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TIMBER FRAME BUILDINGS FOR EMERGENCY SHELTER

US/CRO/92/162

CROATIA

Technical report: "Canadian System" timber frame buildings: precutting and prefabrication *

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

Based on the work of C. R. Francis,
chief technical adviser

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Agro-based Industries Branch

* This document has not been edited.

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1. Introduction

Buildings constructed from closely spaced small dimension timber are widely used in many developed countries. The major use is for single unit houses, but apartment blocks, schools, hospitals and office buildings are also built in this way.

In early times buildings were constructed on site by carpenters working from stacks of timber delivered to the site. Over the years various degrees of pre-manufacture were introduced. These have been the pre-cutting of the wall frames to produce a kitset of components for site assembly, the manufacture of prefabricated trussed rafters, the factory assembly of wall frames into prefabricated units and others.

Factory work is more precise and efficient than site work. The risk of theft of timber is reduced when large components are all that is lying on the construction site at night time.

One result of evolution from complete site construction to more or less complete factory prefabrication is the transfer of skill from the building site to the factory office. Once upon a time a carpenter would offer up a piece of timber to the place where it would be fixed, mark it, cut it and nail it in place. Now a draughtsman calculates the length, a clerk or a computer prepares a cutting list and a sawyer, or a numerically controlled saw makes the cut. The piece then goes to an assembly area where a workman with a nail gun fixes it in place.

This altered and divided responsibility requires the storage and transfer of detailed information from one worker to another. Previously only the carpenter was involved and the information was in his head or marked on the timber. Now the draughtsman must inform the sawyer. The assembly hand must know which piece of timber goes where.

The aim of this report is to describe how a timber frame building is detailed, and how the necessary information is calculated, recorded and transferred between the various workers involved.

Timber frame construction is most widely practiced in English speaking countries - Australia, Canada, New Zealand, USA. It is also recently been adopted by Japan, and to some extent has always been used in Latin America. A specialized vocabulary has grown up to describe the various components. In some languages there are no equivalent words. A glossary has been included as Appendix A which describes these words in detail.

2. The "Canadian System"

There are many variations in detail in how timber frame buildings are constructed in different countries. These reflect differences in timber strength and quality, standard sawn sizes of timber, climate, preferred roof and wall cladding.

The system recommended for use in Croatia most closely follows the building practice of Canada. Even so there are some deviations from Canadian practice which reflect partly Croatian standard timber and joinery sizes and partly the experience of the UNIDO team who are all from New Zealand.

"Timber Frame" refers particularly to wall construction and to a lesser extent ceiling and roof. A timber frame building may be constructed on a concrete slab or a suspended timber floor may be used. In "platform" construction the type of floor has no effect on the walls.

The "Canadian System" is fully described in the book "Canadian Wood-Frame House Construction" second metric edition published by the Canada Mortgage and Housing Corporation, 1988. Readers of this report are strongly advised to obtain a copy of this book, which is hereafter referred to as "CWF".

Study of the drawings in CWF particularly Fig 38 shows that exterior and interior walls consist of a bottom plate, a row of vertical studs and a top plate. In Canada the top plate is doubled. In the buildings constructed by this project only a single top plate is used. This is because the Croatian timber size of 100x48 mm is nearly twice as strong and more than twice as stiff as the Canadian size of 89x38 mm. Also the Croatian buildings designed for this project all have the trussed rafters located directly over a stud. This may not always be the case in a "general" type of building.

The exterior walls are sheathed with 9.5 mm plywood and the lining is 9.5 mm gypsum board. Reference to Table 25 of CWF shows that for a single storey building, stud spacing of 600 mm is acceptable. In practice 611 mm has been used to suit the plywood size.

There are numerous exceptions to this 611 mm spacing. Holes must be provided in the frame for windows and doors. Where this occurs the studs whose positions are occupied by the door or window are displaced to the sides of the opening. Typical details are shown in figure 1.

There are several methods of joining walls together at corners and at intersections. The method adopted for use in Croatia involves the use of a "double stud". This consists of two studs spaced apart by three packing pieces to make an element of width three times the timber thickness. This is placed at the end of one wall in the case of an external corner. For an intersection the double stud is placed on the intersecting wall. In both cases, the studs and packers will provide nailing for the end stud of the adjoining wall and also nailing for the lining boards. These details are shown in figure 2.

The double stud is placed in the wall element which will be erected first. Consequently the plan of the building should be studied and an erection sequence determined and written down. This sequence is also required when deliveries are made so that wall units may be unloaded in the correct order.

3. Dimensioning of Wall Frames

The positioning of the studs in a wall must satisfy several, frequently conflicting, requirements. These are:

1. Code requirements must be satisfied.
2. A stud must be centered at every cladding sheet joint.
3. Rooms must be of required dimensions.
4. Windows and doors must be correctly positioned.

The options open to the draughtsman who prepares the wall frame drawings are determined by the architectural freedom available to him in requirements 3 and 4. If the architect has absolute dimensional requirements, then of course these must be followed.

On the other hand if the architect's plan is only indicative, then the draughtsman has some freedom to place components for maximum economy of materials. In this latter case, a window lintel stud, for example, may be placed so that it also serves as a cladding sheet junction stud.

This explanation is based on the assumption of minimum cutting of exterior cladding sheets, which has been adopted for the UNIDO project. However this may not always apply. Complete plywood sheathing does not always have to be used, as explained in CWF. Horizontal weather boards (Canadian "siding") brick veneer etc. do not require studs to be positioned to suit. In these cases, studs should be spaced to suit the interior lining sheet joints and building code requirements.

In interior partitions it is the lining sheet size which determines the stud spacing.

Before dimensioning can commence, numerous details must be determined.

These are:

- Exact timber size
- Exact cladding sheet size
- Details of window and door frames and method of fixing these
- Exact lining sheet size.

Given this information standard cross sections can be prepared for the typical wall, various sizes of windows and interior and exterior doors.

In Croatia, the relevant dimensions are:

- Timber: 100x48, 150x50, 200x50 (mm)
- Cladding sheet: 2440x1220 (mm). However allow 1222 to give 2 mm clearance between sheets (see CWF page 81).
- Windows: Frame is 10 mm smaller than nominal size.
- Doors: Vary, but for the sizes commonly used, allow openings exterior 2140 high x 1110 wide, interior 2070 high x 800 wide.
- Gypsum sheets: 2500 long x 1200 wide.

From this information the typical cross sections shown in Figure 3 are prepared.

The operation of dimensioning is best explained by examples. Figure 4 shows the architects floor plan of a small house intended for mass production. By agreement with the architect minor changes in the dimensions are acceptable to suit the material sizes available.

The floor is made of close-butted plywood and actually measures 6100 mm x 5490 mm. The walls are drawn as seen from the outside. Wall 1 consists of five plywood sheets. The excess length is taken out in the centre sheet, since this wall is symmetrical.

The drawing will be used by the framing carpenter to set out the top and bottom plates. He will be using a steel tape, so the plan has dimensions shown in running measure, so that stud positions can be marked directly.

Referring to figure 5 the plywood sheet widths are drawn first, 1222, 1222, 1212, 1222, 1222. The wall starts with a double stud giving dimensions 0 and 144. The next stud is centered on the sheet centre at 1222/2 +/- 24 giving 587 and 635.

Next comes a window which requires an opening 1200 wide. The window is centered on the centre of the next sheet, giving the inside faces of the lintel studs at (1222 + 611) +/- 600, equals 1233 and 2433. Then the main window studs will be 1233 - 2 x 48 = 1137 and 2433 + 2 x 48 = 2529. The sill jack studs are at 1233 + 48 = 1281, 2433 - 48 = 2385, and the central jack stud at (1233 + 1200/2) +/- 24 = 1809 and 1857. The central stud is at 6100/2

+/- 24 = 3026 and 3074. The right hand dimensions are obtained by subtracting all these dimensions from 6100. The drawing is completed by drawing in the nogs, sills and lintels from the typical cross sections.

Wall 2 is 200 mm shorter than the floor dimension 5490, since it fits between two side walls numbers 1 and 3. The plywood sheet positions are drawn first, as before, but in this case the excess plywood width is taken off in the half sheet, which has been placed on the right hand end. Note that the plywood must start 100 mm out from the face of the end stud to cover the adjoining walls. For structural reasons a double stud is required at the centre of the wall, that is at 5290/2 +/- 72 = 2573 and 2717. A stud is centered on every sheet junction and sheet centre, giving all the stud positions, that is 1222/2 - 100 +/- 24 = 487 and 535, 1222 - 100 +/- 24 = 1098 and 1146, etc.

The bedroom position intersects this wall, shown on the architects plan at 2200 mm from the left hand end. Placing the double stud to the left of the second sheet junction will give a room size of 2368 - 48 - 24 - 50 = 2246 which is acceptable.

