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TIMBER FRAME BUILDINGS FOR EMERGENCY SHELTER

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CROATIA

Technical report: Trussed rafters for repair of damaged roofs *

Prepared for the Government of the Republic of Croatia
by the United Nations Development Organization

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Agro-based Industries Branch

* This document has not been edited.

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Trussed Rafters for Damaged Roofs

1. Introduction

Many of the houses and other buildings damaged during the war have structural damage more or less limited to the roof. In these cases repair of the roofs will allow the fabric to dry out, and repair to continue in dry conditions. Typical damage is shown in the photographs Figures 1 to 4.

It is recommended that trussed rafters should be used for this repair work. Trussed rafters are lightweight roof trusses erected at close centers to support both the roof covering and the ceiling lining. They are manufactured in factory conditions to engineered designs.

The advantages of trussed rafters include:

- Quick erection
- Guaranteed strength and stiffness
- Uniform dimensions
- Minimum site skills

2. Trussed Rafter Systems

There are various systems of trussed rafters in use around the world. The variations are determined by the various roof coverings, weight of snow loads, availability of timber in different dimensions, availability of different timber connectors, traditional carpentry practice.

The principal connector systems used are:

1. Nailed and glued gussets
2. Toothed plates - "Gang-Nail", "Hydronail" etc.
3. Nail-on steel plates
4. Nailed plywood gussets

Tests in the USA have shown that in the long term, type 1 is strongest and stiffest, type 4 the weakest and least stiff, with types 2 & 3 approximately equally intermediate. Nevertheless, type 4 is widely used, since it is least demanding in infrastructure, facilities and degree of processing of the timber (dryness, dimensional uniformity). Even so, quality requirements of the timber and plywood need to be maintained.

If an industry using nailed plywood gussets is established, it is a relatively simple matter to establish the manufacturing operation for nail-on steel plates.

The timber frame construction project established at Vinkovci is using plywood gussets, since other fastenings are not available. The techniques involved are being demonstrated. At the same time the manufacture of nail-on plates, Type 3, is being actively investigated and is covered in section 7 of this Report.

The spacing and web bracing system adopted derives from a combination of factors. For Croatia the recommendations are:

- Spacing 611 mm (600 if plywood sheathing is not used)
- Timber size for rafter and ceiling joist 100x50 or 150x50 mm nominal dimension.
- Bracing system: Howe or "M"

This form is rather better suited than the other popular "W" arrangement to the steep roof pitches favored in Croatia. Also, it is simple to adapt the geometry to the fabrication of a truss in a top and a bottom piece to limit the height of individual components so that they may be readily transported.

3. Measurement of Houses for Trussed Rafters

This section refers only to gable roofs. In other roof forms specialist advice should be obtained.

There are three measurements required for the manufacture of trussed rafters. These are:

Span Span is defined as the distance from outside of wall to the outside of the opposite wall.

Eaves overhang Eaves overhang is the horizontal distance from outside of wall to inside of fascia board.

Pitch Pitch is the angle in degrees between the slope of the roof and the horizontal. These terms are illustrated in Figure 5.

Measurement of existing houses may be complicated by brickwork not being true to line, and existing gable wall pitches not being identical. In these cases some compromise may be necessary. In any case timber plates should be fixed to the top of the existing walls with masonry bolts and carefully lined and levelled to give equal spans. If the gable wall pitches are not equal, then the steepest one should be chosen as the pitch, and the others built up to this pitch with mortar.

4. Layout of Trussed Rafters

The exact dimensions of trussed rafter components is determined partly by the span, eaves overhang and pitch, and partly by the actual dimensions of the timber used.

With the arrangement shown in Figure 6, all the lengths and angles of the components can be calculated in advance of cutting. This eliminates the need for trial setting out, and considerably speeds up and lowers the cost of manufacture.

The notation adopted is:

L = Span mm

E = Eaves overhang mm

A = Pitch angle

D = Width of timber in rafter

d = Width of timber in other components

The names of the components are shown in Figure 7.

The panel length P is 1/4 (L-d-2d/tan A)

This dimension is required for setting out the trussed rafter on the jig.

The lengths of the components are:

$$Ceiling\ joist\ \frac{L}{2}$$

$$Rafter\ \frac{1}{Cos\ A}\left(\frac{L}{2}\right) + \frac{D}{\tan A}$$

$$Ceiling\ hanger\ P \tan A$$

$$Strut\ \frac{P}{Cos\ A}$$

$$Ridge\ tie\ \tan A\ (2\ P + \frac{d}{2})$$

The points to which these dimensions refer are shown in Figure 8. The angles cut at the ends of the components are also shown. Note that these are determined by the pitch angle only, not by the span of the truss.

It is not difficult to program these functions into a personal computer. The measurements L, E and A will differ for each roof, but D and d will be the same for each source of timber supply.

Typical print-outs of dimensions for both the ridge-top truss and the flat-top and king post trusses are shown in Figures 10 and 11.

5. Oversize Trussed Rafters

While it is possible to design and construct trussed rafters of almost any size, practical considerations of handling and transport may impose limitations on construction practice.

It would be unusual for the span of a domestic house to exceed 10 m, the normal maximum would be around 7.5 m. Even so, with a 40 degrees pitch and a 600 mm overhang, the overall height of such a trussed rafter will be 3.8 m, considerably more than normal legal road width limit of 2.5 m.

One advantage of the "M" braced truss is that it is very easy to make the total triangular shape, with a horizontal joint. In effect, a small triangle sits on top of an equal height trapezium. So even a 10 m x 45 degrees pitch trussed rafter can be manufactured in two components each 2.5 m high.

The geometry and forces in the lower half "Flat-Top" truss are very similar to those of the ridge truss, except that the ceiling joist tension is slightly higher. Consequently the numbers of nails in the various joints are also similar.

