower deflection levels, due to the considerably better performance of the 3"x5" and 5"x5" plates, the more elaborate theoretical methods are even worse predictors than at the higher deflection levels. The simple P/A contact stress calculation method was more accurate for the plate sizes tested than the proposed method of analysis.

# CHAPTER VI

# CONCLUSIONS

A statistical comparison of average stress at ultimate load for repetitive tests of six different heel plate sizes yielded the following conclusions:

1. Plates proportioned three times as long as their breadth are stronger by about 2%, but this is not significantly stronger, than those two times their breadth.
2. Plate lengths ranging from two to three times their breadth are from 13½% to 50% stronger (statistically significant) than those nearly square (one and one-quarter times their width).
3. All plates applied with their long dimension parallel to the bottom chord are significantly stronger than those applied perpendicular to the bottom chord.

A check of the Stress-Coat crack patterns on several plates indicated the following:

4. The shear stress in the steel plate is highest near the crack between the members.

5. The contact area remote from the crack is still flat and is not stressed to the buckling point even when the plate is destroyed at the shear crack if the plate width exceeds the "development width" for shear.
6. Shear stresses in the steel, as well as buckling stresses, are lower in plates applied with the teeth oriented parallel to the bottom chord than in those with teeth oriented perpendicular to the bottom chord.

Inspection of the photographs (confirmed by visual inspection of numerous specimens during failure) reveals:

7. The nearly square plates undergo rotation or sideways distortion during deflection of the heel joint, showing the effect of torsional forces.
8. Buckling resistance is higher when the entire plate area is backed up by wood than when a portion of the truss plate is over the triangular air space between members.

Comparison of matched 8'-0" and 24'-0" specimens showed the following factors to be statistically significant.

9. Douglas fir had about 42% stronger heel joints than white fir. This emphasizes the need to specify the species.
10. The length of heel plate had no effect on joint strength, for plates 3" wide. The 3"x5" plates had 3% more strength per square inch than 3"x8" heel plates.

11. Narrower heel plates are stronger than wider heel plates. The 5"x5" plates were only 82% as strong, on a per square inch basis, as the 3"x5" plates, which was a significant reduction.
12. Small plates are significantly better at the lower levels of deflection (0.015" to 0.040") whereas the larger plates were better at higher levels (0.080" to 0.150"), an inter-action effect of plate size with level of deflection.
13. Moisture content had a highly significant effect on results. The lower moisture content specimens gave better test values.
14. There was no significant effect of specific gravity on stress values. This was an unusual finding since all connector values for mechanical fasteners are based on species groupings by specific gravity.
15. The 8'-0" specimens tested better than the 24'-0" trusses by a significant amount which cannot be explained. The 24'-0" truss heel plates are about 92% as strong as the same plates on the 8'-0" specimen based on the statistical correlation.
16. The small 8'-0" hand-operated test jig provides an accurate heel test not significantly different from results obtained on the Riehle test machine.
17. Wider truss plates are weaker, due to their buckling in the steel, but provide a much more uniform,

predictable load-deflection pattern and greater total deflection than narrower plates. This may be of benefit where a known safety factor is essential.

18. Where two plates are used on each side of the heel joint, both should be oriented the same direction, or their design strengths adjusted in accordance with load-deflection data relating their stiffness.

19. Average ultimate contact area stresses, figured on the straight P/A basis of gross area, were:

| Plate Size | | Doug. Fir | White Fir |
|---|---|---|---|
| 3x5 | | 315 | 226 |
| 3x8 | | 374 | 281 |
| 5x5 | | 264 | 227 |
| 2-7/8x9 | (Hem.) | 335 | |
| 3-11/16x6-3/4 | | 330 | |
| 3-11/16x4-1/2 | | 309 | |
| 5-5/16x6-3/4 | | 290 | (Unequal areas--see text) |
| 5-5/16x4-1/2$\perp$ | | 271 | |
| 5-5/16x6-3/4$\perp$ | | 163 | |

20. Twenty gauge plates with all teeth parallel to bottom chord buckled at loads of about 575 lbs. shear per inch of plate (1150 pli on joint), and 500 pli shear if teeth were perpendicular to crack.

21. Twenty gauge plates with teeth in four directions did not buckle at loads of 675 pli shear (1350 pli on joint), but failed by tooth withdrawal.

# CHAPTER VII

## RECOMMENDATIONS FOR HEEL JOINT DESIGN

The following recommendations are based on this research:

1. Provide sufficient truss plate contact area to accommodate the top and bottom chord axial forces, using the TPI reduction factors for slope effect. An additional reduction factor of 20% is recommended for plates over 4" wide, to account for eccentricity.

2. Twenty gauge heel plates placed parallel to the bottom chord should be kept short enough (probably not exceeding 9" in most cases) to prevent tensile failures in the steel.

3. Twenty gauge heel plates should be kept narrow enough (probably not over -1/2" in most cases) to prevent buckling failure in the steel. If wide plates are used, they should be designed on the basis of their buckling resistance rather than their contact area.

4. Heel plates should be proportional from two to three times as long as their breadth, whenever possible, to increase their rotational resistance to eccentric forces.

5. Tooth values and plate sizes are highly dependent on species of lumber. Care in specifying the species on the

drawings must be followed in the actual production of the trusses, or larger plates used if a less desirable species is substituted in the design.

6. Heel plates should be positioned with the longest possible amount of plate over the crack to resist rotation, with equal contact areas on both members.

7. Heel plates should not be positioned perpendicular to the crack if avoidable, or, if this positioning is unavoidable, appropriately reduced tooth values should be used in the design, plus checking the buckling resistance of the reduced steel shear line.

8. Large sized heel plates, when used for girder trusses, widely spaced trusses, or other trusses with high axial forces, should be checked for buckling strength and tensile strength to prevent a misplaced feeling of confidence based on contact area size.

## CHAPTER VIII

## RECOMMENDATIONS FOR FURTHER RESEARCH

1. Bracing (Bridging) Methods and Requirements for Flat Trusses.
2. Load-Sharing (and Its Stress Increases) as It Applies to Trussed Rafters.
3. Top Chord Column Buckling Resistance Provided by 2"x4" Roof Boards 24" O.C., or 3/8" Plywood Sheathing.
4. Study Methods of Improving Stiffness of Long Span - Shallow Depth Flat Trusses.
5. Long Term Deflection Characteristics of Flat Trusses.
6. Suitability of Metal Plates in Making Joints in Continuous Floor Joists.

# APPENDIX

APPENDIX

LOAD DEFLECTION DATA

This appendix contains the tabular test data obtained experimentally. The tables are grouped as follows:

| Tables | Purpose | Pages |
|---|---|---|
| 27 through 32 | Comparison of Six Plate Sizes. | 163-168 |
| 33 through 38 | Initial Comparison of Plate Size Specimen Length, Species, and Level of Deflection. | 169-174 |
| 39 and 40 | Substantiating Tests for Table 33. | 175-176 |
| 41 through 46 | Tests of 8' Specimens on Riehle Testing Machine to Verify Suitability of Small Hand Hydraulic Jig. | 177-182 |

Table 27. Load Deflection Data for 2-7/8" x 9" Plates.

| Heel Defl. | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #9 | #15 | #20 | #30 | #34 | Ave. | #9 | #15 | #20 | #30 | #34 | Ave | #9 | #15 | #20 | #30 | #34 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 1035 | 2200 | 660 | 285 | 315 | 899 | 40 | 85 | 25 | 11 | 12 | 35 | 162 | 232 | 69 | 30 | 33 | 105 |
| 0.010 | 2070 | 3000 | 1230 | 570 | 630 | 1500 | 80 | 115 | 50 | 22 | 24 | 58 | 324 | 315 | 130 | 60 | 66 | 179 |
| 0.015 | 2930 | 3790 | 1860 | 920 | 1260 | 2152 | 112 | 146 | 75 | 35 | 48 | 83 | 458 | 400 | 196 | 97 | 132 | 257 |
| 0.020 | 3620 | 4480 | 2480 | 1380 | 1660 | 2724 | 139 | 172 | 96 | 53 | 64 | 105 | 562 | 472 | 260 | 145 | 174 | 323 |
| 0.030 | 4735 | 5700 | 3480 | 2440 | 2610 | 3793 | 182 | 219 | 134 | 94 | 100 | 146 | 740 | 600 | 366 | 255 | 275 | 447 |
| 0.040 | 5690 | 6380 | 4080 | 3160 | 3465 | 4555 | 218 | 245 | 156 | 122 | 134 | 175 | 890 | 670 | 430 | 333 | 365 | 537 |
| 0.050 | 6360 | 6940 | 4740 | 3625 | 4030 | 5139 | 245 | 267 | 182 | 139 | 155 | 198 | 990 | 730 | 496 | 381 | 425 | 604 |
| 0.060 | 6750 | 7350 | 5350 | 4130 | 4490 | 5614 | 258 | 282 | 206 | 158 | 172 | 215 | 1060 | 775 | 562 | 435 | 472 | 661 |
| 0.070 | 7050 | 7700 | 5840 | 4740 | 5060 | 6078 | 270 | 296 | 225 | 182 | 194 | 233 | 1100 | 810 | 615 | 498 | 503 | 705 |
| 0.080 | 7280 | 8030 | 6280 | 4970 | 5430 | 6398 | 279 | 308 | 240 | 191 | 209 | 246 | 1140 | 845 | 660 | 522 | 572 | 748 |
| 0.090 | 7450 | 8360 | 6530 | 5300 | 5780 | 6594 | 286 | 321 | 251 | 204 | 221 | 253 | 1160 | 880 | 688 | 558 | 608 | 779 |
| 0.100 | 7600 | 8690 | 6760 | 5430 | 6060 | 6908 | 291 | 333 | 260 | 209 | 233 | 265 | 1190 | 910 | 710 | 572 | 638 | 804 |
| 0.125 | | 8890 | 7350 | | 6600 | 7613** | | 341 | 282 | | 254 | 292 | | 935 | 771 | | 695 | 800 |
| 0.150 | | 9090 | 7900 | | 7015 | 8002** | | 349 | 303 | | 270 | 308 | | 955 | 830 | | 740 | 842 |
| 0.175 | | 9285 | | | 7330 | 8308*** | | 355 | | | 282 | 320 | | 975 | | | 770 | 872 |
| 0.200 | | 9480 | | | | | | 364 | | | | | | 1000 | | | | |
| Ult. | 8270 | 9480 | 9000 | * | 8210 | 8740 | 317 | 364 | 345 | * | 315 | 335 | 1290 | 1000 | 950 | * | 865 | 1034 |

* Opposite top chord broke prior to test joint; therefore ultimate load could not be determined.
** Average based on three specimens.
*** Average based on two specimens.

