A STUDY OF THE GENERAL TYPES OF TIMBER JOINT CONSTRUCTION, TIMBER SPLICES AND BUILT-UP MEMBERS USED IN ROOF TRUSSES

Thesis for the Degree of B. S.

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A Study of the General Types of Timber Joint Construction, Timber Splices and Built-up Members Used in Roof Trusses

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INTRODUCTION

Wherever a roof covering is used, a means of supporting this covering must be provided. This support is commonly obtained by use of a simple truss.

A truss is in the form of a triangle or triangles, or in a shape which can be resolved into triangles. The members are usually arranged in such a way that they are in direct tension or compression. The compression members in the smaller tresses are usually of wood, while the tension members in any truss are usually of steel. When stresses are so great that large cross-sections are necessary in timber construction, the members are usually made of steel regardless of the size of the truss.

In constructing large timber trusses it is necessary to splice some of the members. At times it is also better to use a built-up section. These splices and built-up sections must be capable of developing strengths high enough to withstand the loads applied. Therefore, a splice or a built-up section of high efficiency is desirable; otherwise a larger built-up section will be needed than if the member was solid.

It is the purpose of this study to determine the types of joints, splices, and built-up sections most suitable for construction of timber roof trusses as found from the tests and research of such men as Hool, Kinne, Dewell, and others.

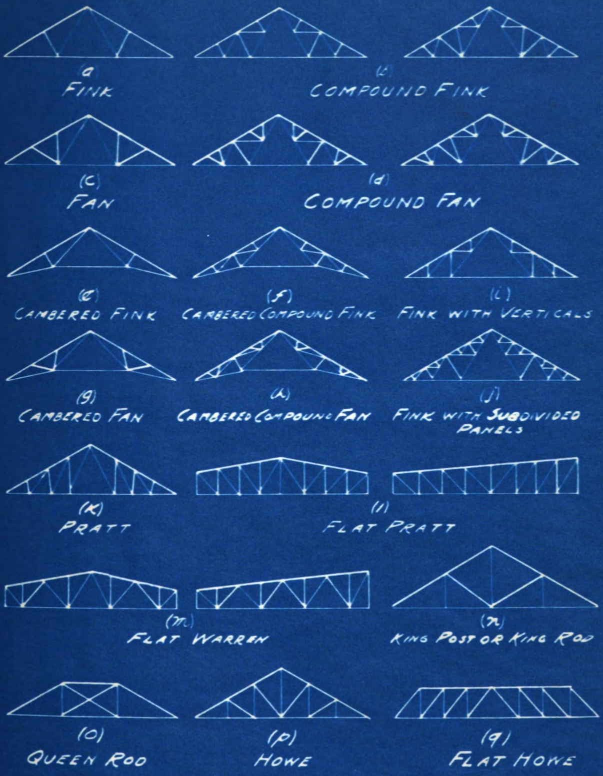
TYPICAL TRUSS JOINTS

W. S. Kinne[1] states that a simple truss is one in which the supporting forces are such that the reactions are vertical under vertical loading, or the reactions due to inclined loading can be determined by a simple statics. The discussion of this study is confined to simple trusses.

There are a great many types of trusses used in building construction, the form depending upon the character of the roof covering and the architectural features of the structure. Figure 1 shows some of the forms of simple trusses in common use for trusses supported on rigid walls.

All of the forms shown in Figure 1 are not adapted to the use of timber. Those of (n) to (q) are best suited for construction in wood, while those of (a) to (m) are best suited for construction in steel. These latter trusses are so arranged that the compression members are the shortest members, while the tension members are the longest members. The dark lines designate compression members, while the light lines designate tension members. Compression members, where possible, are usually made of wood, tension members are made of steel.

The form of truss is determined somewhat by the span length. Suitable spans for the different forms are about as follows: Figure 1, (a) and (e), thirty feet; (c) and (g), forty feet; (b) and (f), fifty to sixty feet; (d) and (h), seventy to eighty feet; and (j), eighty to ninety feet.



SIMPLE TRUSSES

FIG. 1.