Walls 3 and 4 (Figure 6) are dimensioned in a similar manner, with studs placed at sheet centers and joints where possible. However in these walls, architectural requirements preclude the use of only whole and half sheets.

The interior partitions are shown in Figure 7. Architectural requirements determine the positions of double studs and doors. The stud spacing is reduced to 600 mm centers to suit lining sheets 2400 mm wide, fixed vertically.

The revised floor plan is shown in Figure 8.

4. Precutting

Once the drawings for the wall frames are completed, the cutting schedule can be prepared. The first step is to prepare a schedule for each wall and partition. These schedules should be prepared in descending length order. For example the schedule for wall No. 1 would be as shown in Appendix B.

The next stage depends on whether the building is a "one-off" or is to be built in large numbers.

In the case of a "one-off", the individual wall schedules can be passed to the sawyer who will cut the components to length and bundle them by wall number. Since the number of pieces in a wall is not very large, it is not a difficult job for the assembly carpenters to sort them into position.

If a large number of identical units are to be produced, then the individual schedules must be consolidated into a master schedule, again in descending length order. The master schedule for this house is shown in Appendix C. Each length is bundled together, and the length is written on each bundle. Components for wall units are then selected from these bundles.

It will be observed that there are some components which are extremely numerous e.g. studs, intermediate nogs. These may well be stockpiled in advance of detailed cutting for particular buildings.

Cutting must be precise for accurate assembly. Acceptable tolerances are + 0 mm and - 1.5 mm and end squareness 5 mm in 1000 mm. This degree of precision is readily attained with a radial arm saw attached to a roller bench.

5. Assembly

Precut frames may be assembled either on the building site or in a factory. In both cases the top and bottom plates must be marked with the positions of the various studs. These are set out from the left hand end of the plates using a steel tape to avoid cumulative errors. It is for this reason that running dimensions are used, in order that the carpenter does not have to do any arithmetic. Most of the stud positions are the same for both top and bottom plates, but there are some differences around doors and windows.

On the building site frames are assembled on the previously constructed floor platform. This may have the positions of plates, and nogs set out on it by chalk line. Sills and lintels will be positioned vertically by the jack studs. Less commonly occurring members such as interior door heads may be located by means of a lath with the correct position marked on it.

Two 100 mm long nails are used at each joint. For studs these are driven through the plates into the ends of the studs. For nogs one end is nailed as above, but the other end must be skew nailed so that the nogs are in line. Where nogs are used as a backing for a horizontal gypsum board joint it is essential to have them in line. Where the gypsum boards are applied vertically and the nogs serve only to stabilize the stud, the nogs may be staggered about a common line thus avoiding skew nailing. While this simplifies the framing carpenter's work it makes that of the exterior plywood fixers rather more difficult.

Assembly in a factory is very similar except that permanent jigs are used to position the top and bottom plate and the nogs, lintels, etc. Pneumatic nail guns greatly reduce the time and effort of nailing.

Whether the sheathing plywood is applied in the factory, or in the case of site assembled frames,before standing the frames up, depends on the availability of handling equipment. If mechanical handling equipment is available, then large heavy frames may be erected with no problems. If site labour and facilities are limited then sheathing may have to be applied after the frames are stood up. Application of the sheathing first makes the frames stronger and avoids the need for ladders and scaffolds. It also ensures their squareness. In the factory it permits the use of pneumatic nail guns to drive the large number of sheathing nails.

6. Erection

Before standing up, the frames must be made accurately square. If sheathing plywood is not applied at this stage then a temporary diagonal brace must be nailed to the frame on the inside.

After standing up, the frame is made plumb and a temporary brace is fixed between the top plate and the floor. The bottom plate is then nailed to the floor joints and trimmer through the plywood floor. In the case of buildings made accurately to a plywood sheet module this may require skew nailing close to the intersection of the studs and the bottom plate.

Top plates must be straightened to a string line and if necessary extra temporary braces must be placed and left in position until the roof trusses are fixed and sheathed. The rigidity of the roof sheathing will prevent any further movement of the top plate out of line.

Subsequent operations, in order, are:

1. Erection of roof trusses
2. Application of roof sheathing
3. Installation of exterior doors and windows
4. Erection of interior partitions
5. Application of ceiling vapour barrier and lining sheets
6. Installation of wall insulation and vapour barrier
7. Application of wall lining sheets
8. Completion of trim

Working in this order will give a weather and thief proof structure after stage N°3. It may be desirable to alter this sequence slightly. For example, if the span of the roof trusses is long, it makes it much easier to install them if the interior partitions are already in place.

7. Prefabricated Roof Trusses

The prefabrication of roofs is rather more complicated than wall frames. However provided that a suitable layout system is followed, it is not difficult to detail every component in a pitched roof truss. This avoids the time consuming operation of making a prototype and using its components as patterns.

Three roof truss arrangements are discussed. These are:

The Howe	or	M	truss
The Fink	or	W	truss
The Belgian	or	WW	truss

These forms are those most commonly used world wide in the wooden roof truss industry.

The M type truss has been discussed in some detail in the UNIDO report "Croatia - Trussed Rafters for Repair of Damaged Roofs". That report was aimed at a practical solution for a particular problem and did not discuss the reasons for the layout shown. Therefore the M type truss is also included in this discussion.

The standard layouts of the three forms are shown in Figure 9.

Then the node point to node point distances of each component are calculable in terms of the span L and the pitch angle A.

(Note that for Figure 9, L = S)

These dimensions are:

M truss:

$$Rafter = \frac{S}{2 \cos A}$$

$$Ceiling\ hanger = \frac{S \tan A}{4}$$

$$Strut = \frac{S}{4 \cos A}$$

$$Ridge\ tie = \frac{S}{2 \tan A}$$

For the W and WW trusses the interior angles B, C and D must be calculated.

These are:

$$B = \tan^{-1}(3 \tan A)$$
$$C = \tan^{-1}(5 \tan A)$$
$$D = \tan^{-1}(2.5 \tan A)$$

Then:

W truss:

$$Rafter = \frac{S}{2 \cos A}$$

$$Strut = \frac{S \tan A}{6 \sin B}$$

$$Tie = \frac{S \tan A}{3 \sin B} = 2 \; x \; strut$$

WW truss:

$$Rafter = \frac{L}{2 \cos A}$$

$$Strut\ 1 = \frac{S \tan A}{6 \sin C}$$

$$Tie\ 1 = \frac{S \tan A}{3 \sin D}$$

$$Strut\ 2 = \frac{S \tan A}{3 \sin C} = 2 \; x \; strut\ 1$$

$$Tie\ 2 = \frac{S \tan A}{2 \sin C} = 3 \; x \; strut\ 1$$

In practice components have real widths, and some compromise with ideal theory must be made. If the timber used has widths:

Ceiling joist = d

Rafter = D

Ridge tie = d (in the case of the M truss)

than the triangle used to define the truss geometry is taken as the <u>inside</u> triangle formed by the rafters and ceiling joist.

$$\text{Then } S = L - \frac{2\,d}{\tan 1} \quad \text{- for } W \text{ and WW trusses}$$

$$= L - \frac{2\,d}{\tan A} - d \quad \text{- for } M \text{ truss}$$

where L is the construction span as shown in Figure 10 and all the other symbols used in this Report are also shown.

Roofs usually have an eaves overhang "E", and frequently a fascia board thickness "t". Then for all forms of truss the <u>overall</u> length of the rafter will be:

$$\frac{L + E - t}{\cos A} + D \tan A$$

To complete the detailing of roof truss components the angles at the ends of the components are also required. These are shown for all the components in Figure 11 where the dimension face is also shown. Note that in the W and WW trusses the angle at the upper end of Strut 1 will frequently exceed 90°.

In a manufacturing situation it is advisable to prepare a standard cutting sheet which will show all the necessary lengths and angles. This will avoid confusion in reading drawings and also saves on office work by avoiding the need for detailing these. A suitable form of a cutting sheet for M trusses is shown in Appendix D.