Table 28. Load Deflection Data for 3-11/16" x 6-3/4" Plates

| Heel | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #14 | #21 | #23 | #35 | #3 | Ave. | #14 | #21 | #23 | #35 | #3 | Ave | #14 | #21 | #23 | #35 | #3 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 2100 | 790 | 660 | 525 | 330 | 881 | 84 | 32 | 27 | 21 | 13 | 35 | 296 | 111 | 93 | 74 | 46 | 124 |
| 0.010 | 3160 | 1740 | 1240 | 1135 | 660 | 1587 | 127 | 70 | 50 | 46 | 27 | 64 | 445 | 245 | 175 | 160 | 93 | 224 |
| 0.015 | 3950 | 2570 | 1800 | 1890 | 1130 | 2268 | 159 | 103 | 72 | 76 | 45 | 91 | 556 | 362 | 254 | 266 | 159 | 319 |
| 0.020 | 4445 | 3380 | 2370 | 2600 | 1690 | 2897 | 179 | 136 | 95 | 104 | 68 | 116 | 626 | 476 | 334 | 360 | 238 | 408 |
| 0.030 | 5670 | 4610 | 3160 | 3465 | 2720 | 3925 | 228 | 185 | 127 | 139 | 109 | 158 | 799 | 649 | 445 | 488 | 383 | 553 |
| 0.040 | 6375 | 5390 | 3660 | 4210 | 3440 | 4615 | 256 | 216 | 147 | 169 | 138 | 185 | 898 | 759 | 515 | 593 | 485 | 650 |
| 0.050 | 6940 | 6060 | 4110 | 4730 | 4000 | 5168 | 279 | 243 | 165 | 190 | 160 | 208 | 977 | 854 | 579 | 666 | 563 | 728 |
| 0.060 | 7350 | 6520 | 4810 | 5160 | 4460 | 5660 | 295 | 262 | 193 | 208 | 179 | 227 | 1035 | 918 | 677 | 727 | 628 | 797 |
| 0.070 | 7695 | 6850 | 5000 | 5630 | 4910 | 6017 | 309 | 275 | 201 | 226 | 197 | 242 | 1084 | 965 | 704 | 793 | 692 | 847 |
| 0.080 | 8030 | 7160 | 5180 | 6200 | 5320 | 6378 | 322 | 288 | 208 | 249 | 214 | 256 | 1131 | 1008 | 730 | 873 | 749 | 898 |
| 0.090 | 8485 | 7410 | 5365 | 6395 | 5580 | 6647 | 341 | 298 | 215 | 257 | 224 | 267 | 1195 | 1044 | 756 | 901 | 786 | 936 |
| 0.100 | 8690 | 7670 | 5530 | 6545 | 5710 | 6829 | 349 | 308 | 222 | 263 | 229 | 274 | 1224 | 1080 | 779 | 922 | 804 | 962 |
| 0.125 | 8800* | 8080 | 5790 | 6920 | 6010 | 7120 | 353 | 324 | 233 | 278 | 241 | 286 | 1239 | 1138 | 815 | 975 | 846 | 1003 |
| 0.150 | 8900* | 8430 | 6060 | 7250 | 6320 | 7392 | 357 | 339 | 243 | 291 | 254 | 297 | 1254 | 1187 | 854 | 1021 | 890 | 1041 |
| 0.175 | 9000* | 8690 | 6320 | 7580* | 6630* | 7644 | 361 | 349 | 254 | 304 | 266 | 266 | 1268 | 1224 | 890 | 1068 | 934 | 1077 |
| 0.200 | 9100* | 8790* | 6580 | 7580* | 6930* | 7796 | 365 | 353 | 264 | 304 | 278 | 313 | 1282 | 1238 | 927 | 1067 | 976 | 1098 |
| Ult. | 9150 | 8850 | 8200 | 7580 | 7260 | 8208 | 367 | 355 | 329 | 304 | 292 | 330 | 1289 | 1246 | 1155 | 1068 | 1023 | 1156 |

*Estimated data; gauge removed to prevent damage.

*Table 29.* Load Deflection Data for 5-5/16" x 6-3/4"

Table 29. Load Deflection Data for 5-5/16" x 6-3/4"

| Heel Defl. | Top Chord Force lbs. | | | | Contact Area Stress psi | | | | Shear Line Stress pli | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #75 | #76 | #77 | Ave. | #75 | #76 | #77 | Ave | #75 | #76 | #77 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 1900 | 1320 | 1190 | 1470 | 73 | 51 | 38 | 54 | 281 | 195 | 176 | 217 |
| 0.010 | 2550 | 2100 | 1780 | 2143 | 97 | 81 | 57 | 78 | 367 | 310 | 263 | 313 |
| 0.015 | 2990 | 2630 | 2270 | 2630 | 114 | 101 | 72 | 96 | 441 | 388 | 336 | 388 |
| 0.020 | 3370 | 3070 | 2690 | 3043 | 129 | 118 | 85 | 111 | 500 | 454 | 396 | 450 |
| 0.030 | 4110 | 3950 | 3360 | 3807 | 158 | 152 | 107 | 139 | 610 | 585 | 499 | 564 |
| 0.040 | 4820 | 4740 | 3850 | 4470 | 185 | 182 | 122 | 165 | 712 | 700 | 570 | 660 |
| 0.050 | 5240 | 5400 | 4280 | 4973 | 201 | 207 | 136 | 181 | 774 | 800 | 632 | 735 |
| 0.060 | 5660 | 6060 | 4740 | 5487 | 217 | 232 | 151 | 200 | 840 | 900 | 700 | 813 |
| 0.070 | 5980 | 6440 | 5200 | 5873 | 229 | 247 | 166 | 214 | 882 | 981 | 770 | 878 |
| 0.080 | 6320 | 6640 | 5580 | 6180 | 243 | 255 | 177 | 225 | 940 | 980 | 822 | 914 |
| 0.090 | 6620 | 6850 | 5750 | 6407 | 254 | 263 | 183 | 233 | 980 | 1010 | 850 | 947 |
| 0.100 | 6780 | 7050 | 5910 | 6580 | 259 | 270 | 189 | 239 | 1000 | 1040 | 880 | 973 |
| 0.125 | 7130 | 7440 | 6320 | 6963 | 274 | 286 | 201 | 254 | 1055 | 1100 | 940 | 1031 |
| 0.150 | 7470 | 7900 | 6620 | 7330 | 286 | 304 | 211 | 267 | 1100 | 1165 | 980 | 1081 |
| 0.175 | 7780 | 8100 | 7110 | 7663 | 298 | 310 | 226 | 278 | 1145 | 1195 | 1050 | 1130 |
| 0.200 | 8000 | 8300 | 7260 | 7853 | 306 | 317 | 230 | 284 | 1180 | 1225 | 1070 | 1158 |
| Ult. | 8200 | 8500 | 7260 | 7987 | 315 | 325 | 230 | 290 | 1210 | 1255 | 1070 | 1178 |

Since these truss plates were not all positioned equally on the members, the contact area was computed on the basis of the minimum area provided (26.1 $in.^2$ for 75 and 76) (31.5 $in^2$ for 77).

*Table 30. Load Deflection Data for 5-5/16" x 4-1/2"* ⊥ to Bottom Chord.

Table 30. Load Deflection Data for 5-5/16" x 4-1/2" ⊥ to Bottom Chord.

| Heel | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #17 | #65 | #69 | #70 | #71 | Ave. | #17 | #65 | #69 | #70 | #71 | Ave | #17 | #65 | #69 | #70 | #71 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 1900 | 300 | 560 | 650 | 1740 | 1030 | 79 | 13 | 23 | 27 | 73 | 45 | 338 | 56 | 99 | 116 | 310 | 184 |
| 0.010 | 2600 | 610 | 1020 | 1190 | 2480 | 1580 | 108 | 26 | 43 | 50 | 104 | 66 | 463 | 108 | 182 | 212 | 441 | 281 |
| 0.015 | 3160 | 920 | 1840 | 1690 | 3050 | 2132 | 132 | 39 | 77 | 71 | 128 | 89 | 562 | 164 | 327 | 300 | 542 | 379 |
| 0.020 | 3560 | 1250 | 2670 | 2260 | 3600 | 2668 | 148 | 52 | 112 | 95 | 152 | 112 | 635 | 222 | 475 | 402 | 640 | 475 |
| 0.030 | 4250 | 1910 | 3420 | 3220 | 4300 | 3420 | 177 | 80 | 131 | 135 | 180 | 141 | 758 | 340 | 610 | 572 | 765 | 609 |
| 0.040 | 4870 | 2480 | 3950 | 3830 | 4780 | 3982 | 203 | 104 | 166 | 161 | 200 | 167 | 865 | 440 | 703 | 680 | 850 | 708 |
| 0.050 | 5140 | 2860 | 4175 | 4440 | 5150 | 4353 | 214 | 120 | 175 | 186 | 216 | 182 | 915 | 510 | 742 | 790 | 915 | 774 |
| 0.060 | 5400 | 3180 | 4400 | 4880 | 5520 | 4676 | 225 | 134 | 185 | 205 | 232 | 196 | 960 | 567 | 782 | 870 | 985 | 833 |
| 0.070 | 5600 | 3300 | 4630 | 5150 | 5750 | 4886 | 233 | 138 | 194 | 216 | 241 | 204 | 1000 | 587 | 825 | 918 | 1020 | 870 |
| 0.080 | 5745 | 3420 | 4800 | 5420 | 5860 | 5049 | 240 | 144 | 202 | 228 | 246 | 212 | 1020 | 610 | 855 | 965 | 1040 | 898 |
| 0.090 | 5900 | 3540 | 4910 | 5640 | 6080 | 5214 | 245 | 148 | 206 | 237 | 254 | 218 | 1050 | 630 | 875 | 1000 | 1075 | 926 |
| 0.100 | 6030 | 3660 | 5010 | 5830 | 6350 | 5376 | 252 | 154 | 211 | 245 | 266 | 226 | 1070 | 652 | 892 | 1040 | 1125 | 956 |
| 0.125 | 6320 | 3950 | 5270 | 6320 | 6530 | 5678 | 264 | 166 | 221 | 266 | 275 | 238 | 1120 | 705 | 930 | 1120 | 1160 | 1007 |
| 0.150 | 6580 | 4210 | 5420 | 6645 | 6700 | 5911 | 274 | 177 | 228 | 279 | 281 | 248 | 1165 | 750 | 965 | 1180 | 1190 | 1050 |
| 0.175 | 6800 | 4470 | 5560 | 6970 | 6870 | 6134 | 284 | 188 | 234 | 292 | 288 | 257 | 1205 | 795 | 985 | 1235 | 1215 | 1087 |
| 0.200 | 7000 | 4740 | 5700 | 7000 | 7040 | 6296 | 291 | 199 | 239 | 294 | 296 | 264 | 1240 | 842 | 1010 | 1240 | 1250 | 1116 |
| Ult. | 7000 | 5060 | 5700 | 7290 | 7290 | 6468 | 291 | 213 | 239 | 305 | 305 | 271 | 1240 | 900 | 1010 | 1290 | 1290 | 1146 |