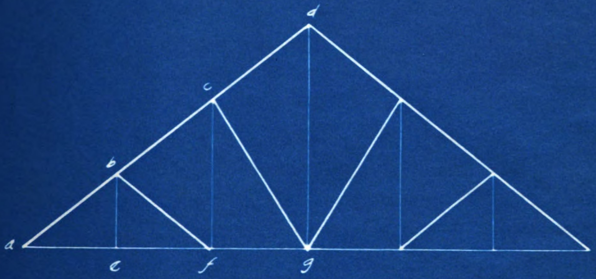
By varying the number of panels, (k), (l), and (m) can be used for spans of from twenty to eighty feet. Wooden trusses such as (n) and (o) can be used for spans of from twenty-five to thirty feet, while (p) and (q) can be used for spans of from twenty to eighty feet by varying the number of panels.

There are a few general ideas and principles which it is well to follow in the designing of joint details. Center lines of members should be made to intersect in a common point. If this can not be done, the additional stresses in the members due to the eccentric connections must be calculated and proper provision made for them.

H. S. Jacoby[2] states that the details at the joints to be designed include the washers, and the depths of notches or indents to resist the longitudinal components of the stresses in the struts, with respect to the chords. Bearing must also be investigated to determine whether a bearing block is necessary. Kinne, in Hool and Johnson "Handbook of Building Construction",[3] adds that in designing the joint details, the stresses transmitted from one member to another must be carefully determined and the bearing areas between the members proportioned to provide for the stresses to be carried. Simple details are desirable, with the joints made up of as few parts as possible. Wherever possible avoid indirect connections and those connections in which the distribution of the stress to the

several parts is indeterminate. Where the stresses are small, one member can be notched into another to form the joint details. Where very large stresses are to be transmitted from one member to another, metal bearing plates or castings, side plates, or bolted connections are necessary.

The most common wooden roof truss is the Howe. It is for this type of truss that the different joint construction and splices are shown. The form of the Howe truss is illustrated in Figure 2.



HOWE TRUSS

NOTE: THE LETTERS DESIGNATE THE JOINTS DESCRIBED.

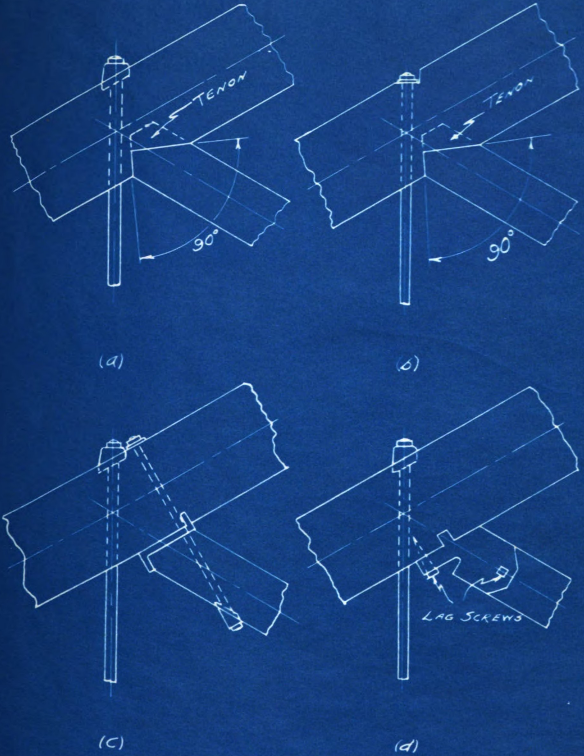
FIG. 2.

Joint b. -

In Figure 3 are shown four types of joints suitable for joint b. The stress transmitted by the member b-f (Figure 2) is comparatively small and a notched joint such as (a) or (b) of Figure 3 may be used. This notch is made with the faces at ninety degrees so that the resultant pressures on the faces will intersect on the center line of the member. A tenon is used in (a) to prevent b-f from slipping out of place due to shrinkage. (b) uses a plate washer to allow the purlin to maintain a greater bearing area and to be placed directly over the joint. In Figure 3, (c) and (d) illustrate the use of a steel plate and a cast-iron angle block, respectively.

