ROOFS AND ROOFING.

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SCHOOL OF ENGINEERING

PROJECT REPORT

AMERICAN UNIVERSITY OF BEIRUT

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ROOFS AND ROOFING.

Presented By:-

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I N D E X

INTRODUCTION

Since his first moment on earth, man has been, and forever will be, in a continous struggle with different enemies, particularly nature with its severe changes in weather, animals, and even his brother man.

Confronted with those enemies, his vital problem was to furnish himself with an adequate residence that will protect him and his family particularly from nature which could not be satisfied with the strong enclosing walls - which may do with the other enemies, but required some more effective measures, i.e. a good dependable roof, which even was more difficult to furnish and construct than the vertical walls, and required much more conditions to be existing in the materials before they could be used on the roof;—the covering of the upper part of the house, to protect it against the penetration of cold, heat, rain or snow, and of good resistance to fire.

In Man's primitive early stage, when he was living on what he gets in a day of hunting, he was pleased in having a good wide cave, which once blocked at the only opening, i.e. the entracne, will give him safety no matter how unhealthy or unclean it may be.

But with the continuous evolution in his way of living, which led him to the stage of shephard that obliged him to live unsettled keeping always changing the place of his residence depending upon the seasons of the year seaking for pastures which fluctuated from one place to the other according to the seasons, the cave became unpractical as a housing unit for two reasons:

a/ The cave was too small to enclose him and his folks which also needed protection from beasts.

b/ The cave was not always found in the neighbourhood of his new pastures.

Moreover, he had to find a sort of a house which will be always present and easy to construct and to be such that it could be capable of being dismantled for reerection, and could be squeezed to as small a volume as possible to simplify its transportation. The tent seemed to be fit for this, easy to dismantle and reerect, easy to transport and available with skin and cattle hair from his folks while the trees furnished him with the vertical and horizontal necessary posts.

Further development in his life, and the introduction of the family and tribe system obliged him to look for some source other than the cattles for his food, so he had to depend on the production of the ground and became a farmer.

Thus a more permanent house was needed which not only will house him and his cattle, but should be so adequate as to store his products and protect his seeds from being spoiled by atmosphere.

However, in the course of his work in his land, removing stones to the sides, preparing the land for farming, he became aware of the suitability of these stones for building permanent walls, specially when he had to get rid of them anyhow. So he was left with the second part of the problem, namely a roof that will, besides protecting him as previously stated, add stability to his dry masonry walls.

This problem seemed not to worry him much as timber beams from the trees with conjunction with wattle and daub covered with grasses, which is actually the father of thatch as a roofing material, gave him the first and oldest type of proper roofing.

By and by he changed these primitive roofing materials with better types which he discovered through experience, such as stone slabs and specially made tiles of which we find remnants from very old days, and which through continuous modification make our modern roofs.

Good examples from old history can be seen in the Roman, Greek and Messopotamian ruins as well as the famous Egyptian Pyramids. In these old examples we notice the use of some injenious devices such as special units for each particular use such as ridges, hips, caves and gutters, and the special lighting appartures in the sides or middle of the roofs.

CHAPTER I

ROOFS STRUCTURE

Roofs in general, whether flat or not, can be resolved into two major parts:

a/ The covering or the roofing which also consists from

(i) Roofing proper which is the protective and covering part, and so it is the main element of the roof in the full meaning of protection and insulation.

(ii) The sheathing which is the intermediate part between the roofing proper and the frame and which may be omitted depending upon the reliability of the roofing proper.

The roofing proper as well as the sheathing, if any, varies very much from one place to another depending upon many conditions which will be discussed in detail under the Roofing Materials' section.

b/ The Bearing structure or the Frame work which as its name indicates supports the roofing proper as well as fixes it to supports and adds rigidity to the whole structure.

This part also consists of systems of joists or beams, each resting on another and transmitting the dead and live loads of the covering part from one system to the next - starting with the smallest joists at the top - usually called purlins - and ending with the largest joists which transmits the total load to the supports and are laid at reasonable intervals depending upon the span, the weight and its stiffness.

However, the use of different kinds as well as sections of the various materials depend upon

1- The kind, size and weight of the roofing material

2- The shape of the roof.

3- The pitch of the roof.

4- The span and spacing of the supports.

But in general it is mostly of either one of the following constructional materials:

a/ Timber, the primitive material used for this use, as being available in the form of trunks of the trees, almost ready for use, costing nothing more than cutting, trimming and fixing in the form of beams ready to receive the lighter joists carrying the roof's load.

b/ Stones and bricks structures utilizing their compressive strength, in the form of arches, vaults, domes and even the primitive dry conical roof still being used in small villages in north Syria. This type of roof seemed to be the only alternative for the first part in regions with few or no trees.

c/ Steel:- Mostly and almost has superceded the use of timber roofs especially in trussed roofs with long spans, due to:-

(1) Ease and speed in preparation and manufacturing.

(2) Ease and fix in erection.

(3) Better strength and stiffness

(4) More economical especially in big spans

(5) Durability when painted.

(6) More practical for transportation due to smaller volume

d/ Reinforced concrete which recently has been in universal use more than any other material on modern roofs, especially when used in conjunction with the proper treatment as to adequate water proofing and insulations, which were the weakest characteristics of these roofs.

This kind of roofing more than any other kind made the use of flat roofs very practical, as it provides monolithic slab with least joints and adequate durability.

Other types of roof frames are some times used such as allu-minium alloys .. etc..

CHAPTER II

ROOFS' SHAPE

Roofs, in general, are mainly either of two shapes:

(1) Flat Roofs

(2) Pitched Roofs, which could be considered as the origin from which other minor shapes have evoluted with its structural principle based on the compressive strength of some of the materials of low tensile strength such as concrete, brick and stones. Such shapes are:

(a) Vaulted Roofs

(b) Arched Roofs

(c) Domed Roofs

(d) Conical Roofs

FLAT ROOFS

These are almost horizontal roofs, except for a small slope in one or more directions - depending upon the roof area and the span and is usually 1/50 to 1/100 - for the idea of diverting rainwater to the system of gutters at the eaves. Such a slope could hardly serve against penetration of water through the roof especially in other than concrete roofs or in roofs of many joints. So the use of such roofs, in old days, seemed to be practical only in arid regions or for temporary summer buildings, and thus the cheaper pitched roof limited the use of flat roof for many reasons the most important of which are:

a/ Most of the old roofing materials that are fit for flat roof such as lead and copper ..etc. were only found in limited areas, and the concrete was not in universal use, and if used, with poor tensile strength.

b/ Lack of monolithic roofing material with no joints which were weak points in flat roofs where water could penetrate.

c/ Last item seemed to be serious especially with rough surface finishings and unsufficient slope which delayed roof draining, giving water time to find its way down through the roof which lacked any protective or water proofing layer.

d/ Most of old constructional materials were of weak structural strength to enable it to carry the roof loads when laid flat, especially the main rafters or beams, unless through the use of closely spaced supports which means bad economy in materials, labour and space.

e/ Difficulty of making good around openings or projecting parts in the roof had limited the use of ceiling openings and ventilators except on pitched roofs, as water found easy passage around such openings. Such openings and fixtures seemed to be inevitable in old houses and factories or mills, especially in crowded residental places.

However, the modern scientific development made possible be reinforced concrete and steel beams, and the application of more suitabl e material than lead, such as asphalt and bitumen as well as the new insulating materials, has made it more practical to employ the flat form which has many advantages over the pitched roof, other things being equal, such as:

(1) Easy and quick to be constructed.

(2) Provides more open space especially in crowded residental places

(3) More economical especially with reinforced concrete roofs.

(4) Can stand traffic more.

(5) Suits such covering materials that will crowl under its weight and creep in heat of sun.

PITCHED ROOFS

Similar to flat roofs in structure but with a considerable slope in one or more directions, depending upon the materials of framework and roofing proper, as well as upon climate and locality.

It is considered to be older than any other type of roofs, its advantages being:

(1) Materials suitable for its covering available everywhere.

(2) Easy to drain with less risk of dampness.

(3) Provides space for tank and plumbing installation as well as interspace which if not used will anyhow provide heat and cold insulation.

(4) The use of necessary roof openings and other projecting places, made practical.

(5) More economical especially for small houses.

(6) Matches, especially with proper covering, with country back ground, with charming architectural effect.

CHAPTER III

TYPES OF ROOFS

Both flat and pitched roofs have many types which differ from each other in one or more aspects such as slope, type of frame work, kind of materials and use. However, each type with its particular roofing material has a special use.

The following articles will deal with the different types, as far as the structural point of view and the particular constructional material are concerned.

I - FLAT ROOFS

(A) TIMBER ROOFS

The simplest and earliest type of flat roofs, was that composed of wooden joists, cut from the trunks of trees, which spanned between two supporting walls or columns, and which served as beams or main rafters on top of which other beams or joists of smaller cross sections and length, which in turn were furnished by big tree branches, were laid. These secondary joists are laid normal to the length of the main rafters and at 2' 0" to 2' 6" c to c. On top of the second syste of joists the covering material which consists mainly of thatch, sugar cane bundles or small tree branches is fixed by sewing.

The main rafters are about 4.00 m long and 0.20 - 0.25 m in diam. and are laid parallel at around 1.5 to 2.5 m c to c, so they are good only for spans up to 4.00 m.

This type of roofs is still used in some villages especially for temporary structures or summer places, its origin being the primitive houses of man in his early life.

Its advantages are:-

(1) Ease and speed of construction.

(2) Economy due to availability of all materials

(3) Good insulator.

Its disadvantages are:-

(1) Of temporary use

(2) Not water tight

(3) Fire risk

(4) Can not stand strong winds.

(B) TIMBER - MUD ROOFS

It is a modification of previous type and is still used in country villages for second class residental quarters. It was widely spread before the introduction of concrete roofs when cheaper roofs than the tiled roofs were required. Fig (1) Shows details of such roofs.

Similar to the previous type, it consists of:

a/ Wooden main rafters or beams from trunks of trees and 4 - 4.5 m long and 0.20 - 0.30 m in dia. spaced apart at 1.5 to 2.5 m c to c or between walls 3 - 5 m apart. These beams bridge the distance between two walls or supports.

b/ Secondary joists, on top of the main rafters and normal to their length spaced at 0.6 to 1.00 m c to c, and are 1.75 - 3.00 m long and 0.10 to 0.20 m in dia. These joists are either of trunks of small trees or of big branches.

c/ The sheathing which is supported by the layer of smaller joist and which forms a foundation for the earth covering. This sheathing consists of either a layer of branches of trees and twigs or a layer of timber boarding which is provided by splitting big trunks into thin boards. These boards are held to the secondary rafters by nailing and by the weight of the earth layer.

d/ The covering material consisting of 0.20 to 0.40 m thick soil layer on top of the sheathing, well compacted and enclosed by parapet walls. On top of this layer, and as a water proofing measure, a layer of mud and tibu plaster is applied which will seal the roof.

For aesthetic beauty the secondary joists with the sheathing may be hidden by a sort of false ceiling, consisting of a layer of wrought timber boards 2.5 cm thick, closely spaced and nailed to the bottom of the secondary joists. This will add to the insulating power of the roof.

This type is still used even in roofs of good houses with a few improvements such as:

(1) Secondary joists to consist of rectangular section, seasoned timber 2.5" x 5" or 3" x 6" . (Fig. 2)

(2) Sheathing to be of good wrought timber boards and may be covered with a layer of felt.

(3) Timber joists for main rafters may be replaced by a wrought iron joist which can span longer spans.

The advantages of these roofs are:-

(1) Economical - all materials at hand

(2) Good insulator

(3) Ease of construction

(4) Adequate slope could be provided easily by varying the thickness of the soil layer.

However, their disadvantages are:-

(1) Not good for spans more than 4.5 m or else main beams have to be supported in the middle by auxiliary support such as timber column or stone column.

(2) Continuous annual maintenance

(3) Liable to decay and rot.

(4) Fire risk

(5) Once moisture finds its way through a crack, it is difficult to dry.

(6) Furnishes good housing for rats .. etc..

(C) <u>EARTH ROOFS - WITH BRICK ARCHES</u>

Last type seemed to be economical as all material - mostly timber - are available, which is not true for arid places with very few trees, where timber is very expensive, especially in clay regions where sunburnt clay bricks are very cheap.

In such regions an ingenious type of roofing is used which is a modification of last item with main timber joist replaced by a series of parallel steel joist, usually I section, spanning between two walls and @ 1.00 to 1.50 m c to c. The gap between each two beams is bridged by a shallow brick vault with the joists as the springing lines and the rise equal to 0.15 - 0.20 m, which serve as sheathing, as shown in Fig. 3.

On the top of this brick-vault sheathing a layer of earth 0.20 - 0.30 m thick is laid similar to previous type, and sealed with a coat of mud and tibn plaster as well.

Advantages of this type are:-

(1) Good insulation

(2) Strength and durability

(3) Good architectural effect ?

(4) Economical.

While the disadvantages are:-

(1) Continuous maintenance

(2) Difficult to construct, requiring special form work.

(D) EARTH ROOFS WITH MASONRY ARCHES

In country places with little timber and no clay bricks a modification of the earth and timber roof is used.

This type is identical with the other except that the main timber beams could be replaced by a set of parallel series of masonry arches with flat top to receive the secondary joists and the earth roofing.

Each series spans from wall to wall with intermediate stove supports usually about 0.30 m in diameter spaced at approximately 3.00 - 4.00 m.

Timber beams may also be replaced by a series of intermediate parallel walls dividing the space in rectangular strips of approximate width of 2.00 - 3.00 m which is bridged by the secondary joists.

This type has the advantages and disadvantages of previous types. The use of any in a certain locality depends upon the availability of the different materials used in that particular type.

(E) EARTH ROOFS ON MASONRY VAULTS

This type of roof is good for places which are poor in brick and timber.

It could be of either:

(1) Barrel vault - (Fig. 4)

(2) Cross vault - (Fig. 5)

The first type consists of a masonry barrel vault that bridges the whole panel, springing from two parallel walls which serve as supports.

These two walls are extended above the masonry vault to a level higher than the crown of the vault by 0.2 - 0.3 m. This part of the wall serves as retaining wall for the fill of stones and earth, which is laid on top of the vault to get a flat roof and to serve as a measure of water proofing and insulation. As with other types of earth roofs, the top surface of the roof may be plastered with a coat of mud reinforced with "tibn".

This type is good only for long and narrow panels and is used mostly in churches and other public buildings, for architectural effect.

The cross-vault type is similar to the barrel vault and consists of two barrel vaults intersecting at right angles with their crowns at the same level; it also has the supporting walls extended upward to support the fill as in the previous type. This type is also restricted in use to churches with the vaults extended beyond the intersection on each side of the other vault, having the shape of a cross; and to residential rooms of almost square shape thus having the out-to-out span of one equal to the length of the other vault, thus having the two vaults resting on four abutments each in one of the four corners, in which case it is known as the level ridge vault (Fig. 6) and is practical for spans of 4.00 - 6.00 m.

For wider spans, the area is divided into two or more almost square pannels, by the use of intermediate masonry columns, each of which will be shared by two or four adjacent pannels depending upon whether it is exterior or interior support respectively.

In all these three types the stones used in the vaults may be either finely dressed in which case the soffit is left with the masonry exposed, or it may be roughly squared in which case the soffit should receive a coat of internal plaster which is of mud and tibn or sand and lime. The second alternative is the cheaper.

This type is not used any more due to its high price as it needs a lot of formwork as well as workmanship, especially when it is possible to use reinforced concrete. An average cost of this type is between LL.50.00 - 60.00 /M.S.

However, the advantages of this type are:-

(1) Good insulator and water proof

(2) Very strong

(3) Practical in remote places where other materials of construction are expensive, particularly for long transportation.

The disadvantages are:-

(1) Very expensive

(2) Needs maintenance

(3) Long time for construction

(4) Very Heavy.

(E) STONE SLABS ROOF (RABAD)

This type of roofing is still used in remote villages in Syria, where they lack the timber and steel and where the rocks could be splitted into fairly long and thin slabs about 1.50 - 2.00 m long, 0.20 - 0.60 m wide and 0.10 - 0.20 m thick, which are used to bridge roofs.

This type of roofing is good only for spans from 2.50 to 3.50 m, otherwise, the area should be divided into strips of a width withing this range by the use of supports that could be either intermediate walls; or, as when more space is required, they may be of a series of arches at about 2.50 to 3.50 m c to c, supported by the walls or by walls and intermediate masonry arches. In any case the top of the support should be flat.

On top of each support a row of closely spaced stone slabs is laid, with their length normal to the direction of the support, overhanging equally on both sides, and with their width in the direction of the support.

The gap between each adjacent pair of rows of slabs is bridged by another row of slabs overlapping equally on both rows, as shown in Fig.7.

The top of these slabs is covered with earth and mud as has been already explained.

Advantages of this type are:-

(1) Cheap for small panels

(2) Water tight

(3) Good insulation

(4) All material locally available

(5) Easy to construct

Disadvantages are:-

(1) Good for small spans only

(2) Not economical in long spans when arches are neaded

(3) Heavy

(4) Rather unstable.

(F) METALLIC ROOFS

These roofs are similar to the timber joists roofs but are of lighter weight and better architectural, as well as water proofing, characteristics, because the heavy permiable earth covering is replaced by other metalic coverings which fit the flat roof.

Moreover, the heavy joists, whether main beams or secondary rafters, are not needed in the same stiffness and size because the dead weight they had to sustain was considerably reduced. These joists were even replaced in some cases by metalic joists such as steel and other alloys especially rolled. However, the joists could be of:-

(A) Timber Joists: The space which is to be roofed is bridged by main rafters of timber joists, the depth of which depend upon their spacing and upon the weight they had to sustain, usually 2' - 4' c to c, and they run normal to the direction of the slope if they have to receive the boarding directly, and in the direction of the slope if they have to support a layer of purlins. These main rafters span between supports for small spans of 6' - 8' approximately; otherwise, they have to be supported by intermediate beams.

On top of the rafters, or the rafters and purlins, the sheathing, consisting of timber boarding, is laid with their length parallel to the direction of the slope of the roof - 1/50 to 1/80 - so as not to obstruct water if the boards get twisted due to heat and moisture.

The covering material is laid on top of the sheathing, with or without an insulating and water proofing covering material such as felt .. etc.. on top of the sheating. Most important covering materials are lead, copper, zinc and asphalt with felts; these will be discussed later.

As some metalic coverings such as lead, zinc and copper have a relatively high coefficient of expansion, they should be fixed on roof in a way which will allow these material to expand and contract easily in the direction of the fall, i.e. the direction of their length.

This is provided by fixing the different sheets to the sheathing by the means of rolls in the direction of the fall and by drips in the direction normal to the fall, all placed at the junction of the sheets as follows:-

Rolls:

(1) Hollow rolls: consisting of a metal tack nailed to the sheathing at the junction of two sheets and bent vertically with its free end hooked, these two sheets on each side are bent against the tack as shown inf Fig. 8, with the free end of one of them hooked inside the hook of the tack. The three pieces are bent in the form of a circle as shown in the figure. This will allow free expansion and provide water tightness.

(2) Timber rolls: ($1\frac{1}{2}$"x2") rounded or splayed, which is nailed to sheathing along the joints of the sheets at a distance c to c equal to width of sheet minus the lap.

The edges of the two adjacent sheets are bent on top of this roll one on top of the other from one bottom edge to the opposite edge of the timber roll as shown inf Fig (8a). One sheet forms the undercloak, and the other the overcloak. These cloaks are held in place by special clips.

In some cases the edge of each sheet is bent vertically only against the near face of the roll, which is rectangular or splayed, and a special U-shaped cap encloses the roll and the bent edges and it is also held in place by nailing to the rolls, as shown inf Fig. (8B).

Drip:

Is used along horizontal joints where a step is formed in the sheathing $2\frac{1}{2}$" high, against which the edge of the lower edge is bent with its edge flush with top of step. Then the upper sheet is laid with its edge over hanging over this step for $2\frac{1}{2}$" which part is formed in the shape of a semicircle as shown inf Fig (8c) or is bent downward against the partof the lower sheet which is bent as inf fig (8d).

Welted Joints:

The drip is sometimes replaced by a welted joint by forming the adjacent edges of the sheets in the form of flat hooks which interlock each other with an intermediate hooked clip which is nailed to the boarding to hold the sheets in place as shown inf Fig (8e). This is used on slopes steeper than 1/8.

Corrugated Steel Roofs:

In second class buildings and in temporary roofs the covering on the purlins, without the sheathing, may be of corrugated iron sheets both new or old, and may be painted or galvanised.

These sheets are fixed to the purlins with nails and washers or with hook bolts and washers - both lead and steel washers.

For further precautions against water leakage and for insulation, the top of these sheets may be covered with a layer of any of:-

(a) Felt with asphaltic compounds

(b) Concrete or cement screeding

(c) Mud and tibn layer - on old sheets.

(d) Grass or thatch

(e) Paint.

If a still better job is required, a timber sheathing with felt on top of it may be used.

Asbestos Sheets

These are either plain or corrugated, fixed in a similar way to corrugated iron sheets but to a less extent on the timber joists.