The lengths of the various truss components are:

$$P = \frac{1}{4}\ (L - d - \frac{2\ d}{\tan A})\ \text{as for ridge truss}$$

$$Ceiling\ joist = \frac{L}{2}\ \text{as for ridge truss}$$

$$Rafter = \frac{1}{Cos\ a}\ (P + E) + \frac{d}{\sin A}$$

Ceiling hanger = P tan A as for ridge truss

$$Strut = \frac{P}{Cos\ A}\ \text{as for ridge truss}$$

Centre vertical = P tan A

$$Top\ chord = 2\ P + d\ \frac{2\ d}{\sin a} = T$$

The flat-top truss must be accompanied by a corresponding triangular king-post truss which sits on top of the flat-top truss to make up the whole roof shape.

The lengths of the king-post truss components are:

$$Rafter = \frac{T}{2\cos A} - \frac{D}{Cos\ A\ \sin A} = R$$

$$Lower\ chord = 2\ R\cos A - \frac{2\ D}{Sin\ A} = C$$

$$King\ post = \frac{C\tan A}{2} - d$$

The points to which these dimensions apply are shown in Figure 9.

TABLE I

NAILING SCHEDULE

		Ridge Truss						
Roof Pitch - degrees		30	32.5	35	37.5	40	42.5	45
5 m span Joint	A	10	9	9	8	8	7	7
	B	3	3	3	3	3	3	3
	C	3	3	3	3	3	3	3
	D	4	4	4	4	4	4	4
	E	5	4	4	4	4	4	3
	F	8	7	6	6	5	5	5
6 m span Joint	A	12	11	10	10	9	9	8
	B	3	3	3	3	3	3	3
	C	3	3	3	3	3	3	3
	D	4	4	4	4	4	4	4
	E	6	5	5	5	4	4	4
	F	9	8	8	7	6	6	6
7 m span Joint	A	14	13	12	11	11	10	10
	B	3	3	3	3	3	3	3
	C	3	3	3	3	3	3	3
	D	4	4	4	4	4	4	4
	E	6	6	6	5	5	5	5
	F	11	10	9	8	7	7	6
8 m span Joint	A	16	15	14	13	12	12	11
	B	4	4	3	3	3	3	3
	C	4	4	4	4	4	4	4
	D	4	4	4	4	4	4	4
	E	7	7	6	6	6	5	5
	F	12	11	10	9	8	8	7
9 m span Joint	A	17	16	15	14	14	13	12
	B	4	4	4	4	3	3	3
	C	4	4	4	4	4	4	4
	D	4	4	4	4	4	4	4
	E	8	8	7	7	6	6	6
	F	14	12	11	10	9	9	8
10 m span Joint	A	19	18	17	16	15	14	14
	B	5	4	4	4	4	4	3
	C	5	5	5	5	5	5	5
	D	5	5	5	5	5	5	5
	E	9	8	8	7	7	7	6
	F	15	14	12	11	10	10	9

6. Timber

The timber used in trussed rafters is the most important structural component and is also the item subject to the greatest variations.

The designs in this report have been prepared on the basis of F7 stress grade, that is timber which has a basic stress in bending of 6.9 N/mm2. This stress is appropriate for a medium density softwood of 50% strength ratio, that is with knots no greater than 1/4 the face width and slope of grain not greater than 1 in 8. A large proportion of the softwood seen in Croatia would be of at least this quality.

The designs call for nominal 100x50 mm timber for most components and spans up to 10 m. Above 8 m spans the rafters and top chords must be nominal 150x50.

For the components to fit together accurately and for the gusset plates to lie flat on the face of the truss, fairly accurately sized timber is required. A variation of +/- 1 mm in width and thickness is acceptable. In practice this can be consistently produced by a well maintained frame saw. If variations are greater than +/- 1.5 mm then planer thicknessing will be required.

This thicknessing need only be on one edge and one face. Four-side surfacing should only be necessary if the timber is consistently out of square or is extremely roughly sawn. Four sided surfacing on the rafters at least may also be required if decorative exposed eaves are to be a feature of the roof.

Timber may be surfaced down to 5 mm under nominal thickness i.e. 45 mm and 10 mm under nominal width i.e. 90 and 140 mm. The North American sizes of 89x38 and 140x38 are too scant for these F7 stress grade designs, both for the timber itself and also for the joints.

At joint positions i.e. both ends of all interior members, and the ridge and heel joint position of the rafters, the wood should be free of large defects. Pin knots up to 10 mm diameter may be permitted in these zones.

7. Nail-On Plates

Thin steel plates with holes punched to take suitable nails have been manufactured in wood-using Western countries for many years. They have found most use when folded for use as joist hangers etc. Their development more or less coincided with the development of toothed plates. The toothed plate is eminently suited to large-scale trussed rafter manufacture and requires a minimum of hand labour. Nail-on plates require a significant amount of hand labour and consequently they never found much favor as a basic truss connector. Nevertheless they are physically an excellent connector.

Nail-on plates have several advantages over plywood. The punched holes provide correct nail spacing. The lack of slip between the nail and the steel allows slightly higher nail loads to be used. The Australian design code allows an increase of 9% over nails driven through plywood gussets with a corresponding reduction in the number of nails required.

Compared with toothed plates, the area of a nail-on plate is rather larger to give the same holding power. The steel quality requirements are less stringent in so far as cold working properties are concerned and the manufacture is much simpler. In emergencies they can even be made with hand tools.

Several nail hole punching patterns have been used. One successful pattern is shown full size in Figure 12. The 125 mm wide plate may be cropped to lengths of 40, 80, 120 etc. mm.

The steel requirements are not demanding. 1.5 mm thick steel of minimum yield stress of 240 MPa is quite adequate. The basic design loads for pairs of these plates are:

Plate width	Tensile load KN	Transverse shear KN
40 mm	14.4	10.8
80 mm	28.8	21.6
125 mm	45.4	34.0

Nail-on plates should be punched from galvanized sheet.

8. Nails

The nails used in nail-on plates are short and fat. Nails with wire diameter 3.15 mm and 30 mm long under the head have proved satisfactory. They should be hot-dipped galvanized.

For the softwoods available in Croatia (Australian designation JD5) the basic nail load is 276 N each, or 552 N per pair when a truss joint is drawn in elevation, since the nails are driven in from both sides of the truss.