Joint c. -

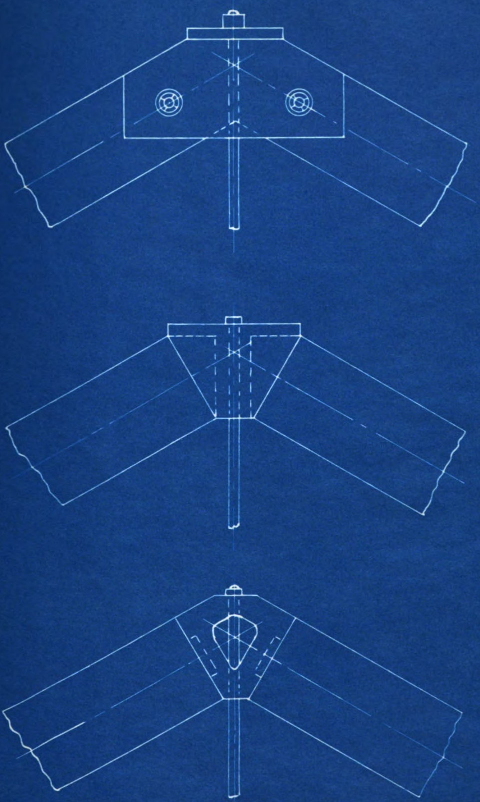
Any of the forms used for joint b may be used for joint c, also. Due to the angle at which member c-g (Figure 2) and the top chord intersect, a solid clock is more suitable than the block used in (d), Figure 3.



JOINT b
FIG. 3.

Joint d. -

In Figure 4 are shown the three types of joints that are suitable for joint d. This is a butt joint in which provision must be made for the proper area between abutting surfaces and bearing under the washer on the vertical member d-g. Figure 2) Rigid fastenings must be used in order to hold the members in line.



JOINT d

FIG. 4

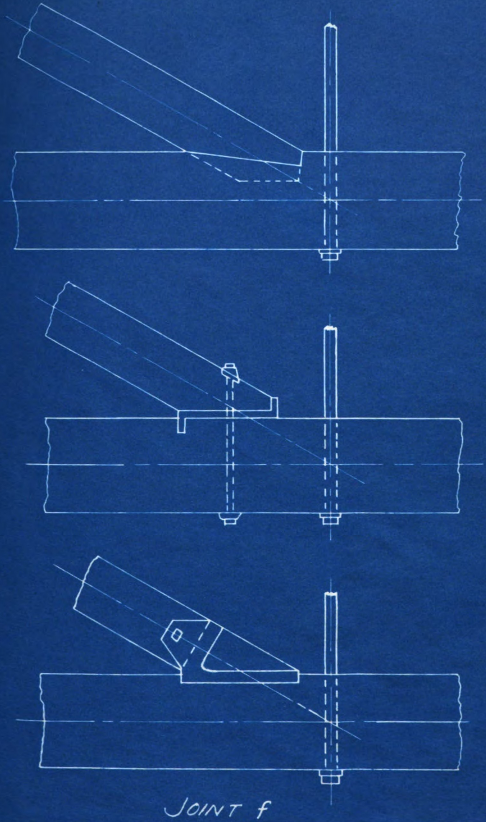
Joint f. -

Details for joint f can be arranged as those for joint b. Figure 5 shows a design for notching, for a bent strap, and for a cast-iron shoe.

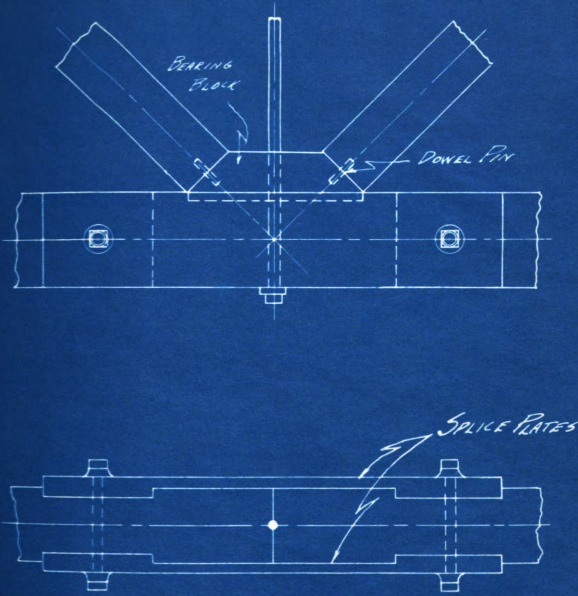
Joint g. -

The details for joint g are shown in Figure 6. The wooden block set into the top of the chord member gives sufficient bearing area for the diagonal members. Since the wind stress in one of the diagonals is zero, the bearing block must be notched into the top of the chord member in order to keep the diagonals in place.