(B) Steel Joists:

The timber rafters and purlins could be replaced, for the sake of strength and durability, as well as a quicker job, by steel members in any of the following shapes:

(1) Steel pipes 2" - 4" in diameter as rafters and purlins, especially with corrugated iron sheetings which are built in the supporting walls. The same coverings for corrugated sheets recommended in the previous articles are recommended here also.

(2) Rolled Joists: used in better and more permanent buildings, and are of special cross sections either small channels or small I - beams over which asbestos sheets or iron sheets are fixed or, if a somewhat tougher job is required, thin steel plates will be welded to the top of these joists and covered with some insulating layer such as earth, asphalt, cinder or foam concrete. However, these joists, if laid in a special way, may be covered with precast slabs of concrete or other material which will be discussed under concrete roofs.

(3) Steel Trusses: These are similar to other trusses, which will be discussed later, but of special shape having their top member parallel to the bottom chords and horizontal. These are of three types, warren, prat and howe, the latter more common in flat roofs, and are good for spans between 40' to 130', and having their depth almost equal to 1/5 of the span.

On top of the upper chords and starting from the middle of the span in both directions, a series of fairly close vertical supports are fixed, diminishing in height so that to have their tops sloping outwards in both directions at a gentle slope (Fig. 9).

On top of these supports and in direction of the slopes, the common rafters are fixed, and on top of these horizontal purlins normal to direction of slope are fixed to receive the sheathing or the covering material.

(4) Steel Troughs: Used in quick jobs and for small spans. These troughs of sheet metal of trapezoidal shape with wide base at the top and with the two legs bent at the top outward for a distance almost 2/3 of the small base. This hanging part is drilled for a row of bolts, at a distance from the end of the wide base equal to ½ the small base, by which the troughs are fixed to each other by bolts.

The troughs are laid with their ends on the walls and their overhanging parts upward with the holes in one exactly on top of the holes in the legs of the adjacent trough, and are bolted to each other.

On top of these troughs some water proofing material is applied such as asphalt or concrete and on top of that a layer of earth is deposited to add more insulation and to make the surface level with a small slope for drainage. This type is shown in Fig. 11.

As these troughs are tightly bolted at the ridge by closely spaced bolts, they could be relied upon for water proofing, but not insulation, if proper drainage is achieved and the troughs are sloped a bit. In this case the top of these troughs may be painted with lead paint which reflects the heat and in this case they may be left with no covering.

(G) CONCRETE ROOFS:

Although this type of roof is rather a new subject, yet it has almost superceded every other type of roofing especially when economy in expense and time is considered.

As to principle, it is actually a modification of the old types of roofs, especially that of joist supported on a series of arches as beams which in turn are supported by stone columns, except for the only substitution of reinforced concrete members for almost all other members, from column to roofing material; all built monolithically with each other, except for few expansion joints and thus increasing the stabilizing and waterproofing characteristics of the roof.

In general, the concrete roofs are growing in popularity due to the following:

(1) Ease of construction

(2) Needs no time for preparation - design or fabrication.

(3) Could be applied to any reasonable span and shape, thus producing good architectural effects.

(4) Can stand very heavy traffic and is more rigid.

(5) Monolithic surface with less risk to leakage

(6) Economical in transport of materials and in first cost as all materials could be found locally except steel, and as well it is evonomical in construction and maintenance.

(7) Fire Proof

(8) Long life

(9) When used in conjunction with some hallow block, it provides good insulation.

(10) Made the use of flat roofs very practical.

However, the main disadvantages are:

(1) Poor thermal and sound insulation

(2) If improperly laid, it is not water proof and very difficult to repair.

(3) Heavy

(4) Takes longer time in construction than steel.

But these disadvantages are loosing their importance especially with modern development in ways of construction and in waterproofing and insulating materials, such as:

1- A layer of cinder or foam concrete on top of concrete slab

2- Bitumastic compounds with felts and cork

3- Use of Hollow blocks in ribbed construction

4- Cinder fill (over which slab is poured).

5- Double roofing - light slab on top of main slab

6- Suspended or false ceiling

7- Fixing some insulating slabs on top of the concrete slab through timber beads imbeded in the concrete.

8- Special water proofing tiles on top of concrete slabs cemented to it with igasol and rebated joints filled with mastic.

9- Fixing cork or thatch boards to button of concrete slabs by ~~screws~~ bolts fixed prior to casting the slab which imbeds them.

10- A plaster of cement mortar applied to the soffit and preferable rough cast, or as in better jobs, a layer of itex plaster is applied.

Concrete roofs are mostly flat, divided according to principle of construction and shape into the following:

(1) Beam and girder

(2) Beam and slab

(3) Flat slabs

(4) Ribbed roofs

(5) Steel joists and slab

(6) Precast slabs on steel joists

(7) Prestressed concrete roof.

(A) beam and girder

This type is based on the principle of the old types with the load transmitted to the column by huge widely spaced girders which frame in to and is supported by reinforced concrete columns, and which in turn support a series of more closely spaced concrete beams which frame into the girders and transmit to them the load which the beams receive from the slab which forms the flange of the beams, by being built monolithically with the beams. This slab is actually a flat beam supported by the main beams, and so serves for the covering material, the sheathing and the purlins. The soffit of this slab is either plastered with cement mortar or lined with some insulation boards or treated with itex ..etc..

The monolithic construction of slab beams and girders has the following advantages

(1) Good water proofing due to least joints

(2) The slab is able to support itself through the reinforcement, less beams are needed.

(3) More rigidity

(4) Economy in materials due to the stiffness of continuous structures over simply supported members.

(5) Columns and supports could be put at wider spacing ranging 16' - 32' with the load on slab between 40-400 lb/sq. ft.

The disadvantages of this type are:-

(1) Not economical with two wide spans and heavy live load

(2) Bulky

(3) Obstructs light by Girders

(4) Bad thermal insulation.

(B) Beam & Slab

This type of roofs is a modification of the previous type, but with the slab built monolithically with the reinforced concrete beams which frame directly in columns or other type of supports.

Such roofs are economical for narrow and long panels with beams parallel to the length of the panel and the slab reinforcement running normal to the direction of the beams, although it may be used successfully in more or less square pannels of small spans with slab reinforced in two directions.

(C) Flat Slab Roofs

These are used when the roof is supposed to sustain heavy weights, or when the architectural design requires this; e.g. for the sake of the facade, or as in the case of very low roofs, the beams are not desireable as they will obstruct light.

These roofs consist of a relatively thick slab with reinforcement in two directions and along the diagonals, with the load transmitted directly from the slab to the columns, (Fig. 12 c)

This is economical in slabs up to 30' and for live loads 100 - 300 lbs/sq.ft, its advantages being:-

(1) Economical in heavy loading

(2) Easier formwork and construction

(3) Saves space be getting rid of too deep girders and beams

(4) Admits more light and air

(5) Better architecture is possible through high windows, etc..

However, the disadvantages are:-

(1) More intricate steel work

(2) Economical only in square panels or where the ratio of one side to the other is between 0.75 - 1.33

(D) Ribbed Roofs

These are modifications of the first and second types, here the slab and beams are replaced by a system of small closely spaced parallel ribs, transmitting the load to larger beams and girders or to the beams only and carrying a thinner slab which forms the flanges of small T-beams with the ribs as the webs of these T-beams.

These ribs, which are usually spaced at 1'6" to 2'0" may be in one or two directions depending upon the shape of the panel and the span, with the space between them left freee or filled with a filler which could be of many kinds.

The introduction of this type to concrete roofs has improved these roofs in the following respects:

(1) The use of false ceiling, fixed to the bottom of the ribs, such as plaster, metal lath or boards of insulating material or the use of special joist facers with hollow blocks, have facilitated the use of concealed electrical and other installations.

(2) The dead space between the ribs, aspecially with fillers had improved the Heat and Sound hollow insulation of the concrete roof.

(3) The possibility of placing fixed load anywhere on the roof became practical.

The filler used between these ribs is of various kinds, some of the important of which being:

(1) Clay Tile Blocks: They are clay blocks; clay which is burnt in the kiln, and are usually hollow for the following reasons:-

(1) Provides better insulation

(2) Lighter dead weight

(3) Easier for cutting when fixing installation as well as providing space for these installations.

(4) More economical.

These blocks are of standard size usually 12" x 12" and 4"-12" thick or 8"X6" and 5"-7½" thick, and are laid in rows between the faces of the concrete ribs which are usually 4-5" wide.

The soffit of this roof could be treated with any of the following:

(a) Plaster applied directly to the roof after hacking the concrete ribs, the blocks being molded with rough bottom.

(b) Plaster applied on metal lath fixed to the bottom of the ribs.

(c) Special clay joist facers which fit to the bottom of the rib and are supported by two grooves in the lower edges of blocks. These facers are usually $1\frac{1}{2}$" - $1\frac{3}{4}$" thick (Fig. 13 a), and are laid on the shuttering with their bottom flush with the bottom of the blocks before concrete being casted on top of both.

(d) The Blocks should be having a projecting nib at the lower edges $1\frac{1}{2}$" thick and projecting a distance equal to half the width of the concrete rib.

II - Hollow Concrete Blocks; (Hourdeis): The previous type is expensive especially in regions which are not clayy. So the cheaper hollow concrete blocks are used as the filler and are laid on the same principle as the clay blocks.

They are mostly of regtangular cross section with a slight champher at the top corners, for easier laying of concrete; with the bottom and sides rough enough to provide good adhesion, and with two or three cavities in the centre, in the direction of their length which cavities may be circular or rectangular. For providing vertical support to the blocks, beside adhesion with concrete, the blocks are sometimes made of trapezoidal cross section with the short base at the bottom or the blocks are made with a rebate at the lower edges where concrete will be forced forming a nib as a support for the blocks. However, more complete knowledge of of concrete strength has almos proved the unnecessity of these devices.

These blocks, (Fig 13 b), usually 8"x16"x5½"-7½" and are placed in single or double rows both in one or two directions, over which concrete ribs, usually 4" wide and concrete slab, 3" thick, both reinforced and monolithic are poured.

As to the treatment of the soffit, what has been stated for clay blocks may be recommended here.

These blocks are more popular here in the near east than any other kind of hollow blocks as they are more available and their price considerably less, the price of each block being between 35 & 50 LP for the 15 cm and 25 cm. thick respectively. The price of roof with these blocks at reasonable spans is between 17 and 20 LL per square meter of the roof.

III - Gypsum hollow tiles: They are similar in principle and the method of construction as well as treatment of c eiling of soffits, to clay tiles only differing in shape.

They have the merits, over the clay blocks, of being light and easy to break or cut to fit the required size, but have the disadvantage of great wastage through breakage if not properly handled, especially when transported; moreover, they are more expensive.

They are of two main sizes: (1) 19" long, 12" wide, with rectangular cavities parallel to 12" side and are placed at 24" c to c, the rib being 5" wide. (2) 30" long x 12" wide with circular cavities parallel to the 30", and 3 to 8" thick, weighing 9.4 - 22.4 lb/sq.ft. They are placed at 16" c to c, leaving 4" for width of concrete rib.

IV - Terra-Cotta blocks: These are of a special kind of clay and of the best nature and mix. They are either solid or hollow.

The solid are also either (1) dense, hard and with high compressive foree, or (2) porous or semiporous, the voids being made by mixing saw dust which will burn in the kiln leaving empty space voids; these will reduce its weight as well as add to the insulation power of the blocks and help for better adhesion with the concrete.

The voids are 20% for semi porous and 33% for porous blocks. The advantages of these blocks are:

(1) They can be cut by the saw to any shape desired
(2) Could be nailed
(3) Good surface for bonding with concrete.

The hollow type are used for lighter construction in a similar way to other hollow blocks. The size being 12" x (18" x 24") x 3" and weighing 20 - 22 lb/sq.ft.

V - Steel tile fillers: These are special form of inverted U - channels, tapering in section with its wider base at the bottom, and are used either to stay in place with metal lath for plaster welded to them or as temporary shuttering for forming the ribs only with metal lath or other false ceiling fixed to wooden strips or wedges embeded in the bottom of the concrete ribs. The latter method is the most commonly used due to its economy in steel tiles and shuttering.

These tiles are of special staddard size 30" - 36" long and 4" - 14" thick and the width at the bottom from 10 - 31"; a width of 20" is the more common.

Near the supports, where more concrete is needed for the shearing force, special tiles are used with blocked ends and tapering in width in both horizontal and vertical sections as well as tapering in their height, the lower being the blocked side.

This type of fillers is becoming popular especially in buildings where a good speed in construction is needed, and where the saving in cost of fillers is more than cost of insulating layer fixed to the bottom of the ribs, to compensate for the Hollow fillers insulation.

VI - Hollow Slabs: The slab in this type of roofs may be either monolithically built with beams and girders or be laid on some other support, with the slab poured with a series of circular and parallel cavities, closely spaced, formed around rubber cylinders with compressed air inside them which air may be evacuated after pouring and setting of the concrete and the rubber tubes taken out, thus leaving the slab in the shape of I - ribs with edges of flanges touching each other.

This type, Fig. 13 d, known by the name of Hourdis Rogeir is liked as being very quick in construction, strong, and cheap as saving concrete with very small expenses on forms, But losing some of the merits of other alternatives in ribbed roofs.

VII - Glass Blocks: In roofs of special design such as in workshops needing light, in roof gardens and Hospitals, glass blocks may be substituted for other blocks as fillers between the concrete ribs.

Such design is very expensive and delicate and used only for luxury and for special use.

These blocks are of special ingenious design, (Fig. 13 e), and of special shape. They are used both in flat and arched roofs, and may as well be used for the whole roof or for special openings in the roof.

VIII - Precast Trusses: (Fig 13 f): A new patent which is used for very heavy loaded roofs and is remarkable for its easy fixing of the steel reinforcement as well as the economy in the quantity and workmanship needed in the shuttering.

It is better than any other filling for long spans and heavy leading especially with conscentrated loads which can be placed any where on the roof, because this unit is designed to carry some load which it transmits by arch truss action to the ribs.

It is remarkable also for the economy in the concrete/unit area, both of which are used in the rib and in the manufacturing of this filler. Moreover, it has a lot of empty space, and so a very good insulating property.

However, its use is somewhat limited becaust it is a new patent and of a considerable height, thus making it practical on large spans only, which need thick slabs.

(E) Steel Joint Roofs

This type of concrete roofs differs from the others in having the slab simply supported on a series of closely spaced parallel and shallow joists in the form of trusses on actually shallow steel trusses, from the pratt, warren or double warren type, supported on the ends on steel or concrete beams or on supporting walls.

These joists carry a thin slab of concrete slightly reinforced or precast concrete or gypsum slabs filled with mastic aththe joints. On top of this slab or slabs an insulating and water proofing layer is applied which may consist of either felt and asphalt, felt and cork, cinder concrete, or foam concrete.

These joists are of standard sizes which range between 8" - 16" deep and 4' - 32' long and are placed at 12" - 30" c to c, and are sometimes braced laterally with smaller joists normal to the main ones.

This type of roofing is economical in places of light occupancy, with no vibrating loads as they are easy to construct and prepare, with less transport expenses except for very far places, and saves a lot on concrete. They can also be dismantled on demolishing of roof and reused again. Moreover, similar to rib construction, they can be made good insulators and could provide ample space for hiding any roof installation by fixing easily to the bottom of the joists either metal lath with plaster or any other insulating material, leaving dead space between these insulators and the concrete slab.

A modification of last type, is the concrete slab supported on steel beams and is used in buildings of inferior importance in which these prefabricated joists are replaced by a series of rolled steel beams of I or H - cross section, spanning between two supports at the spacing of 8' - 10' c to c. Over these beams comes the continuous slab 4" - 5" thick, which unlike the previous type, should be self supporting with special reinforcement running normal to the steel beams.

For insulation and water proofing the top of the slab may be covered with the same layers described for the previous types, or else the space between the steel beams, but at closer spacing, may be bridged with shallow vaults of clay bricks or other thin hollow blocks, as described under the "Brick & Earth Flat Roofs". In this case, the slab needs reinforcement only for temperature with no tension reinforcement, as its weight and the weight it sustains are carried by the arch action of the bricks thus economizing a lot on steel.

(F) Precast Slabs on Steel Beams

Still a further modification of the last type in which the space to be covered is bridged by a series of parallel stiff I - beams at suitable spacing to which other lateral joists of smaller section are tied by welding or by bolting with the top of the smaller joists either flush with the main joists or lower by a fixed small amount according to the design of the covering they have to support. The area is then covered with any of the following prefabricated slabs:

(i) Cocnrete long span channel slabs - Fig. 10, consisting of flat concrete slabs about 1" thick and 9" - 2' 0" wide and 6' 0" - 8' 0" long with projecting nibs along the two long sides, which fit in $\frac{3}{4}$" deep notches in the lateral joists or on top of the main joists. The length of the slabs is equal to the spacing c to c. of the later al smaller joists.

The joints between theses slabs is filled with mortar and a layer of concrete screeding or cinder concrete is laid on top of them alone or with other insulating covering.

(ii) Flat long spans $2\frac{1}{8}$" - 3" thick and weighing 11 - 16 lb/sq.ft, 4' 0" - 6' 0" in length, fixed in a similar way and with a similar surface treatment - (Fig. 10 a).

(iii) Flat Gypsum planks, 1' 0" wide and 4' 0" - 6' 0" long with one side grooved and the other tongued so as to fit beside each other firmly by tooth and tongue. Again, the joists are filled with mortar and mastic and the same surface treatment applied - (Fig. 10 b).

(iv) Sheatrock or Weather Wood Pyrofill: They are gypsum, concrete slabs, and are fixed a different system consisting of main I - beam, spaced at maximum 10' c to c, on top of which are fixed rolled steel rails as purlins at 2' 8½" c to c, thus dividing the space into rectangular panels equal to size of sheet rock slabs, which are supported by the rails and the main rafters; on top of these slabs pyrofill slab is poured reinforced with galvanized reinforcement. The thickness of the pyrofill is 8" - 9" with 2" cover on top of the steel nails. On top of this the insulating layer is applied - (Fig. 10c).

All these items are expensive and for quick use though the construction is easy.

(G) Prestressed Concrete Roofs

This very new type of concrete structure has a limited application in this part of the world, besides being uneconomical due to the reason that all members and units should be imported from outside at a very high cost and with a delay in the construction because there are no factories for their local fabrication.

The principle involved in these structures consists of precasting different units of concrete in standard sizes for different structural members, e.g. columns, beams, slabs, etc.. with each unit being reinforced with prestressed wires of steel to carry the tension whenever these members are in action, and this is done by releasing from the prestressed tension an equal amount to the developed tensile force. The prestressing of these steel wires prior to casting concrete of the member is done by special heavy machines which are not available here. The erection of such structures consists of assembling two or more units of the standard size according to the cross section and dimensions of the whole structure. Then these members are fixed to each other at the joints by pouring some concrete around the projecting dowels at the ends of each member.

This type is remarkable for its ease and speed in construction as well as the economy in steel which is very expensive in concrete structures. Moreover, the weight of these structures is considerably decressed by ommitting most of the ineffective concrete in the tensile side. So, this type of structures may be very economical whenever the necessary equipment could be installed in neighbourhood of construction site. Once the structure is complete the usual treatment to the top of this roof - for insulation and water proofing - will be applied. However, Since a part of the concrete is omitted it could be considered that this type of roofing has its own insolation.

Approximate Cost: It is rather difficult to state one figure as being reliable to give a clear and fixed price for concrete roofs , so a range of prices will be given for each type, because the cost varies depending upon: (1) Span. (2) Live load. (3) Height of story and its number.

The price could be analyzed to the following:

(1) concrete. (2) Steel . (3) formwork.

(A) Beam and girder Roofs, the slab will be 0.10 to 0.15m thick to which an average of 0.04 m. cube per miter square of roof to compensate for concrete used on beams and girders making a total of 0.14 to 0.20 m.c. per square metre of roof which is equivelant to LL. 5.6 to 10.00 per m.s. and LL. 4.0 to 5.0 per m.s. for formwork plus 14 Kg to 20Kg of steel per metre squp equivelant to LL. 7.0 to LL.10.0 making a total of 16.6 to LL.25.0 per metre squp of roof for the concrete struture .

(B) Ribbed roofs the price will be 20% more to afford extra concrete blocks and steel, however the difference will be less as the span gets longer and even it will get negligable so a round figure of LL. 20.0 to LL. 28.0 per metre sup could be taken as an average.

(C) Flat slab roofs differ from the above two in that the concrete will be taken for the thickness of the slab only, as there are no concrete beams and girders, so the price will be a s follow:

Slab 0.20 to 0.25 m.c./ms equivelant to LL. 7.0 to LL.10.0 per ms.

Steel 35 to 50 kg. per m.s. " " LL.17.0 to LL.25.0 per ms.

Formwork will be less than above and " "LL. 3.0 to 4 per ms.

This will make a total of LL. 20.5 to LL. 39.0 per metre sup also for the concrete work only.

Concrete arches are more difficult to price as the price varies in a wider range depending upon mayfactors such as span, rise and the slope of the sides at the springing lines and on whether of solid slab or of ribbed slab with hollow blocks.

More over these prices are for the concrete work only to which should be added the price of the plaster to the ceiling (equivelant to LL.2.0 to LL. 2.5 if it is plane plaster or LL.4.0 to LL.4.5 if rough cast for sound insulation) and the price of the top water proofing and insulating treatment which is variable and ranges from LL.3.0 to LL.4.0 for felt and bitumen to LL.10.0 to LL.14.0 for special Sika tiles laid on a layer of Igasol and filled along the joint with Igol.