*Table 31. Load Deflection Data for 3-11/16" x 4-1/2" Plates.*

Table 31. Load Deflection Data for 3-11/16" x 4-1/2" Plates.

| Heel Def. | Top Chord Force lbs. | | | | | | Stress In Contact Area psi | | | | | | Stress In Shear Line pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4/12 Pitch | | | 6/12 Pitch | | | 4/12 Pitch | | | 6/12 Pitch | | | 4/12 Pitch | | | 6/12 Pitch | | |
| | #67 | #68 | Ave. | #7 | #8 | Ave. | #67 | #68 | Ave | #7 | #8 | Ave | #67 | #68 | Ave | #7 | #8 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 440 | 350 | 395 | 800 | 450 | 625 | 26 | 21 | 24 | 48 | 27 | 38 | 93 | 73 | 83 | 168 | 100 | 134 |
| 0.010 | 870 | 720 | 795 | 1820 | 1010 | 1415 | 52 | 44 | 48 | 110 | 61 | 85 | 182 | 150 | 166 | 383 | 224 | 304 |
| 0.015 | 1270 | 1020 | 1145 | 2350 | 1675 | 2015 | 77 | 62 | 70 | 142 | 100 | 121 | 266 | 214 | 240 | 495 | 372 | 434 |
| 0.020 | 1620 | 1300 | 1460 | 2650 | 2235 | 2445 | 98 | 79 | 88 | 158 | 134 | 146 | 340 | 272 | 306 | 554 | 497 | 577 |
| 0.030 | 2040 | 1680 | 1860 | 3350 | 2900 | 3125 | 123 | 102 | 112 | 201 | 174 | 188 | 424 | 351 | 390 | 705 | 644 | 674 |
| 0.040 | 2440 | 2070 | 2255 | 3730 | 3535 | 3435 | 147 | 125 | 136 | 224 | 213 | 219 | 510 | 435 | 474 | 785 | 786 | 786 |
| 0.050 | 2800 | 2370 | 2585 | 4070 | 3920 | 3995 | 169 | 143 | 156 | 245 | 236 | 240 | 589 | 495 | 540 | 857 | 871 | 864 |
| 0.060 | 3160 | 2440 | 2800 | 4360 | 4030 | 4195 | 191 | 147 | 169 | 262 | 242 | 252 | 665 | 511 | 576 | 918 | 896 | 907 |
| 0.070 | 3230 | 2510 | 2870 | 4520 | 4140 | 4330 | 195 | 152 | 174 | 272 | 249 | 260 | 675 | 528 | 600 | 952 | 920 | 936 |
| 0.080 | 3300 | 2580 | 2940 | 4600 | 4250 | 4425 | 199 | 156 | 178 | 277 | 256 | 266 | 690 | 540 | 615 | 968 | 944 | 956 |
| 0.090 | 3370 | 2650 | 3010 | 4680 | 4360 | 4520 | 204 | 160 | 182 | 281 | 262 | 271 | 708 | 555 | 632 | 985 | 969 | 977 |
| 0.100 | 3440 | 2720 | 3080 | 4810 | 4470 | 4640 | 208 | 164 | 186 | 289 | 269 | 279 | 720 | 570 | 650 | 1012 | 993 | 1003 |
| 0.125 | 3620 | 2910 | 3270 | 5020 | 4700 | 4800 | 218 | 176 | 196 | 302 | 283 | 293 | 760 | 610 | 685 | 1057 | 1044 | 1050 |
| 0.150 | 3800 | 3100 | 3450 | 5140 | 4885 | 5010 | 229 | 187 | 208 | 309 | 294 | 301 | 796 | 650 | 723 | 1082 | 1086 | 1084 |
| 0.175 | 3800 | 3210 | 3505 | 5200* | 4890* | 5040 | 229 | 194 | 212 | 313 | 294 | 304 | 796 | 675 | 735 | 1095 | 1087 | 1091 |
| 0.200 | 3800 | 3310 | 3555 | 5250* | 4900* | 5075 | 229 | 200 | 215 | 316 | 295 | 306 | 796 | 695 | 745 | 1105 | 1089 | 1097 |
| Ult. | 3800 | 3470 | 3635 | 5360 | 4920 | 5140 | 229 | 209 | 219 | 323 | 296 | 309 | 796 | 730 | 763 | 1110 | 1093 | 1102 |

#7 - parallel to bottom chord in 6/12 - 8'0" specimen.
#67 - #68 parallel to bottom chord in 4/12 - 8'0" specimen.
#8 - parallel to bottom crack in 6/12 - 8'0" specimen.

*Estimated values; gage removed to prevent damage.

Table 32. *Load Deflection Data for* 5-5/16" x 6-3/4" ⊥ to Crack

| | Top Chord Force | Contact Area Stress | Shear Line Stress |
|---|---|---|---|

Table 32. Load Deflection Data for 5-5/16" x 6-3/4" ⊥ to Crack

| Heel | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #24 | #72 | #73 | #74 | Ave. | #24 | #72 | #73 | #74 | Ave | #24 | #72 | #73 | #74 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 1050 | 1260 | 920 | 1270 | 1125 | 29 | 35 | 26 | 35 | 31 | 148 | 238 | 173 | 239 | 199 |
| 0.010 | 1710 | 2020 | 1580 | 1910 | 1805 | 47 | 56 | 44 | 53 | 50 | 240 | 380 | 296 | 359 | 319 |
| 0.015 | 2370 | 2550 | 2070 | 2460 | 2362 | 66 | 71 | 58 | 69 | 69 | 334 | 480 | 389 | 463 | 416 |
| 0.020 | 2930 | 2990 | 2510 | 2900 | 2832 | 81 | 83 | 70 | 81 | 79 | 412 | 560 | 471 | 545 | 497 |
| 0.030 | 3500 | 3580 | 3210 | 3580 | 3467 | 97 | 100 | 89 | 100 | 97 | 492 | 673 | 604 | 671 | 610 |
| 0.040 | 3900 | 4030 | 3700 | 4030 | 3915 | 108 | 112 | 103 | 112 | 109 | 550 | 758 | 695 | 759 | 690 |
| 0.050 | 4275 | 4320 | 4090 | 4250 | 4234 | 118 | 120 | 114 | 118 | 118 | 600 | 810 | 768 | 800 | 744 |
| 0.060 | 4630 | 4600 | 4370 | 4460 | 4515 | 128 | 128 | 122 | 125 | 126 | 650 | 865 | 820 | 840 | 794 |
| 0.070 | 4830 | 4840 | 4650 | 4680 | 4750 | 134 | 134 | 130 | 130 | 132 | 680 | 910 | 872 | 880 | 835 |
| 0.080 | 4950 | 5040 | 4840 | 4770 | 4900 | 138 | 140 | 135 | 133 | 137 | 700 | 950 | 910 | 898 | 864 |
| 0.090 | 5080 | 5230 | 4980 | 4810 | 5025 | 140 | 146 | 138 | 134 | 140 | 710 | 980 | 935 | 905 | 882 |
| 0.100 | 5200 | 5430 | 5120 | 4850 | 5150 | 144 | 152 | 142 | 135 | 143 | 730 | 1020 | 965 | 910 | 906 |
| 0.125 | 5520 | 5650 | 5470 | 4950 | 5397 | 153 | 157 | 152 | 138 | 150 | 780 | 1060 | 1025 | 930 | 949 |
| 0.150 | 5600 | 5790 | 5570 | 5050 | 5502 | 155 | 161 | 155 | 141 | 153 | 790 | 1080 | 1040 | 950 | 965 |
| 0.175 | 5700 | 5940 | 5620 | 5150 | 5602 | 158 | 166 | 157 | 144 | 156 | 800 | 1115 | 1055 | 970 | 985 |
| 0.200 | 5800 | 6080 | 5670 | 5250 | 5700 | 161 | 169 | 158 | 146 | 159 | 820 | 1135 | 1060 | 990 | 1001 |
| Ult. | 5980 | 6320 | 5700 | 5380 | 5845 | 166 | 176 | 159 | 150 | 163 | 840 | 1190 | 1065 | 1010 | 1026 |

Table 33. *Load Deflection Data for 8' vs. 24' - 3"x5" - Doug. Fir.*

... Line Stress

Table 33. Load Deflection Data for 8' vs. 24' - 3"x5" - Doug. Fir.