The bottom chord member is usually spliced at this point as shown in the figure. The detail of this splice and others will be covered under the topic of TIMBER SPLICES.



JOINT f
FIG. 5.



JOINT 9

FIG. 6.

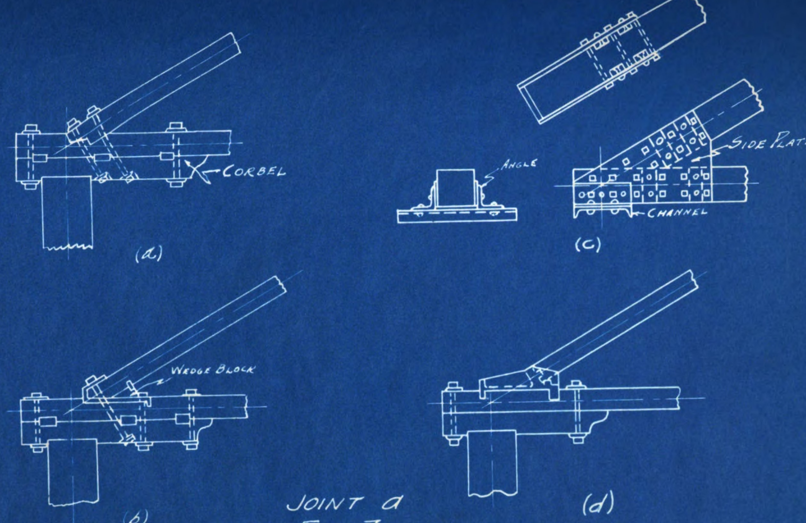
Joint a. -

In Figure 7 are shown four types of joints suitable for joint a. This joint takes stresses which are greater than at any other point in the truss. The design, therefore, requires careful consideration. It is necessary in the design of this joint as well as in the design of the other joints to maintain the required bearing area so that the stress may be transferred from one member to another.

In (a) and (b), Figure 7, a corbel is used so that the bottom chord member will not be excessively cut and the net area reduced to the danger point. An oversized chord member would be necessary if the corbel was omitted. Keys are inserted between the lower chord member and the corbel to prevent any movements of the parts due to the probable bolt stresses being inclined to the axis of the corbel.

A form of joint such as (c) is useful for trusses in which the distance from the intersection point of the center lines of members and the end of the truss is limited, as, for example, in structures in which the walls are built up above the lower chord of the truss. In this design the stresses in the top and bottom chord members are transferred to steel side plates by means of lugs riveted to the plates. The load is transferred from the side plates to the wall by means of a shoe composed of angles riveted to a short piece of rolled channel.

In (d), Figure 7, is illustrated a design for joint a in which a cast shoe is used. The horizontal component of the top chord stress is transferred to the bottom chord member by means of lugs set into the lower chord. The vertical component of the top chord stress is transferred to the bottom chord member in bearing on its upper fibers. It is usually assumed in the design of a shoe of the form shown to assume that the bearing on the surface between the lugs is uniformly distributed over the area of contact between the shoe and the chord member. This assumption holds true only when the vertical component of the top chord stress is applied at the center of the bearing area on the chord member.



JOINT a
FIG. 7.

From the study of the joint details, it is seen that the parts are as few as possible and assembled as simply as possible. This is desirable in order to eliminate the additional stresses in the members due to eccentric connections that are formed in more complicated designs.

The stresses at the joints are transferred from one member to another at an angle. The joint details must be such, therefore, to resist both horizontal and vertical forces. The horizontal forces are resisted by notches or lugs, while the vertical forces are resisted by bearing areas of the members themselves or by bearing plates.

It has not been the object of this study to determine the size of notches and bearing areas necessary to resist given loads. The object of the study is to determine the method of joining the chord members and the manner of resisting the applied loads.