In general for ordinary load use solid slab for small spans and ribbed for long spans, and flat slab for high live loading and almost Square panels.

II - PITCHED ROOFS

This very old type of roofs was once very popular due to many reasons some of which have been already mentioned under flat roofs, and may be summerized in:-

(1) Speed and effieiency in draining the roof from rain water.

(2) Most of roofing members work in compression - specially in the trusses - so, such materials with low tensile strength, as timber, and which were very available in old times, found good field for application in these roofs.

(3) Most of old materials used for covering were of small sizes with the result of having too many joints in the middle of the panel, so this type of roofs was practical in diverting water before it had time to find its way through these joints.

(4) These roofs are very suitable for domestic use and possess very beautiful architectural affect, especially in country places and when used in conjunction with proper gutters and water down-pipes.

(5) Most of the cheap available old roofing materials were fit only for sloping roofs. Such materials are tiles, clay, slates ..Etc.

(6) They are economical in construction and initial cost.

(7) They provide enough space above the ceiling for tanks and storage, etc. as well as a place for hidden installations.

In general, the comfortable appearance of a roof depends upon the way itssprings from and fits on the walls. It may, by spreading far from them, look as if it were a hat too large for its wearer, on the other hand, if it has no overhanging eves, it may look mean and pinched.

Gutters are one of the main items on pitched roofs, and the way they are connected to these roofs, as well as the material of which they are constructed, influence greatly the liveliness of the roofs. Such gutters are mostly exposed with secret gutters sometimes used to a less extent in valleys. The main material entering their construction is either lead, zinc or felt.

The following kinds of lead are for the special use indicated against them; each type, being known by the weight of this material in pounds / sq. ft.

4 - 5 lb. lead	for soakers
5 lb. lead	flashing and aprons
6 - 7 lb. lead	ridges, hips and small gutters
7 - 8 lb. lead	main gutters and lead flat roofs.

However, the actual pitch employed,gives character to the building; e.g. a 45^{0} pitch is noncommital and dull; a 50^{0} gives alivlier air to a roof tiled with ordinary tiles, while certain kinds of tile or slate can be used satisfactorilly, both aesthetically and practically on pitches considerably lower than 45^{0}, and as a rule for pitches above 45^{0} use tiles while for lower pitches use slates. Moreover, it is adviaable to give the hips a steeper slope than the general roof, which will lengthen the ridge and add to the effect of serenity.

A general injunction be "Let a single building have singleness of character, seldom use hips and gables on same building; simple and direct means of roofing are most satisfactory, numerous gables and tortured shapes may give a restless shape".

Pitched roofs - to conclude - are desirable on both domestic and industrial buildings with a certain kind of pitch and covering material suited for each particular case.

The different types of pitched roofs and the history of their development are listed briefly in the followings, which may be better read in conjunction with figure 15, to show the meaning of different expressions used in pitched roofs such as hips, eaves, ridges, etc..

(A) Lean to Roof:- The simplest and almost the earliest type of pitched roofs, and is similar to the oldest type of flat roofs but, with the only difference of having one of the supporting walls higher than the other thus leaving the roof sloping in one direction.

The space is bridged by rafters spaning in the direction of the slope - at suitable intervals - on top of which lateral joists are laid horizontaly from one rafter to the other or to a wall. On top of these smaller joists (purlins) the covering with or without the sheathing is laid.

The covering material and the sheathing could be any of many types or kinds which will be discussed later, each for a special pitch and use. The oldest types of rafters were trunks of trees, then good wrought timber, and in some cases it is replaced by steel pipes.

(B) Couple Roof (Fig. 16 b): The preceeding type of roof though succeeding in solving the problem of drainage was good only for small spans, while on wider spans, this type proved to be impractical due to the following:-

(1) One side would be too high

(2) Or roof would be too flat

(3) Large roof drained to one gutter only

(4) Rafters and purlins should increase tremendously in weight and cross section, to an uneconomical structure.

So far spans above 8' - 10', a roof was used, having two pitched roofs meeting at the high side of each, (the ridge), and sloping in opposite directions towards the eaves where they were fixed, through a wall tie well embeded at the top of the wall, thus securing the rafters to the wall and distributing the load uniformly to the walls. The ridge may be supported by an intermediate wall or the rafters support each other through a rigid junction.

(C) Couple Closed Roofs: The preceding type also had a difficulty in spans above 12', namely creating a horizontal push outward on the top of the wall, which may overturn the wall rather than stabilize it. So, the feet of every fifth or fourth pair of meeting rafters from the two sloping sides had to be pushed inward by a tie rod, unless a ceiling had to be fixed to the bottom of these ties in which case tie rods were fixed to the feet of each pair of meeting rafters. This provided space for store and installation of any equipment as well as good insulation and aesthetic beauty. This type is good for spans upto 20', but the spans betwen 18 and 20' had the tie rod supported from the middle by special vertical king post joining it to the ridge.

(D) Collar R oofs: (Fig. 16 d): Are applicable to spans upto 18' and are almost identical with the last type except that the tie rod fixed at the middle or lower third point of the main rafter for the following:-

(1) Gain more space for the room, espocially when the upper space was not utilised, and without raising the walls

(2) The ridge was kept at a lower height to avoid extra taxes.

However, this was done on the cost of the strength of the tie rod.

(E) Mansard Roofs: For wider spans in which the ridge will come to a very high level, thus incurring more taxes, an ingenious modification of the last item was used, having the principal rafters consisting of two slopes with the steeper one being the lower, thus achieving the following:

(1) More space in the room with lower walls

(2) The space above the ties could be utilized as a second storey, with dormer windows fixed at this steep side.

(3) The top flat part of the roof could be covered with covering materials suitable for flat roofs such as lead, copper and zinc, giving better appearance and insulation.

This type is good for domestic dwellings and for spans up to 20' and even may be applied to spans of 30', in which case, the tie rod should be supported to the rafter by means of vertical posts and supported at the walls by brackets.

(F) Roof Trusses: For spans above 30' and without intermediate supports, the previous types were not suitable for the following reasons:-

(1) Mainrafters had to be very high

(2) Structures became weak

(3) Otherwise members had to be very heavy with more expenses.

So, a modification of the previously mentioned types was used and consisted of:

(1) The Principal (Truss) which is the rafters and tie rod modified for heavy weights by taking advantage of rigidity of triangulated structures. These were spaced at 8 to 16' c to c.

(2) Purlins or horizontal members running normal to the direction of the slope. On top of these purlins are fixed the common rafters parallel to the main rafters and more closely spaced, to which the sheathing and the covering were fixed. These common rafters were sometimes omitted specially when covering materials could support its weight in which case they were supported directly on the purlins. The purlins are usually spaced from 4 to 10' c to c, the common rafters from $1\frac{1}{2}$ to $2\frac{1}{2}$'.

(3) The covering which consisted of

(a) Sheathing usually timber boards and battens, battens alone or boards alone, and it is fixed between the covering material and the purlins.

(b) Covering proper which varries depending upon many factors and which will be discussed later.

The oldest types of roof trusses were mainly of timber, being the available material. Then, composit trusses of steel for tension and timber for compression were used, and recently, steel trusses or even other matllic alloys were used.

First: <u>Timber Trusses</u>: They are also of many types:-

(1) King Post truss, Fig 17 a, this type is suitable for spans upto 30', and is almost the couple close roof with the middle of the tie rod supported to the ridge through a vertical post, (King Post), and two strutts connecting the middle of the rafter to the foot of the post and to the middle of the tie rod. A purlin is applied to each rafter at the panel points, i.e. ridge and eave and above the intersection of the rafter with the diagonal strutt.

(2) Queen Post Truss: This is suitable for spans upto 45' and is similar to the king post truss except with the king post replaced by two vertical queen posts joining the upper quarter point of the rafter to two points on the tie rod below them, and two diagonal strutts joining the feet of these queen posts to the lower third points of the rafter, and having one purlin more at the extra new panel point, (Fig. 17 b).

For spans above 45' the main tie beam may be supported by more than two vertical supports called princesses. However, as this struss has the middle panel of a rectangular shape, it is a weak structure and this panel should be reinforced by one of its diagonals joined.

(3) Open Timber Roofs - (Fig. 17 c): These types of roofs were used in the medieval ages having their outlines from previous pitched roofs slightly modified by having the tie beam supported by masonry arch or other internal wall. The different types of these roofs are many, the most important are:

(a) Collar beam truss and tie beam truss; These have timber vaults instead of masonry vaults, the only use of masonry besides walls was to support the arches. Such types were used in churches with steep pitch almost 60°.

(b) Arched Tie beam: The stone arches were replaced here by timber truss in the form of arch acting as a beam which receive the covering through lateral smaller beams.

(c) Arched Collar Beam Truss: It has a wooden rib in place of the arch inserted in the collar beam truss described in part (a).

(d) Hammer Beam Truss: Used for spans above 20' in which a hammer beam projecting from the top of the wall where it is also rigidly fixed to the foot of main rafter. This beam is also bracketed to a corbel projecting from the wall at a distance below the foot of the principal rafter thus triangulating the arch at the end of the beam; as shown in (Fig. 17 c). Two different types of this truss were used:

(i) Arched hammer beam truss

(ii) Bracketted hammer beam truss.

(e) Curved Rib Truss: In this case the maximum interior height of buildings has been attained. This truss (Fig. 17 c) is made in two ways:

(1) Built up curved vertical plates

(2) Built up ribs with thin plates bent to the contour of the curve, the plates being bonded by the built up method.

(f) Belfast or Bow Strung Truss: This cheap truss is used for temporary or semi-permanent houses with its covering consisting from timber boards with felt or corrugated iron sheets of circular shape to fit the contour of the main rafter. These sheets may also be laid on purlins at 2' to 2'6" c to c, and the span can go up to 100' with the rise of the truss betwean $\frac{1}{8}$ to 1/10 of the span.

Second : Steel Trusses

The oldest roof trusses were mostly of timber which was preferred to steel due to the ease of cutting and manufacturing of timber structures and the lack of skill needed for steel structures at that time, e.g. rolling and manufacturing steel units were difficult and special shapes were rather impossible to get at that time, due to inadequate means.

However, the development in both the ways of extraction and manufacturing of steel members,as well as better scientific methods for constructions, had led in the recent years to push steel construction ahead of timber construction, and even supercede it due to the following reasons:

(1) Steel is stiffer, stronger, more durable and of longer life.

(2) It is easier to fabricate to any shape and to construct in a less time.

(3) For the same strength it takes less volume which makes it more convenient and economical for transportation.

(4) It can be prefabricated to dimensions with precision without risk of warping and damage while transported, and if bent it could be repaired easily at site.

(5) More flexible for extension or modification, and to compensate for any mistake in manufacturing.

They are on the same principle as timber trusses, the principle rafters are of T or I joist, channels, double or single steel angles. The main ties are mostly horizontal and may be given a slight camber at the middle in long spans. The principal rafters and ties are connected by verticals and diagonals of single or double steel angles which divide the space between the main rafters and the main tie into a set of reasonable triangles. On top of the main rafters horizontal perlins of I joists or channels or steel angles are fixed, which receive the covering through or without sheating.

A good example of roof of steel trusses is the Cardiff Railway Station with span of 150' and trusses are at 30' c to c.

Steel trusses are mostly with pitched top chords. The most important types of steel trusses used in buildings for roofs are:

(1) Fink Truss; (Fig 18 a): This type shown in the figure consists of three main treiangles: one almost équilateral at the middle, and two isococeles triangles one on each side, and the base of the

one being the main rafter on that side. These two triangles are divided into smaller triangles the number of which varies depending upon the span. This characteristic makes this truss applicable to any span, and are preferred to other types for the following reasons:-

(a) Presentable, being of harmonical division

(b) Could be extended to any span upto 150'

(c) Economical

(d) Could be used for very wide halls in the shape of multi-aisle with intermediate supports between every two trusses applied at every fourth or fifth or third row of trusses. The top of these columns are connected by stiff I beams or shallow trusses running normal to the span of the truss and work as supports for the gutters and for the covering at the eaves.

Fink trusses are generally spaced between 8' to 20' c to c, but the most practical and economical spacing is 12' to 14' for the following reasons:

(a) Planks of timber used on scaffolding for erection and fixing of covering and perlins are almost 4 - 4.50 m long, i.e. 13 - 15'.

(b) With more spacing, heavier perlins are needed which will ingolve more loss on perlins than is saved on trusses.

In this locality and in most cases the principal rafters and bottom chords are single or double angles depending upon the span and weight and between $2\frac{1}{2}$" x 2" angles - 5" x $3\frac{1}{2}$".

These trusses are usually covered with corrugated iron sheets and asbestos - cement sheets, and sometimes to carry special precast concrete or gypsum slabs in which case the purlins are of T - section with the web upward to support the edge of the slab, (Fig 18 b).

In long spans and where heavy loading is expected the purlins may consist of shallow trusses noram to and supported by the principal rafters of the main trusses, otherwise, they are of angle iron spaced at 3' - 6' c to c, depending upon the cove ing material, but in general the following number of purlins is used for each span:-

for span of 15' - 25' use one purlin per rafter

" " " 25' - 40' " two " " "

" " " 40' - 60' " Three " " "

The weight of steel used per unit area varies and depends upon the span, the pitch and the live load, but in general on pitch of 2/5 in this locality it is between 25 kgs/m.s. to 50 kgs/m.s., and the cost of the complete truss including everything except the covering is LL.1.10 - LL.125 /kg of steel, thus making the cost of square meter of roof between LL.30.00 & LL.60.00 for the steel only, to which the cost of the covering and its erection should be added, which amounts to LL.6.50 to LL.12.50, which makes a total of LL.36.50 - LL.72.50 /sq.m. of finished roof area.

(2) Warren Truss: Consisting as in (Fig. 19a) of principal top rafter - flat or pitched - and a bottom chord, both divided into panel points at suitable intervals, with the panel points in one chord just above or below ~~the mid point of~~ the middle point in the panel of the other chord.

These Pannel points are braced by diagonals, each panel point tied to the end of the opposite panel in the other chord, thus as in the fink truss the truss is divided into system of triangles.

In heavy loadings these triangle may be braced by a vertical tie from the vertex to the middle point of its base.

This type is more or less similar to the fink truss in cost and the way of fixing covering materials, .. etc.

(3) Pratt Truss : Similar to the Warren and consists of top and bottom chords both divided into panels which come exactly on top of each other, these chords are braced to each other at the panel points by vertical members thus dividing the truss into trapezoids or rectangles, depending upon whether it is with sloping top member or flat top member; these trapezoids or rectangles are further braced by one of their diagonals joining the inner panel point on the bottom chord to the outer panel point on the top chord if it is a rectangle or visa versa if it is a trapezoid, thus the whole truss is divided into triangles, as shown in Fig. 19 b.

(4) Howe Truss (Fig. 19 d) : This is identical with the pratt truss and differs only in that the diagonals are joined exactly contrary to the pratt in both cases.

(5) North Light Roof Truss : This type is used widely in factories and large buildings where a lot of lighting and ventilation are required, In shape it is similar to the fink truss but having one of its rafters much shorter and steeper than the other. It is more efficient when used on the multi-aisle system in which it is known as SAW TEETH TRUSS (Fig. 19 a), with the steeper side used for fixing windows for roof lighting and ventilation . This type is very convenient in windy places by facing the wind with the gentle slope thus reducing the height and correspondingly the wind effect.

(6) Other types of roof trusses are occasionaly used and which are of inferior importance and are almost rare in use, such as scisors,truss, ..etc..

(7) Reinforced Concrete Trusses: These are used over large spans and in roofs of big public halls, and its use is popular for the following reasons:-

(a) It sustains very heavy loading

(b) Continuous and monolithic roof over very wide halls could be achieved cheaply by these trusses.

(c) It is economical for concrete and steel than any other type of concrete roofs.

These roofs may be of any of the preceding trusses en-cased in concrete for fire proofing, or, it may be on the shape of one of these trusses with the members being of reinforced concrete. One of the advantages of this roof is that it could be used for supporting ornamental ceilings on large halls by use of ties hanging from the panel points of the truss.

III - VAULTS

This type of roofing works on the principle of the arch and its main advantage is that it can sustain high loads and be built of either stones or bricks, especially when other materials of construction are not available. However, its use now is limited to architectural requirements. It can be found in any of the following shapes:-

(a) Barrel Vault, consisting of a continuous masonry arch supported by two walls and may be single or double vaults intersecting at right angles with their crowns at the same level; both types are still used in churches. When built of masonry the stones may be either finely dressed in which case the soffit is left with the masonry exposed, or fairly squared in which case the soffit should be plastered. This type is now obsolete for the high cost of the form work involved in its construction, especially when made of concrete where double form work is needed, which over balances the merrits of the rigidity of ~~complete~~ concrete structures.

(b) Ribbed Vaults - Fig. 20: Consist of a series of masonry arches of equal span and rise with their crowns at the same level, and are spaced at suitable intervals. These arches are used as beams which support lateral joists and covering following the shape of a vault. This type is very common with the arches and the lateral beams consisting of reinforced concrete members, with the arches exposed on the top in the form of ribs and its soffit flush with the soffit of the slab supported by these arches. This arrangement is done to speed the job up by spending less time on the form work as well as money by nearly shifting it from one place to the other without dismantling it.

The concrete slab which bridges the spaces between these arches or ribs may be either solid or of the ribbed construction with the ribs normal and resting on the main arches. This is good for insulation and water proofing, but is very uneconomical especially with very steep sides because the shuttering for each rib and the concrete slab it supports which is to the width of one row of hollow blocks, should be assembled separately to allow laying of the next row of the hollow blocks whenever double shuttering is needed.

(c) Metalic Vaults: These consist of metalic semi-circular ribs fixed to concrete bases by holding down bolts and spaced at suitable intervals usually from 6 - 10'. These ribs may be of bent metalic pipes supporting horizontal smaller pipes as perlins or it may by of special T - joists with the web upward, fixed in a similar way. Over these inverted T - joists timber perlins, usually 2" x 4" are fixed by hook bolts. The covering on these ribs consists of two layers of corrugated iron sheetings. The first layer resting with its narrow edges on the top of the flanges, i.e. the sheets run parallel to the length of the vault. The next layer consists of three raws of steel sheets bent in its direction to suit the curvature of the ribs and supported by nailing to the timber rafters with the middle raw, which is on the top of this vault, overlaping the other two raws which are on both sides of the vault. This two layers system helps a lot for a better insulation and water proofing. Moveover, this type of roof is remarkable as being cheap, easy to dismantle and reerect with little transportation troubles.

IV - DOMES

This type of roofing gets its name from the Roman word Duomo, and is any roof of ovoidal or hemispherical or conical vault approaching the true dome in shape.

In its earlier days it was mainly of clay blocks or stones from which we still find many examples in the ruins of Mesopotamian Valley, which are of high elliptical form having its idea from the tent.

As the dwellings deviated from the ciruclar shape to the square this type of roofing was rather difficult and the problem was solved, by building it from horizontal cirular rings diminishing in radius as they go up. The next step was in the Roman Empire by introducing the cloister vault with ovoidal vaults springing from four sides equally. Then the Byzantians applied the dome to almost any shape especially in churches and temples and to domes of 50' diameter supported on diagonal arches, which type is still used in this country for big domestic halls and worship plces.

The French medieval domes were remarkable for their pointed arches having the curve of the dome and pendentive continuous having a projecting moulding at the base.

The Renaisance domes were influenced deeply with the Roman cloistered vaults, with double shells supported and connected by stone ribs which turned to be a combination of drum and pendentive and of dome and lantern. The double shells were mainly for architectural reasons and for insulation; the idea behind it is to raise the exterior shape of the dome without raising the interior unnecessarily.

In general, domes could be considered as a shell of uniform thickness or as an arched rib vault stiffened with horizontal rings filled in between with slabs. The covering material on these domes may be brick, mud plaster on masonry or lead, copper or iron sheetings, etc.. supported by timbe or steel structure. Concrete slabs 3" deep fixed on rebated concrete ribs 5" deep which are supported to the exterior of the dome thus leaving a 2" of dead space for insulation. Furthermore, the top of these slabs may be treated with bitumistic or other water proofing compounds.

However, the use of these domes in this country is mostly restricted to worship places and institutional buildings, and are mostly of stone or concrete with few of clay bricks. Some of the primitive type may be seen in places of brick masonry with small square rooms with small domes in the middle of the roof.

A modification of this type of roofing, particularly the construction depending on the action of horizontal rings is the primitive conical roofs of dry masonry used in north Syria. Another example is the conical roof consisting of a conical shell with straight small branches of trees meeting at the top with their bases equally spaced at the circumference of a circle. The covering material here is the straw and thatch.

Conical steel roofs consisting of $\frac{1}{8}$" thick plates welded to each other with reinforcing ribs or without these ribs used on spans uptil 20', for the 2nd and above 20' for the first. This type of roofing is very heavy and uneconomical.

CHAPTER IV

ROOFING MATERIALS

So far we have been dealing with roofs as from the structural point of view neglecting the architectural side which is the true sense of the roof, namely - protection from penetration of wind and rain and adequate insulation against heat, cold and rain; and sound, which depends upon the cover or the roofing material.