| Heel | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | |
| Defl. | #38 | #39 | Ave. | #44 | #45 | Ave. | #38 | #39 | Ave | #44 | #45 | Ave | #38 | #39 | Ave | #44 | #45 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 330 | 200 | 265 | 420 | 465 | 440 | 22 | 13 | 18 | 28 | 31 | 29 | 63 | 38 | 50 | 80 | 83 | 84 |
| 0.010 | 660 | 400 | 530 | 835 | 1370 | 1100 | 44 | 27 | 35 | 56 | 91 | 73 | 125 | 76 | 100 | 158 | 260 | 207 |
| 0.015 | 940 | 600 | 770 | 1530 | 1910 | 1720 | 63 | 40 | 51 | 102 | 127 | 115 | 178 | 114 | 146 | 290 | 362 | 326 |
| 0.020 | 1230 | 790 | 1010 | 2230 | 2340 | 2285 | 82 | 53 | 67 | 148 | 156 | 152 | 233 | 150 | 192 | 423 | 444 | 434 |
| 0.030 | 1820 | 1855 | 1840 | 2890 | 3020 | 2955 | 118 | 120 | 119 | 193 | 201 | 197 | 336 | 531 | 339 | 549 | 573 | 560 |
| 0.040 | 2230 | 2460 | 2345 | 3550 | 3420 | 3485 | 148 | 164 | 156 | 236 | 228 | 232 | 423 | 410 | 445 | 673 | 649 | 661 |
| 0.050 | 2550 | 2930 | 2740 | 4200 | 3820 | 4010 | 170 | 195 | 183 | 280 | 254 | 267 | 484 | 556 | 520 | 800 | 725 | 760 |
| 0.060 | 2790 | 3270 | 3030 | 4290 | 4230 | 4260 | 186 | 218 | 202 | 286 | 282 | 284 | 529 | 620 | 575 | 815 | 804 | 810 |
| 0.070 | 3040 | 3480 | 3260 | 4380 | 4510 | 4445 | 203 | 232 | 217 | 292 | 301 | 296 | 577 | 660 | 619 | 831 | 855 | 840 |
| 0.080 | 3220 | 3690 | 3455 | 4470 | 4700 | 4585 | 215 | 246 | 230 | 298 | 313 | 305 | 611 | 700 | 656 | 846 | 881 | 860 |
| 0.090 | 3340 | 3930 | 3635 | 4560 | 4860 | 4710 | 222 | 262 | 242 | 304 | 324 | 314 | 634 | 746 | 690 | 865 | 922 | 885 |
| 0.100 | 3480 | 4160 | 3820 | 4660 | 5030 | 4845 | 232 | 278 | 255 | 310 | 335 | 322 | 660 | 789 | 725 | 884 | 955 | 919 |
| 0.125 | 3480* | 4520 | 4000 | " | " | " | " | 302 | 267 | " | " | " | " | 858 | 759 | " | " | " |
| 0.150 | 3480* | 4740 | 4110 | " | " | " | " | 316 | 274 | " | " | " | " | 899 | 780 | " | " | " |
| 0.175 | | | | " | " | " | | | | " | " | " | | | | " | " | " |
| Ult. | 3480 | 5530 | 4505 | 4660 | 5030 | 4845 | 232 | 368 | 301 | 310 | 335 | 322 | 660 | 1049 | 855 | 884 | 955 | 919 |

*Deflection estimated. Gauge removed to prevent damage.

Table 34. Load Deflection Data for 8' vs. 24' - 3"x8" - Doug. Fir.

Table 34. Load Deflection Data for 8' vs. 24' - 3"x8" - Doug. Fir.

| Heel Defl. | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | |
| | #40 | #41 | Ave. | #46 | #47 | Ave. | #40 | #41 | Ave | #46 | #47 | Ave | #40 | #41 | Ave | #46 | #46 | Ave. |
| 0.005 | 550 | 440 | 495 | 600 | 346 | 475 | 23 | 18 | 21 | 25 | 14 | 20 | 65 | 52 | 58 | 70 | 41 | 56 |
| 0.010 | 1380 | 950 | 1165 | 1120 | 1310 | 1215 | 57 | 40 | 49 | 47 | 54 | 51 | 162 | 112 | 137 | 132 | 154 | 143 |
| 0.015 | 2370 | 1740 | 2055 | 1740 | 1840 | 1790 | 99 | 73 | 86 | 72 | 77 | 75 | 279 | 205 | 242 | 205 | 216 | 210 |
| 0.020 | 3420 | 2500 | 2960 | 2090 | 2120 | 2150 | 143 | 104 | 123 | 87 | 88 | 88 | 402 | 294 | 348 | 246 | 250 | 248 |
| 0.030 | 4650 | 3530 | 4090 | 3070 | 3090 | 3080 | 194 | 147 | 174 | 128 | 129 | 129 | 558 | 424 | 491 | 344 | 245 | 345 |
| 0.040 | 5830 | 4740 | 5285 | 3260 | 3560 | 3410 | 243 | 198 | 220 | 136 | 148 | 142 | 686 | 558 | 622 | 393 | 420 | 402 |
| 0.050 | 6570 | 5180 | 5875 | 4390 | 4050 | 4220 | 274 | 216 | 245 | 183 | 169 | 176 | 773 | 609 | 691 | 515 | 476 | 496 |
| 0.060 | 7100 | 5570 | 6335 | 4750 | 4720 | 4735 | 296 | 232 | 264 | 198 | 196 | 197 | 835 | 655 | 745 | 558 | 550 | 554 |
| 0.070 | 7560 | 5760 | 6660 | 5440 | 5320 | 5380 | 315 | 240 | 278 | 227 | 222 | 224 | 889 | 678 | 783 | 640 | 626 | 634 |
| 0.080 | 7900 | 5950 | 6925 | 5870 | 5710 | 5790 | 329 | 248 | 289 | 245 | 238 | 241 | 929 | 700 | 815 | 690 | 671 | 680 |
| 0.090 | 8200* | 6140 | 7170 | 6280 | 6140 | 6210 | 342 | 256 | 299 | 262 | 256 | 259 | 965 | 722 | 843 | 739 | 722 | 731 |
| 0.100 | 8400* | 6320 | 7360 | 6740 | 6640 | 6690 | 343 | 258 | 307 | 281 | 277 | 279 | 988 | 743 | 866 | 776 | 765 | 770 |
| 0.125 | 8450* | 6420 | 7435 | 7250 | 7200 | 7225 | 352 | 268 | 310 | 302 | 300 | 301 | 994 | 755 | 875 | 853 | 846 | 850 |
| 0.150 | 8500* | 6520 | 7510 | 7590 | 7800 | 7695 | 354 | 272 | 313 | 316 | 325 | 320 | 1000 | 767 | 883 | 892 | 918 | 905 |
| 0.175 | | | | 7920 | 8330 | 8125 | | | | 330 | 347 | 338 | | | | 930 | 980 | 955 |
| 0.200 | | | | 8250* | 8860 | 8555 | | | | 344 | 370 | 356 | | | | 970 | 1040 | 1010 |
| Ult. | 8540 | 6640 | 7615 | 9450* | 10800 | 10125 | 349 | 273 | 317 | 394 | 451 | 422 | 1005 | 787 | 896 | 1090 | 1250 | 1170 |

* Top chord was buckling sideways very severely which increased the deflection reading due to the gauge location. The test joint did not fail despite this lateral buckling. Ultimate joint load was estimated.

Table 35. *Load Deflection Data for 8' vs. 24' - 5"x5" - Doug. Fir.*

| | |
|---|---|
| | Stress In Shear Line |

Table 35. Load Deflection Data for 8' vs. 24' - 5"x5" - Doug. Fir.

| Heel | Top Chord Force | | | | | | Stress In Contact Area | | | | | | Stress In Shear Line | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24' Truss | | | 8' Test | | | 24' Truss | | | 8' Test | | | 24' Truss | | | 8' Test | | |
| Defl | #48 | #49 | Ave. | #57 | #58 | Ave. | #48 | #49 | Ave | #57 | #58 | Ave | #48 | #49 | Ave. | #57 | #58 | Ave. |
| .000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| .005 | 712 | 635 | 675 | 396 | 1030 | 715 | 28 | 26 | 27 | 15 | 41 | 28 | 135 | 120 | 128 | 75 | 194 | 135 |
| .010 | 1240 | 1070 | 1255 | 792 | 1395 | 1093 | 50 | 43 | 47 | 32 | 56 | 44 | 236 | 198 | 217 | 150 | 264 | 207 |
| .015 | 1785 | 1860 | 1825 | 1470 | 1980 | 1725 | 72 | 75 | 74 | 59 | 79 | 69 | 338 | 352 | 345 | 279 | 376 | 326 |
| .020 | 2200 | 2280 | 2240 | 2070 | 2610 | 2340 | 88 | 91 | 90 | 83 | 104 | 94 | 418 | 432 | 425 | 392 | 495 | 443 |
| .030 | 2870 | 2920 | 2895 | 3160 | 3320 | 3240 | 115 | 117 | 116 | 126 | 134 | 130 | 544 | 555 | 550 | 600 | 630 | 615 |
| .040 | 3540 | 3620 | 3580 | 3820 | 4070 | 3950 | 142 | 145 | 143 | 153 | 163 | 158 | 672 | 688 | 680 | 724 | 770 | 750 |
| .050 | 4020 | 4210 | 4115 | 4450 | 4670 | 4560 | 161 | 169 | 165 | 178 | 186 | 182 | 762 | 798 | 780 | 842 | 886 | 864 |
| .060 | 4510 | 4640 | 4575 | 4990 | 5420 | 5155 | 180 | 186 | 183 | 200 | 218 | 209 | 855 | 878 | 867 | 940 | 1030 | 985 |
| .070 | 4960 | 4990 | 4850 | 5420 | 5920 | 5670 | 198 | 199 | 198 | 218 | 236 | 227 | 940 | 948 | 944 | 1030 | 1120 | 1075 |
| .080 | 5280 | 5350 | 5315 | 5580 | 6290 | 5935 | 211 | 213 | 212 | 222 | 252 | 237 | 1000 | 1015 | 1008 | 1060 | 1190 | 1125 |
| .090 | 5590 | 5790 | 5690 | 5740 | 6510 | 6125 | 223 | 232 | 228 | 229 | 261 | 244 | 1060 | 1095 | 1080 | 1090 | 1240 | 1165 |
| .100 | 5850 | 6070 | 5960 | 5850 | 6700 | 6275 | 235 | 243 | 239 | 234 | 268 | 251 | 1110 | 1150 | 1130 | 1108 | 1270 | 1190 |
| .125 | 6310 | 6430 | 6370 | 6200 | 7180 | 6690 | 252 | 257 | 255 | 247 | 287 | 267 | 1195 | 1215 | 1205 | 1175 | 1360 | 1268 |
| .150 | 6460 | 6670 | 6565 | 6350 | 7610 | 6980 | 259 | 267 | 263 | 254 | 305 | 279 | 1228 | 1268 | 1248 | 1205 | 1440 | 1322 |
| .175 | 6650 | 6910 | 6780 | 6500 | 7750 | 7125 | 266 | 276 | 271 | 261 | 310 | 286 | 1265 | 1305 | 1285 | 1235 | 1470 | 1350 |
| .200 | 6820 | 7160 | 6990 | 6580 | 7750 | 7165 | 272 | 287 | 280 | 264 | 310 | 287 | 1295 | 1345 | 1320 | 1243 | 1470 | 1358 |
| Ult. | 6820 | 7700 | 7260 | 6580 | 7750 | 7165 | 272 | 308 | 290 | 264 | 310 | 287 | 1295 | 1460 | 1375 | 1243 | 1470 | 1358 |

Table 36. Load Deflection Data for 8' vs. 24' - 3"x5" - White Fir.