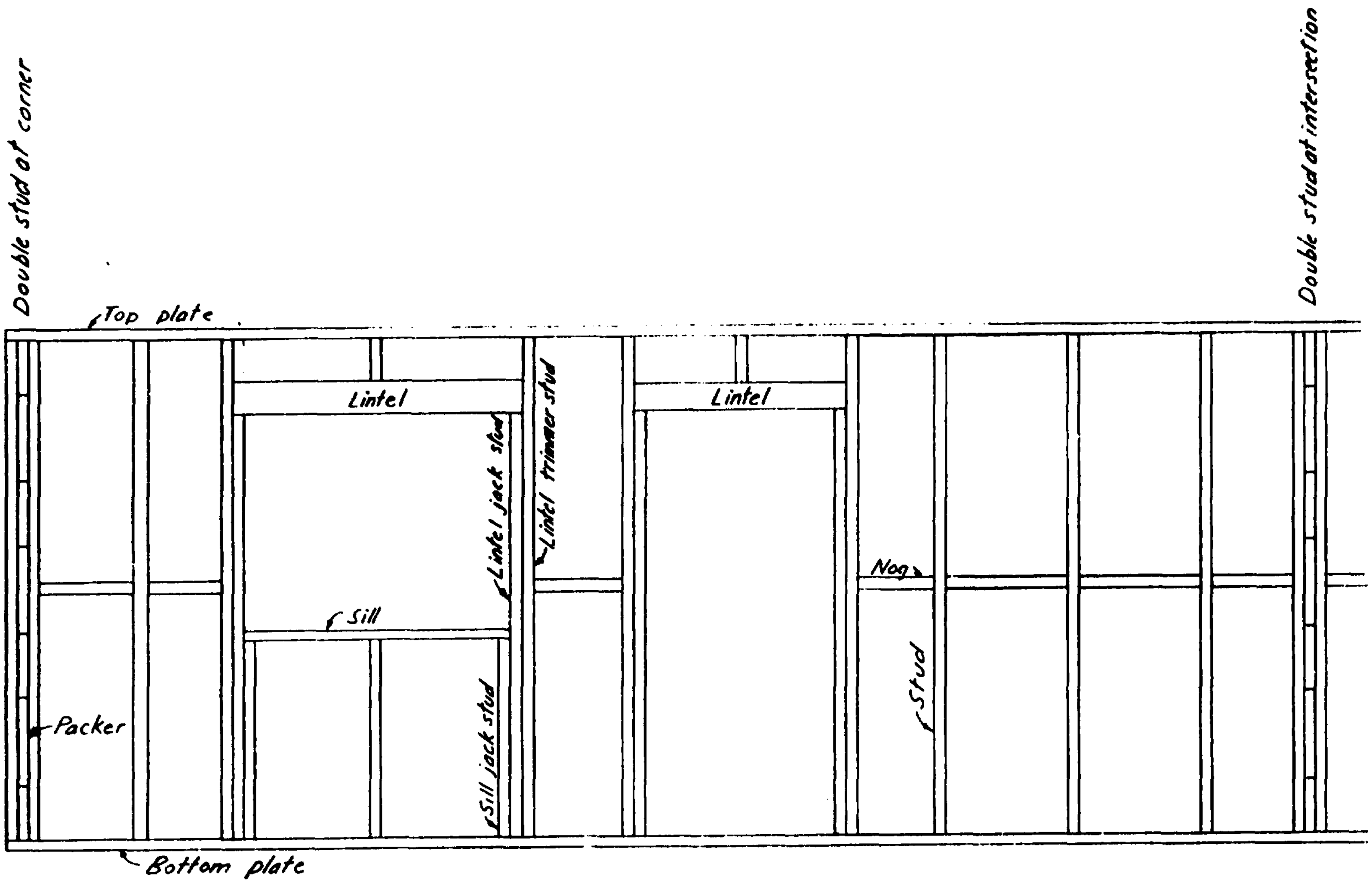
Discerning structural designers will have noticed that the layouts shown have compromised in favor of ease of calculation and manufacture. Structural design codes usually require the axes of intersecting members to meet in one point. In general this is not the case with the layouts shown. Experience in the roof truss industry covering the performance of millions of trusses around the world is that the eccentricities involved are negligible except in the case of the heel joint. Here a special check is required.

The advantages of the layouts shown for the **W** and **WW** trusses are a guarantee of fit of the interior components regardless of their actual width. Also only a single cut is required at each end of every component. The **M** truss is not so ideal in this respect.

If any but a small number of different trusses is to be made the above formulae should be programmed into a computer. This can also print out timber volumes and optimize cutting from commercial (4 m) length timber.

The structural design of the individual components and joint details is beyond the scope of this Report.

The subject of roof truss fabrication, assembly and erection is covered in the report "Trussed Rafters for Repair of Damaged Roofs". Although that report covers only **M** type trusses the principles are equally applicable to other forms.