Roofing materials can be of many different kinds the use of any depending upon availability, climate and the slope of the roof, as well as on the nature of the use of the respective building, e.g.

(a) For domestic buildings : Slates, stone tiles, stone slabs, clay tiles, concrete tiles, shingles, asphaltic roofs and felts, straw and thatch.

(b) For industrial buildings : The roofing may be either of a flexible material of good quality such as lead, copper and zinc, etc..; or a heavy strong metal such as corrugated or plain steel and asbestos-cement sheets.

However, the relative merit of a certain kind over the other depends upon:

(1) Ease of fixing

(2) Damp and heat insulation

(3) Weather resistance and durability

(4) Length of life

(5) Fire resistance

(6) Aesthetic beauty

(7) Comparative light weight

(8) Economical in both initial and maintenance costs

Durability and Weather Resistance

These important characteristics depend upon the quality of the material as to:

(1) Whether of good resistance to chemical and physical disintegration, and

(2) As in slates, tiles and other manufactured materials, to be sound althrough the unit, non absorbent, free from cracks or falts which are the results of any impurity in the mix. Moreover, some materials will get oxidized when exposed to the atmosphere and will be self protecting while others such as iron sheetings will deteriorate if not painted or protected.

However, the way of fixing of the material as to freedom of expansion, lap, pointing and proper ventillation to timber plays a good deal in determing the durability of the material, especially with good maintenance.

Aesthetic Value

This is very important especially in slates and tiles which could be achieved through harmony or pleasant contast in the colour.

However, brick and tiles in general can produce a pleasant combination, particularly as both can be found in a range of various colours and textures which both depend upon the degree and method of burning, as well as on the constituent and surface finishing materials. On the other hand, stones, tiles and slabs produce good combination when used on pitched roofs over stone walls.

As a general rule: For permanent works the initial cost should not be the determining factor, but the suitability from the joint stand points of efficiency, durability and aesthetic value and occasionaly, fire resistance.

I - SLATES

This very old type of roofing materials was once very popular but it is now giving way to the tile roofing. It is from laminated argillaceous, clay or other rocks which split easily along certain planes which are the result of long exposure to heat and pressure and shearing action, and should not be coincident with the planes of the original grains. These slates have the advantages of being non-absorbant, durable, resisting to atmospheric agencies, very cheap in initial cost, except for the cost of transport, easy to prepare and fix, and on top of that, match aesthetically on masonry walls from the same or neighbouring quarries, and could be used on roofs of relatively flat pitch.

Good slates should be hard, tough and of a fine and easily distinguished planes, free from dark veins, with least lines of cleavage to avoid crumbling by force action, and should be tested before use for the following:

(a) Should not when soaked for 12 hours in water absorb more than .005 of its weight, nor the water should raise more than $\frac{1}{8}$ of an inch.

(b) Should be tough enough to ring when struck by the knuckles, and to be neither too soft so as to get loose around nail holes, nor to be too hard to splinter while trimming.

(c) Should be of a pleasant colour in harmony with the under masonry, free from patches or iron pyrites which decompose easily.

(d) The texture should be of fine and regular grain, and in the direction of its length.

Characteristic

Thinner slates are better, neater and lighter, but less durable and weaker. Slates are differentiated by colour and weather action which are related to each other, e.g. the Welsh slates are grey, grey green or rustic red, while the hard durable Burlington slates are blue grey and resist acid fumes and fire; on the other hand, Scotch reddish slates are coarser and thicker often containing iron pyrites. The slates are of various sizes from the Randoms, larger size slates, to the Peggies, and may be either of one size on the roof or both used on the same roof with the Randoms at the eaves, diminishing towards the ridges where the Peggies are laid. However, the slates are usually between 36 x 24" & 10 x 5", with the smaller size used on steep pitches. Slates are of three main categories:

(a) Firsts or Bests, straight, thin and regular thickness

(b) Seconds, less uniform, thicker and heavier

(c) Thirds, still less uniform.

Method of Fixing

In general slates suit pitched roofs and are fixed to the steep main rafters by either of the following:

(a) Battens parallel to the eaves which gives least insulation

(b) Timbered boarding covered with felt

(c) Timber boarding covered with felt with battins on top of them laid parallel to the eaves. This gives better insulation.

(d) As (c) with another layer of battins normal to the first layer between it and the boards. This gives best insulation and provides adequate ventillation for timber against rot, as well as drains quickly any water that passes through defficiency in the slates.

In any of these methods the slates are fixed to the sheathing by nails in two ways:

(1) Head nailing - (Fig 22 e). This is economical as it leaves little margin and it is more water proof as two layers of slate cover the same nail hole. The battens are laid at the gauge of ($\frac{1}{2}$length - $\frac{1}{2}$ lap - $\frac{1}{2}$"), and the lap is between $2\frac{1}{2}$ to 4", the 4" being on the exposed surface. The nails holes are at about $1\frac{1}{2}$ to 3" from the head.

(2) Center nailing - (Fig 22 f). This is stronger in resisting the wind levering action. The battens are at the gauge of ($\frac{1}{2}$ length - $\frac{1}{2}$ lap) and the nails at the middle of the length of the slate at about $1\frac{1}{2}$ to 3" from each side.

However, another method, but rarely used due to the bad water-proofing and insulation except over sheds and temporary buildings, is the open slating method, (Fig 22 g), in which the slates are still nailed by two nails, but not edge to edge and with open space between them for economy, The battens are usually 3/4 to 1" thick x $1\frac{1}{2}$ to 3" wide. The nails should be of special kind such as a composition of iron, copper, zinc, with lead or tin; sinc nails are no good and cast nails are brittle, iron nails are malleable, and lead nails used for repair works.

Slate are laid in horizontal courses starting from the eaves with double course there, the first one tilted by means of a sprocket or a facia board and is laid up-side-down so as to deviate water to the gutters and block air and wind. At the ridge double course is also used with the first course bedded with cement water and the second course tourched. For draingage at the intersection of two planes at the hips and the ridges, a row of special tiles is used, of a special shape, such as half round or bonnete, (Fig. 22 h), or the hip and the ridge may be covered with a timber roll and lead flushing. Similarly the valley is done by special tiles or by boarding with lead or felt covering.

To make the slate-roofs water proof a good standrad of work should be achieved besides the following:

(1) Vertical joints should be in the middle of the slates directly above and below it. This means that every other raw a special slate of $1\frac{1}{2}$ or $\frac{1}{2}$ the length of normal slates should be used at the end.

(2) Valleys are formed by fixing timber boarding covered with lead, as flushing, or felt lining.

(3) Slates should be tourched, i.e. the internal joints pointed with hair mortar.

(4) Slates are sometimes rendered, i.e. imbeded in hair mortar; shouldering is sometimes used i.e. forming a 2" seal of mortar above the joints.

However, mortar should not be used if timber is not seasoned or gets destroyed by the mortar, or if they block the ventillation for the roof timber.

And as a final word, slates may give good architectural appearance by alternating purple and green slates and these roofs will match more with masonry rather than brick walls.

II - STONE SLATES

These are not slates in the full meaning but thin slabs of lime stone that could split. Its use is mostly for architectural requirements especially when covered with moss and finished with half round red ridge or hip tiles.

They are fairly non absorbant used on steep pitch. They are heavy, especially after the rain and they are rather thick, and of good insulation. Limited in use due to its weight and the heavy supports it needs, but in places where it is found plenty these slates are used and supported on a series of arches with larger ones at the eaves and diminishing in size towards smaller ones at the ridges.

Fixing is almost similar to ordinary slates, or when better insulation is needed, battens are fixed on the rafters and lath in between the two covered with limewater to be flush with the battens over which the slates are fixed by galvanised iron or oak nails with mortar pointing.

The hips, ridges, valleys and eaves are treated in a similar way to the ordinary slates. The preparation of these slates is by stacking the stones with their beds vertical and leaving them through the winter to be split by frost action. However, they are not used here due to unavailability and high cost of imported ones.

III - CLAY TILES

These and the slates shared most of old roofs each in the locality where it is available. We have good examples of old roofs with clay tiles still existing in the ruins of Pompei with special shapes of clay tile with special names such as Imprex and Tegula.

These tiles are used in clay regions and are manufactured from a special tenatious and well prepared mix which is burnt carefully in a special kiln, and then tempered, cured and dried carefully to get a non-absorbent tile which will stand weather action.

These tiles are manufactured in two ways:

(a) Hand made (Old Process) which gives tiles that are coarser, harder, more absorbtive, but less laible to lamination than the other type, and they weather to colour of red and brown which may spoil the roof whenever tiles from the two kinds are used on the same roof.

(b) Machine made and artificially dried tiles which are better if properly prepared and do not weather in colour.

However, the nature of the clay (as whether it contains iron oxide and to what percentage), the method of burning, the special surface treatment, as well as the method of manufacturing all effect the weather properties, texture and the colour of the tile, e.g. over-burnt tiles are strong but warped, while under-burnt are weak, porous and nondurable.

As to the shape and size, these tiles are of three main types:

(a) Flat Plane tiles

(b) Pan tiles (Single lap)

(c) Various single lap tiles of special patterns.

Plain Tiles

These are flat tiles mostly $10\frac{1}{2} \times 6\frac{1}{2} \times \frac{1}{2}2$ with two holes for nailing to the battens in each tile; and similar to slates they are laid with double overlap and break joint sidewise. Some tiles have also two projecting nibs at the top by which they are hung to the battens and so they are nailed only every fourth or fifth course. These tiles are cambered in their length and are laid convex upoward to ensure tighteness at the tail and to reduce the effect of wind lifting and blocks the way of the rain and wind inside the roof. As these tiles are more absorbtive than slates, they are never laid on pitches flater than 45° while slates are laid on pitches of 25° to 30°.

The fixing of these tiles is similar to the slates and in the same order as to double courses at the eaves and ridges, special head tiles but having the first course at the ridge and the eave of flat tiles with no nibs and the tiles embedded with mortar and tourched.

Valleys also are similar to the slates and they may be also secret or open with the following special units:

(1) Special angular tile which bonds with the tiles

(2) Flat curved tiles convex downward and laid similar to the angular tiles

(3) By special V shape or trapezoidal boarding nailed to the valley rafter and lined with felt or zinc.

Pan Tiles (Single Lap)

They are of traditional shape of red, grey or buff colour, plesing in line and appearance as it gives bold texture, but are not suitable for small places or placed where they have to be cut and trimmed such as around chimney of dormer windows, or with a lot of valleys and hips.

As their name indicates, they are laid with one lap only, i.e. with double covering than tripple as in the case with slates and plane tiles. This leads to economy in tiles as well as timber, framework (due to longer gauge and to lighter weight), so it consumes ¼ as much of timber battens and ⅓ less of tiles, combined with easier fixing and could be fixed even to the flat part of the mansard roof as well as on pitches as flat as 35° if they are without interlocking, and on flat roofs almost completely, if laid interlocking.

They have the diadvantage of inferior insulation and water proofing, so they should not be used on exposed cases except with felt and double layers of battens on top of the felt for better insulation and draingage. Moreover, it is difficult to replace the broken tiles and as it is almost obsolete kind, a good lot of spare tiles should be kept extra for repair works which means a lot of initial cost extra.

These types are of fantastic design especially when glazed, in which case they match wonderfully on white masonry. As they are of Ogee section they permit a side lap which if properly torched provides good water proofing. They are usually 9½" x 13½" and weighin g 5 lbs/tile with or without nibs and overlaping 1½ to 3" on the edges and 1½" on the side, thus leaving a clear area per tile of 8" x 10"- 12".

The fixing of these tiles is similar to the plana tiles especially at the ridges and the eaves and the hips, but the first course at the eaves and the ridges should be of plane tiles and having the gabs in the edges of the second pan tile course blocked with cement mortar and tile chippings or else this second row should be of special design with blocked in - (Fig 23 a). Hips also should be used in the same way, i.e. the gaps filled with mortar and plate chipping or else special tiles with block sides to be used.

The covering over the double courses at the hips or the ridges is similar to plain tiles and slates.

Special type of these tiles having the section of almost a channel is laid on ridge and valley system (Fig 23 B), with courses laid vertically instead of horizontally alternating between ridge and valley shape starting with one course from ridge to eave as channels and the two rows on either side laid inverted in the shape of ridges, thus having quick and efficient drainage towards the gutters.

Other types

These are similar to the pan tiles in principle but special pattern; the most important are:-

(1) Corrugated tiles of ordinary shape and angular flutes

(2) Italian shape with double roll

(3) Fosters

(4) Pooles bonding roll tile.

Clay tiles are widely used here, especially in mountains and of the Marselles patent costing 38 LP per tile, 13 of which make 1 sq. m. and the cost is LL.30.00 to LL.40.00 per square meter of floor area.

IV - Concrete Roofing Tiles

Cocnrete tiles, similar in shape to ordinary plane tiles may also be obtained by mixing sand and rapid hardening cement with some colouring pigment, thus matching plane tiles in form and colour, with red colours inferior to grey and buff and brown ones. These tiles should be left to cure after casting before being used.

They are heavy, easier to prepare than clay tiles, cheaper but are difficult to cut and liable to breakage in transport, and need heavier support. They are similar to clay tiles in texture, thickness and camber requirements, and are laid in almost the same way. They are of various patterns, the most of importance are:-

(1) Brosely tiles, 10½" x 6⅝" almost identical with plane tiles

(2) Interlocking tiles, 15" x 9" x ½", with two nibs and two nail holes.

(3) Corrugated tiles 16" x 7½" with two corrugations.

(4) Other types of flat tiles of gypsum or concrete or other combinations which have been discussed under flat and pitched roofs, and are to be treated with mastic along the joints and some bitumistic or other insulating and water proofing layers, by the use of which good and cheap roofs will be achieved, but with less aesthetic beauty than other special concrete tiles.

V - METALLIC COVERING

This type of roofing is almost restricted in use due to the unavailability of these metals and to the substitution of the reinforced concrete for them. However, a brief word will be given about every kind that could be used on roof:

(A) Lead

It is used mainly on flat roofs as a covering material and almost in every type of roofs for flashings and lining of gutter, rolls, etc.. due to its flexibility and easy workmanship. It is used in the form of sheets of different thicknesses for different usages, as has been already explained.

It is very ductile and malleable and so it can not be used alone over large spans except with sheathing such as timber boardings, but not oak as this contains an acid which will attack the lead. As it is soft, plastic and malleable, it will crowl under its own weight if used on steep roofs.

It is found in two kinds: Cast and milled, both being durable and subject to expansion to a good extent, and so should be laid free to expand and contract by means of rolls and drips, (Fig. 8a & 8c) with no nailing or soldering at all.

However, cast lead is thicker, heavier, leas uniform, more durable and less liable to crack under the heat of the sun than the milled lead. Its advantage is that it is flexible, durable, adaptable to be moulded in any shape particularly ornamental places, corners and gutters.

Lead when fixed is started with at the cesspools then in horizontal rows starting from the eaves towards the ridge. When the roof intercepts a vertical wall, the sheets are turned against the wall over a triangular fillet at the corner and then the edge of the sheet is turned and built in the wall with a piece of flashing over it. Gutters lined with lead should be with a base of narrow strips of timber boards to minimize the effect of warping of the timber board s by moisture.

(B) Copper

It is a well tried material which has been used for centuries on flat, pitched and even on domed roofs. Its advantages which made its use popular specailly in the recent years are:

(1) It is stronger than lead and does not creep under its own weight if used over pitched roofs.

(2) Weight to weight, copper is stronger than lead, and most of the other materials, and for the same roof we need from copper $\frac{1}{8}$ in weight as we need from lead. 100 sq.ft. of roof needs 1.2 CWT from copper, 8.5 CWT from 6 lb lead, 13.2 CWT from tiles, 6 - 12 CWT from slates and $3\frac{1}{2}$ CWT from zinc. It is durable and stand more traffic than lead. It is less attacked by heat than lead

(3) It is more durable than steel but weaker.

Moreover, it is ductile, workable and when exposed to the atmosphere it gets coated with a green coat of oxide which will protect it from further deterioration, add to its beauty, and save the xpense of its painting.

On the other hand it is bad insulator and it deteriorates in heat unless protected with felt covering; it is very expensive in initial cost inspite of its long life and the saving on the frame work, and though it could be strong enough when very thin, the saving in the material will be overweighed by the extra cost of manufacturing in this thin shape. It is formed in sheets 4' to 5'3" long and 2' to 3'6" wide and weighing 16 to 19 oz. per sq. ft. with thickness of 0.022"to 0.024". It also may be found in the form of corrugated sheets which are almost obsolete now. Its way of fixing is similar to that of lead. Steel nails should not be used but rather copper nails,and in first class jobs even these nails should be covered by a layer of felt or cork applied to the top of the board sheeting. Copper should not be hammered otherwise it will harthen.

When used on pitched more than 1/8 the drips over the horizontal joints may be replaced by welted joints.

(C) ZINC

Extracted from the sulphide, oxide or carbonate. If properly treated, it is cheaper, lighter than lead and will stand corrosion to a good extent, provided that it is not contacted with other material to avoid the risk of electrolyssis effect and that it is not used on oak sheathings. Furthermore, it should not be used in atmosphere with a lot of acid in it such as industrial cities.

It is stronger weight to weight but less durable than most of the materials except iron, copper & steel, as well as it is less liable to break than slates, bricks and glass, and can be used on steep roofs as will creep under its own weight. Similar to copper it gets oxidized with a protective layer.

On the other hand, similar to copper, it is bad insulator, needing some insulating material and it is not suitable for industrial places or sea shore cities, unless heavily galvanised or painted to protect it from corrosion. Its fire resistance is very poor, and when heated it gives inflamable vapour.

It is used in the form of flat sheets, 7'8" long, 2' 8" - 3'0" wide, and weighs 11½ to 25 oz. pe r square foot with a thickness of 19 to 25 S.W.G. or corrugated sheets with the corrugations at 15" c toc, supported on common rafters at the same spacing with their top corners rounded to fit inside the corrogations.

The preparation of roofs to receive zinc sheets is similar to lead, with the roll differing in details, (Fig 8 b), i.e. the sheets are bent at the two sides against the vertical faces of the rolls which are near the sheet, and fixed to the roll by clips with inverted U shaped caps enclosing both and nailed at the top to the roll, by special zinc nails. Again soldering should be prevented here.

(D) Tin Sheets

These are actually rolled iron sheets 14" x 20" or double this size quated with tin or zinc.

When fixing these sheets or tiles, they should be used in conjunction with some insulating material such as felt or cork which should be laid below the metal and to be thoroughly dry when the metal is laid. In first class jobs the seams may be soldered, each sheet being fixed to the roof by two or three tin cleats and its life may be doubled by painting which in turn adds to the cost a lot.

(E) Corrugated Iron Sheets

Aesthetically it is difficult to see that this material can be used for other than temporary or sem-temporary buildings. It has a comparatively short life which could be lengthened and rather should be, by painting or other protective cover such as galvanizing, asbestos, tar or asphalt. However, painting is generally preferred to galvanizing as any scratch in the galvanizing will be a weak point from where corrosion will attach the sheet.

These sheets are of good quality iron with corrugations paral el to the length of the sheet at 3", 4" or 5" c to c. These corrugations serve as gutters for draining water besides strengthening the sheet to be able to support itself, and they are supported by purlins normal to the direction of the corrugations spaced at 5' to 10' centers depending upon live weight, pitch and the strength and stiffness of the purlin. These sheets are remarkable for being able to be used in large sheets which means less joints and less risk of water penetration. They are of variable thickness from 18 to 24 S.W.G. and variable size also 2' 3" to 2' 6" in width, and 5' to 10' in length. The most practically used here are 5 mm thick for domestic buildings, and 10 mm thick for limited use.

Special Italian Patent with eigant appearance has similar zinc sheets corrugations at 15" c to c. The disadvantages of this type of roofing material are:

(1) Short life

(2) Troublesome noise of rain and hail falling on these roofs.

(3) Difficult to be water tight

(4) Bad insulation power unless with other insulators.

FIXING

As has been stated this type of roofing materila is self supporting and so it can be supported by widely spaced purlins which may be either of:

(1) Steel angles, channels, or small joists to which the sheets are fixed by the use of hook bolts hooking the purlin and passing through the layer of two sheets at the ridge of the corrugations with lead and steel round and bevelled washers.

(2) Timber purlins usually 2" x 4" at 4' c to c, fixed also with hook bolts or by nailing the sheet to the purlin by nails applied at the ridges with flat top and the same washers.

In both cases the sheets are laid in horizontal rows with corrugations parallel to the direction of slope and are laid starting from the eave end which is nearer to the prevailing wind towards the other end of the eave with side lap of 1½ corrugation at least. Then the other layer overlapping this layer is fixed in the same way with an overlap of 6". After completing the whole roof, both horizontal and vertical laps are sewed together by seam bolts with washers and spaced at 9" c to c.

In good jobs the sheets should be laid on top of tar which is fixed to a sheathing of timber boarding between the purlin and the steel sheets for insulation purposes. This type is widely used in this part of the world, especially of the 5 mm thickness in which case the meter square of this metal will cost LL.7 approximately including cost of material and erection and painting.