| Heel | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | |
| Defl. | #51 | #52 | Ave. | #59 | #60 | Ave. | #51 | #52 | Ave | #59 | #60 | Ave | #51 | #52 | Ave | #59 | #60 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 725 | 870 | 800 | 520 | 730 | 625 | 48 | 58 | 53 | 35 | 48 | 42 | 138 | 165 | 151 | 99 | 138 | 119 |
| 0.010 | 1390 | 1100 | 1245 | 770 | 915 | 842 | 93 | 74 | 84 | 51 | 61 | 56 | 262 | 210 | 236 | 146 | 173 | 160 |
| 0.015 | 1685 | 1350 | 1520 | 890 | 1100 | 995 | 113 | 90 | 96 | 60 | 74 | 67 | 319 | 256 | 288 | 169 | 208 | 189 |
| 0.020 | 1790 | 1630 | 1710 | 1005 | 1280 | 1140 | 119 | 108 | 114 | 67 | 85 | 76 | 339 | 310 | 324 | 191 | 242 | 166 |
| 0.030 | 1960 | 2060 | 2010 | 1280 | 1580 | 1430 | 131 | 138 | 135 | 86 | 107 | 97 | 372 | 390 | 381 | 243 | 300 | 271 |
| 0.040 | 2150 | 2450 | 2300 | 1500 | 1780 | 1640 | 144 | 163 | 153 | 100 | 119 | 110 | 408 | 464 | 436 | 286 | 337 | 314 |
| 0.050 | 2340 | 2600 | 2470 | 1770 | 1960 | 1865 | 156 | 173 | 164 | 118 | 131 | 125 | 443 | 492 | 466 | 337 | 372 | 353 |
| 0.060 | 2440 | 2770 | 2605 | 2165 | 2130 | 2150 | 162 | 184 | 173 | 145 | 143 | 144 | 461 | 525 | 494 | 410 | 405 | 408 |
| 0.070 | 2470 | 2920 | 2695 | 2510 | 2295 | 2400 | 165 | 195 | 180 | 168 | 154 | 161 | 470 | 555 | 512 | 475 | 435 | 455 |
| 0.080 | 2525 | 3090 | 2810 | 2640 | 2410 | 2525 | 169 | 207 | 188 | 175 | 161 | 168 | 478 | 586 | 532 | 500 | 456 | 478 |
| 0.090 | 2550 | 3190 | 2870 | 2780 | 2500 | 2640 | 170 | 213 | 192 | 186 | 168 | 177 | 483 | 605 | 545 | 526 | 474 | 500 |
| 0.100 | 2600 | 3260 | 2930 | 2960 | 2640 | 2800 | 174 | 218 | 196 | 198 | 177 | 187 | 493 | 618 | 555 | 560 | 502 | 531 |
| 0.125 | 2800 | 3530 | 3165 | 3080 | 2880 | 2980 | 187 | 236 | 212 | 206 | 192 | 199 | 530 | 670 | 600 | 584 | 546 | 565 |
| 0.150 | 2950 | 3610 | 3280 | 3220 | 3090 | 3155 | 197 | 241 | 219 | 215 | 206 | 210 | 560 | 685 | 622 | 611 | 585 | 598 |
| 0.175 | 3060 | 3790 | 3425 | 3360 | 3280 | 3320 | 204 | 253 | 229 | 224 | 220 | 222 | 580 | 720 | 650 | 635 | 622 | 629 |
| 0.200 | 3160 | 3800 | 3480 | 3480 | 3475 | 3475 | 211 | 254 | 232 | 233 | 233 | 233 | 600 | 720 | 660 | 660 | 660 | 660 |
| Ult. | 3160 | 3800 | 3480 | 3480* | 3475 | 3475 | 211 | 254 | 232 | 233 | 233 | 233 | 600 | 720 | 660 | 660 | 660 | 660 |

*Overload from 560 lbs. to about 250 lbs. Immediately backed off, but affected readings.

Table 37. Load Deflection Data for 8' vs. 24' - 3"x8" - White Fir.

| | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heel | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | |
| Defl. | #53 | #54 | Ave. | #61 | #62 | Ave. | #53 | #54 | Ave | #61 | #62 | Ave | #53 | #54 | Ave | #61 | #62 | Ave |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 605 | 440 | 522 | 402 | 712 | 557 | 25 | 18 | 22 | 16 | 29 | 22 | 72 | 52 | 62 | 48 | 84 | 66 |
| 0.010 | 1080 | 870 | 975 | 635 | 1020 | 828 | 45 | 36 | 41 | 27 | 42 | 34 | 128 | 103 | 115 | 75 | 120 | 98 |
| 0.015 | 1500 | 1260 | 1380 | 900 | 1250 | 1075 | 63 | 52 | 58 | 37 | 53 | 45 | 178 | 149 | 163 | 106 | 148 | 127 |
| 0.020 | 1935 | 1715 | 1825 | 1140 | 1700 | 1420 | 81 | 71 | 76 | 47 | 71 | 59 | 229 | 203 | 216 | 135 | 202 | 169 |
| 0.030 | 2730 | 2500 | 2615 | 1610 | 2240 | 1950 | 114 | 104 | 109 | 68 | 97 | 82 | 324 | 296 | 310 | 191 | 270 | 230 |
| 0.040 | 3270 | 3050 | 3160 | 2000 | 2740 | 2370 | 136 | 127 | 132 | 83 | 114 | 99 | 387 | 361 | 374 | 238 | 325 | 282 |
| 0.050 | 3560 | 3480 | 3520 | 2190 | 3100 | 2645 | 148 | 145 | 147 | 92 | 131 | 112 | 421 | 412 | 416 | 260 | 374 | 317 |
| 0.060 | 3950 | 3880 | 3920 | 2550 | 3320 | 2935 | 164 | 162 | 163 | 106 | 138 | 122 | 467 | 460 | 464 | 302 | 394 | 348 |
| 0.070 | 4130 | 4100 | 4115 | 2900 | 3620 | 3260 | 172 | 171 | 171 | 121 | 151 | 136 | 490 | 485 | 488 | 344 | 430 | 387 |
| 0.080 | 4380 | 4380 | 4380 | 3110 | 3900 | 3505 | 182 | 181 | 182 | 130 | 163 | 146 | 519 | 519 | 519 | 368 | 462 | 415 |
| 0.090 | 4650 | 4650 | 4650 | 3270 | 4160 | 3715 | 189 | 189 | 189 | 136 | 171 | 153 | 549 | 549 | 549 | 387 | 492 | 440 |
| 0.100 | 4840 | 4790 | 5010 | 3450 | 4260 | 3855 | 202 | 200 | 201 | 144 | 178 | 161 | 573 | 566 | 570 | 409 | 505 | 458 |
| 0.125 | 4950 | 5140 | 5040 | 3610 | 4600 | 4105 | 206 | 214 | 210 | 151 | 192 | 172 | 586 | 608 | 597 | 428 | 546 | 487 |
| 0.150 | 5060 | 5430 | 5245 | 3770 | 4800 | 4235 | 210 | 226 | 218 | 157 | 200 | 178 | 599 | 642 | 620 | 446 | 566 | 506 |
| 0.175 | 5160 | 5490 | 5325 | 3920 | 4990 | 4460 | 215 | 228 | 222 | 163 | 208 | 185 | 612 | 650 | 631 | 465 | 591 | 528 |
| 0.200 | 5260 | 5540 | 5400 | 4100 | 5190 | 4645 | 219 | 230 | 225 | 170 | 216 | 193 | 623 | 656 | 639 | 485 | 623 | 554 |
| Ult. | 5260 | 5580 | 5425 | 4100 | 5190 | 4645 | 219 | 232 | 225 | 170 | 216 | 193 | 623 | 656 | 639 | 485 | 623 | 554 |

Table 38. Load Deflection Data for 8' vs. 24' - 5"x5" - White Fir.

| Heel | Top Chord Force lbs. | | | | | | Contact Area Stress psi | | | | | | Shear Line Stress pli | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | | 8' Specimen | | | 24' Truss | | |
| Defl. | #55 | #56 | Ave. | #63 | #64 | Ave. | #55 | #56 | Ave | #63 | #64 | Ave | #55 | #56 | Ave. | #63 | #64 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 440 | 1120 | 780 | 484 | 724 | 605 | 18 | 45 | 31 | 19 | 29 | 24 | 83 | 212 | 148 | 92 | 137 | 115 |
| 0.010 | 955 | 1720 | 1340 | 730 | 1280 | 1005 | 38 | 69 | 54 | 29 | 51 | 40 | 181 | 326 | 254 | 138 | 242 | 192 |
| 0.015 | 1360 | 2140 | 1750 | 1005 | 1725 | 1365 | 55 | 86 | 70 | 40 | 70 | 55 | 258 | 405 | 332 | 192 | 328 | 259 |
| 0.020 | 1675 | 2520 | 2100 | 1280 | 2020 | 1650 | 67 | 101 | 84 | 51 | 81 | 66 | 318 | 477 | 398 | 243 | 383 | 314 |
| 0.030 | 2130 | 3040 | 2585 | 1920 | 2440 | 2180 | 85 | 122 | 103 | 77 | 97 | 87 | 403 | 576 | 488 | 364 | 463 | 414 |
| 0.040 | 2520 | 3460 | 2985 | 2180 | 2800 | 2490 | 101 | 138 | 119 | 87 | 112 | 100 | 478 | 656 | 568 | 414 | 531 | 473 |
| 0.050 | 2800 | 3785 | 3290 | 2440 | 3130 | 2790 | 112 | 151 | 131 | 97 | 126 | 112 | 531 | 718 | 625 | 463 | 594 | 530 |
| 0.060 | 3070 | 4060 | 3565 | 2650 | 3440 | 3045 | 123 | 162 | 143 | 106 | 138 | 122 | 582 | 770 | 676 | 503 | 652 | 578 |
| 0.070 | 3270 | 4200 | 3740 | 2910 | 3680 | 3300 | 131 | 168 | 149 | 117 | 147 | 132 | 620 | 796 | 710 | 552 | 700 | 625 |
| 0.080 | 3420 | 4430 | 3920 | 3140 | 3920 | 3530 | 137 | 177 | 157 | 126 | 157 | 142 | 648 | 840 | 743 | 596 | 744 | 670 |
| 0.090 | 3570 | 4650 | 4115 | 3300 | 4090 | 3695 | 143 | 186 | 165 | 132 | 164 | 148 | 677 | 881 | 790 | 626 | 775 | 700 |
| 0.100 | 3720 | 4770 | 4240 | 3500 | 4210 | 3855 | 149 | 191 | 170 | 140 | 168 | 154 | 706 | 905 | 805 | 664 | 800 | 731 |
| 0.125 | 4060 | 5100 | 4580 | 3840 | 4620 | 4230 | 162 | 204 | 183 | 154 | 185 | 169 | 770 | 966 | 868 | 728 | 877 | 804 |
| 0.150 | 4250 | 5420 | 4835 | 4160 | 4800 | 4480 | 173 | 217 | 195 | 167 | 192 | 179 | 806 | 1030 | 918 | 790 | 911 | 850 |
| 0.175 | 4520 | 5650 | 5085 | 4520 | 5000 | 4760 | 181 | 226 | 204 | 181 | 200 | 191 | 867 | 1070 | 964 | 857 | 950 | 904 |
| 0.200 | 4720 | 5880 | 5300 | 4740 | 5190 | 4965 | 189 | 236 | 212 | 190 | 208 | 199 | 894 | 1115 | 1005 | 900 | 985 | 942 |
| Ult. | 5100 | 5880 | 5490 | 4740 | 5310 | 5025 | 204 | 236 | 220 | 190 | 213 | 202 | 965 | 1115 | 1040 | 898 | 1005 | 954 |