TYPICAL CONSTRUCTION DETAILS

FIG. 1

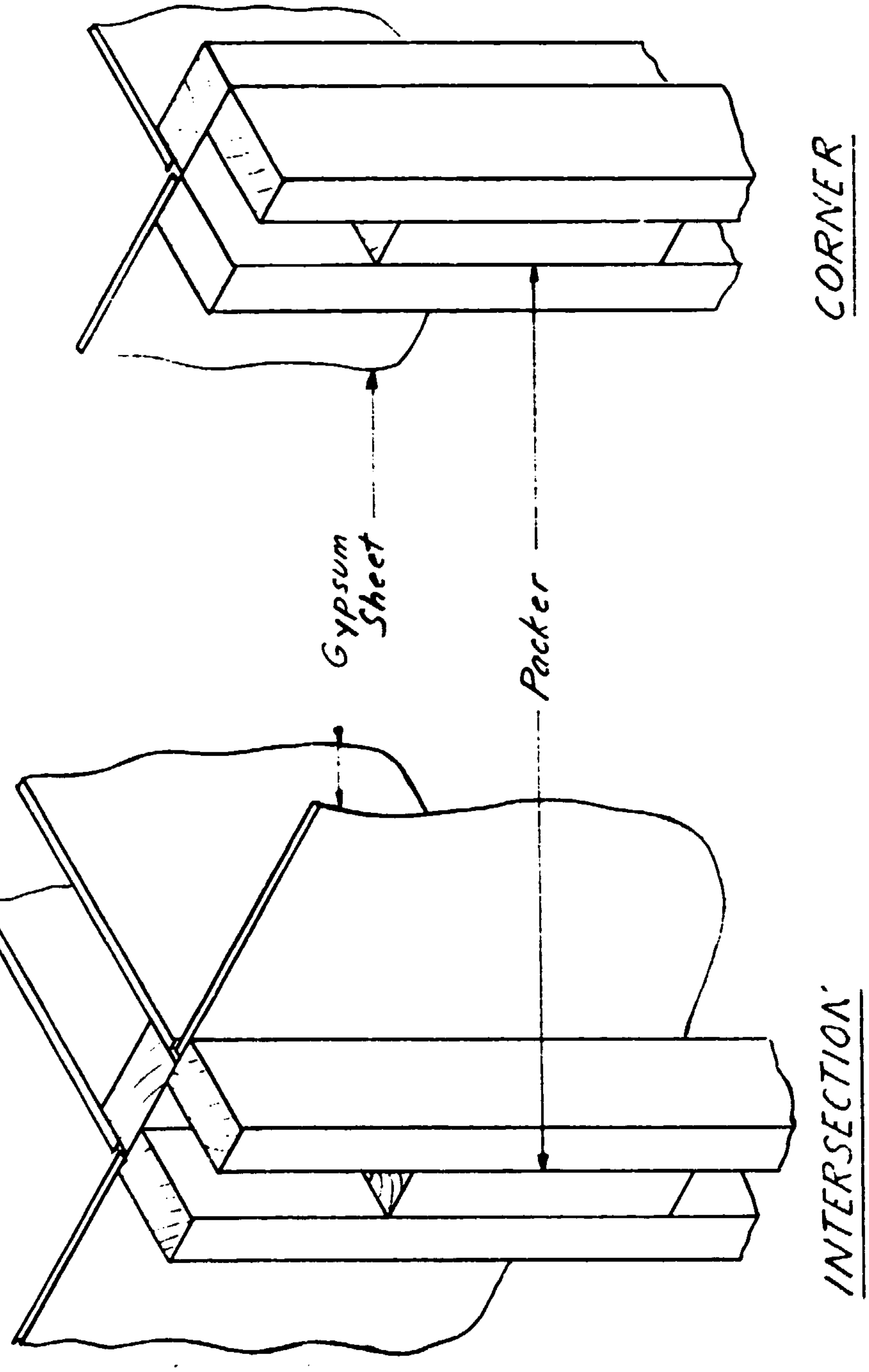


FIG. 2

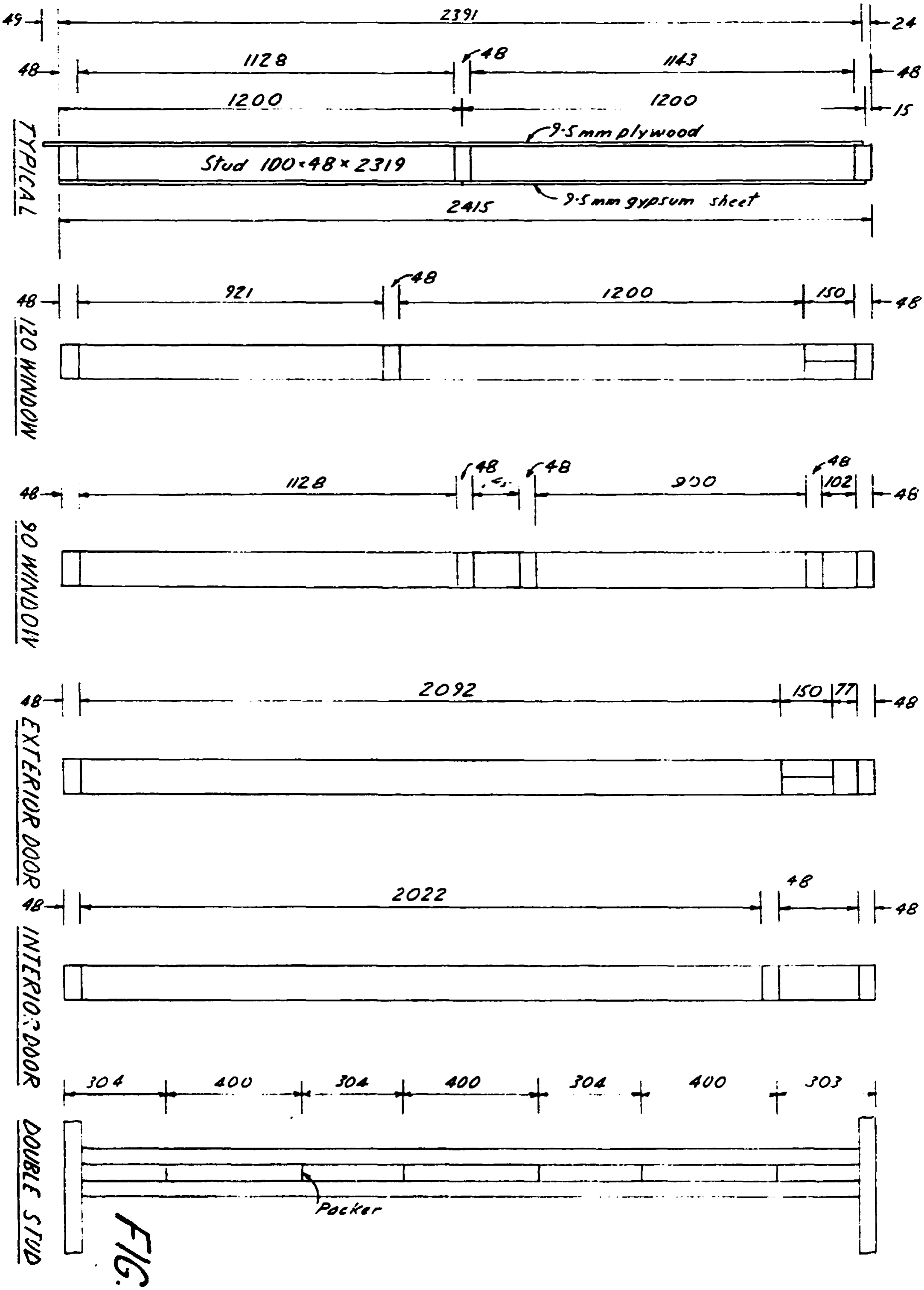
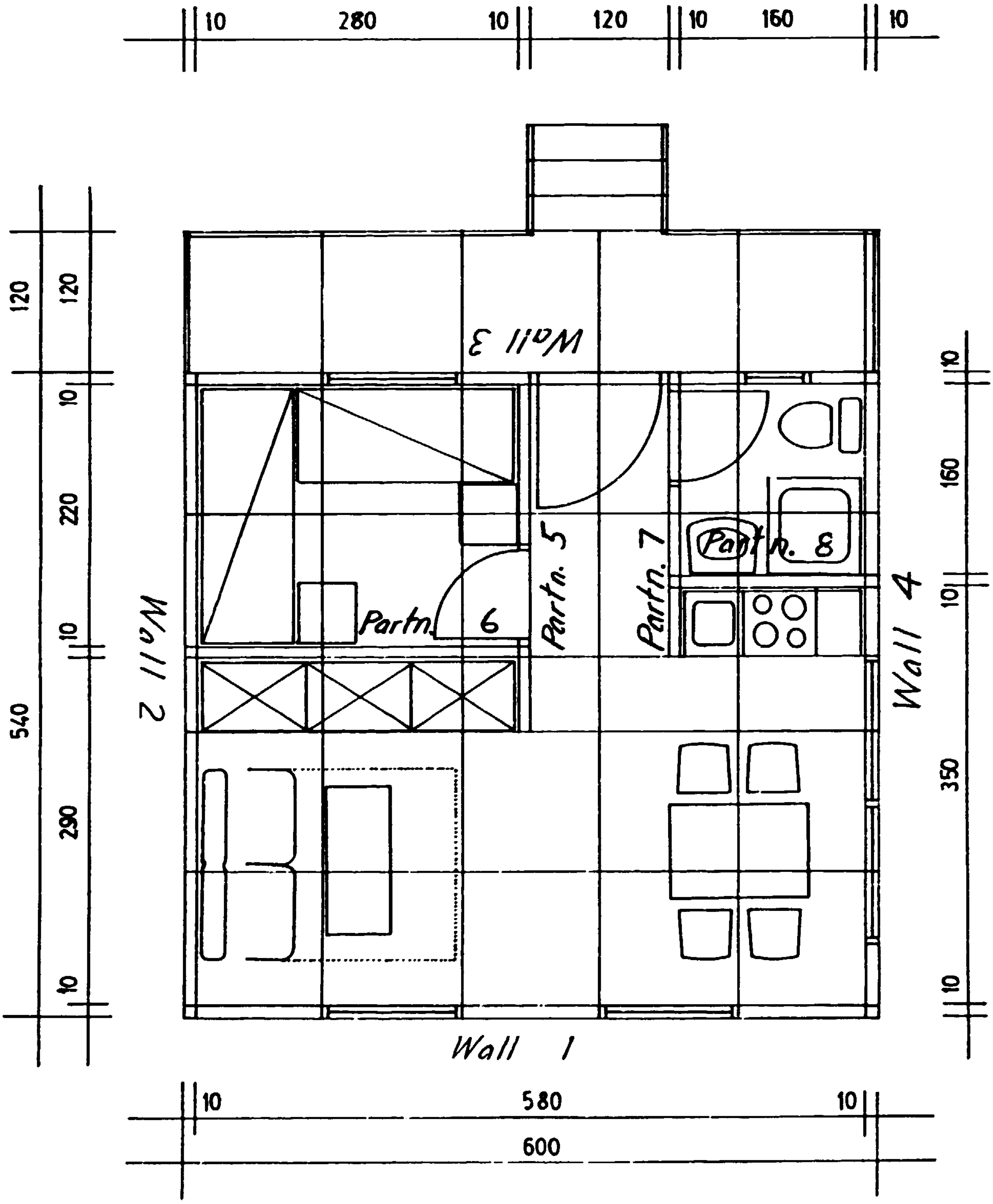

49
2391
24
48
1128
48
1143
48
1200
1200
15
9·5 mm plywood
Stud 100×48×2319
9·5 mm gypsum sheet
2415
TYPICAL
48
921
48
1200
150
48
120 WINDOW
48
1128
48
48
900
48
102
48
90 WINDOW
48
2092
150
77
48
EXTERIOR DOOR
48
2022
48
48
INTERIOR DOOR
304
400
304
400
304
400
303
Packer
DOUBLE STUD