VI - ASBESTOS - CEMENT ROOFING

This type of roofing is known here under the name of eternite and is fabricated from asbestos fibre and portland cement. It generally suffers from the aesthetic disadvantage of smoothness and thinness, but efforts are being made to overcome these defects and produce something more satisfying to the trained eye. This is important as the materials has many possibilities.

This material in general is non-permiable, strong, fire resisting, durable, and will stand the atmosphere with its acids besides being a good insulator. It could be moulded in many shapes from slate to tiles, and from plane sheets and corrugated sheets to the thin diamond size type which is rather objectionable to the eye. The corrugated sheets are light in weight with also light framework to support them, so they have a good field of application in big buildings like, sheds, barns and factories.

Moreover, this material could be of various colours depending on the pigment that is added to the mix. In general, the happy happy grey sheets and the white aspestos which counteracts the drab tone of portland cement are preferred to the harsh red clay tile.

The disadvantages of this material are:

(1) It is very difficult to cut

(2) Should be handled very carefully to avoid breakage which connot be repaired contrary to the iron sheets which could be welded or adjusted if bent.

(3) Can not sustain heavy traffic and being brittle will

break easily under live loads which makes it dangerous to walk on while erecting.

(4) Contrary to the iron sheets it is difficult to dismantle and reuse again.

The various forms of this material are:

(a) Asbestos cement slates, rectangular in shape and of size 24 x 12" to 20 x 10" of changing colour from green to greeen brown to brown and blue. Being very light they save a lot of timber.

Slates may be laid on boarding or on batten supported on rafters at 2' 6" c to c, with 4" overlap, and with a vertical batten fixed to the rafter, and supporting a ceiling at the bottom for better insulation and water proofing. The slates are fixed by center nail with a disc rivet between each pair of slates against wind action, (Fig.25), and usually having three courses at the eaves. The same treatments as for ordinary slates will be used here for ridge, hips, eaves and valleys.

(b) Pantiles of two sizes $15\frac{3}{4}$ x $13\frac{1}{4}$ " and $15\frac{3}{4}$" x 9 7/16", used on pitches of 40° when without boarding and on 30° pitch when supported by boarding. It has special stop end pan tiles for eaves, special twin pan tiles for hips, double rolled tiles, strips of asbestos cement covered with expanded metal as an undercoarse on which the tiles are bedded at the verges, and special hip and ridge round tiles lined with concrete for a better key.

In general these are cheap but not of a beautiful colour.

(c) Asbestos cement corrugated sheets : These are tough and durable in any climate, and are $41\frac{1}{2}$"x 3' to 10' long with Changing colour. It has special closed end sheets for eaves and ridges.

As to the method of fixing, it is similar to corrugated iron sheetings already explained, (Fig 26). This type of corrugated sheets is finding now great popularity in use over the C.G.I. sheets due to its cheapness and lightness in weight. The sheet of this type 6' x 2½' costs LL.7.00 at the average of LL.4.00 per sq. meter to which the cost of erection of LL.150 /sq. m. should be added making a total of average LL.6.00 to LL.6.50 per meter square of complete roof.

VII - ASPHALT ROOFS

This includes all bituminous materials or compounds whether the natural rock, the bitumen, the artificial asphalts and even the tar, and in general to all mastic asphalts which consist of mineral particles bound with and asphaltic cement;

(1) Natural rock (Lime Stone) consisting of 8 to 20% bitumen which is ground mixed with grit and bitumen and reduced to mastic.

(2) Bitumen which is the real asphalt

(3) Artificial asphalts which are mixtures of some of the following materials: lime, pitch, saw dust, ground iron slag, coal, tar pitch, chalk and sand.

The mastics are of three grades:-

(1) Fine

(2) Fine gritted which is mainly used on roofs

(3) Course gritted used on roads

However, the introduction of asphalt mixes and compounds in roof construction was for water proofing and insulating purposes, although now good asphalt layers on some concrete or metal lath supported by joists has proved to be practical, The use of these asphalts also facilitated the easy use of flat rrofs by reducing the number of joints and having a continuous surface at the top of the roof especially when applied to the concrete roof slab, besides being applied to the timber and other roofing materials with an undercoat of felt with slate and tiled roofs.

In general the advantages of asphalt roofing lie in the fact that it is sanitary, damp resisting, non absorbant and easily applied.

FIXING

Before this covering material can be applied to roofs, all other operations or constructional work should be completed with nothing left to be done later, with the foundation surface ready to receive the asphalting material. On flat roofs the foundations should be made to a slope of 1 in 80, although some claim that it could be made flat as the presence of some water on top of the roof is good for protecting roof from heat of the sun. In case of concrete roofs the fall is given by special screed applied to the top of the slab.

When some thermal insulating material is to be sued with the asphalt such as cork the screedings necessary to give thefall can be placed either directly over the conret, or the other roofing foundations; or the screedings are alternatively superimposed over a water proof paper or the insulating medium.

However, a modern alternative is to employ one of the light inorganic screeds as the insulating medium over which the asphalt is laid.

KEYS

Since asphalt is plastic material, it has disadvantage of being viscous especially in hot climates which makes it run under sun heat. The remedy of this to a small extent may be mixing with the asphalt some filler such as sand or stone dust which will make it more solid. However, this is not enough and special keys should be formed in the foundation surface which will make asphalt stick to this surphace, especially on sloping surfaces. These keys differ with different types of the surfaces, and on a steep roof a special lath should be provided.

UNDERLAYS

Where the foundation is liable to movement, true vibration, thermal movement or other cause, direct contact with the asphalt should be prevented by an intermedient insulating member which will obviate such movement from being transmitted to the asphalt, and will also prevent vapours of the moisture on the foundation from spoiling the asphalt. Such membranes are used on: cork or other insulating material, concrete with shallow steel, porous concrete foundations. In the absence of such underlay which should be kept clean and dry, enough care should be taken to be sure that the foundation surface is thoroughly clean dna dry.

APPLICATION OF ASPHALT

1- On horizontal roofs in two layers of 3/8 to ½" each to a total of 3/4" aver age and 1" where heavy traffic is expected.

2- On vertical sections such as skirtings in two coats to a total thickness not less than ½"

In first class jobs, the tendency is to use these coats with an undercoat of felt cemented to each other by a coat of bitumastic paint, (Fig. 27) shows the application of asphalt on roofs .

Asphalted roofs are mainly for thermal insulation for two reasons:

(1) To avoid partial movement of roof under heat of sun

(2) To protect inside of roof from loss of heat or too much heating.

The methods generally used are:

(1) The use of special material such as felt, cork, etc.. whose efficiency depends on percentage of dead space in it.

(2) By use of special tile to be cemented to the top of the roof by a coat of Igasol and the rebated joints at the edges of the tiles filled with Igasol mastic, (Fig 28), at the rate of LL.10 to 13/sq.m.

(3) By use of reflecting metal or painted surface with some reflecting paint.

ROOFING FELT

This type was once considered as temporary cover or as an auxiliary to the asphalt roofing on top of other foundations, especially in water proofing. But with proper maintenance and good workmanship it may produce a good roof especially if laid on a lath.

It is a fabric of animal or vegitable fiber treated with bituminous preperation to make it capable of resisting the weather, especially when treated with a compound of tar and slaked lime, well boiled and applied hot, on tp of which sand is applied as a sealing.

It is found in the market in three kinds:

(1) Bitumen felt consisting of a fibrous base impregnated with asphaltic bitumen.

(2) Hair felt of cow hair and flux, or jute impregnated with tar or pitch.

(3) Tar felts of various fibers and coal tar pitch.

In general, the life of felt roofs depends upon the surfacing layer such as sand, mica or granules of minerals which are cemented to the felt by hot bituminour solution.

The advantages of this roofing material are:-

(1) Very light needing very light framework

(2) Very water proof but needs good ventilation, especially when laid on timber roofs, which should have the joints of butt and not tounged system.

The felt comes in rolls 30" wide x 25"-30 yards long, which should be unfolded and cut to the required size, and kept flat for a certain time before use in order to take its final shape, and the method of its application varies with foundation material:-

(A) Timber:

The boarding should be firm unsagging, and the felt applied in rows overlapping by 3" - 4" and starting from eave to eave or from eave to ridge, but not from eave to the opposite eave over the ridge. The felt should be applied in two layers the first is nailed to the boarding and the other ~~boarded~~ nailed at the underlap. This upper layer is cemented to the lower and to the underlap by mastic solution with few nails - of flat heads - along the laps. These nails, as well as all the joints along the edges, should be sealed with mastic compounds. The gutters always should be overlapped with 1" which should be bent downward, nailed and sealed.

(B) Concrete:

The surface of the concrete should be thoroughly cleaned and painted with bitumastic 80/100 solution, then the first layer is applied while paint is still hot, then the second coat of paint is applied to cement the second coat of felt to the first layer; then the second layer of felt is sealed along the joints by bitumen. The average cost of this is LL.3.25 to 3.75 per M.S.

In a better job the top of the second layer is coated with bitumen to which while hot a layer of sand or gravel is applied. In this case, the average cost is LL.400 - 4.50 / M.S.

A still better way is to coat the roof with two coats of 80/100 bitumen then a coat of idealite over it a coat of 20/30 bitumen over it a layer of Latqia asphalt then the sealing coat of bitumen and sand. This operation costs from LL.5.50 - 6.50 /M.S.

In all kinds of roofs, box and tappered gutters may be lined with felts using traiangulated fillets at the corners to avoid sharp corners. The operation onvolves nailing the first layer, then cementing the second layer to the first by bitumastic solution, nailing it and sealing the joints and the nails.

SHINGLES:

It is becomg rather popular, due to its durability, beauty and architectural charm, especially in a country background:-

These are similar to slates in appearance and are thin slabs of timber of durable kinds, the most important are:-

(1) Oak slabs longitudinally splitted, and are of common size 12"x4", with two holes for nailing the the sheathing with oak nails or by copper nails. They are suitable for high church spikes and summer houses, and have good qualities as they weather to a very beautiful grey colour which is restfull. Moreover, they are unobstructive in rural surroundings.

(2) Canadian Wester Cedar, which is cheaper and more durable than oak, as it has weather resisting, provides a bone dug roof, is not resisting, laps so closely as to resist the strongest gales, and of a long life, and high insulating power. On top of that, it does not need any preservative treatment. A major advantage of these files over tiles is that when laid at 5" exposure they will weight 1/10 as that of clay tiles, thus economising in timber.

The usual size is 16" long and 3"-14" wide and 2/5" thick and tapering in their length to ensure close fit at the tail.

(3) Red Wood & White Pine: These are less durable and have to be coated with creosate.

In general these roofs are very much liked for their cheapness and light weight and good insulating power, as well as ease of fixing. The only major disadvantage is their fire risk which is no more so serious if shingles are treated with special compounds.

These tiles should be laid on a slope at least of 30° in which case the exposure is $5\frac{1}{2}$"; for lesser slopes down to 27° the exposure should be 3 3/4".

These tiles are laid on the sheathing by two nails of oak or galvanized nails according to the following specifications:

(a) The shingles should lap $1\frac{1}{2}$" to avoid having continuous vertical seam in two adjacent courses.

(b) Shingles should have a gap of 1/8" - $\frac{1}{4}$" to allow for swelling in winter.

(c) Form a double course at eaves as with ordinary tiles.

(d) As with slates and clay tiles, there should be special tiles for hips, valleys, ridges, etc.., lapping each other 4" wide.

The sheathing is either:-

(1) 1" x 2" battens at 5" c to c, or

(2) On felt and boaring. This type is less durable but more windproof and of better insulation.

Thatch

This ancient and beautiful roof covering was once in common use, and is to a certain exten still in use in rural districts. Its revival in the recent days has produced some goodx examples especially when properly combined with architectural constructions.

Among the many advantages of thatch are;-

(1) It insulates the building against heat, cold & noise.

(2) It can frequently be procured locally and cheaply

(3) It is practically and comparatively cheap

(4) It saves timber and other materials

(5) Being unbreakable, it is good for sports pavilion.

(6) From an aesthetic point of view, its colour tones with its setting and it needs simplicity of treatment; it excercises a definite influence on design.

(7) Does not need gutters and down pipes, but the paving around walls should be slpped.

On the other hand its disadvantages are:-

(1) Fire risk which is reduced by treating it with special compounds

(2) Should not be placed under trees or group of telegraph wires to avoid its penetration by continuous drops of water.

(3) Not fit for plans with many valleys

(4) Birds are tempted to build their nests in the roof as well as houses of rats or other insects.

(5) Not suitable for slopes less than 45°.

(6) Short life

(7) Weak against storms

(8) Needs a lot of maintenance.

There are two kinds of thatch:

(A) Water grown reeds

(B) Wheat straw - for farm buildings and small cottages or unimportant places.

In both cases, the reeds are cut at the end of winter.

Thatch is usually laid on 1½" x 1" battens, which are fixed on rafters at 2' 0" c to c, and are laid starting from eaves to ridge, the bundles are sewn together and to the battens by tarred twins or hazel rods. The thickness varies from 12" - 16".

Thatch in the form of 2" thich flat bundles or rather boards are used in combination with flat concrete roofs as internal lining, fastened to the concrete by hook bolts which are imbedded in the concrete. This gives a very good insulation and architectural effect.

Canvas Roofs

The use of treated canvas is advisable ti ensure against mildew and damage from oil in paints, canvas to be nailed with 3/4" copper tacks laid in heavy bed of white lead, then painted 2 coats of lead and oil, and repainted every two or three years.

It comes in widths of 30" & 36", and could be fixed either over concrete slabs by special wooden sleepers laid while pouring to nail the canvas to it, or over boarding which is fixed over trusses or pitched roofs.

GLASS ROOFING:

In large glassed roofs the bars are usually of steel rolled to special sections, so as to carry the condensation water. The steel bars and caps that fix the glass in position are mainly of steel which may be shaathed with lead, and with special arrangement to prevent the glass from cracking, although timber bars are used sometimes. However, the following are some of the most important patents:-

(1) Sheathed steel bars

(2) Special bars not requiring sheathing

(3) Special glazing bars supported on steel or timber

(4) Steel grooved bars.

Glass & Concrete Roofs:

The large roofs spanning open spaces often required in modern buildings, the wide continuous canopies to stores, theatres and railway stations have lead to the construction of domed and flat roofs constructed of concrete and glass in some respects similar to pavements lights. Well-known examples of this type of roofing are Lenscrete, Glasscrete, Novalux and Crete-o-lux. This type of flat glazed roof is suitable for use over the lower floors of buildings with large open light areas above. Curved and domical soffits allow very effective internal archi-tectural treatment, and the light received being top or zenith light, the whole enclosed area is well lighted. This form of construction may be used on top of lantern lights in ordinary flats instead of slopes glazed with the roof light bars referred to previously. These flat tops have a wide margin all round formed in ferro-concrete with weathered tops, rounded edge and drip underneath. They may be supported on curbs of concrete or on side-lights. The lenses are insulated in order to allow for expansion and contraction of the glass.

If ther is a possibility that water from condensation will be troublesome the makers of this type of roof construction recommend double glass with an air space between.

When the lenses are thin it is claim d that the glass may be annealed more completely and therefore will not be so liable to fracture from internal stresses. The lenses may be toughtened.

Provided the first cost is not prohibitive, the upper surface of the concrete may be protected by asphalt, this with the glass forming a perfectly watertight covering.

CHAPTER V

CONCLUSION

From this brief report on the different types of roofs, we can find our way to decide on a certain type which could be considered as the most suitable for local use.

However, in chosing any type, we should consider the roof from the following points of view:-

(1) Economy

(2) Suitability

(3) Aesthetic Beauty

On the other hand, we cannot find any one type which could be suitable everywhere in this locality, but rather divide the locality in the following regions with a particular type for each:-

(A) Sea shore and low altitudes

(B) Mountainous region of high altitude

(C) Desert.

A - For sea-shore and mountains of low altitudes, where there is a good quantity of rainfall as well as ample heat, the concrete roofs seam to be the most suitable as being very cheap especially with cheap cement and gravel.

Moreover, the ribbed roof with hallow blocks - which are improving in quality and in economical construction,- could give adequate heat and cold insulation, especailly when combined with some asphaltic water proofing.

It is worth mentioning that although this type of roofing is more expensive than the solid slab type for moderate spans, yet the more expensemay be compensated by less needing insulation and water proofing.

Moreover, as the roof is seldom seen from above in these regions, there is no risk or fear that they will look aesthetically unbeautiful, even the flat surfaces with the recent waterproofing tiles look somewhat pleasant to the eye.

Again, due to the heavy rainfall, the concrete roofs furnish the best drainage by being monolithic and continuous surface.

The ceilings could be plastered either with Itex or rough cast plaster or else the ceiling could be lined with someix insulating beatiful boards of special design.

On the other side, for factories and large stores etc.., concrete trusses could be quite satisfactory or else steel trusses preferably of the fink type covered with eternite or corrugated iron sheets. **With a ceiling of insolating material supported by the main ties.**

B - Mountainous Regions with High Altitudes

Here we have double½phase problem of drainage, i.e. rain and snow on top of that a better cold insulation should be provided.

So the pitched roofs should be quite satisfactory for this type with the covering to be either from clay tiles for high class jobs or eternite tiles or concrete tiles for secondayy jobs, especially with the factories for such items already in action.

Moreover, the pitched roofs give adequate insulation and waterproofing if used in conjunction with a good ceiling and a sheathing of boarding and felt.

On top of that pitched roofs match more than any other type with country backgrounds.

C - Desert Places:

This region being arid and hot its vital problem is heat insulation rather than waterproofing; combined with economy.

As for insulation, the earthcovered roofs have proved to be the best, particularly if laid on rigid foundation to avoid cracks or sugging.

On the other hand, concrete and metallic roofs are bad insulators besides being uneconomical.

Moreover, the materials, other than metalic coverings which when used on pitched roofs could give adequate insulations, are very expensiveand uneconomical while clay bricks are very available and cheap and good insulators.

So a roof of earth layer, as insulator, on top a series of shallow vaults built in clay bricks will be a very convenient roof for such regions. The only problem that stands unsolved is the longitudinal supports along intersections of adjacent vaults; e.g. the steel joists already described under flat roofs.

The most convenient type for such supports will be reinforced concrete ribs, which are more economical than expensive steel joists.

However for any special case other alternative may be used which will suit that case more than those enumerated here.

For example, a good alternative to be used in the desert for second class jobs where it is hot and where timber is very scarce while clay blocks reinforced with straw are cheap; is to divide the area into square panels and to cover each with a dome roof of bricks, with no shuttering; by a special devise.

This ingenious method consists of driving a timber post exactly in the centre of the panel with its top on the same level with the top of the walls (fig 21). Another guiding rule of timber is fastened to the top of the post in a way allowing the rule to rotate around the joint vertically and horizontaly, and its length being equal to half of the diagonal of the room or panel.

Then the walls are raised up by half circles with the diameters as the tops of the walls. Then the gaps between these cemicircles are closed by segments of horizontal rings, diminishing in radius as they go up, and built with their internal face touching the edge of the guiding rule . Once the gapes are closed, ending at the top of the cemicircles with a horizontal circle, this new circle is roofed with a dome also built in horizontal rings one after the other with their soffits always touching the edge of the rotating rule.

Thus a cheap and good roof - especially if covered with mud - will be achieved.

As a last word before I close this short report:- We should not look after better materials only, but we should combine a suitable materials with proper technical methods of construction, as well as the other water proofing and insulating accessories in order to get an adequate roof which will satisfy the requirements of the roof- already stated- and to be cheap, economical and a esthetically beautiful without sacrificing the strength of the whole structure for the sake of the roof.

APPENDIX

COST ANALYSIS OF CONCRETE & STEEL ROOFS

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FIRST: CONCRETE ROOFS

A- BEAM & SLAB - EQUAL SPANS

Estimated uniform weight :-

① dead weight of slab	=	60-80 #/ft²
② " " of tiles, sand etc =		40 #/ft²
③ Live load	=	30 #/ft²
Total	=	130-150 #/ft²

Design of Slab, Beams & Columns

① 10'0" x 10'0" span :-

Design of slab :- $w = 130/2 = 65$ #/ft²

$M = 1/12 \times 65 \times 10^2 \times 12 = 6,500$ in lb.

$d = \sqrt{M/12 \times 173} = 1.75"$ use 2"

Total thickness of slab = 3 ½"

$A_{s_1} = 6500 - (18000 \times 2 \times 7/8) = 0.206$ □"

use 3/8" φ bars C 6 ¼" C to C.

$A_{s_2} = 6500 \div (18000 \times 2\,3/8 \times 7/8) = 0.175$ □"

use 3/8" φ bars C 7½" cts.

Design of beams :- $w = 65 \times 10 + 100 = 750$ #/1

$M = 1/12 \times 750 \times 10^2 \times 12 = 75,000$ in. lb.

$V = 750 \times \frac{10}{2} = 3,750$ lb. at support.

$b'd = 3750 \div (7/8 \times 150) = 28.5 \square''$

use $5'' \times 6''$

total depth below slab $= 5\frac{1}{2}''$

$A_s = 75000 \div (18000 \times 7/8 \times 6) = 0.79 \square''$

use $2 - 3/4'' \phi$ bars & stirrups $1/4'' \phi$ c $8''$ cts.