Table 39. Load Deflection Data for 8' Small Jig - 3"x5" - Doug. Fir.

| Heel Defl. | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #78 | #79 | #80 | #81 | Ave. | #78 | #79 | #80 | #81 | Ave | #78 | #79 | #80 | #81 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 725 | 1630 | 620 | 1120 | 1024 | 48 | 109 | 41 | 75 | 68 | 137 | 310 | 118 | 212 | 194 |
| 0.010 | 1305 | 2180 | 1070 | 1730 | 1571 | 87 | 145 | 71 | 115 | 105 | 248 | 414 | 203 | 328 | 298 |
| 0.015 | 1800 | 2650 | 1420 | 2210 | 2020 | 120 | 177 | 95 | 147 | 135 | 342 | 503 | 270 | 420 | 383 |
| 0.020 | 2230 | 3075 | 1740 | 2630 | 2419 | 149 | 205 | 116 | 175 | 161 | 423 | 584 | 330 | 500 | 458 |
| 0.030 | 2950 | 3630 | 2290 | 3290 | 3040 | 197 | 242 | 153 | 219 | 203 | 560 | 690 | 435 | 625 | 578 |
| 0.040 | 3360 | 3960 | 2720 | 3760 | 3450 | 224 | 264 | 181 | 250 | 230 | 637 | 751 | 516 | 714 | 655 |
| 0.050 | 3650 | 4010 | 3120 | 4080 | 3715 | 244 | 268 | 208 | 272 | 248 | 693 | 761 | 592 | 774 | 705 |
| 0.060 | 3940 | 4065 | 3320 | 4350 | 3919 | 263 | 271 | 222 | 290 | 261 | 748 | 771 | 630 | 825 | 743 |
| 0.070 | 4000 | 4120 | 3500 | 4620 | 4060 | 266 | 274 | 234 | 308 | 271 | 760 | 781 | 664 | 876 | 770 |
| 0.080 | 4060 | 4170 | 3685 | 4670 | 4146 | 271 | 278 | 246 | 311 | 276 | 770 | 791 | 700 | 886 | 785 |
| 0.090 | 4120 | 4220 | 3870 | 4720 | 4232 | 274 | 282 | 258 | 314 | 282 | 781 | 800 | 735 | 895 | 804 |
| 0.100 | 4160 | 4270 | 4020 | 4770 | 4300 | 278 | 286 | 268 | 317 | 287 | 790 | 810 | 763 | 905 | 816 |
| 0.125 | 4290 | 4405 | 4095 | 4890 | 4420 | 286 | 294 | 273 | 326 | 295 | 814 | 836 | 775 | 929 | 840 |
| 0.150 | 4420 | 4535 | 4170 | 5015 | 4535 | 295 | 302 | 278 | 334 | 302 | 840 | 860 | 791 | 951 | 860 |
| 0.175 | 4550 | 4650 | 4255 | 5140 | 4649 | 304 | 310 | 284 | 342 | 310 | 862 | 882 | 809 | 975 | 880 |
| 0.200 | 4650 | 4960 | 4340 | 5260 | 4800 | 310 | 331 | 289 | 350 | 320 | 881 | 941 | 824 | 998 | 910 |
| Ult. | 4650 | 4960 | 4340. | 5260 | 4800 | 310 | 331 | 289 | 350 | 320 | 881 | 941 | 824 | 998 | 910 |

Table 40. Load Deflection Data for 24' Full Scale - 3"x5" - Doug. Fir.

| Heel Defl. | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #82 | #83 | #84 | #85 | Ave. | #82 | #83 | #84 | #85 | Ave | #82 | #83 | #84 | #85 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 525 | 400 | 560 | 400 | 470 | 35 | 27 | 37 | 27 | 32 | 95 | 72 | 101 | 72 | 84 |
| 0.010 | 880 | 1230 | 920 | 815 | 960 | 59 | 82 | 61 | 54 | 64 | 158 | 221 | 166 | 147 | 173 |
| 0.015 | 1235 | 1675 | 1285 | 1230 | 1360 | 83 | 112 | 86 | 83 | 90 | 222 | 301 | 231 | 220 | 244 |
| 0.020 | 1550 | 1875 | 1730 | 1530 | 1670 | 103 | 125 | 115 | 104 | 111 | 279 | 337 | 310 | 275 | 301 |
| 0.030 | 2050 | 2055 | 2240 | 2050 | 2000 | 137 | 137 | 149 | 137 | 140 | 370 | 371 | 404 | 370 | 378 |
| 0.040 | 2540 | 2235 | 2570 | 2550 | 2470 | 169 | 149 | 171 | 170 | 165 | 458 | 403 | 464 | 458 | 446 |
| 0.050 | 2900 | 2790 | 2790 | 2930 | 2855 | 194 | 186 | 186 | 196 | 190 | 521 | 502 | 502 | 528 | 512 |
| 0.060 | 3250 | 3160 | 3190 | 3170 | 3190 | 217 | 211 | 213 | 212 | 214 | 585 | 569 | 573 | 570 | 576 |
| 0.070 | 3460 | 3370 | 3630 | 3475 | 3485 | 231 | 225 | 242 | 232 | 233 | 624 | 609 | 654 | 627 | 629 |
| 0.080 | 3610 | 3470 | 3910 | 3620 | 3655 | 241 | 232 | 261 | 242 | 244 | 651 | 625 | 705 | 652 | 659 |
| 0.090 | 3760 | 3570 | 4170 | 3910 | 3855 | 251 | 238 | 277 | 261 | 258 | 678 | 642 | 752 | 704 | 695 |
| 0.100 | 3910 | 3630 | 4430 | 4190 | 4050 | 261 | 242 | 296 | 279 | 272 | 704 | 654 | 798 | 753 | 729 |
| 0.125 | 4320 | 3830 | 4690 | 4450 | 4330 | 288 | 256 | 313 | 297 | 289 | 780 | 690 | 844 | 802 | 779 |
| 0.150 | 4470 | 4030 | 4760 | 4760 | 4505 | 298 | 269 | 318 | 318 | 301 | 805 | 725 | 860 | 860 | 815 |
| 0.175 | 4750 | 4230 | 4830 | 4935 | 4685 | 316 | 282 | 322 | 329 | 313 | 860 | 762 | 870 | 890 | 845 |
| 0.200 | 5030 | 4460 | 4910 | 5190 | 4900 | 335 | 298 | 328 | 346 | 326 | 910 | 805 | 888 | 932 | 881 |
| Ult. | 5030 | 4460 | 4910 | 5190 | 4900 | 335 | 298 | 328 | 346 | 326 | 910 | 805 | 888 | 932 | 881 |

Table 41. Load Deflection Data for 8' Riehle - 3"x5" - Doug. Fir.

| Heel Defl. | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #98 | #99 | #100 | #101 | Ave. | #98 | #99 | 100 | 101 | Ave | #98 | #99 | 100 | 101 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 740 | 790 | 420 | 950 | 725 | 49 | 53 | 28 | 63 | 48 | 140 | 150 | 80 | 180 | 138 |
| 0.010 | 1190 | 1190 | 870 | 1320 | 1142 | 79 | 79 | 58 | 88 | 76 | 226 | 226 | 165 | 250 | 217 |
| 0.015 | 1510 | 1470 | 1260 | 1640 | 1470 | 101 | 98 | 84 | 109 | 98 | 286 | 279 | 239 | 311 | 279 |
| 0.020 | 1900 | 1740 | 1830 | 1940 | 1852 | 127 | 116 | 122 | 129 | 124 | 361 | 330 | 348 | 368 | 352 |
| 0.030 | 2410 | 2210 | 2000 | 2410 | 2257 | 161 | 147 | 133 | 161 | 150 | 457 | 420 | 380 | 457 | 428 |
| 0.040 | 2810 | 2600 | 2530 | 2780 | 2480 | 187 | 173 | 169 | 185 | 165 | 534 | 494 | 480 | 528 | 471 |
| 0.050 | 3160 | 2915 | 2880 | 3050 | 3001 | 210 | 194 | 192 | 204 | 200 | 600 | 554 | 546 | 580 | 570 |
| 0.060 | 3400 | 3160 | 3190 | 3240 | 3247 | 227 | 210 | 212 | 216 | 217 | 646 | 600 | 606 | 615 | 617 |
| 0.070 | 3620 | 3320 | 3380 | 3360 | 3420 | 242 | 221 | 225 | 224 | 228 | 687 | 630 | 642 | 638 | 650 |
| 0.080 | 3800 | 3480 | 3580 | 3480 | 3585 | 253 | 232 | 238 | 232 | 239 | 721 | 661 | 680 | 661 | 681 |
| 0.090 | 3950 | 3630 | 3790 | 3680 | 3762 | 263 | 242 | 252 | 245 | 251 | 750 | 689 | 720 | 698 | 715 |
| 0.100 | 4100 | 3800 | 4040 | 3870 | 3952 | 274 | 254 | 269 | 258 | 263 | 779 | 722 | 766 | 735 | 751 |
| 0.125 | 4420 | 4000 | 4300 | 4200 | 4230 | 294 | 266 | 286 | 280 | 282 | 839 | 760 | 816 | 797 | 804 |
| 0.150 | 4580 | 4150 | 4490 | 4450 | 4417 | 305 | 276 | 299 | 296 | 294 | 870 | 788 | 852 | 845 | 838 |
| 0.175 | 4680 | 4250 | 4590 | 4600 | 4530 | 312 | 283 | 306 | 307 | 302 | 888 | 806 | 871 | 874 | 860 |
| 0.200 | 4700 | 4280 | 4600 | 4680 | 4565 | 314 | 286 | 306 | 312 | 305 | 893 | 813 | 874 | 889 | 868 |
| Ult. | 4710 | 4310 | 4610 | 4680 | 4580 | 314 | 287 | 307 | 312 | 303 | 895 | 820 | 875 | 889 | 870 |