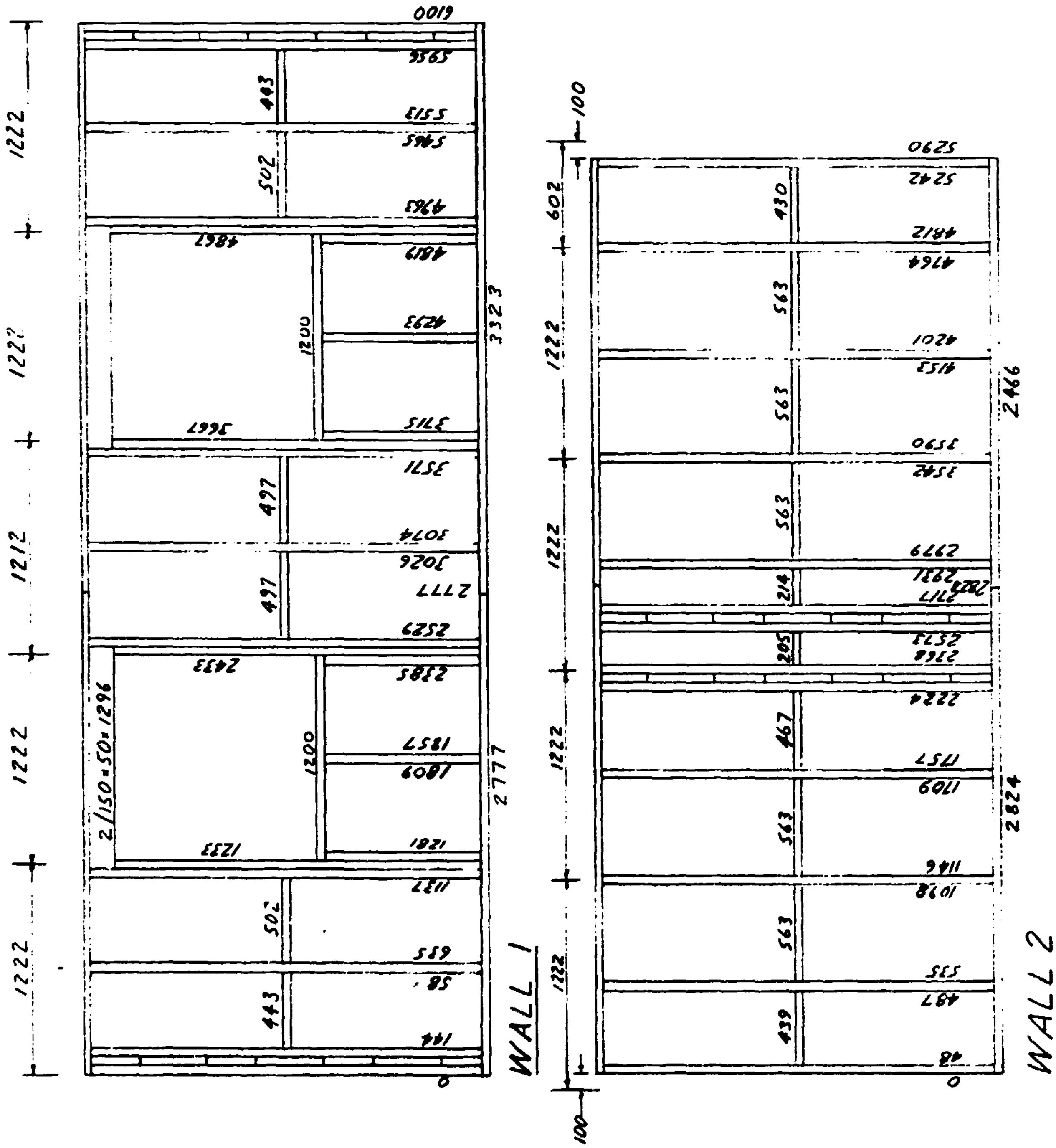
FIG.3



TLOCRT PRIZEMLJA 1: 50

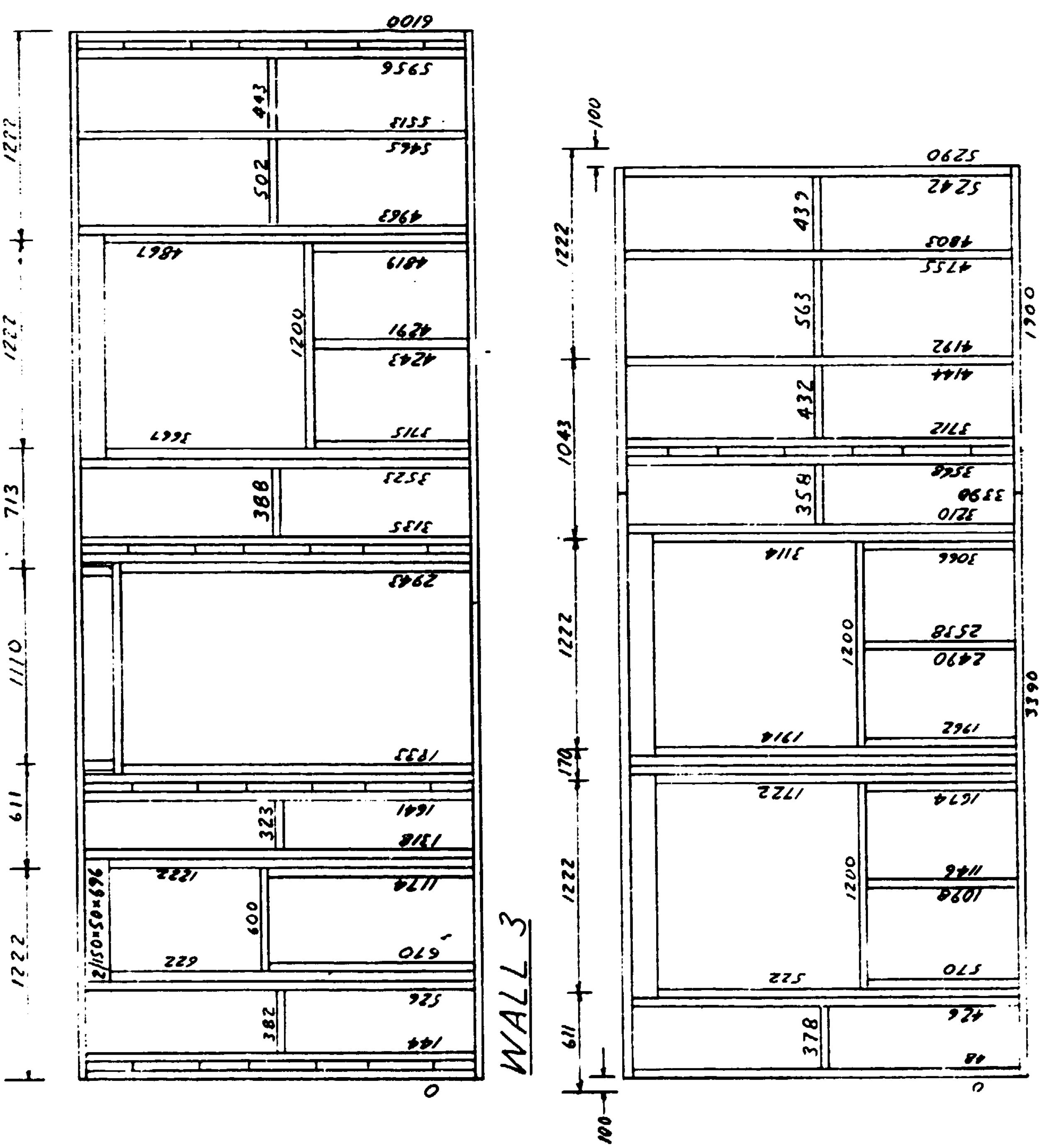
FIG. 4

FIG. 5



OSIJEK HOUSE TYPE 2

FIG. 6



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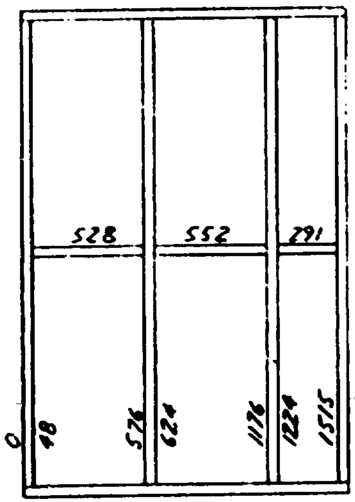

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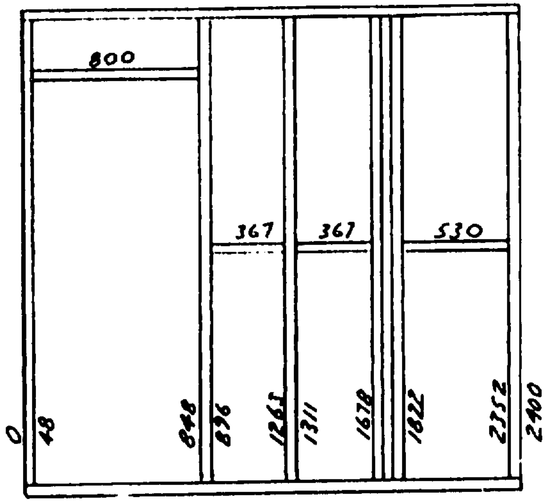

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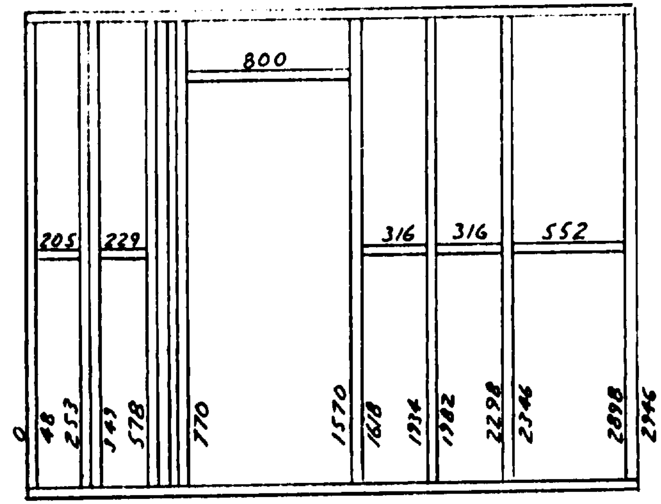