Column (12'0" high) :- use 10"x10"

reinforced with $4 - 1/2'' \phi$ bars $4\ 1/4'' \phi$ stirrups c 8" cts.

(2) - 15'0" x 15'0" span :- Slab :-

$M = 1/12 \times 65 \times \overline{15'}^2 \times 12 = 15,100$ in lb.

$d = \sqrt{15100 \div (12 \times 173)} = 2.75''$ total depth $= 4''$

$A_{s_1} = 15100 \div (18000 \times 7/8 \times 3.12) = 0.320 \square''$

use $3/8'' \phi$ bars c 4" cts.

Beams : $w' = 15 \times 65 + 125 = 1100$ #/1

$M = 1/12 \times 1100 \times \overline{15}^2 \times 12 = 247500$ in lb.

V = at support $= 1100 \times \frac{15}{2} = 8250$ lb.

$b'd = 8250 \div (7/8 \times 150) = 63$ use $6'' \times 12''$

total depth below slab $= 9''$

$A_s = 247500 \div (7/8 \times 18000 \times 10.5) = 1.5 \square''$. use $2 - 1'' \phi$ bars & $1/4'' \phi$ stirups c 6" cts

Column : same as last design for 10'x10'

(5) 20′0″ x 20′0″ span :- slab :-

$M = \frac{1}{12} \times 65 \times \overline{20}^2 \times 12$ = 26000 in-lb

$d = \sqrt{26000 \div (12 \times 175)} = 3.5''$ total depth = 5″

$As_1 = 26000 \div (7/8 \times 18000 \times 3.5 = 0.47$ □″

use ½″ φ bars c 5″ cts.

$As_2 = 26000 \div (7/8 \times 18000 \times 4) = 0.414$ □″

use ½′ φ bars c 5¾ cts.

Beams = $w = 20 \times 65 + 150$ = 1450 #/′

$M = \frac{1}{12} \times 1450 \times 400 \times 12$ = 580,000 in lb.

V at support = $1450 \times \frac{20}{2}$ = 14500 lb.

$b'd = 14500 \div (7/8 \times 150)$ = 110 □″

use 8″ x 14″ total depth below slab = 12½″

$As = 580\,000 \div [18000 \times (14 - 2.5)]$ = 2.8 □″

use 2-7/8″ φ + 4-¾″ φ bars & ¼″ φ stirups c 6″ cts.

Column :- Weight transmitted :-

slab	=	400 x 130	= 52,000 #
Beams	=	2 x 20 x 100	= 4 000 #
Column	=	assumed	= 2 000 #
		Total W	= 58 000 #

selected section :- 12″ x 12″

As = 1.44 □″ use 4-¾″ φ bars & ¼″ φ stirups c 6″ cts.

(4) - 25'0" x 25'0" span :- Slab

$M = \frac{1}{12} \times 70 \times 25^2 \times 12$ = 45700 in. lb.

$d = \sqrt{45700 \div (12 \times 173)}$ = 4.5" total depth = 6"

A_s = 45700 ÷ (7/8 × 18000 × 4.5) = 0.575 □"

use = 1/2" φ bars C 4" cts.

A_{s_L} = 43700 ÷ (7/8 × 18000 × 5) = 0.515 □"

use = 1/2" φ bars C 4 1/2" cts.

Beams :- w = 70 × 25 + 100 = 1850 #/'

M = 1/12 × 1850 × 625 × 12 = 1,160,000 in lb.

V = 1/2 × 1850 × 25 = 23 200 #

b'd = 23200 ÷ (7/8 × 150) = 177 □" use

10" × 22" total depth below Slab = 19 1/2"

A_s = 1160000 ÷ [18000 (22 - 3)] = 3.4 □"

use 6 - 7/8" φ bars & 3/8" φ stirups C 8" cts.

Column :- Weight transmitted :-

Slab	=	140 × 625	=	87,000 #
beams	=	2 × 25 × 200	=	10 000
column	=	assumed	=	3 000
Total				100 000 #

use 14" × 14" column reinforced with 8 - 5/8" φ bars & 1/4" φ stirups C 6" cts.

(5) - 30'0" x 30'0" span :- Slab

$M = 1/12 \times 75 \times 30^2 \times 12$ = 67 500 in. lb.

$d = \sqrt{67500 / 12 \times 173}$ = 5.75 total depth = 7½"

$As_1 = 67500 \div (18000 \times 7/8 \times 5.75) = 0.815$ □"

use 5/8" ϕ C 4 ½" cts.

$As_2 = 67500 \div (18000 \times 7/8 \times 6.40 = 0.73$ □"

use 5/8 ϕ C 5" cts.

Beams :- actual w = 80 #/ft² : W = 30 × 80 + 250

$M = 1/12 \times 2650 \times 900 \times 12$ = 2 385 000 "#

$V = 2650 \times 30/2$ = 39 750 #

$bd = 39750 \div (7/8 \times 150)$ = 300 □"

use 12" × 25", depth below slab = 21"

$As = 2385000 \div [18000 (25 - 3.5)] = 6.15$ □"

use 8 - 1" ϕ bars + 3/8" ϕ st. C 6" cts.

Column :- Weight transmitted :-

slab = 160 × 900 = 144 000 #

beams = 60 × 262.5 = 15 750

Column = assumed = 2 250

Total 162 000 #

use 18" × 18" column reinforced with 8 - 3/4" ϕ bars & 3/8" ϕ stirups C 6" cts.

⑥– 35′0″ x 35′0″ span :– slab :–

$M = 1/12 \times 85 \times 35^2 \times 12 = 104,000$ in.lb.

$d = \sqrt{M/12 \times 173} = 7''$ total depth $= 8\,5/8''$

$A_{s_1} = 104000 \div (7/8 \times 18000 \times 7) = 0.95$ □″

use: 5/8″ ϕ c 3 3/4″ cts.

$A_{s_2} = 104000 \div (7/8 \times 18000 \times 7\,5/8) = 0.875$ □″

use: 5/8″ ϕ c 4 1/4″ cts.

Beams = $W = 80 \times 35 + 250 = 3100$

$M = 1/12 \times 3100 \times \overline{35}^2 \times 12 = 3,800,000$ ″#

$V = 3100 \times 35/2 = 54\,250$ #

$bd = 54250 \div (7/8 \times 150) = 415$ □″

use 14 x 31 . depth below slab = 26″

$A_s = 3.800\,000 \div [18000\,(31 - 4\,1/4)] = 7.85$ □″

use 10 – 1″ ϕ + 3/8″ ϕ st c 6″ cts.

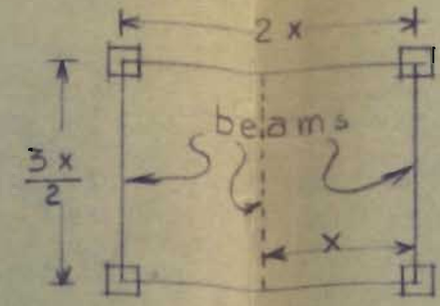
Column : Weight transmitted :–

slab	= 160 x $\overline{35}^2$ =	196 000 #
Beams	= 70 x 375 =	26 000 #
Column	= assumed =	3 000 #
	Total	225 000 #

Use 20″ x 20″ A_s = 4.00 □″

Use = 4 – 3/4″ ϕ bars + 4 – 7/8″ ϕ bars & 3/8″ ϕ st c 6″ cts.

SPAN	CONCRETE TYPE	CONCRETE MEASUREMENTS	STEEL TYPE	STEEL MEASUREMENTS
10'x10' = 1000'	Slab	100 x 7/2 x 1/12 = 29 ft^3	Bars	100 x 12/8 x 0.38 = 57#
			"	100 x 12/6.25 x 0.38 = 73 "
	Beams	2 x 10 x (5x11)/144 = 4 ft^3	"	2 x 12 x 2 x 1.5 = 72 "
			St.	2 x 12 12/8 x 2 x 0.17 = 12 "
	Column	(1 x 10 x 10)/144 x 12 = 8	Bars	4 x 12 x 0.17 = 33 "
				12 x 12/8 x 3 x 0.17 = 9 "
		total in c.f = 41 add 5% wastage = 2 Grand total = 43 c.f		total in # 256 add 12% for lap = 34 Grand totale = 290 #
15'x15' = 225□	Slab	225 x 4/12 = 75 c.f.	Bars	225 x 3 x 0.38 } 550#
			"	225 x 3.2 x 0.38 }
	Beams	2 x 15 x ½ x ¾ = 11 "	"	2 x 17 x 2 x 2.67 = 180 "
			St	2 x 15 x 2 x 3 x 0.17 = 30 "
	Column	(10 x 10)/144 x 12 = 8 "	bars	4 x 12 x 0.67 = 33 "
				12 x 2 x 3 x 0.17 = 14 "
		total = 94 " add 5% wastage 5 " Grand totale = 99 c.f		total = 787 " + 12% for lap & waste = 98 " Grand total 885#
20x20 = 400 s.f	Slab	400 x 5/12 = 167 c.f	Bars	400(2.4 + 12/5.25) x 0.67 = 1255#
	Beams	2 x 20 x 8/12 x 12.5/12 = 28	"	2 x 22.5(2 x 2.04 + 4 x 1.50) = 454
			St.	2 x 20 x 3.5 x 2 x 0.17 = 48
	Column	1 x 1 x 12 = 12	Bars	4 x 12 x 1.50 = 72
			St.	2 x 12 x 4.5 x 0.17 = 18
		total = 207 c.f x 1.05 = 217		total = 1847 x 1.12 = 2080#
25x25 = 625 Sq.ft.	Slab	625 x 1/2 = 313 c.f	Bars	625 (3 + 2.68) x 0.67 = 2365#
	Beams	2 x 25 x (10 x 19.5)/144 = 68 "	"	2 x 6 x 28 x 2.04 = 685
			St.	2 x 28 x 12/8 x 5 x 0.38 = 160
	Column	(14 x 14)/144 x 12 = 17 "	Bars	8 x 12 x 4.04 = 100
				24 x 5 x 0.17 = 21
		398 " x 1.05 = total = 420 c.f		3331# x 1.12 total = 4145#
30'x30' = 900 Sq.ft	Slab	900 x 7.5/12 = 525 c.f	Bars	900(2.4 + 2.67) x 1.04 = 5050#
	Beams	2 x 30 x 1 x 21/12 = 105	"	2 x 8 x 34 x 2.67 = 1455
			St	2 x 30 x 2 x 6 x 0.38 = 275
	Column	3/2 x 3/2 x 12 = 27	Bars	8 x 12 x 1.50 = 144
			St	12 x 2 x 5.5 x 0.38 = 50
		657 c.f x 1.05 for wastage total = 690 c.f		6974# x 12 total = 7845#
35'x35' = 1225 Sq.ft	Slab	1225 x 8.62/12 = 882 c.f	Bars	1225(12/3.75 + 12/4.25) x 1.04 = 7675#
	Beams	2 x 35 x (14 x 26)/144 = 177 "	"	2 x 39 x 10 x 2.67 = 2080
			St	2 x 70 x 6.5 x 0.38 = 346
	Column	(20 x 20)/144 x 12 = 33	Bars	4 x 12 (1.50 + 2.04) = 170
			St	12 x 2 x 6 x 0.38 = 55
		1092 x 1.05 total = 1150		10326 x 1.12 11600#



-B- Slab, Beam & Girder

each panel consisting of a slab supported by tree beams, two girders and 4 columns. The ratio of the sides are shown in the Fig.

1) 8'x12' panel, w = 130 #/ft2

$M = 1/12 \times 130 \times \overline{8}^2 \times 12 =$ 8350 in. lb.

$d = \sqrt{M/12K}$ = 2" total depth = 3 1/2"

$A_s = M/f_s j d$ = 0.26 □"

use 3/8 φ c 5" c/oc. & 1/4" φ c 12" cts in long direction.

Beams: w = 130 x 8 + 60 = 1100 #/1

$M = 1/12 \times 1100 \times \overline{12}^2 \times 12 =$ 158000 in. lb.

$V = 1100 \times 12/2$ = 6600 #

$b'd = 6600 - (7/8 \times 150)$ = 61

use 6x10' total depth below Slab = 8 1/2"

$A_s = M/f_s j d$ = 0.84 □" use 2-3/4" φ + 1/4" φ st. c 8" cts.

Girders: (neglecting its own weight :-

W = 12 x 1100 = 13200#

V = 6600 - use 6" x 12"

$M = 1/8 \times 13200 \times 16 \times 12 =$ 425000 in. lb.

$As = M/f_s j d = 1.93$ □" = use 2-5/8" φ + 2-7/8" φ & 1/4" φ st. c 6" cts.

Column: min. size = 10" x 10" with 4-5/8" φ & 1/4 φ st. c 8" cts.

2) – $18'0'' \times 24'0''$ – Slab :-

$M = \frac{1}{12} \times 130 \times \overline{18}^2 \times 12$ = 18700 ''#

$d = \sqrt{M/12K}$ = 3'' , total depth = 4''

$A_s = M/f_s jd$ = 0.395 □'' use ½'' φ C 6'' cts & ¼'' φ C 12'' cts in long direction.

Beams = W = 12 × 130 + 140 = 1600 #/1

$M = \frac{1}{12} \times 1600 \times \overline{18}^2 \times 12$ = 518000

$V = 1600 \times 18/2$ = 14400

$b'd = 14400 \div (7/8 \times 150)$ = 110

use 8'' × 14 , depth below slab = 15''

$A_s = 518000 \div (18000(14-2)) = 2.35$ □''

use 4 - 7/8'' φ & ¼'' φ st C 6'' cts

Girder: W = 18 × 1600 = 28800 #

Use = 8'' × 18'' , d below slab = 18.5''

$M = \frac{1}{8} \times 28800 \times 24 \times 12$ = 1040000 ''#

$A_s = 1040000 \div [18000(18-2)] = 3.6$ □''

use 6 - 7/8'' φ bars & 3/8'' φ st C 8'' cts.

Column: Total load transmitted :-

Slab	= 130 × 18 × 24	=	55000
beams	= 2 × 18 × 150	=	5400
Girder	= 24 × 150	=	3600
Column	= assume	=	1000
	Total	=	65000

use 12'' × 12'' with 8 - ½'' φ & ¼'' φ st C 8'' cts.

3). 24'0" x 32'0" - Slab :-

$M = 140/12 \times \overline{16}^2 \times 12$ = 35.800 in.lb.

$d = \sqrt{35800/(12 \times 173)}$ = 4.25" total depth = 5"

$A_s = M/f_s j d$ = 0.535 □" use ½" φ C 4 ¼" cts. & ¼ φ C 12" cts in long dir.

Beams: $w = 140 \times 16 + 160$ = 2400 #/1

$M = 1/12 \times 2400 \times \overline{24}^2 \times 12$ = 1380000 " #.

$V = 2400 \times 24/2$ = 28.800 #.

$b'd = 28800/(7/8 \times 150)$ = 220 □"

use 10" x 22"; depth below slab = 18.5"

$A_s = M \div (18000 \times (22 - 2\tfrac{1}{2}))$ = 3.95 □"

use 4-¾ φ + 4-⅞ φ & ¼ φ St. C 6" cts.

Girder: W = 22800 x 2 = 45600

use 10" x 26", depth below slab = 22.5"

$M = 1/8 \times 45600 \times 32 \times 12$ = 2,190,000 " #

$A_s = 219000 - [(26 - 2\tfrac{1}{2}) \times 18000]$ = 5.16 □

use 6-⅞ φ + 2-1" φ & ⅜" φ st. C 6"

Column: Weight transmitted :-

slab	= 24 x 32 x 140	=	105000 #
beams	= 2 x 24 x 200	=	9600 #
Girder	= 1 x 32 x 250	=	8000 #
Column	= assume	=	2400 #
			125000 #

use 16" x 16" with 8-⅝" φ & ¼" φ st C 6" cts.

<u>4)- 30'0" x 40'0"</u> - slab

M = 150/12 × $\overline{20}^2$ × 12 = 60000 "#

d = 5.5" total depth = 6.5"

As = 0.69 □" use 5/8" φ c 5¼" cts. & 3/8 φ c12" sts in long dir.

<u>Beams</u> :- w = 20 × 150 + 250 = 3250 #/'

M = 3250/12 × $\overline{30}^2$ × 12 = 2925000"#

V = 3250 × 30/2 = 48750 # , b'd = 372 □"

use 14" × 26.5" depth below Slab = 23.5"

As = 2925000 / 18000 (26.5 - 3.25) = 6.95 □"

use 6-1" φ + 4-7/8" φ & 3/8" φ st c 6" cts.

<u>Girder</u> :- W = 2 × 48750 = 97500" , use 14' × 35"

M = 1/8 × 97500 × 40 × 12 = 5,850,000 "#

As = 10.2 □" use 13-1" φ (three rows : & 3/8" φ st c 4" cts.

<u>Column</u> = Weight transmitted :-

slab	= 40 × 30 × 150	=	180000#
beams	= 2 × 30 × 350	=	21 000#
Girder	= 1 × 40 × 450	=	18 000#
Column	= assume	=	4 000#
		Total =	223000#

use 20" × 24" & 8-7/8" φ + 3/8" φ st. c 6" cts.

SUMMARY

SPAN	CONCRETE			STEEL	
	TYPE	Volume in c.f.		TYPE	Weight in #
12'×16' = 192 □'	Slab	192 × 3½/12 =	56	bar	192 (24×0.38+0.17) = 2[illegible]3
	beam	2 × (10.25×10)/144 × 12 =	17	bar / st.	2×2×13×1.50 = 78 2×18×2×0.17 = 13
	Girder	1 × ½ × 1 × 16 =	8	b. / r.	1×2×18(2.04+1.04) = 112 32×3.5×0.17 = 13
	Column	10/12 × 10/12 × 12 =	8	b. / st.	4×12×1.04 = 50 18×2⅔×0.17 = 8
			89		487
		× 1.05 =	94		× 1.12 = 550
18'×24' = 432 sq ft	Slab	432 × ⅓ =	144	bars	432 (2×0.67+0.38) = 745
	beam	2 × 8/12 × 18.5/12 × 18 =	31	bars / St.	2×4×21×2.04 = 345 2×18×2×4×0.17 = 49
	Girder	1 × ⅔ × 18.5/12 × 24 =	25	bar / St	6×28×2.04 = 345 36×4×0.38 = 55
	Column	1×1×12 =	12	bar / St	8×12×0.67 = 65 18×4×0.17 = 13
			212		1617
		× 1.05	312		+ 12 % 1820
24'×32' = 768 sq ft	Slab	768 × 5/12 =	320	bar	768 (2.81×0.67+0.17) - 1581
	beams	2 × 24 × 10/12 × 18.5/12 =	62	bars / St	2×27×4(150+2.04 = 650 2×24×2×4×0.17 = 65
	Girder	32 × 10/12 × 22.5/12 =	50	bars / St	35×(6×2.04×2×2.67) = 617 2×32×5.5×0.38 = 134
			c.f. 432		c/f 3047

SPAN	CONCRETE			STEEL		
	TYPE	Volume in c.f.		TYPE	Weight in #	
		B.F.	432		B.F.	3047
	Column	12 × 4/3 × 4/3 =	21	bar	8×12×1.04 =	100
				St	24×5×0.17 =	20
			453			3167
		+5%	475		+12%	3560
30'×40'	Slab	1200 × 6.5/12 =	650	bars	$1200\left(\frac{12}{5.25}\times 1.04+0.38\right)$ =	3305
1200 sq ft	beams	2×30×14/12×23.5/12 =	121	bars	2×34(6×2.67+4×2.04) =	1650
				St.	2×30×2×6×0.38 =	275
	Girder	40×14/12×11/4 =	128	bars	46×13×2.67 =	1670
				St	120×7.5×0.38 =	340
	Column	$\frac{20}{12}$×2×12	40	bars	8×12×2.04 =	200
				St.	8×24×0.38 =	70
			939			7510
		+5%	990		+12%	8450

DATA FOR COST GRAPH

SPAN	AREA	CONCRETE			STEEL			Total cost	Cost per unit area
	Sq.ft.	Vol. c.f.	Rate L.L.	Cost L.L.	Wght #	Rate L.L.	Cost L.L.	L.L.	L.L./□'
		FIRST : Equal Spans							
10'	100	43	1,33	57	290	0.25	73	130	1.30
15'	225	99	"	132	885	"	221	353	1.57
20'	400	217	"	290	2080	"	520	810	2.02
25'	625	420	"	560	4145	"	1036	1596	2.55
30'	900	690	"	920	7845	"	1961	2881	3.2
35	1225	1150	"	1533	11600	"	2900	4433	3.60
		SECOND: Rectangular Panels $L_1/L = 1\frac{1}{3}$							
L.									
16'	193	94	1.33	125	550	0.25	138	263	1.38
24'	432	312	"	416	1820	"	455	871	2.02
32'	768	475	"	633	3560	"	890	1523	1.98
40'	1200	990	"	1320	8450	"	2113	3433	2.85

SECOND - STEEL TRUSSES

A Fink truss will be chosen for the investigation of the cost of the steel trussed roofs covered with corrugated iron sheets. First trusses with spans of 30', 60' and 90' will be designed to determine the weight of steel needed and consequantly the cost of roof per unit area, for each span evalvated; then the cost per unit area for these roofs will be determined from standard tobler from hand books

A - Determination of weights and loads.-

1.- 30' span, trusses C 12' cts.