If designs are taken to include snow load then this load may be increased by 20% to 660 N per pair. The nailing schedules in Table 1 are prepared on this basis.

Regardless of calculation all joints should have a minimum strength. It is recommended that at least 3 nails should be on each side of each joint, giving a short-term strength of 2.0 kN. This number has been shown in for example the fixings of the ceiling hanger fastening which carries no load when ceiling dead load is neglected in the overall truss calculation.

Nails which carry structural loads must not be driven too close to either the end or the edge of a piece of timber if they are to carry their assigned loads. For medium density softwoods the minimum distances recommended are:

End distance: 30 mm
Edge distance: 15 mm

The best way to position nail-on plates to include the required number of nails in the various members of a joint and also to fulfill the end and edge distance requirements is to use a transparent template on a large scale drawing of the joint. Two examples of this are shown in Figure 13. The end and edge distance boundaries are drawn, then the template is moved until the required number of nails can be placed in each member. A suitable template at a scale of 1 : 2.5 is also shown in Figure 13.

9. Plywood Gussets

Detailed designs for plywood gusset plates are not given in this report. The designs for nail-on plates may be adapted under the following conditions:

Plywood Use exterior-bonded plywood 12 mm thick for gusset plates, cut the plates so that the face grain is parallel to the ceiling joist for all except:

Ceiling hanger/strut plate - parallel to rafter

Ceiling hanger/ceiling joist plate - perpendicular to ceiling joist

Nailing may be achieved in either of two ways.

1. Use 55 or 60 mm x 2.8 mm diameter nails, driven from both sides. Increase the number of nails 30% over the numbers shown in Table 1 and in the drawings
2. Use 85 or 90 mm x 3.75 mm diameter nails driven right through both sheets of plywood. Clench the protruding points at 90 degrees to the grain of the plywood. Reduce the number of nails shown in Table 1 by 17.5%

If insulating board (softboard) is placed under the lower gusset plate while the nails are being driven it can be easily removed from the nail points.

Nail spacing should be:

	2.8 mm dia	3.75 mm dia
Parallel to grain	50 mm	70 mm
Across grain	25 mm	35 mm
End distance	25 mm	35 mm
Edge distance	12 mm	16 mm

10. Fabrication and Assembly

The ideal machine for small-scale manufacture of trussed rafters is the semi-universal radial arm saw. This should have a 3 HP (2.2 KW) motor and a 14 inch (350 mm) diameter blade, preferably tungsten carbide tipped.

This type of machine can cut angles up to 45°. Angles flatter than this such as are found in the heel cut of the ceiling joist should be cut by having the joist resting on an auxiliary stand at right angles to the saw fence. In this case, the joist must be clamped to the saw table. This avoids the danger of the wedge-end of the joist jamming the saw in the fence at the conclusion of the cut.

Where possible, angle cuts should be made first, then the component is cut to length with a square cut. This will apply to 2-piece ceiling joists, hangers and ridge ties. In all cases components should be cut to length against a stop firmly clamped to the rear fence of the outfeed table.

Specialized component cutting saws are available, but their expense is only warranted in large scale production of over about 100 trusses per day.

One of the advantages of trussed rafters quoted in Section 1 is their dimensional uniformity. This eliminates the need for any trimming and packing on the building site provided the bearing plates have been accurately lined and levelled.

For dimensional uniformity to be achieved it is essential that assembly of the precut components should be carried out on a jig table. The jig table must be solidly built to take the punishment of continual hammering. A suitable table is shown in Figure 13. The spacing apart of the planks which form the surface and the long slots in the fixture angles allow the positioning of these angles anywhere as required.

After the precut components are placed in the jig, the nail-on plates or plywood gussets are positioned in accordance with the drawings and nailed to specification. The truss is then turned over, replaced in the jig and the second side is nailed.

A factory with one jig table can produce 16 to 20 trussed rafters per day. For higher rates of production a second table without fixture angles is required for the second side nailing.

11. Bracing and Erection

Trussed rafters are manufactured from quite thin timber. This has the result that they have very little lateral stiffness: they are "floppy" sideways. Lateral bracing is essential if they are to develop their full strength. This bracing is necessary particularly in the plane of the roof where the rafters are in compression. It is also required in the ceiling plane and may be required in the planes of some of the web members.

The most effective bracing in the plane of the roof is achieved by the use of 9.5 mm sheathing plywood over the whole of the roof surface. Besides providing strength, plywood also keeps draughts out of the roof space when tiles are used as roof covering, and provides some insulation. Diagonal sarking (thin boarding) will also provide adequate lateral bracing.

The ridge tie should have a 100x50 longitudinal brace running the full length of the building and rigidly fixed to the gable walls.

If gypsum sheets are used for the ceiling and these are fixed directly to the ceiling joists, then these will provide adequate lateral bracing for the bottom chords of the trusses. Some other forms of ceiling e.g. T&G boarding will also provide diaphragm bracing.

If none of these are provided, or if the roof will remain without a ceiling for an appreciable period, then a longitudinal 100x50 should nailed at the bottom of each ceiling hanger, and to the bottom of the ridge tie. These braces must be securely fixed to the gable wall.

Before erecting trussed rafters, their positions should be marked out on the timber plates on top of the eaves walls. If there is a masonry gable wall then the first truss to be stood up should be securely fixed back to this wall at the ridge and mid-points of the rafters. If a projecting gable is to be constructed with outrigger rafters, then these should be fixed at this stage. They will provide the necessary lateral support.

Succeeding trusses are stood up in position on the eaves walls, lined up to a string set either at the ridge or one eave, then fixed to the eaves plates. Fixing to the eaves plates should be by three 100 mm nails or two angled wire dogs at each end. Each truss is temporarily braced back to the preceding one.