Table 42. Load Deflection Data for 8' Riehle - 3"x8" - Doug. Fir.

| Heel | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #86 | #87 | #88 | #89 | Ave. | #86 | #87 | #88 | #89 | Ave | #86 | #87 | #88 | #89 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 790 | 1060 | 870 | 1110 | 957 | 33 | 44 | 36 | 46 | 40 | 94 | 125 | 103 | 131 | 113 |
| 0.010 | 1260 | 1580 | 1340 | 1680 | 1465 | 53 | 66 | 56 | 70 | 61 | 149 | 187 | 158 | 199 | 173 |
| 0.015 | 2060 | 2210 | 1740 | 2310 | 2080 | 66 | 92 | 73 | 96 | 87 | 244 | 261 | 206 | 273 | 246 |
| 0.020 | 2740 | 2740 | 2140 | 2840 | 2615 | 115 | 115 | 89 | 118 | 109 | 324 | 324 | 253 | 337 | 309 |
| 0.030 | 3905 | 3900 | 3000 | 3720 | 3631 | 161 | 161 | 124 | 154 | 150 | 462 | 461 | 354 | 439 | 430 |
| 0.040 | 4900 | 4740 | 3860 | 4500 | 4500 | 203 | 196 | 160 | 186 | 186 | 580 | 560 | 456 | 532 | 532 |
| 0.050 | 5610 | 5450 | 4490 | 5210 | 5190 | 232 | 225 | 186 | 216 | 214 | 664 | 644 | 531 | 616 | 614 |
| 0.060 | 6320 | 6240 | 5180 | 5800 | 5885 | 263 | 260 | 216 | 242 | 245 | 747 | 737 | 613 | 686 | 696 |
| 0.070 | 6840 | 6800 | 5800 | 6270 | 6427 | 285 | 284 | 245 | 262 | 268 | 809 | 804 | 686 | 742 | 760 |
| 0.080 | 7350 | 7270 | 6320 | 6700 | 6910 | 306 | 303 | 263 | 278 | 288 | 869 | 860 | 747 | 792 | 817 |
| 0.090 | 7825 | 7600 | 6800 | 7040 | 7316 | 326 | 316 | 283 | 292 | 304 | 925 | 900 | 804 | 831 | 865 |
| 0.100 | 8232 | 7900 | 7160 | 7330 | 7655 | 342 | 329 | 298 | 306 | 320 | 974 | 935 | 847 | 866 | 906 |
| 0.125 | 8850 | 8390 | 7900 | 7920 | 8265 | 370 | 350 | 330 | 331 | 345 | 1045 | 990 | 935 | 936 | 975 |
| 0.150 | 9260 | 8700 | 8390 | 8270 | 8655 | 386 | 363 | 350 | 345 | 362 | 1095 | 1028 | 990 | 978 | 1023 |
| 0.175 | 9480 | 8930 | 8700 | 8370 | 8870 | 392 | 369 | 360 | 346 | 367 | 1120 | 1055 | 1029 | 989 | 1050 |
| 0.200 | 9640 | 8940 | 9010 | 8470 | 9015 | 401 | 372 | 376 | 353 | 376 | 1140 | 1058 | 1067 | 1000 | 1065 |
| Ult. | 9640 | 8960 | 9200 | 8470 | 9067 | 401 | 373 | 384 | 353 | 378 | 1140 | 1060 | 1089 | 1000 | 1072 |

Table 43. Load Deflection Data for 8' Riehle - 5"x5" - Doug. Fir.

| Heel | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #90 | #91 | #92 | #93 | Ave. | #90 | #91 | #92 | #93 | Ave | #90 | #91 | #92 | #93 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 950 | 840 | 1740 | 1110 | 1160 | 38 | 34 | 70 | 44 | 46 | 180 | 160 | 330 | 210 | 220 |
| 0.010 | 1420 | 1580 | 2530 | 1740 | 1817 | 57 | 63 | 101 | 70 | 73 | 270 | 300 | 480 | 330 | 345 |
| 0.015 | 1900 | 2110 | 2840 | 2320 | 2292 | 76 | 84 | 114 | 93 | 92 | 360 | 400 | 540 | 440 | 435 |
| 0.020 | 2290 | 2610 | 3260 | 2770 | 2732 | 92 | 105 | 130 | 111 | 109 | 435 | 495 | 620 | 525 | 520 |
| 0.030 | 2980 | 3470 | 4010 | 3540 | 3500 | 119 | 139 | 161 | 142 | 140 | 565 | 660 | 765 | 670 | 665 |
| 0.040 | 3580 | 4060 | 4460 | 4160 | 4065 | 143 | 162 | 178 | 166 | 162 | 680 | 770 | 850 | 790 | 770 |
| 0.050 | 4080 | 4460 | 4760 | 4530 | 4457 | 163 | 178 | 190 | 181 | 178 | 775 | 850 | 905 | 860 | 845 |
| 0.060 | 4460 | 4830 | 5000 | 4855 | 4786 | 179 | 193 | 200 | 194 | 191 | 850 | 915 | 950 | 925 | 910 |
| 0.070 | 4740 | 5110 | 5170 | 5120 | 5035 | 190 | 204 | 207 | 205 | 201 | 900 | 970 | 980 | 970 | 960 |
| 0.080 | 4980 | 5350 | 5340 | 5330 | 5250 | 199 | 216 | 216 | 215 | 211 | 945 | 1010 | 1010 | 1040 | 1025 |
| 0.090 | 5200 | 5520 | 5420 | 5470 | 5402 | 208 | 221 | 217 | 219 | 216 | 990 | 1050 | 1030 | 1035 | 1025 |
| 0.100 | 5380 | 5690 | 5500 | 5590 | 5540 | 215 | 228 | 220 | 224 | 222 | 1020 | 1080 | 1045 | 1060 | 1050 |
| 0.125 | 5670 | 5885 | 5590 | 5850 | 5749 | 227 | 235 | 224 | 234 | 230 | 1075 | 1115 | 1060 | 1110 | 1090 |
| 0.150 | 5750 | 6080 | 5680 | 6000 | 5877 | 230 | 244 | 228 | 240 | 235 | 1090 | 1150 | 1080 | 1140 | 1115 |
| 0.175 | 5810 | 6110 | 5770 | 6015 | 5926 | 232 | 245 | 231 | 241 | 237 | 1110 | 1165 | 1090 | 1145 | 1125 |
| 0.200 | 5920 | 6140 | 5770 | 6030 | 5965 | 237 | 246 | 231 | 242 | 239 | 1125 | 1170 | 1095 | 1150 | 1130 |
| Ult. | 5980 | 6140 | 5770 | 6030 | 5980 | 239 | 245 | 231 | 241 | 239 | 1135 | 1170 | 1095 | 1150 | 1135 |

Table 44. Load Deflection Data for 8' Riehle - 3"x5" - White Fir.

| Heel | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #102 | #103 | #104 | #105 | Ave. | 102 | 103 | 104 | 105 | Ave | 102 | 103 | 104 | 105 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 780 | 520 | 680 | 570 | 637 | 52 | 35 | 45 | 38 | 42 | 148 | 99 | 129 | 108 | 121 |
| 0.010 | 1140 | 830 | 950 | 820 | 935 | 76 | 55 | 63 | 55 | 62 | 216 | 157 | 180 | 156 | 178 |
| 0.015 | 1390 | 1085 | 1150 | 1030 | 1164 | 93 | 72 | 76 | 68 | 77 | 264 | 206 | 218 | 196 | 221 |
| 0.020 | 1580 | 1300 | 1330 | 1220 | 1357 | 105 | 86 | 88 | 81 | 90 | 300 | 247 | 252 | 232 | 258 |
| 0.030 | 1990 | 1680 | 1770 | 1550 | 1730 | 132 | 111 | 113 | 103 | 115 | 378 | 319 | 323 | 294 | 328 |
| 0.040 | 2260 | 2010 | 2020 | 1820 | 2022 | 150 | 133 | 134 | 121 | 134 | 430 | 382 | 384 | 346 | 384 |
| 0.050 | 2480 | 2270 | 2290 | 2050 | 2247 | 164 | 151 | 152 | 136 | 150 | 470 | 430 | 436 | 388 | 426 |
| 0.060 | 2620 | 2470 | 2530 | 2250 | 2467 | 174 | 164 | 168 | 150 | 164 | 498 | 469 | 480 | 427 | 468 |
| 0.070 | 2740 | 2560 | 2720 | 2440 | 2615 | 183 | 170 | 181 | 162 | 174 | 521 | 486 | 516 | 464 | 496 |
| 0.080 | 2840 | 2660 | 2930 | 2590 | 2755 | 189 | 177 | 195 | 173 | 184 | 540 | 505 | 556 | 492 | 523 |
| 0.090 | 2950 | 2840 | 3000 | 2640 | 2857 | 197 | 189 | 200 | 176 | 191 | 560 | 540 | 570 | 502 | 542 |
| 0.100 | 3020 | 3040 | 3060 | 2680 | 2950 | 202 | 203 | 204 | 179 | 197 | 574 | 577 | 581 | 509 | 560 |
| 0.125 | 3160 | 3190 | 3300 | 3160 | 3202 | 210 | 212 | 220 | 210 | 214 | 600 | 605 | 626 | 600 | 610 |
| 0.150 | 3160* | 3310 | 3300* | 3340 | 3277 | 210 | 221 | 220 | 223 | 218 | 600 | 628 | 626 | 634 | 621 |
| 0.175 | 3160* | 3310* | 3300* | 3420 | 3297 | 210 | 221 | 220 | 223 | 219 | 600 | 628 | 626 | 649 | 626 |
| 0.200 | 3160* | 3310* | 3300* | 3420* | 3297 | 210 | 221 | 220 | 223 | 219 | 600 | 628 | 626 | 649 | 626 |
| Ult. | 3160 | 3310 | 3300 | 3420 | 3297 | 212 | 221 | 220 | 228 | 220 | 600 | 628 | 626 | 649 | 626 |

*Plate did not deflect this far. Estimated readings.