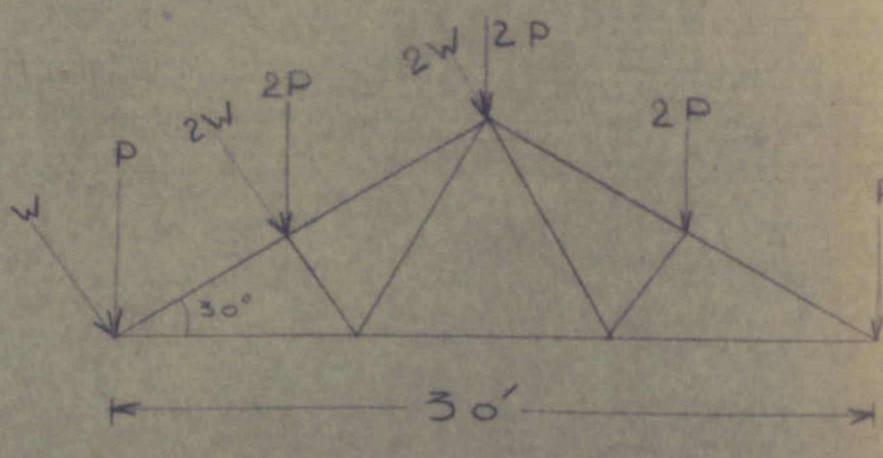
pitch = 30° 3 panel points on each top chord C 8.66' cts. Wind load estimated = 24 #/ft²

W = 24 × 12 × 8.66 - 2 = **1250 #**

Dead load and live load :-

Roofing and Purlins	=	3.5 #/Ft²	assume
Truss dead weight	=	5.0 "	"
Live load	=	25.0 "	"
Total		33.5 #/□'	

$P = \frac{33.5}{2} \times 12 \times 8.66 = 1750$ #



2- 90'0" span trusses c 15'0" cts 5 panel points at each top chord c 8.66' spacing
Wind force = 24#/ft²
Dead and live loads .-

1)	Roofing & purlins estimated c		4.5#/ft²
2)	Dead weight of truss	=	6.75 "
3)	Live load	=	25.0 "
	Total	=	36.25 "

$P = \frac{36.25}{2} \times 15 \times 8.66 = 2350^{\#}$

$W = \frac{24}{2} \times 15 \times 8.66 = 1550^{\#}$

3- 90'0" span truss c 16'0" cts 7 panel points c.8.66 cts at each topchord wind force = 24 #/□'
Dead and live weight.-

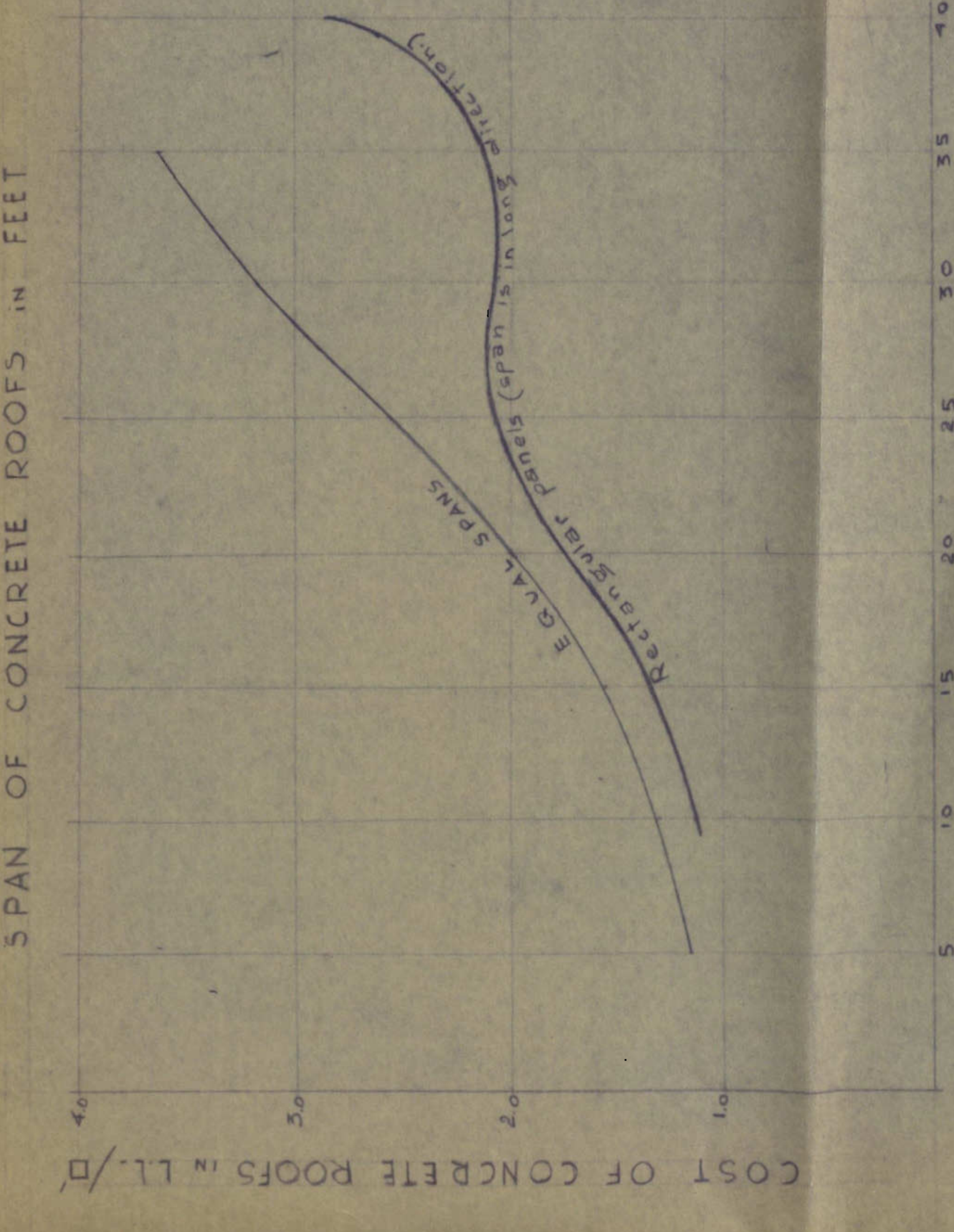
1)	Roofing and purlins estimated	=	5.5 #/□'
2)	Dead weight of truss	=	8.5 "
3)	Live load	=	25.0 "
	Total	=	39.0 "

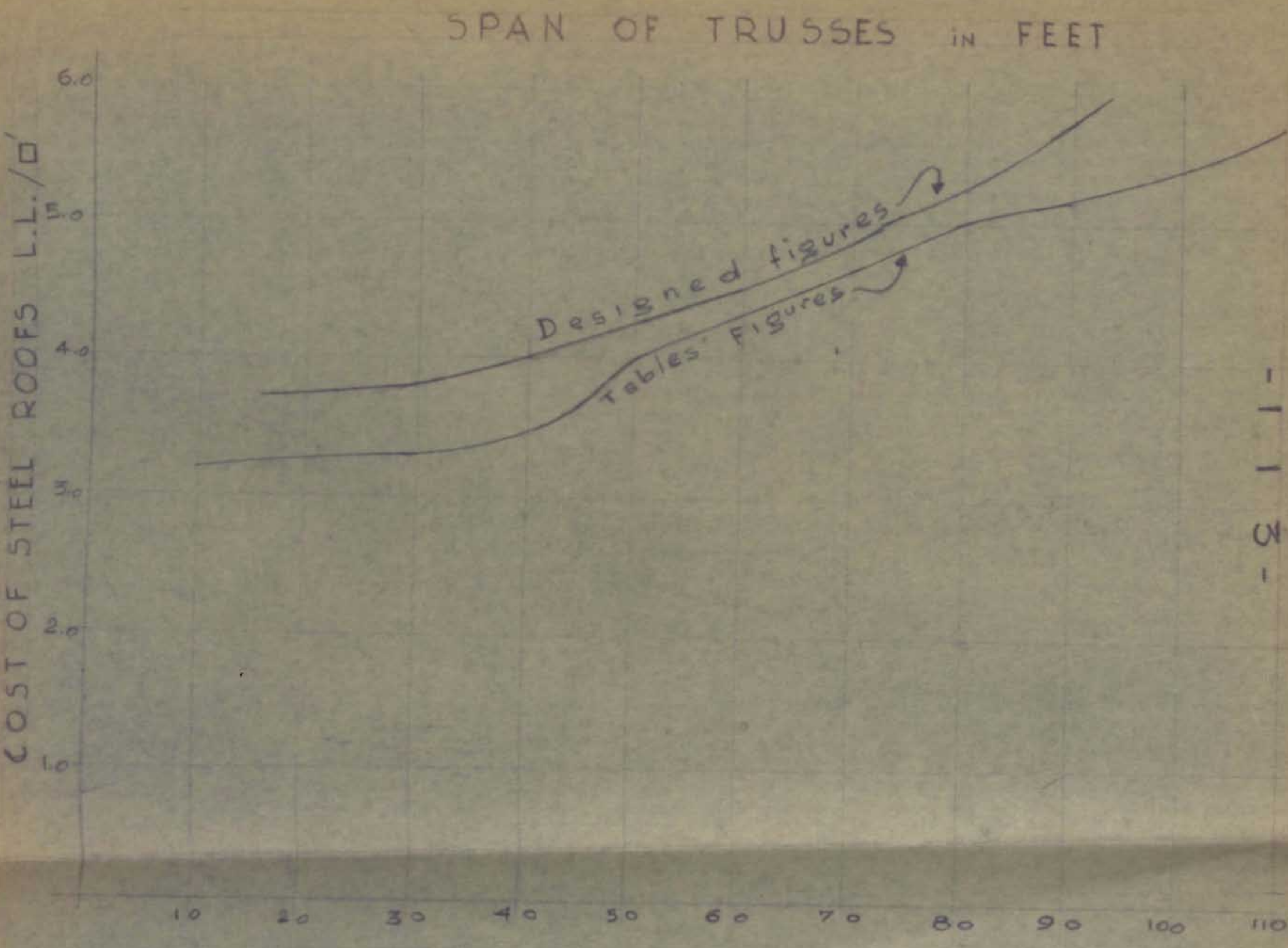
$P = 39/2 \times 16 \times 8.66 = 2700^{\#}$
$W = 24/2 \times 16 \times 8.66 = 1700^{\#}$

DATA FOR COST GRAPH

STEEL TRUSS ROOFS

SPAN	TRUSS			ROOFING			TOTAL
	Weight /□'	Rate L.L/□'	Cost L.L./□'	Cost of material L.L./□'	Cost of Fixing L.L./□'	Total cost L.L/□'	COST, L.L./□'
		FIRST : DESIGNED FIGURES					
15'	5.7	0.525	3.00	0.50	0.15	0.75	3.75
30'	5.84	"	3.08	"	"	"	3.83
60'	7.40	"	3.88	"	"	"	4.63
90	9.70	"	5.10	"	"	"	5.85
		SECOND : TABLES' FIGURES					
0-40'	5.25	0.525	2.75	0.50	0.15	0.75	3.50
45	5.75	"	3.00	"	"	"	3.75
55	6.75	"	3.55	"	"	"	4.30
65	7.25	"	3.80	"	"	"	4.55
75	7.75	"	4.06	"	"	"	4.81
90	8.5	"	4.46	"	"	"	5.21
110	9.5	"	4.98	"	"	"	5.73


SPAN OF CONCRETE ROOFS IN FEET
COST OF CONCRETE ROOFS IN LL./□'
EQUAL SPANS
Rectangular panels (span is in long direction.)
5
10
15
20
25
30
35
40
1.0
2.0
3.0
4.0


SPAN OF TRUSSES in FEET
COST OF STEEL ROOFS L.L./□'
6.0
5.0
4.0
3.0
2.0
1.0
10
20
30
40
50
60
70
80
90
100
110
Designed figures
Tables' Figures

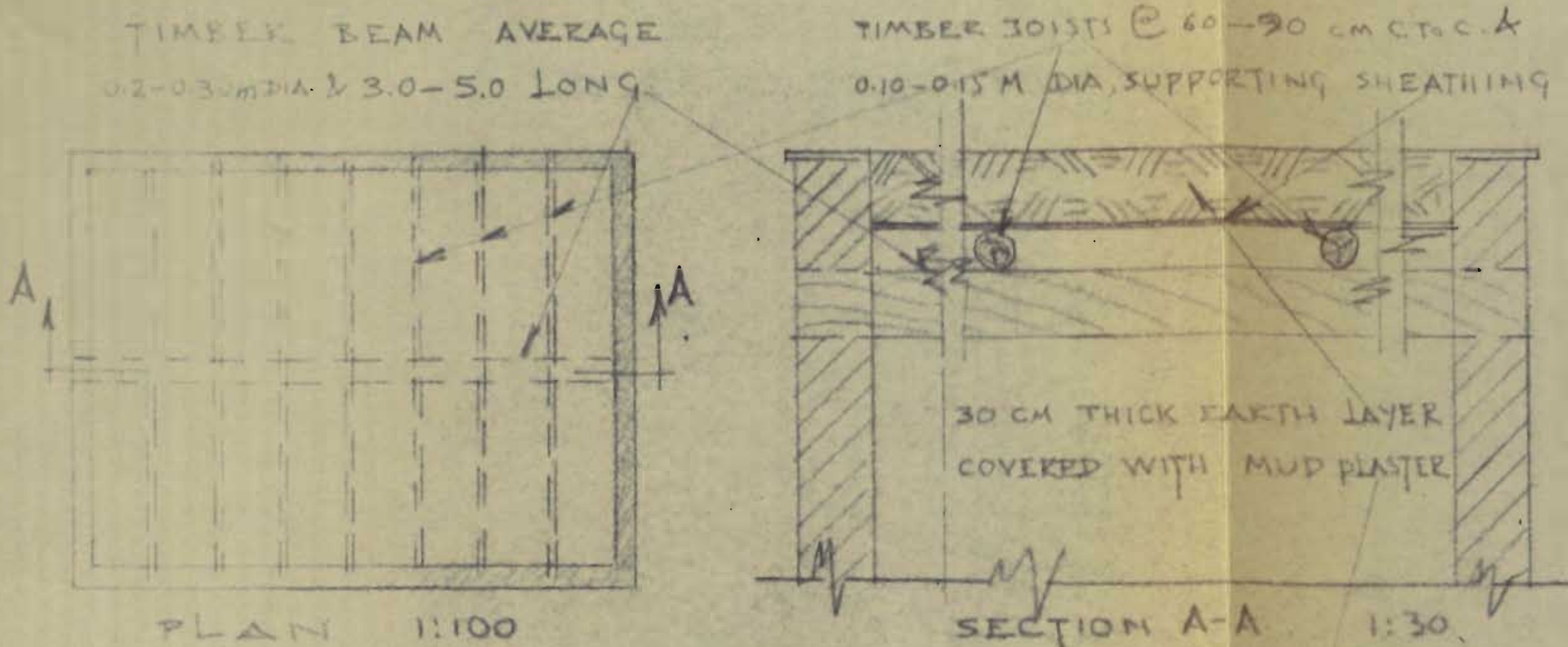
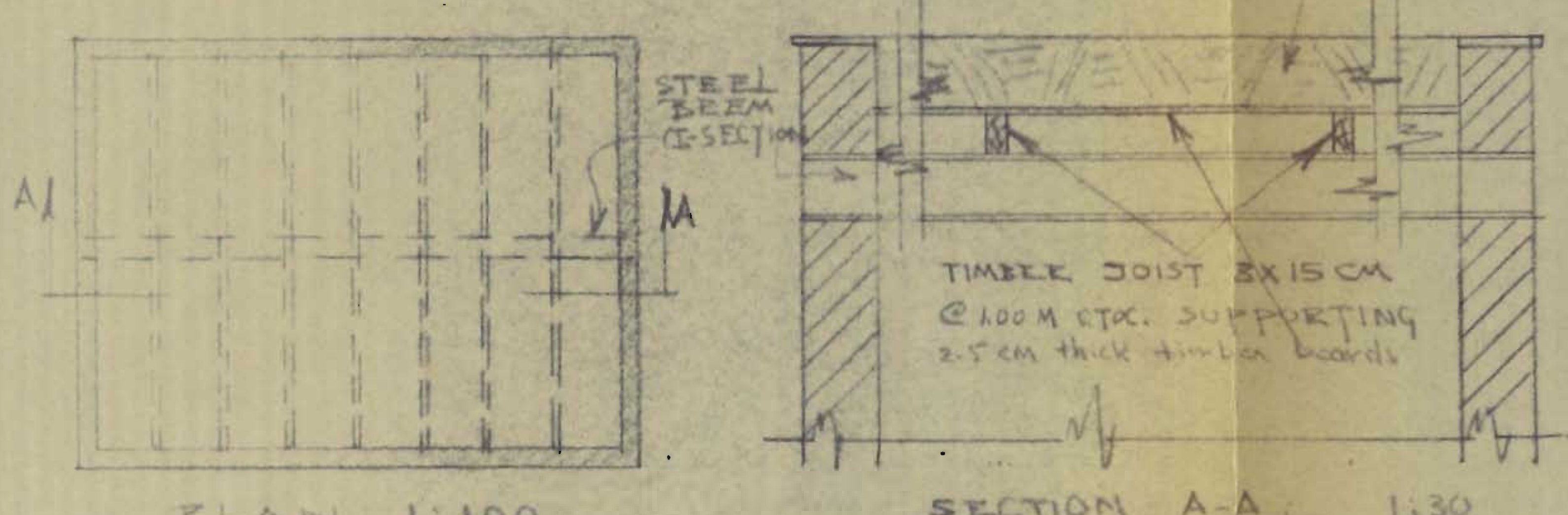
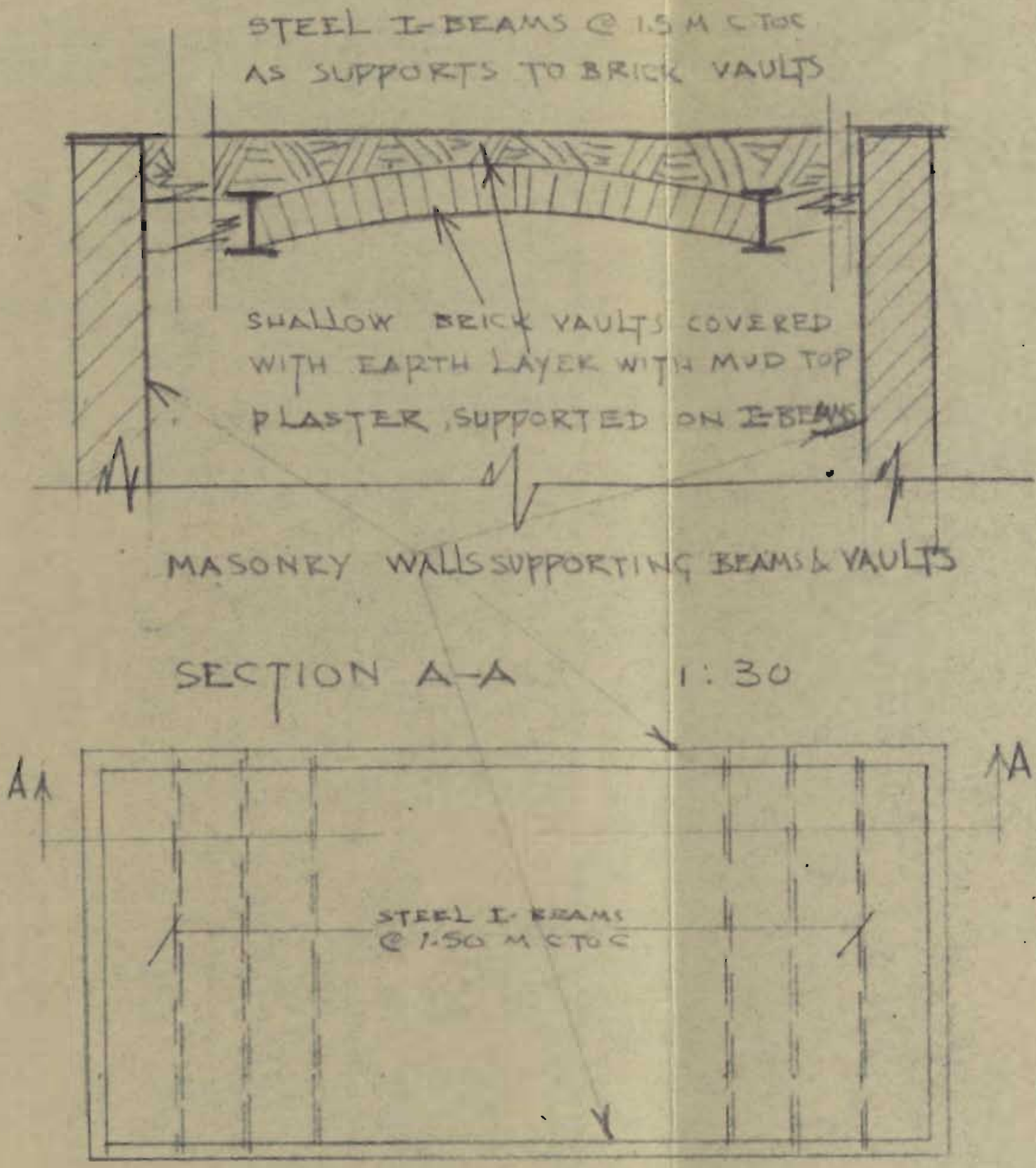


FIG I - EARTH & TIMBER ROOF



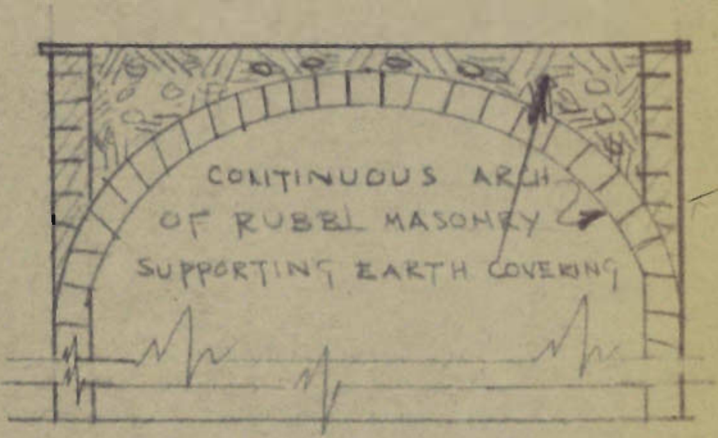
EARTH & STEEL BEAM ROOF.