As soon as sufficient trusses are erected the plywood, diagonal sarking or permanent diagonal bracing, whichever is to be used, should be nailed in place. It is not safe practice to have the trusses for a complete roof supported only by temporary bracing.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

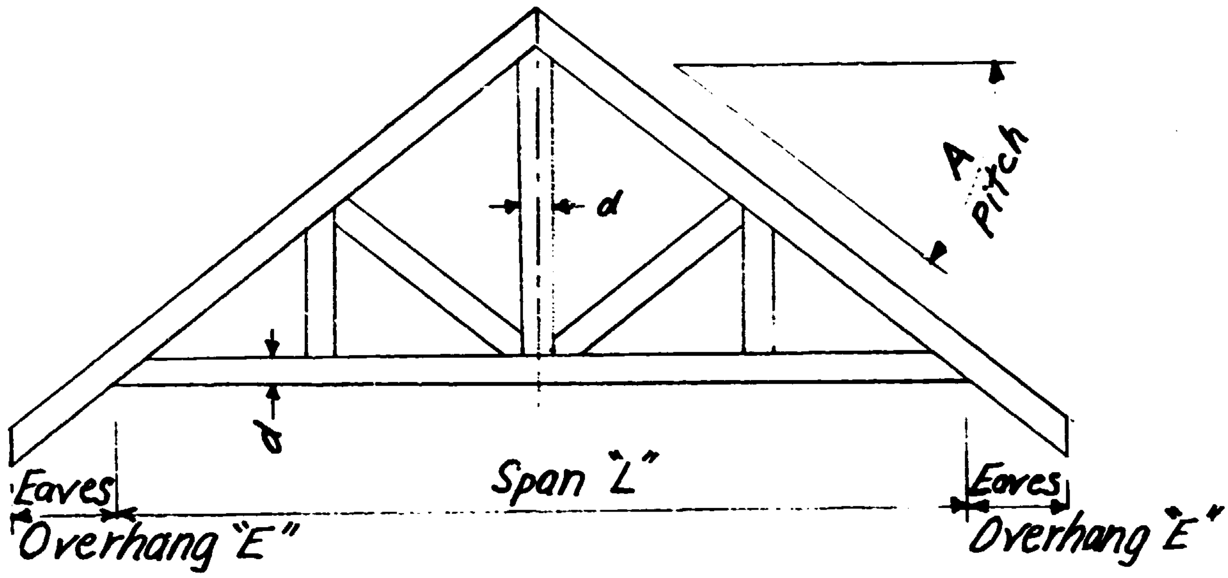


FIG. 5

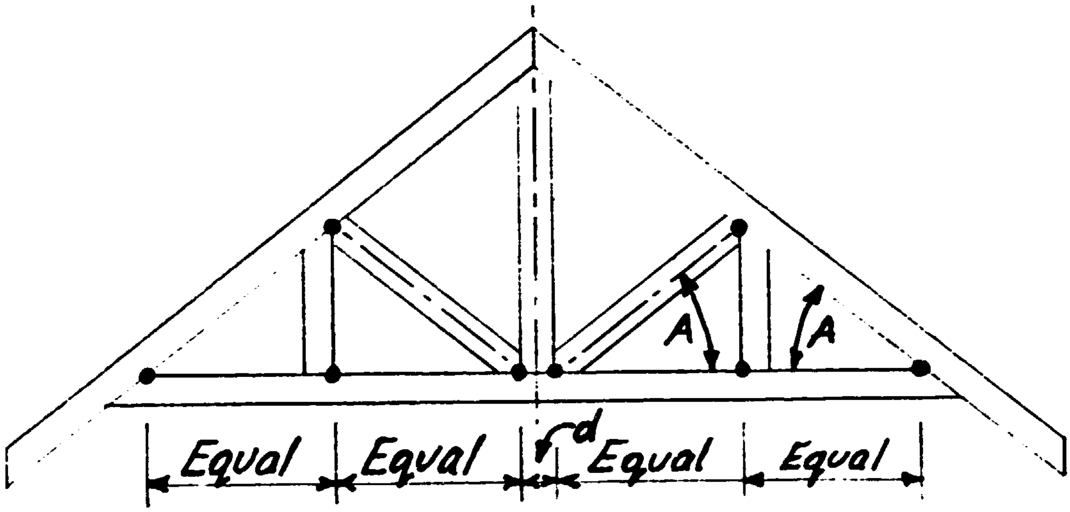


FIG. 6

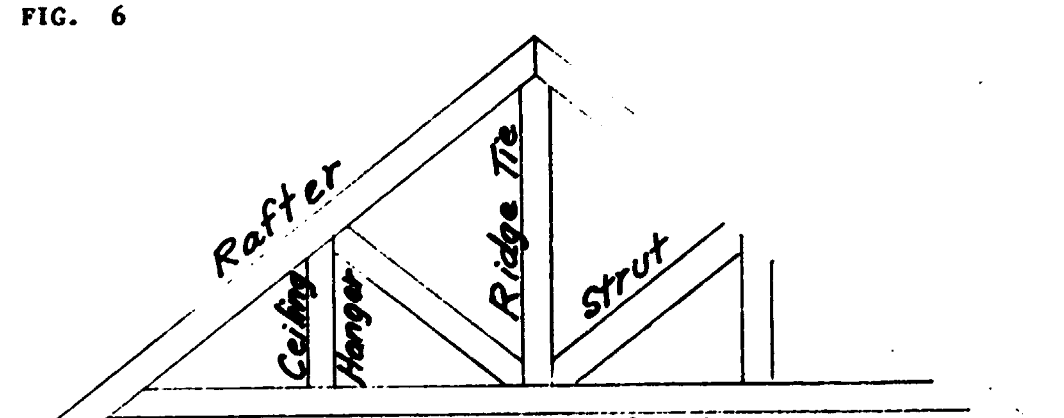
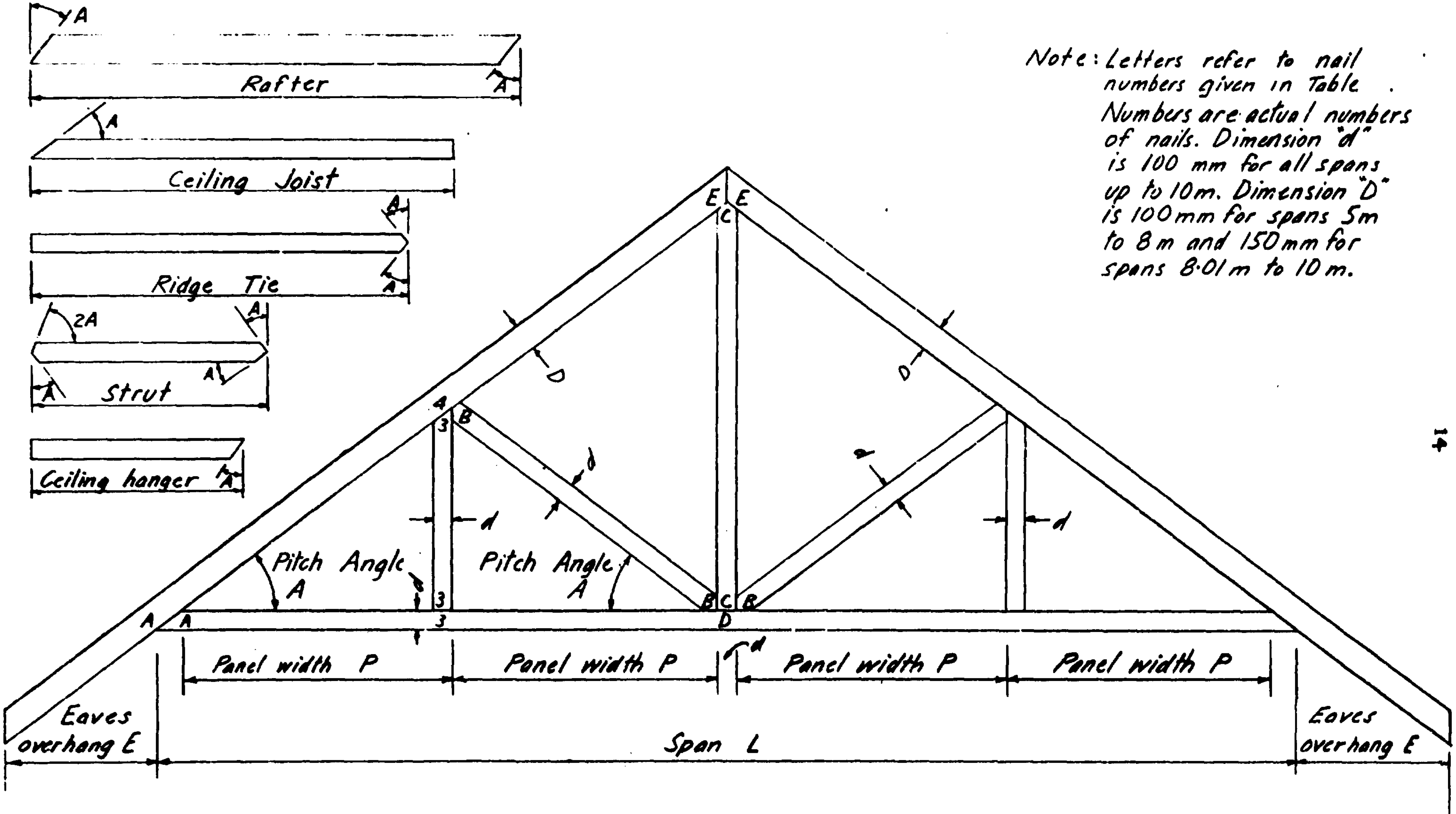
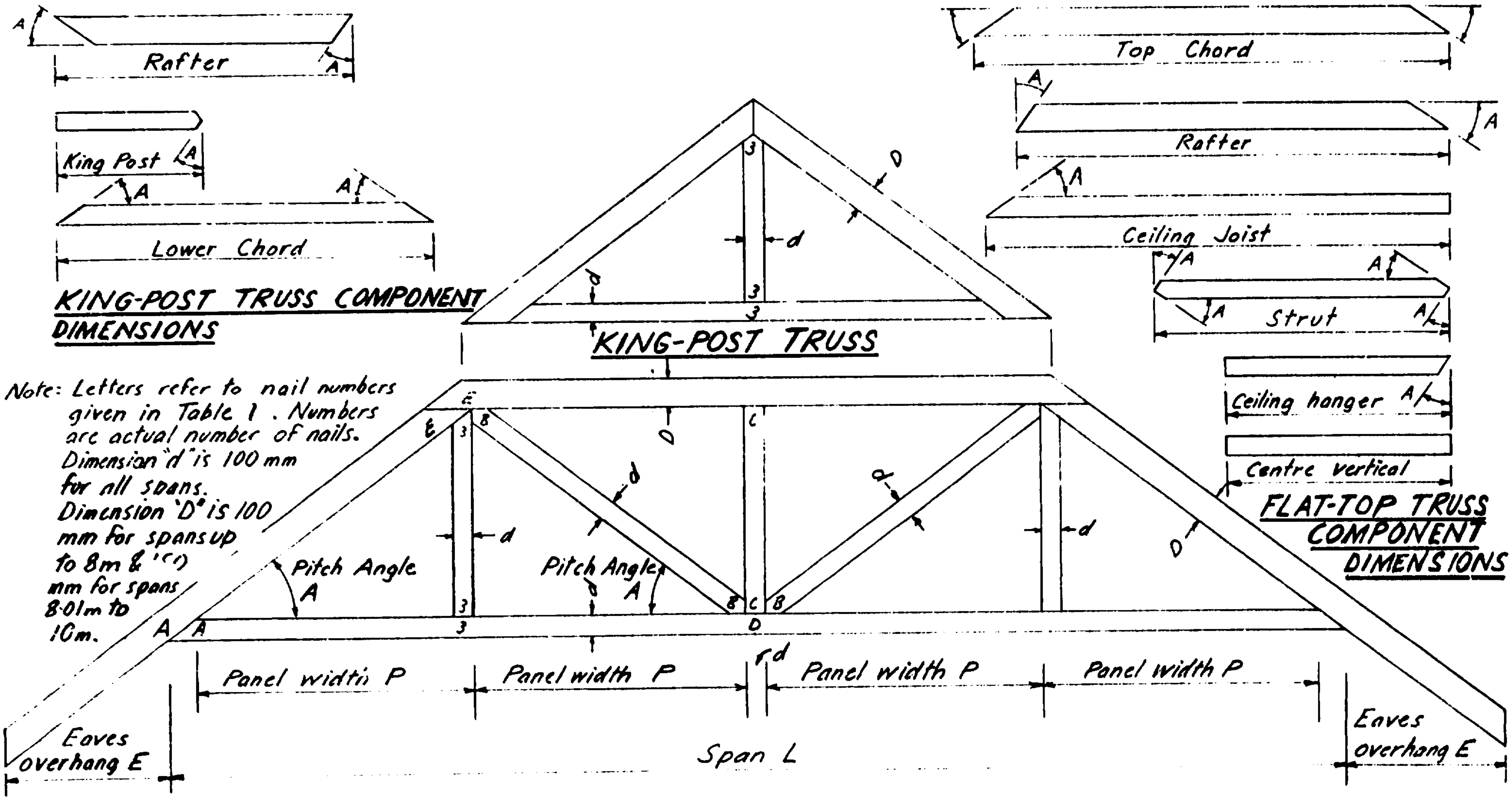