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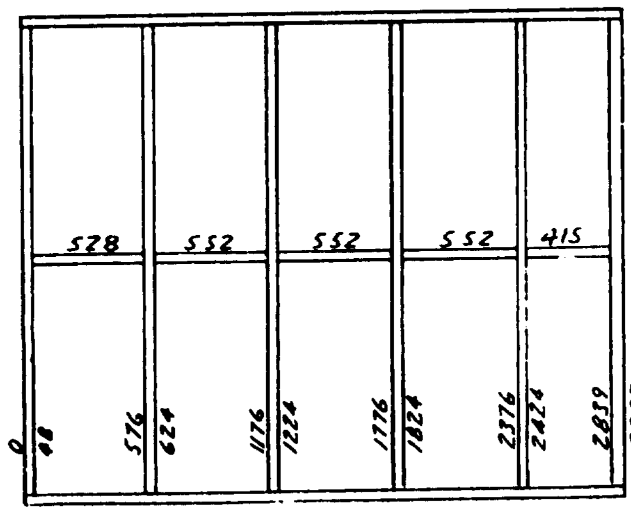


PARTN 8

OSIJEK HOUSE TYPE 2 FIG. 7

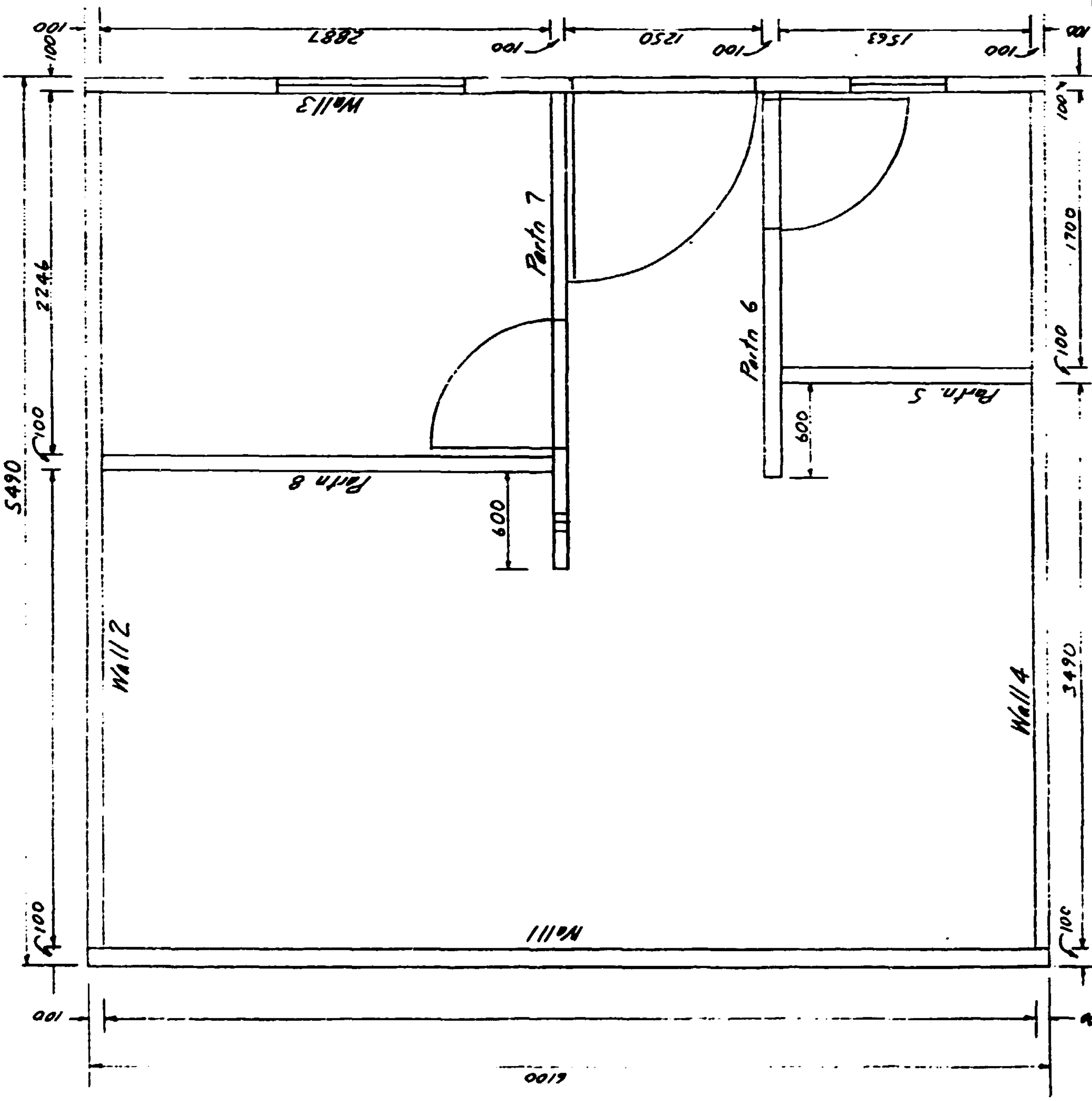


FIG. 8

OSIJEK HOUSE TYPE 2

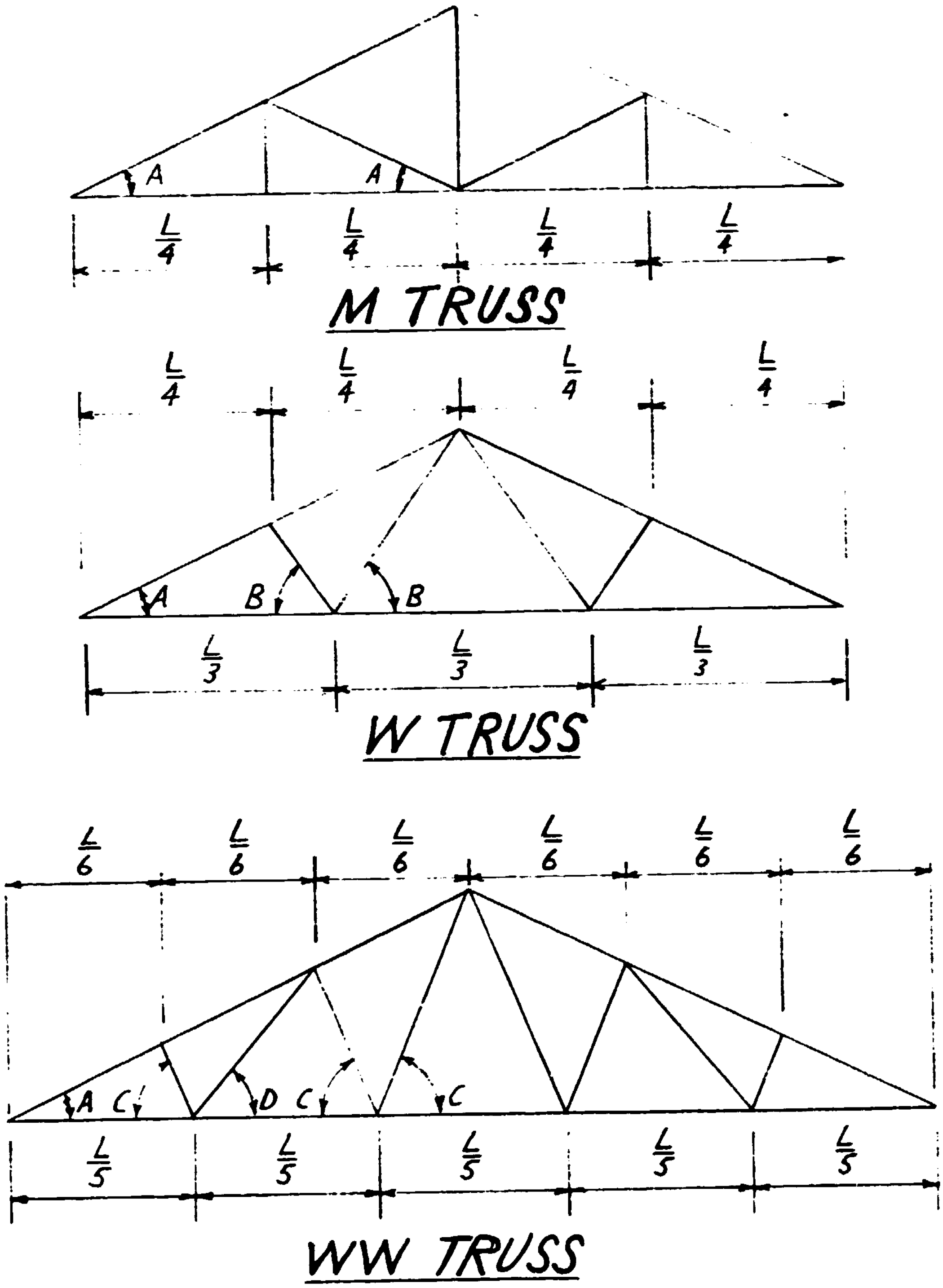
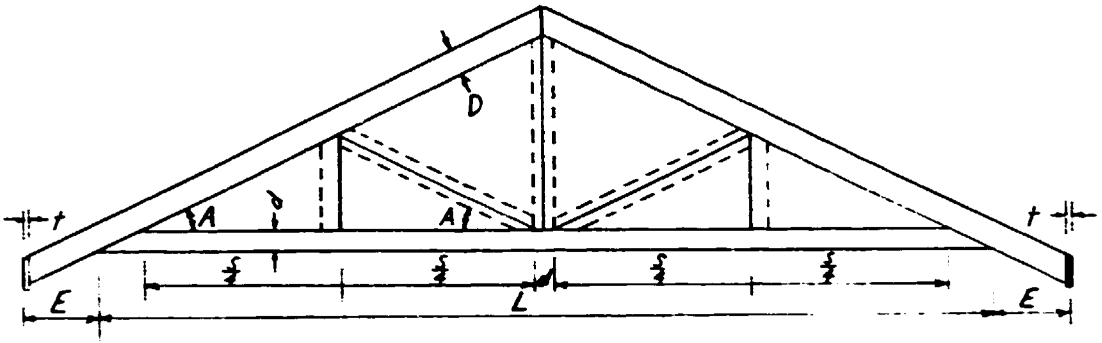
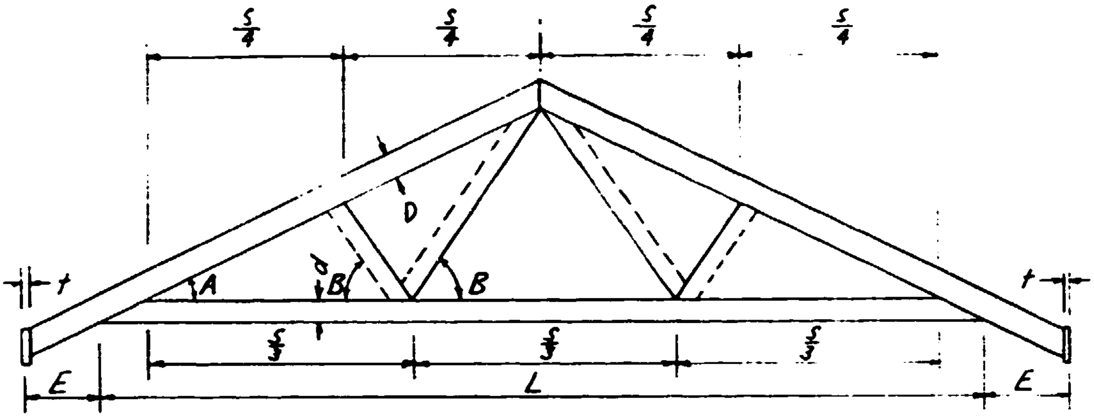