TIMBER SPLICES

Dewell[3] states that "the tension splice in timber building construction occurs usually in the lower chord of a roof truss. This detail is probably the most troublesome to design and frame efficiently of all timber joints. A detail that is efficient on paper is often very unsatisfactory when viewed in the field. Any detail that depends for its action on the simultaneous bearing of more than two contact faces is to be avoided if possible, although it is often impracticable to so limit the design. Again, that detail which is so designed that the bearing faces of splicing members and the bearing faces of the spliced or main timbers may be pulled together in the field after the joint is framed, has a very decided advantage over any other type of tension splice. The ideal splice, just described, will be found to give a low efficiency when measured in terms of effective area of main timbers for resisting tension. However, in many cases, such inefficiency may be allowed, in order to secure certain definite action of the splice joint. Importance of the connection, cost of materials, quality of workmanship to be anticipated, possibility of only occasional or no inspection after completion are all factors that should be carefully considered before deciding upon the particular type of tension splice to be adopted."

Some of the common types of tension splices are as follows:

1. Bolted wooden fish plate
2. Modified wooden fish plate
3. Bolted steel fish plate
4. Tabled fish plate.
5. Steel tabled fish plate
6. Tenon bar splice
7. Shear pin splice

These different types are illustrated in Figure 8.

Bolted wooden fish plate: In this joint the main timbers are spliced end to end by means of two fish plates and connecting bolts. The stress is transmitted from each main timber to the fish plates through the bolts acting as beams.

Jacoby and Davis[2] state that the stress is first carried by the continuos fibers past the bolts, and then transferred to the fibers directly behind the bolts, through their lateral cohesion or the shearing strength parallel to the fibers. The pressure on the ends of these fibers constitutes the load on the bolt beam, whereas the reactions consist of the corresponding pressures of the fish plates.

Theoretically, the best arrangement would be to use square bolts with their sides respectively parallel and perpendicular to the fibers of the wood, since the flexural

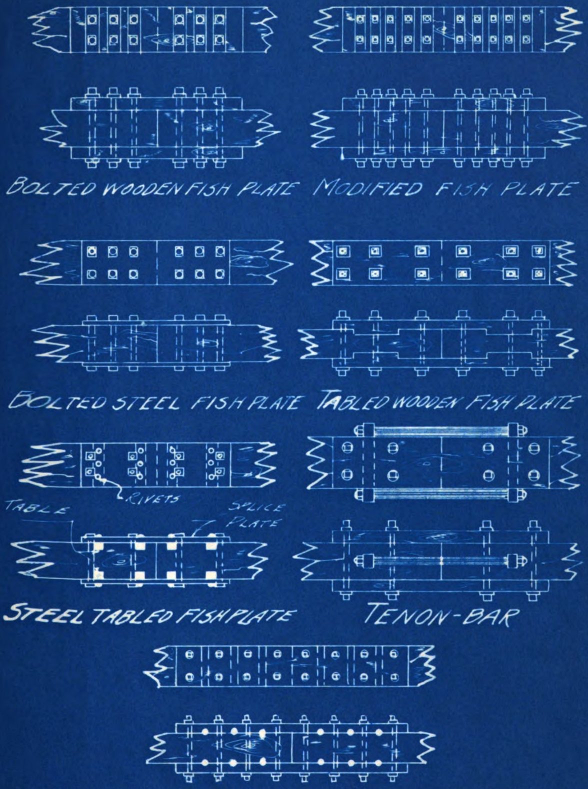


FIG. 8. TIMBER SPLICES

strength of a square bolt is sixty seven percent larger than that of a round bolt of the same diameter, whereas the corresponding effective bearing areas of the wood may differ by from about twenty five percent to over sixty percent. The increase in cost due to difficulties in construction has prevented the adoption of square bolts.

In the design of the fish plate joint the following facts must be kept in mind: First, the reduction in the effective bearing area of the wood against the bolt on account of the cylindrical surface of the bolt. Second, the wood tends to shear in two surfaces not tangent to the bolt, but closer together due to the unequal pressure around the surface of the bolt. Third, the transverse components of the pressure on the bolts tends to split the timber at or near the axial plane of the bolts. Fourth, on account of the low shearing strength of the wood parallel to the grain, the bolts are placed directly opposite when more than one row is used with wooden fish plates. Fifth, the maximum bending moment equals the stress in the fish plate multiplied by the distance from the center of the fish plate to the quarter point of the main girder.