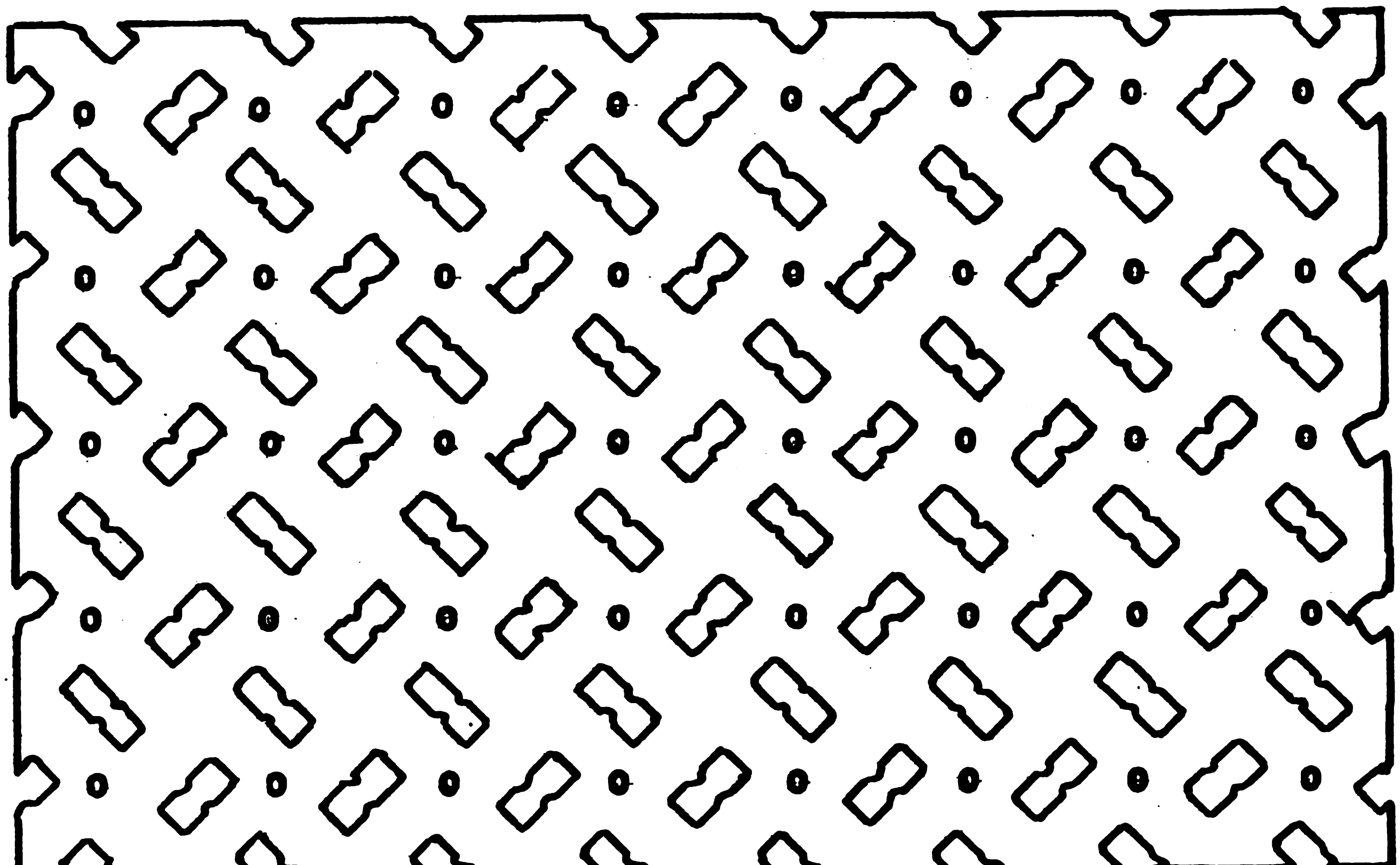
Table 45. Load Deflection Data for 8' Riehle - 3"x8" - White Fir.

| Heel | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Defl. | #94 | #95 | #96 | #97 | Ave. | #94 | #95 | #96 | #97 | Ave | #94 | #95 | #96 | #97 | Ave |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 842 | 1028 | 948 | 790 | 902 | 35 | 43 | 40 | 33 | 38 | 100 | 122 | 102 | 93 | 106 |
| 0.010 | 1344 | 1430 | 1474 | 1140 | 1347 | 43 | 60 | 61 | 48 | 56 | 159 | 169 | 174 | 135 | 159 |
| 0.015 | 1740 | 1706 | 2000 | 1450 | 1724 | 72 | 71 | 83 | 60 | 72 | 206 | 202 | 236 | 172 | 204 |
| 0.020 | 2086 | 2012 | 2452 | 1740 | 2072 | 87 | 84 | 102 | 72 | 86 | 247 | 238 | 290 | 206 | 245 |
| 0.030 | 2581 | 2573 | 3220 | 2320 | 2673 | 108 | 107 | 134 | 97 | 111 | 306 | 304 | 381 | 274 | 316 |
| 0.040 | 2844 | 3004 | 3918 | 2840 | 3151 | 118 | 125 | 163 | 118 | 131 | 336 | 360 | 463 | 336 | 373 |
| 0.050 | 3430 | 3400 | 4487 | 3280 | 3649 | 143 | 142 | 187 | 136 | 152 | 406 | 402 | 531 | 388 | 432 |
| 0.060 | 3850 | 3736 | 4980 | 3630 | 4049 | 160 | 155 | 208 | 151 | 168 | 455 | 442 | 590 | 429 | 478 |
| 0.070 | 4213 | 3952 | 5372 | 4000 | 4384 | 176 | 164 | 224 | 167 | 183 | 498 | 467 | 636 | 463 | 519 |
| 0.080 | 4550 | 4140 | 5658 | 4310 | 4664 | 189 | 172 | 236 | 180 | 195 | 538 | 490 | 670 | 510 | 553 |
| 0.090 | 4864 | 4424 | 5920 | 4590 | 4949 | 202 | 184 | 246 | 191 | 206 | 576 | 523 | 700 | 543 | 585 |
| 0.100 | 5124 | 4664 | 6180 | 4840 | 5202 | 214 | 194 | 258 | 202 | 217 | 606 | 553 | 731 | 572 | 616 |
| 0.125 | 5538 | 5167 | 6250* | 5370 | 5581 | 222 | 215 | 260 | 224 | 232 | 655 | 612 | 740 | 635 | 660 |
| 0.150 | 5690 | 5540 | 6325* | 5430 | 5746 | 237 | 231 | 264 | 226 | 240 | 673 | 655 | 749 | 643 | 680 |
| 0.175 | 5730 | 5930 | 6400* | 5490 | 5887 | 239 | 247 | 266 | 229 | 245 | 679 | 702 | 757 | 650 | 696 |
| 0.200 | 5760 | 6160 | 6490* | 5540 | 5987 | 240 | 257 | 270 | 231 | 250 | 682 | 730 | 768 | 655 | 709 |
| Ult. | 5768 | 6500 | 6490 | 5540 | 6075 | 240 | 271 | 270 | 230 | 253 | 684 | 770 | 768 | 655 | 719 |

*Top chord of #96 buckled. These are estimated.

Table 46. Load Deflection Data for 8' Riehle - 5"x5" - White Fir.

| Heel Defl. | Top Chord Force lbs. | | | | | Contact Area Stress psi | | | | | Shear Line Stress pli | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | #106 | #107 | #108 | #109 | Ave. | 106 | 107 | 108 | 109 | Ave | #106 | #107 | #108 | #109 | Ave. |
| 0.000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.005 | 840 | 710 | 740 | 950 | 810 | 34 | 28 | 30 | 38 | 32 | 159 | 135 | 140 | 180 | 154 |
| 0.010 | 1340 | 1110 | 1190 | 1340 | 1245 | 54 | 44 | 47 | 54 | 50 | 254 | 211 | 226 | 254 | 236 |
| 0.015 | 1740 | 1420 | 1640 | 1710 | 1627 | 70 | 57 | 65 | 68 | 65 | 330 | 270 | 312 | 324 | 309 |
| 0.020 | 2090 | 1740 | 1950 | 2030 | 1952 | 83 | 69 | 78 | 81 | 78 | 396 | 330 | 370 | 386 | 371 |
| 0.030 | 2690 | 2310 | 2590 | 2650 | 2560 | 107 | 92 | 103 | 106 | 106 | 511 | 439 | 492 | 503 | 486 |
| 0.040 | 3210 | 2760 | 3115 | 3160 | 3061 | 128 | 110 | 125 | 126 | 122 | 610 | 525 | 591 | 600 | 581 |
| 0.050 | 3630 | 3125 | 3510 | 3630 | 3474 | 145 | 125 | 140 | 145 | 140 | 690 | 594 | 666 | 690 | 660 |
| 0.060 | 4025 | 3480 | 3820 | 4000 | 3841 | 161 | 139 | 153 | 160 | 154 | 765 | 661 | 725 | 760 | 730 |
| 0.070 | 4420 | 3950 | 4190 | 4240 | 4200 | 177 | 158 | 168 | 169 | 168 | 840 | 750 | 795 | 805 | 797 |
| 0.080 | 4740 | 4320 | 4550 | 4420 | 4507 | 189 | 173 | 182 | 177 | 181 | 900 | 820 | 865 | 840 | 856 |
| 0.090 | 4980 | 4580 | 4830 | 4740 | 4782 | 199 | 183 | 193 | 190 | 191 | 946 | 870 | 917 | 900 | 910 |
| 0.100 | 5130 | 4840 | 5050 | 5060 | 5020 | 205 | 194 | 202 | 202 | 201 | 975 | 920 | 960 | 962 | 955 |
| 0.125 | 5330 | 5220 | 5440 | 5530 | 5380 | 213 | 209 | 217 | 221 | 215 | 1012 | 991 | 1031 | 1050 | 1021 |
| 0.150 | 5570 | 5420 | 5600 | 5920 | 5627 | 223 | 217 | 224 | 237 | 225 | 1058 | 1027 | 1062 | 1123 | 1069 |
| 0.175 | 5730 | 5520 | 5830 | 6160 | 5810 | 227 | 218 | 229 | 244 | 230 | 1087 | 1049 | 1108 | 1170 | 1103 |
| 0.200 | 5750 | 5610 | 5830 | 6400 | 5897 | 226 | 221 | 229 | 252 | 231 | 1091 | 1066 | 1108 | 1215 | 1118 |
| Ult. | 5750 | 5610 | 5850 | 6550 | 5940 | 230 | 225 | 234 | 262 | 243 | 1091 | 1066 | 1112 | 1243 | 1128 |



Two teeth per hole and teeth point in four opposing directions. No positioning nails were used in this project.

Figure 60. Full-Scale Tooth Layout for 3"x5", 3"x8", and 5"x5" Plates.

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