A
A
L/4
L/4
L/4
L/4
M TRUSS
L/4
L/4
L/4
L/4
A
B
B
L/3
L/3
L/3
W TRUSS
L/6
L/6
L/6
L/6
L/6
L/6
A
C'
D
C
C
L/5
L/5
L/5
L/5
L/5
WW TRUSS

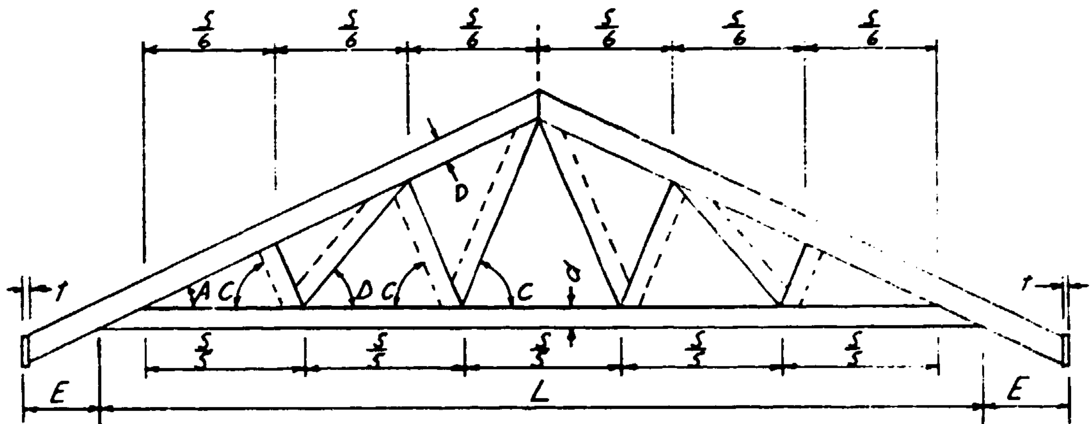
FIG. 9



M TRUSS

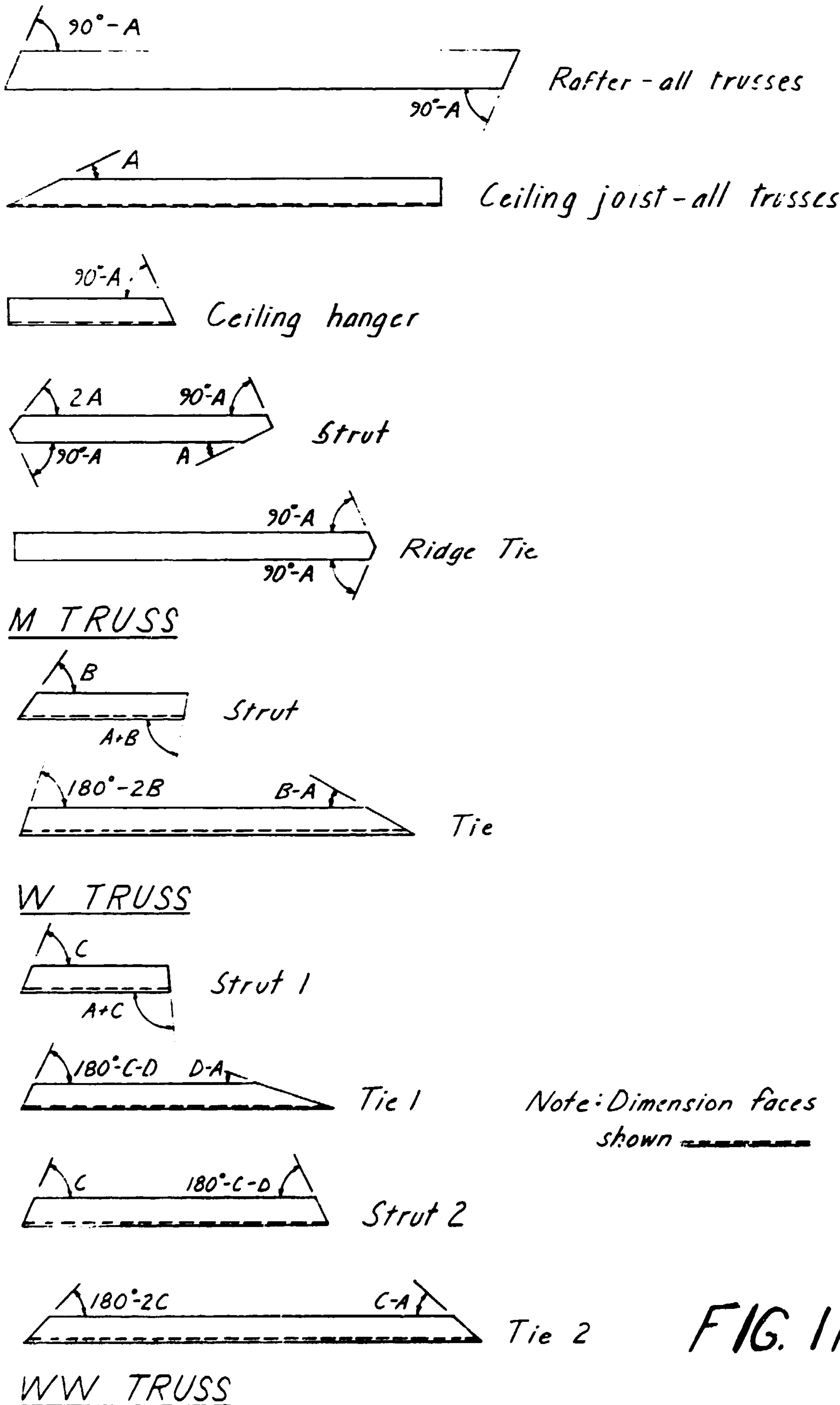


W TRUSS



WW TRUSS

FIG. 10



90°-A
90°-A
Rafter-all trusses
A
Ceiling joist-all trusses
90°-A
Ceiling hanger
2A
90°-A
90°-A
A
Strut
90°-A
90°-A
Ridge Tie
M TRUSS
B
A+B
Strut
180°-2B
B-A
Tie
W TRUSS
C
A+C
Strut 1
180°-C-D
D-A
Tie 1
Note: Dimension faces shown
C
180°-C-D
Strut 2
180°-2C
C-A
Tie 2
WW TRUSS