Modified wooden fish plate: This splice is very similar to the previous one. A fairly small size of bolt, say one inch, is assumed and the spacing for such a bolt is determined. This design requires more bolts than the plain wooden fish plate.

Bolted steel fish plate: In this type of splice the bending in the bolts is reduced from that in the first type due to the smaller lever arm. The section of steel plate must be sufficient for tension, and for bearing on the bolts. The rest of the design is similar to that of the bolted fish plate splice.

Tabled fish plate: The points to be investigated in this design are: First, net section of main timber and splice pad; second, bearing between splice pad and main timber; third, length of table of fish plate for shear; fourth, tension in bolts; and fifth, possibility of bending on splice pads if bolts become loose because of shrinkage of timbers.

Steel tabled fish plate: The points to be investigated are: First, necessary net area of the plate to resist tension; second, required thickness of tables to keep the bearing of tables against the ends of the fibers of the timber within the safe working stresses; third, number of rivets between tables and fish plates; fourth, distance between table, limited by longitudinal shear in the timber; and, fifth, bolts required to hold the tables in the notches in the timber.

Tenon bar splice: The tenon bar splice is one of the oldest types of splice design used. It is not seen so often today, however. This is probably the cheapest and most efficient tension splice made. The points to be computed are: First, size of rod for tension; second, width of bar for proper bearing against the timber, and also for the hole for the rod passing through the ends; third, depth of bar for bending; fourth, distance of bar from end of timber to provide sufficient bearing area; and, fifth, net section of timber.

Shear pin splice: In making a shear pin splice two pads are spiked to the sides of the timber to be spliced. Holes are bored and then bolts are driven into those holes and nuts screwed up. Holes for the circular pins are then bored and the pins driven. This type of splice is easily made and is inexpensive, but it is suitable only with well seasoned timber, since any shrinkage will allow slipping. In designing this type of joint the following must be considered: tension in the main timber and splice pads, bearing by the pins on the timber and splice pads, shearing and distortion of the pins, and tension in the bolts.

Comparison of Tension Splices:

1. Bolted wooden fish plate: Effective, but cumbersome. Large bolts make it unsuited for high stresses.

2. Modified wooden fish plate: Effective for small stresses and where inspection sees that bolts are driven into close fitting holes.

3. Bolted steel fish plate: Neat appearing for exposed work. Economical for moderate stresses.

4. Tabled fish plate: Effective where there is only one table in each splice pad either side of joint. Possibility that all contact faces will not act at the same time.

5. Steel tabled fish plate: Same as 4.

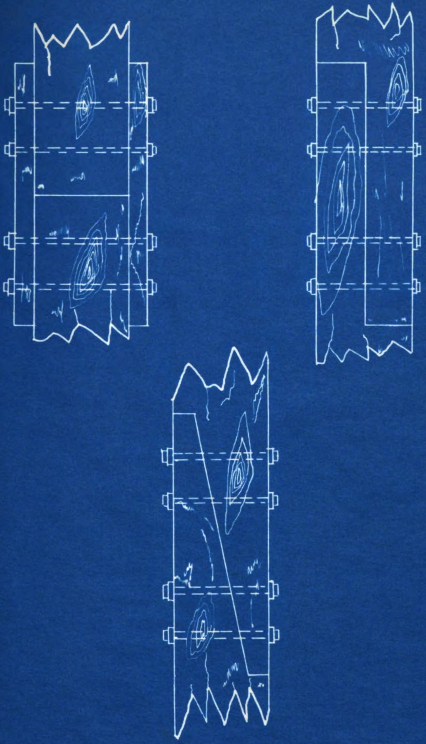
6. Tenon bar splice: When it can be used it is to be recommended. Action is direct; shrinkage of timber ineffective; there being but one bearing surface, the splice will act as designed; two sections drawn tightly together in the field; fool proof.