FIG. 7



COMPONENT DIMENSIONS & NAILING FOR RIDGE TRUSS

FIG. 8



COMPONENT DIMENSIONS AND NAILING FOR FLAT-TOP AND KING-POST TRUSSES.

FIG. 9

RIDGE TRUSS COMPONENT DIMENSIONS

INPUT NECCESARY DATA		DATA INPUT FIELDS
1.	Span L (in mm) =	5000
2	Eaves overhang E (in mm) =	500
3.	Pitch A (in deg. and dec.) =	40
4.	Framing timber depth d (in mm) =	100
5.	Rafter timber depth D (in mm) =	150

RIDGE-TOP TRUSS:

Panel width P:	1165
Rafter:	3916
Ceiling joist:	2500
Ceiling hanger and centre vertical:	978
Strut:	1521
Ridge tie:	1998

FIG. 10

FLAT-TOP TRUSS COMPONENT DIMENSIONS

INPUT NECCESARY DATA		DATA INPUT FIELDS
1.	Span L (in mm) =	6500
2.	Eaves overhang E (in mm) =	850
3.	Pitch A (in deg. and dec.) =	35
4.	Framing timber depth d (in mm) =	100
5.	Rafter timber depth D (in mm) =	150

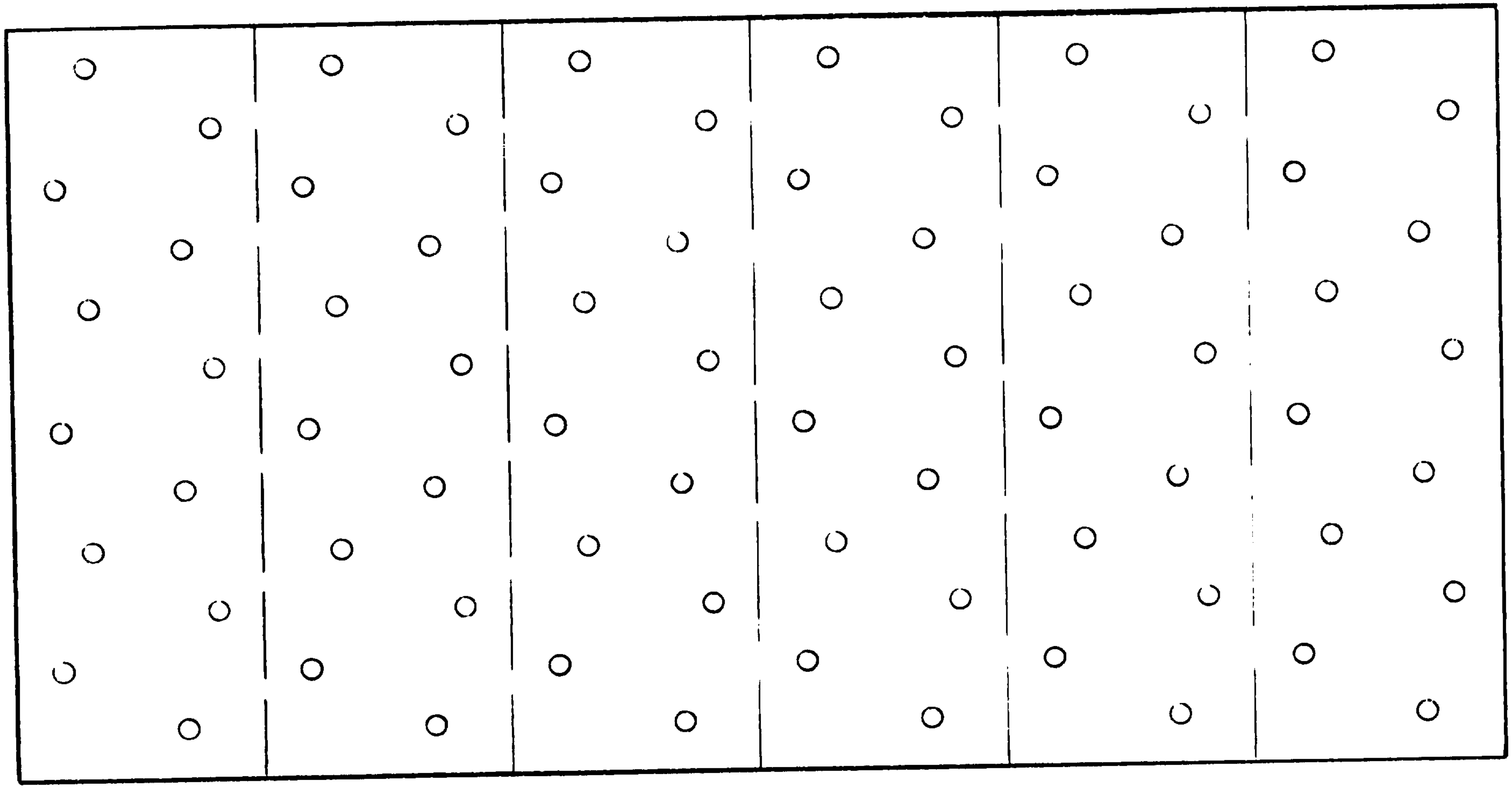
I. FLAT-TOP TRUSS:

Panel width P:	1529
Rafter:	3078
Ceiling joist:	3250
Ceiling hanger and centre vertical:	1070
Strut:	1866
Top chord:	3419

II. KING-POST TRUSS

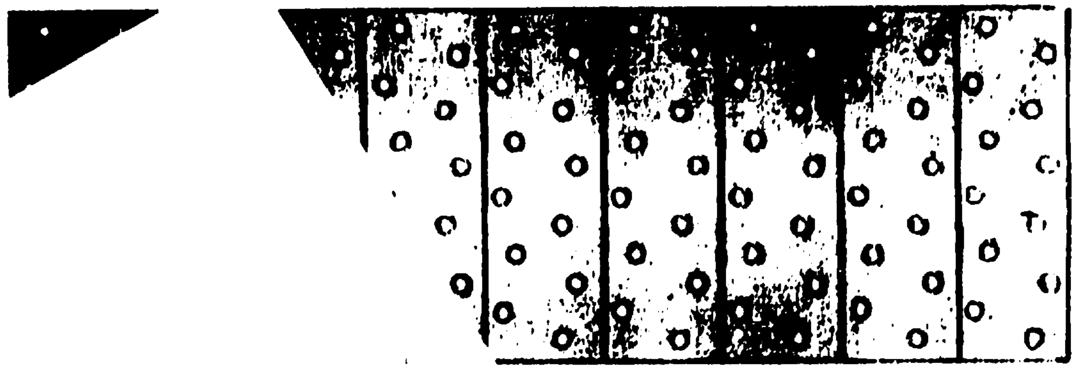
Rafter:	1767
Lower chord:	3012
King post:	1738