FIG. 11

Appendix A

Glossary

Fascia	Board covering the ends of rafters along the eaves
Head	Horizontal piece on its flat over a window or door opening
Jack Stud	A stud of less than full length
Joist	One of a series of regularly spaced light beams supporting a floor or ceiling
Lintel	Horizontal beam over a window or door opening
Lintel (jack) stud	Stud supporting a lintel
Nog	Short horizontal piece between studs. Also "dwang"
Packer	Piece of timber separating two studs or joists
Plate	Horizontal timber on its flat at bottom and top of wall. Thus "bottom plate" & "top plate"
Sill	Horizontal member at the bottom of a window
Skew nail	A nail driven at other than right angles to the face of the timber
Stud	Vertical member in a wall extending from bottom to top plate
Trim	Finishing timber round doors, windows etc.
Trimmer	Horizontal member covering the ends of joists
Trussed rafter	Lightweight closely spaced roof truss

Appendix B

6.1 x 5.5 m House

Wall 1		Total length
100x48		
Plates	2/3323, 2/2777	12 200
Studs	11/2319	25 509
Lintel studs	4/2169	8 676
Sills	2/1200	2 400
Sill jack studs	6/921	5 526
Nogs	2/502, 2/497, 2/443	2 884
Packers	6/400	2 400
	Total	59 595
	Volume	0.298 m^3

150x50		
Lintels	4/1296	5 184
	Volume	0.039 m^3
	Total volume	0.337 m^3

Appendix C

6.1 m x 5.5 m House

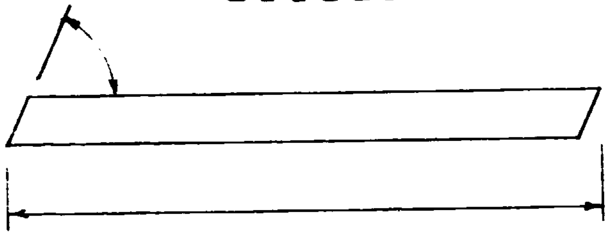
Cutting schedule, walls

100x48		100x48		150x50	
2	3390	2	497	10	1296
4	3323	1	467	2	696
2	2946	1	443		
2	2887	2	439		
2	2824	1	432		
4	2777	1	430		
2	2466	1	415		
2	2400	33	400		
73	2319	1	388		
12	2169	1	382		
2	2092	1	378		
2	1900	1	358		
2	1563	2	367		
2	1221	1	323		
1	1206	2	316		
5	1200	1	291		
15	921	1	229		
2	800	1	214		
1	600	2	205		
6	563	2	179		
5	552				
1	530				
2	528				
3	502				

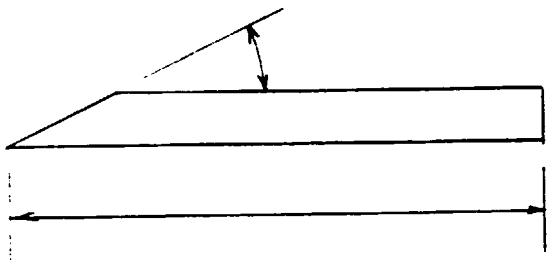
Appendix D

M-truss Cutting Schedule

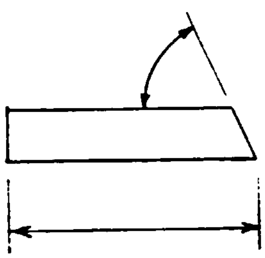
Job N° _______ Number required ______



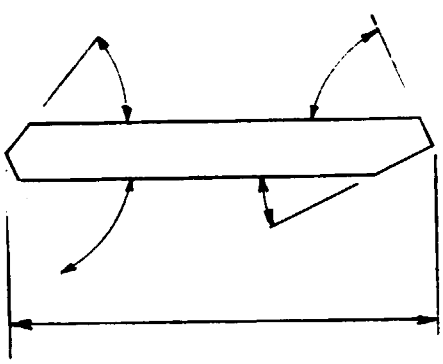
Rafter. Cut
Size x



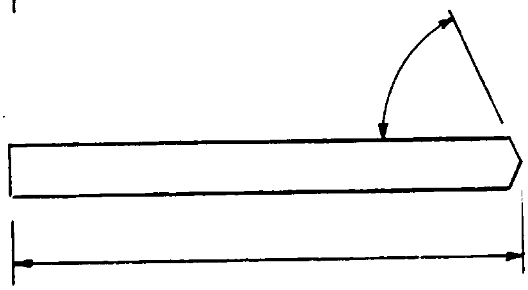
Ceiling joist. Cut
Size x



Ceiling hanger. Cut
Size x



Strut. Cut
Size x

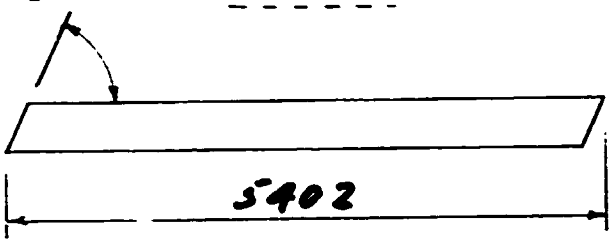


Ridge tie. Cut
Size x

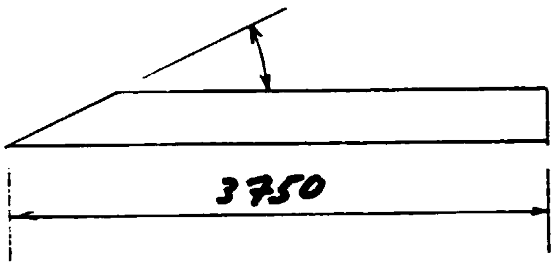
Appendix D

M-truss Cutting Schedule

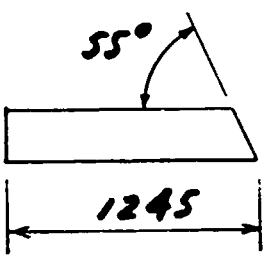
Job N° 123 Number required 21



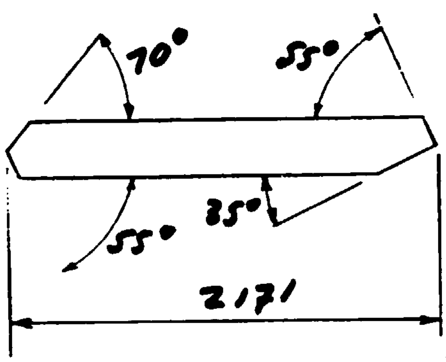
Rafter. Cut 42
Size 150 x 48



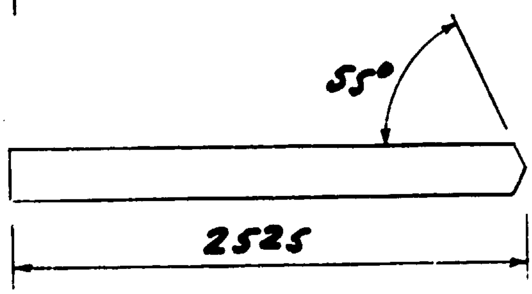
Ceiling joist. Cut 42
Size 65 x 48



Ceiling hanger. Cut 42
Size 65 x 48



Strut. Cut 42
Size 65 x 48



Ridge tie. Cut 21
Size 100 x 48

Appendix E

Backstopping Officer's Comments

The report gives a detailed description of how a timber frame building is planned and "detailed", with clear instructions on specifications for materials. It is very practical and explains how, beginning with an architect's drawing or a client's outline plan of room arrangement, window and door placement and overall dimensions, the dimensioning is done to fit the standard material sizes, cut down on waste and enable site work to be done efficiently.

Although it was done as part of this emergency shelter project in Croatia, it can also serve a general technical training manual for any project aimed at introducing the light timber framing, building method and labour-intensive prefabrication ("Canadian System") into a country. It has clear drawings and illustrations for parts, joints, wall panels and trussed rafters and could also be the basis of an illustrated lecture on the subject.