7. Shear pin splice: Effective, simple. Has disadvantage of shrinkage, allowing pins to loosen.

Compression splices are divided into two divisions: Those joints which take only uniform compression at all times and those joints which, while compression is the principal stress, may be called upon at some time to take either flexure, or tension, or a combination of both.

Three common joints are shown in Figure 9: (a) the butt joint, (b) the half lap, and (c) the oblique scarf.

The butt joint has one surface in contact, and is therefore superior for uniform compression. The half lap is good for moderate stress, both in compression and in flexure. The oblique scarf is strong in flexure, but weak in compression.



COMPRESSION SPLICE

FIG. 9.

BUILT-UP MEMBERS

Built-up members are very often used in timber roof truss design. The most common use is as a lower chord member. Other uses are made of built-up members as beams. The writer has personally worked on a construction in which four 2 x 8 inch planks were spiked and bolted together to form a ridge member. The member was placed so that the width of plank was vertical.

Built-up wooden girders may be divided into the following types:

1. Girders constructed of planking set side by side, width of plank vertical.

2. Girders constructed of two or more planks set on top of one another, but not fastened together.

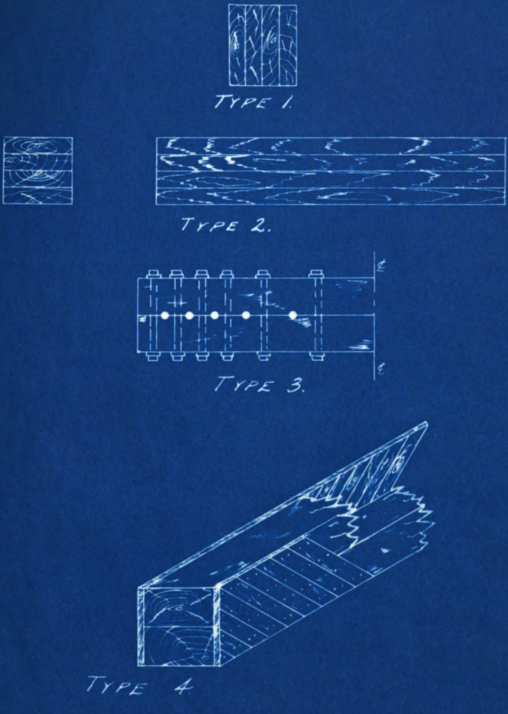
3. Girders constructed of two or more timbers set on top of one another, and effectively fastened together by means of hard wood or metal keys or pins combined with bolting.

4. Girders constructed of two or more timbers set on top of one another, and diagonally sheather with boards or planking.

All four types of built-up girders are illustrated in Figure 10.

Characteristics of each type:

1. A girder of this type, if all planking extends full length of the girder, is of full nominal thickness, and is



BUILT-UP GIRDERS

FIG. 10.

well spiked and bolted together. It is generally given credit for being somewhat stronger than a solid beam of the same size. This is doubtful, however, as insufficient spiking, lack of proper bolting, probability of planking under-running in thickness, thus giving an actual size of finished beam less than the solid section, possibility of some planks being spliced, and the probability of the upper surface of the girder being uneven--i.e., one plank projecting higher than another, giving uneven bearing for joists--are practical reasons for advocating a solid beam.

2. Never use. The strength of the combined section is no more than the sum of the strengths of the component sticks each acting as a separate beam. Even nails are unable to keep the sticks from slipping.

3. The tendency of one timber to slip over another is resisted by wedges, keys, or pins driven into contact faces. The resistance is by bearing against the ends of the fibers of the timbers, and by pressure across the fibers of the timbers. The action of the keys is such as to tend to put tension in the bolts. This tension is governed by the shape of the key. A square key causes more tension than a rectangular one, and a circular key causes the most tension in the bolts. The number and size of the keys is to be determined by the consideration of horizontal shear. Size of bolts are assumed and designed to take only tension. Kidwell's

series of tests on girders shows efficiency of seventy five percent with white oak keys and eighty percent with iron keys.