FIG. 11

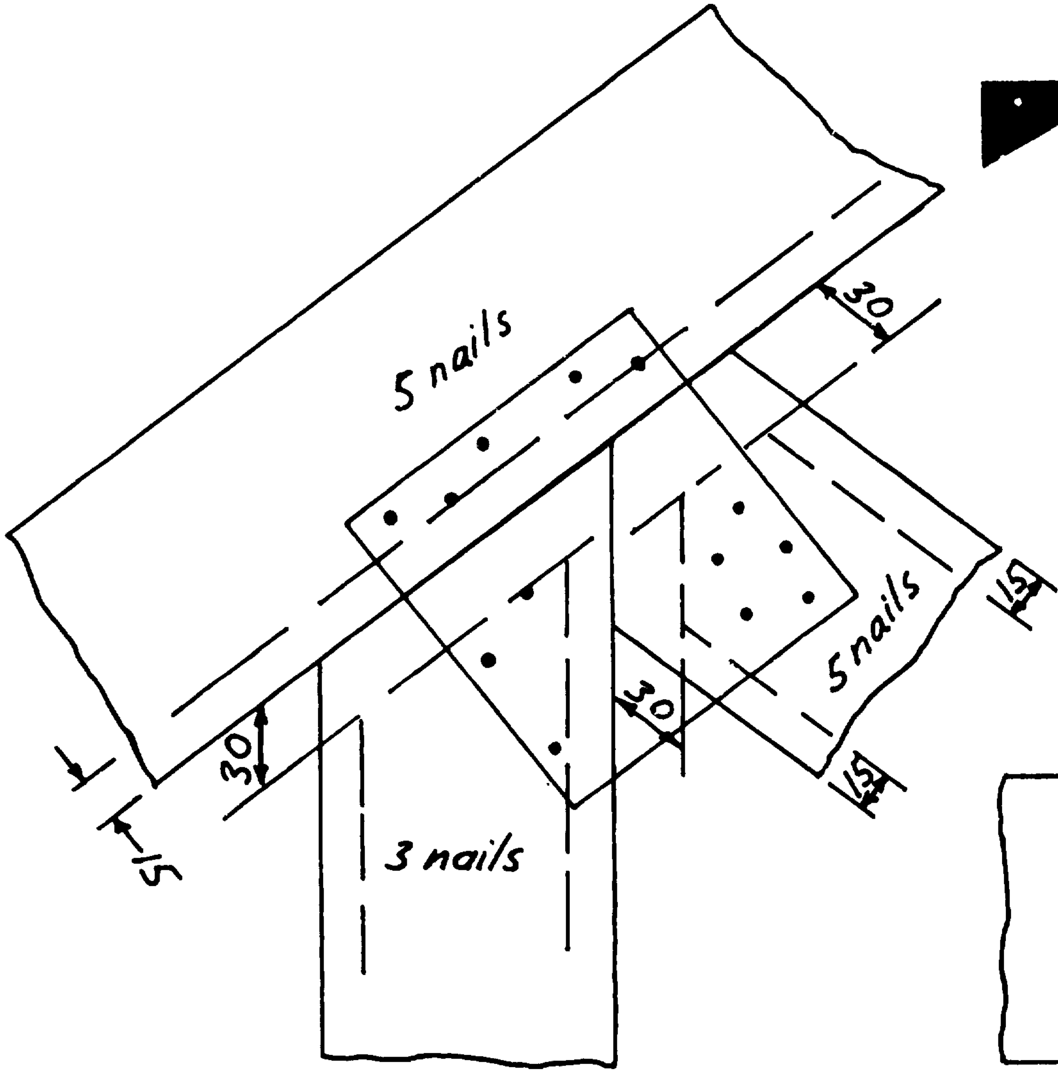


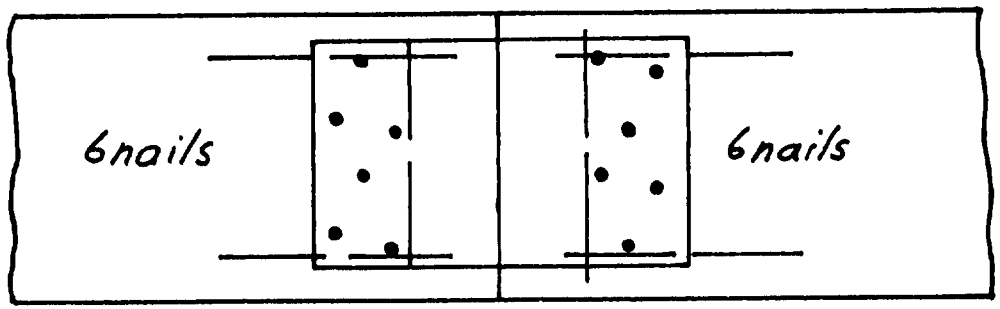
NAIL-ON PLATE

FIG. 12



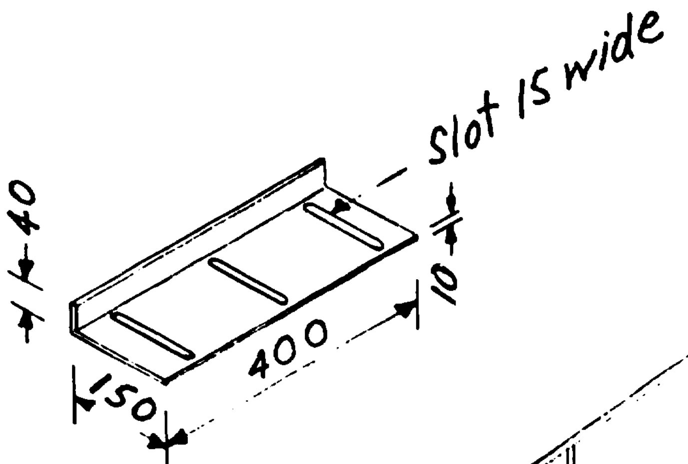
TEMPLATE



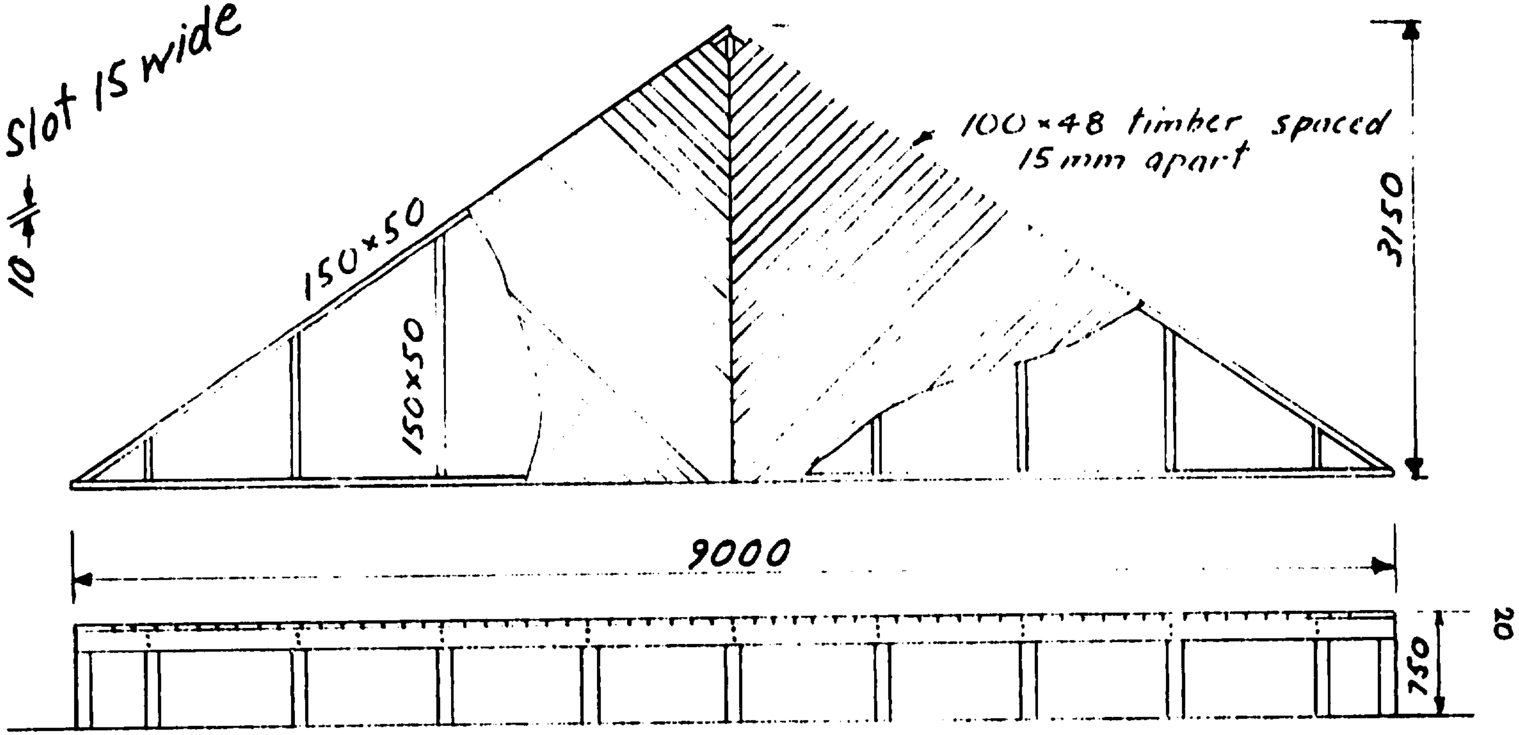


JOINT DETAILING

FIG. 13



FIXTURE



ASSEMBLY JIG TABLE

Fig. 14

BACKSTOPPING OFFICER'S COMMENTS

This is a detailed and practical report explaining, with ample illustrations, the design and fabrication on a small-scale of trussed rafter roofing. It is particularly suitable for Croatian conditions owing to the great need to replace roofs of war-damaged houses to enable interior repair work to proceed in protected conditions.