4. In this type, as in the previous type, the object of all connection is to eliminate relative motion between the members. If this condition of no-slip is obtained, the built-up beam acts more nearly as a solid member. Tests made by Edgar Kidwell (see Trans. Am. Soc. Mining Engineers, 1897, vol. 27) showed an efficiency of approximately seventy percent based on the ultimate strength as compared to a beam of solid section, while the efficiency factor based on deflection was about fifty percent. Sheathing should be at forty-five degrees with the length of girder, and not less than one and one-fourth inch and not over two inches thick. Because the sheathing is subject to bending moments, the nails take unequal loading. Any slip of the nails allows a corresponding slip of the plane of contact of the two main girders.

The end connection of girders is very important as the girders of a building, along with the posts, usually form the stiffening frame of the building against lateral forces.

Wooden girders are computed as simple beams even when continuous over two spans.

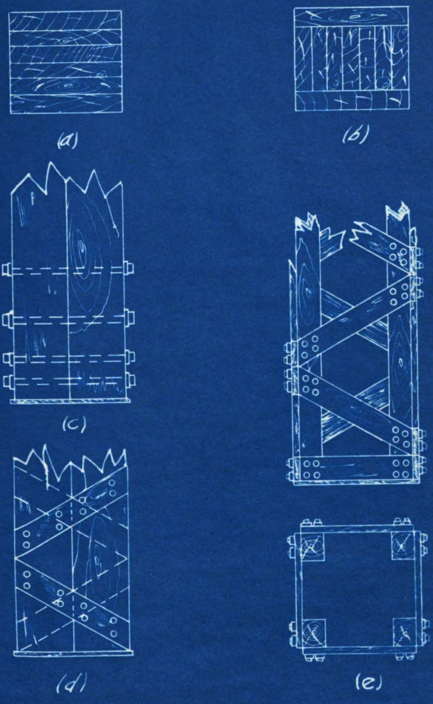
In large, heavy buildings the roof truss is very often supported by columns. These columns are usually steel or reinforced concrete. However, a situation might arise in which a wooden, built-up column would be used.

Built-up columns may be divided into two types: 1. Those of solid section made up of thin planking and nailed, or nailed and bolted; 2. Columns of solid section bolted and keyed together, also latticed and trussed columns.

These columns are illustrated in Figure 11.

Characteristics of Built-up Columns:

1. Generally not very good. Tests have shown that a column of two or three pieces of timber blocked apart and bolted together at the ends and middle has no greater strength than the sum of the component sticks, each acting as an independent, simple column. When a column such as (a) is thoroughly spiked, in addition to being bolted, the strength of the column is undoubtedly greater than the sum of the component parts. Tests show an efficiency of eighty percent of the mean of the strength computed, first, as a solid stick, and, second, as a summation of the strength of the individual sticks considered as individual columns. For (b) the strength is recommended as eighty percent of the strength of an equal sized solid stick. These recommendations are for balanced loading about the gravity center and not for columns taking moment.



BUILT-UP COLUMNS

FIG. 11.

2. Heavier columns may be constructed as (c), (d), and (e). The lacing may be spiked, bolted, or attached by means of lag screws, as determined usually by consideration of the stresses in the lacing due to wind shear. For dead loads the component timbers are assumed to act alone. Lacing is at forty-five or sixty degrees with the axis of the column.

It must be borne in mind that the columns as shown do not rest directly upon the foundation bearing surface. They rest on a concrete footing with a base plate between the column and footing. This base plate is a necessity for two reasons: 1. To distribute the column pressure over the footing without exceeding the safe unit bearing pressure for concrete; and, 2, to prevent rotting of the bottom of the column through entrance of moisture.

CONCLUSION

A few general principles may be noted in regard to the design of roof truss members as discussed in this paper:

Joints:

Parts should be as few as possible. Center lines of the members should intersect at the same point. The members should be designed to resist both horizontal and vertical stresses.

Tension Splices:

Fish plate splices are effective for small and moderate stresses. The tenon bar splice, although not seen very often, is to be recommended for use wherever possible. The shear pin splice is effective, simple and inexpensive.

Compression Splice:

Simple butt joint is most often used for direct uniform compression. Half lap and oblique scarf used for resisting flexure.

Built-up Members:

Bolted and keyed built-up members give the greatest efficiency. The idea of built-up members having the same or even greater strength than a solid member of the same size is wrong. Tests have proven this theory to be false.

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