FIG 2

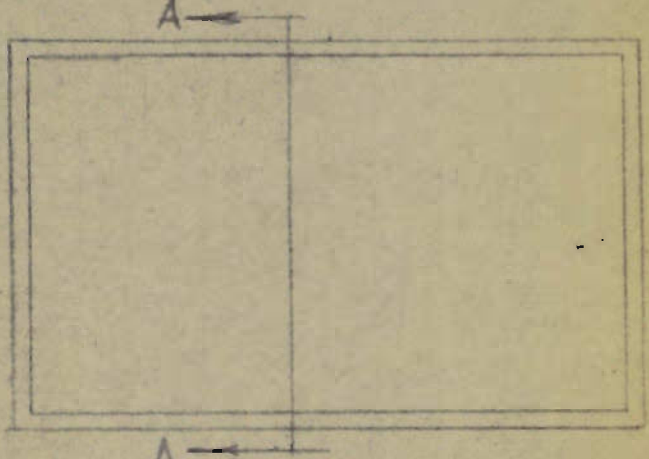


BRICK AND STEEL JOISTS - EARTH ROOF.
1:100

FIG 3



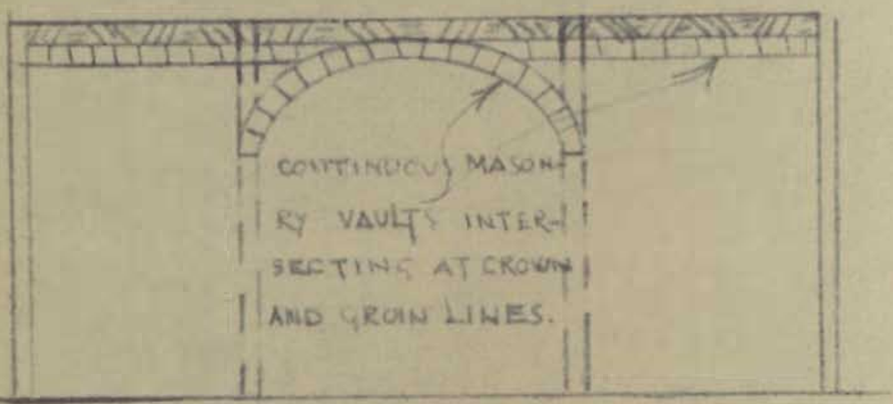
SECTION A-A 1:60



PLAN 1:100

BARREL VAULT

FIG 4



SECTIONS A-A

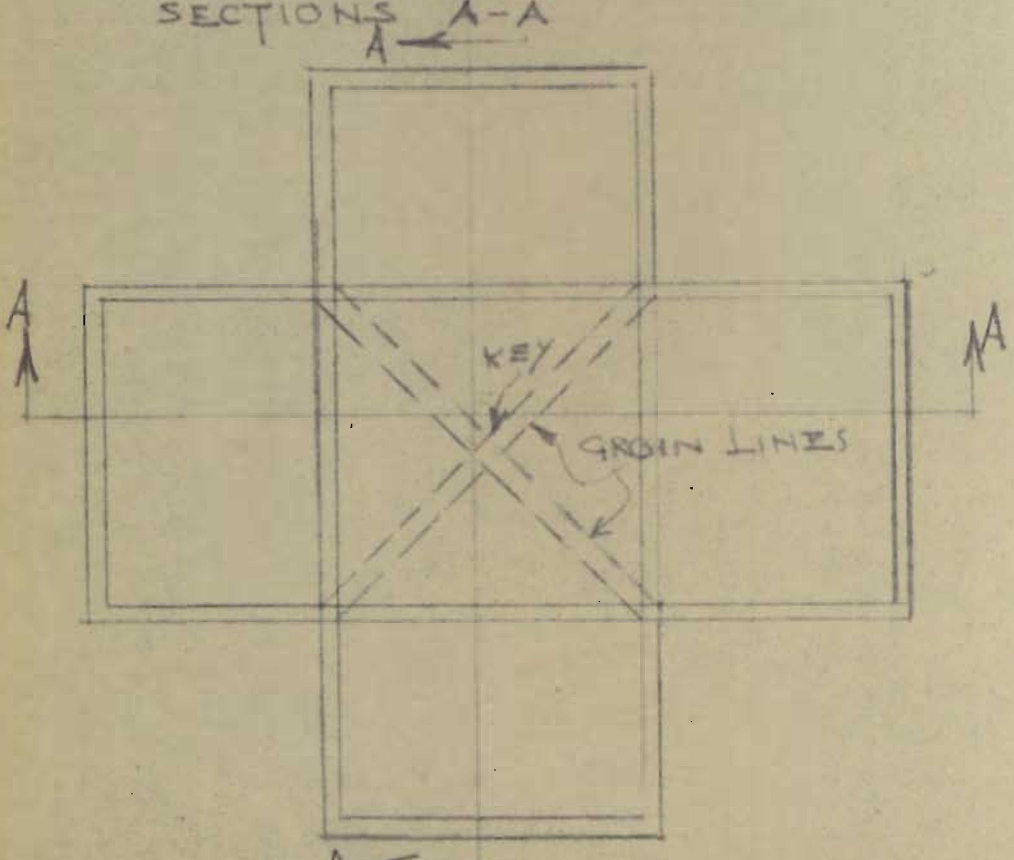
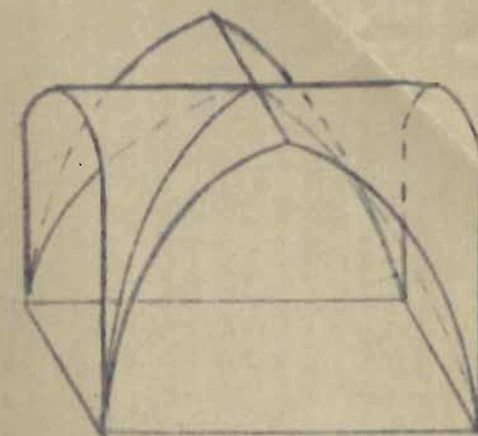
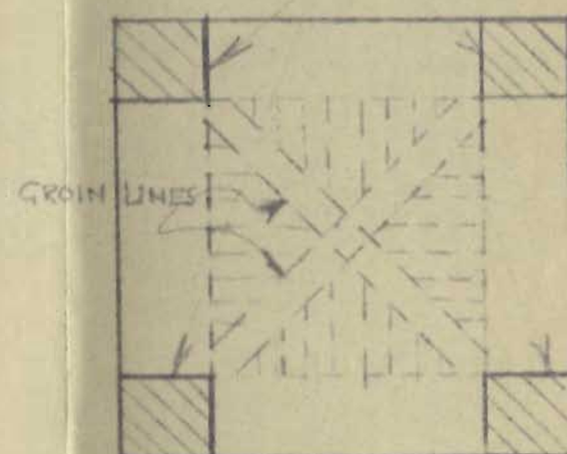


FIG 5. CROSS BARREL VAULT



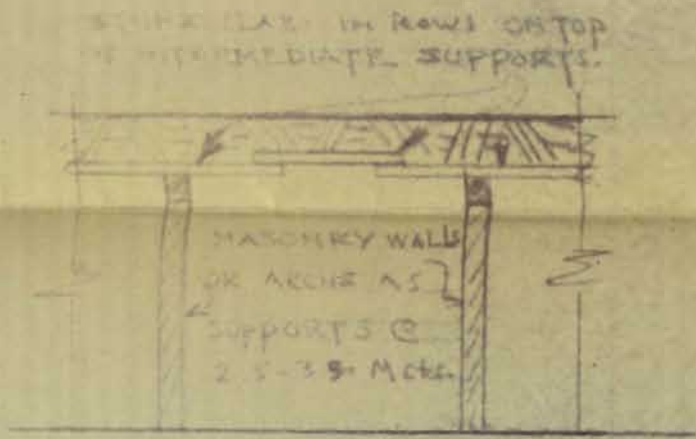
LINE ISOMETRIC DIAGRAM OF LEVEL RIDGE VAULT.

4 No. ABUTMENTS



LEVEL RIDGE VAULT 1:100

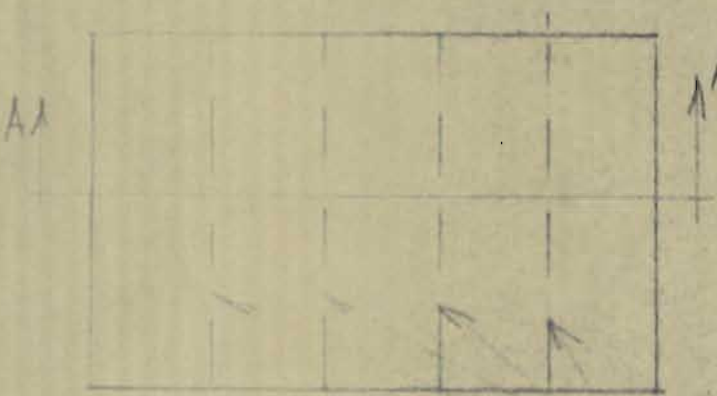
FIG 6



SECTION A-A

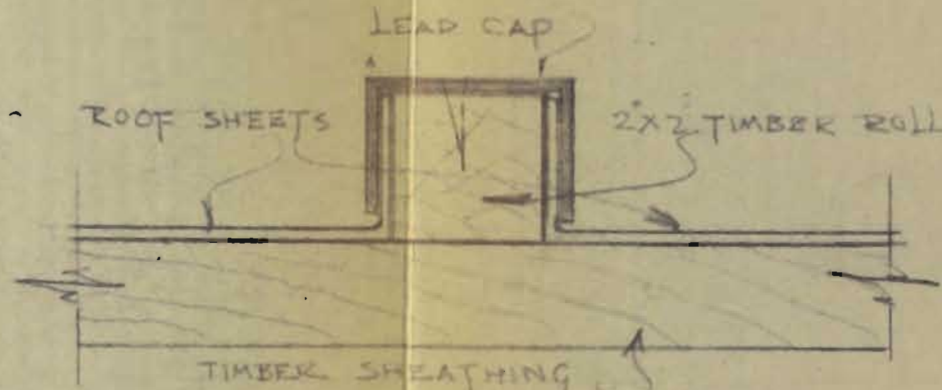
ROUND TIMBER ROLL.

FIG 8a



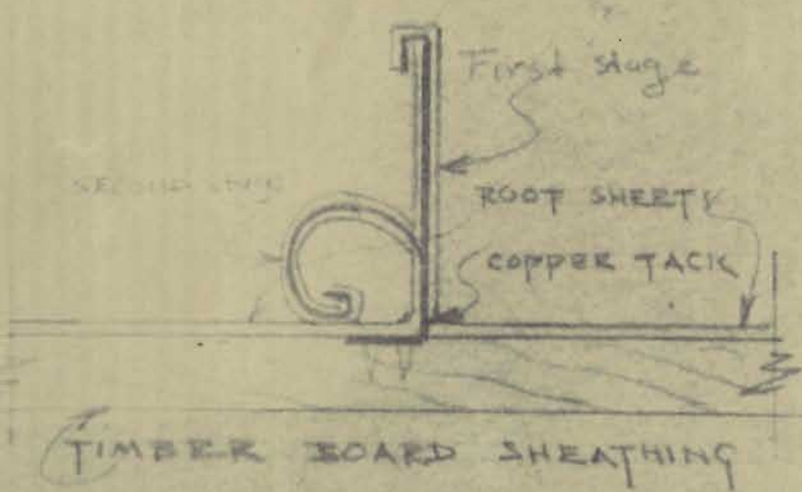
INTERMEDIATE WALLS
AS SUPPORTS
LINE DIAGRAM
ROOFING.

FIG 7

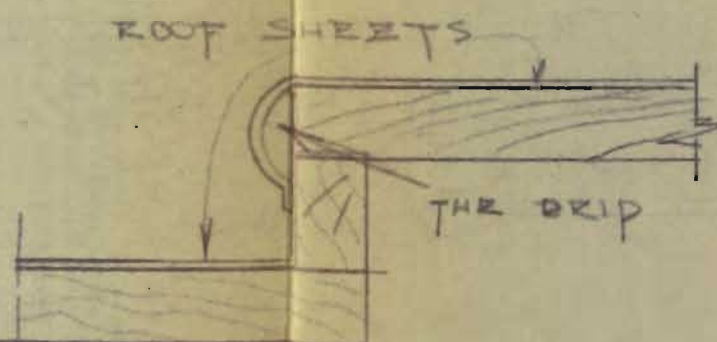


RECTANGULAR ROLL

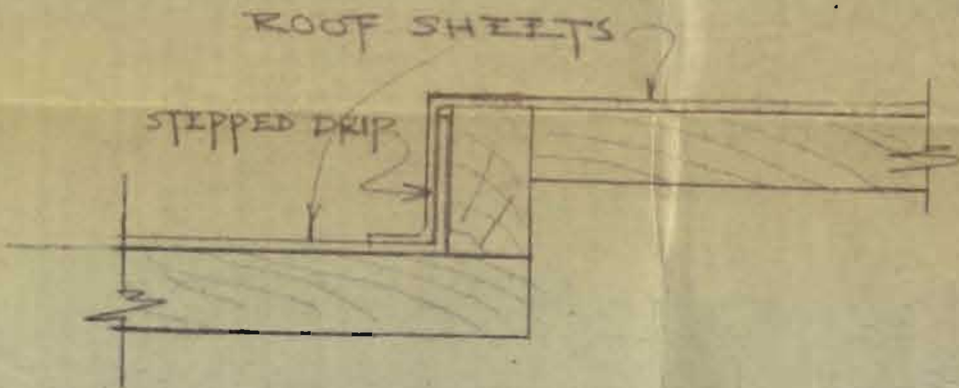
FIG 8b



HOLLOW ROLL
FIG 8

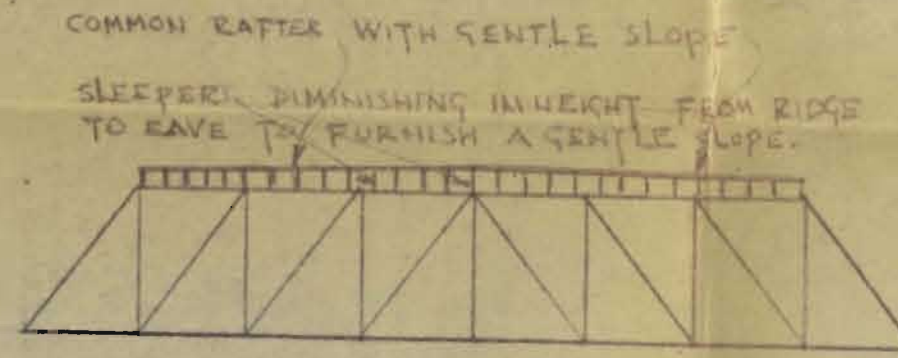


ROUND DRIP
FIG 8C



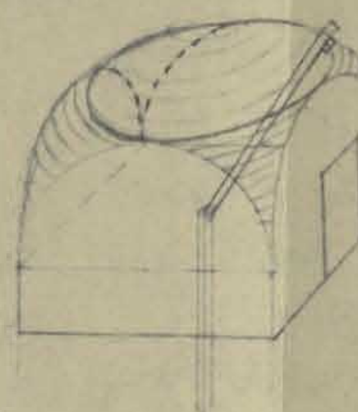
STEPPED DRIP

FIG 8d



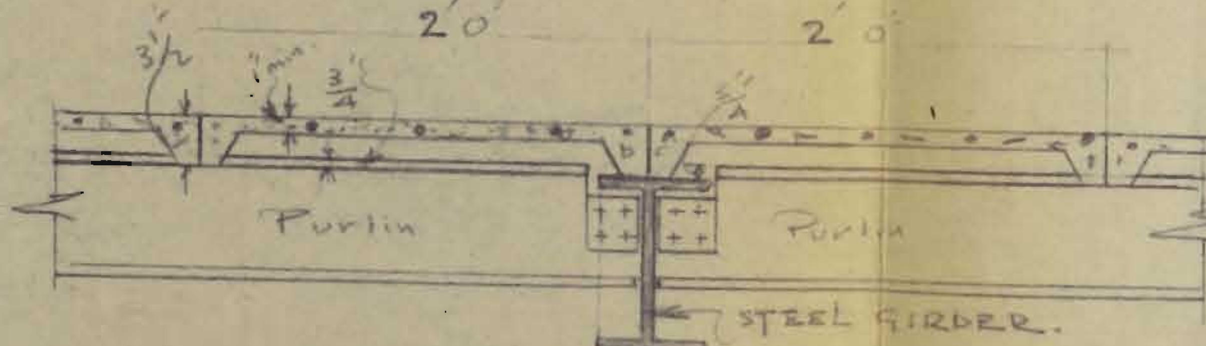
HOWE TRUSS WITH FLAT TOP CHORD

FIG 9



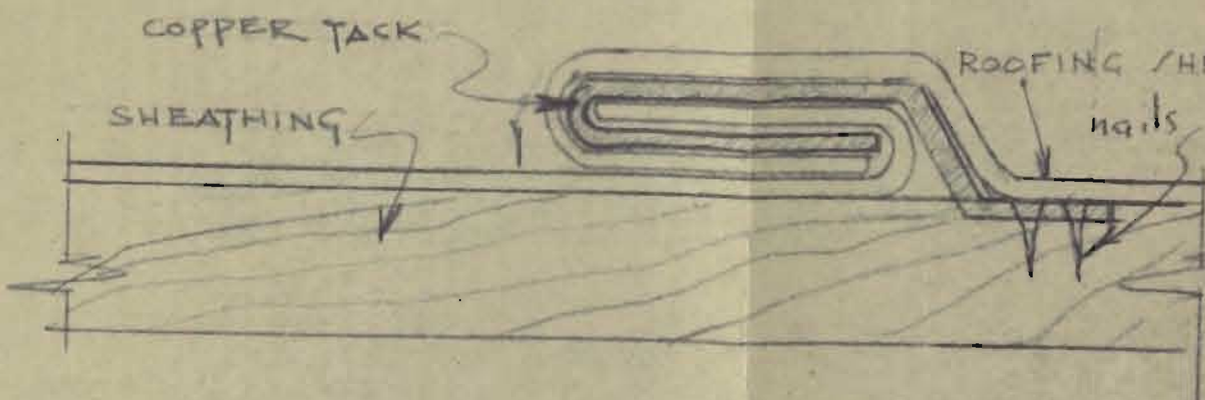
BUILDING DOME ROOF WITHOUT SHUTTERING

FIG 21



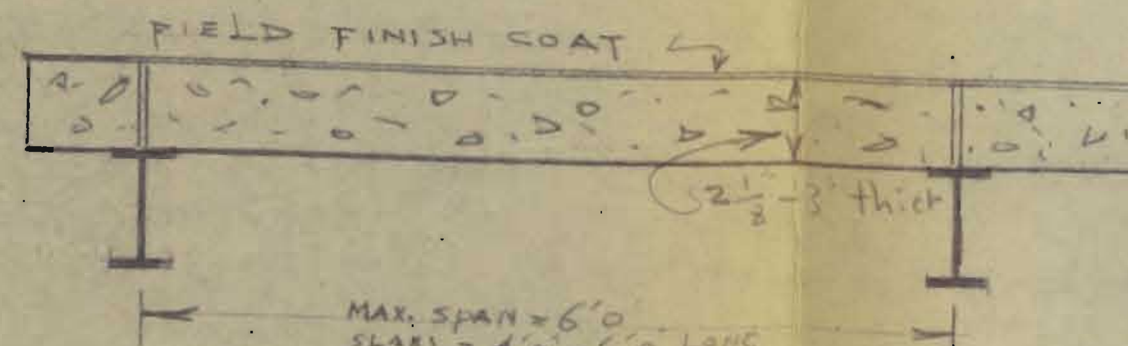
LONG SPAN CHANNEL SLAB

FIG 10



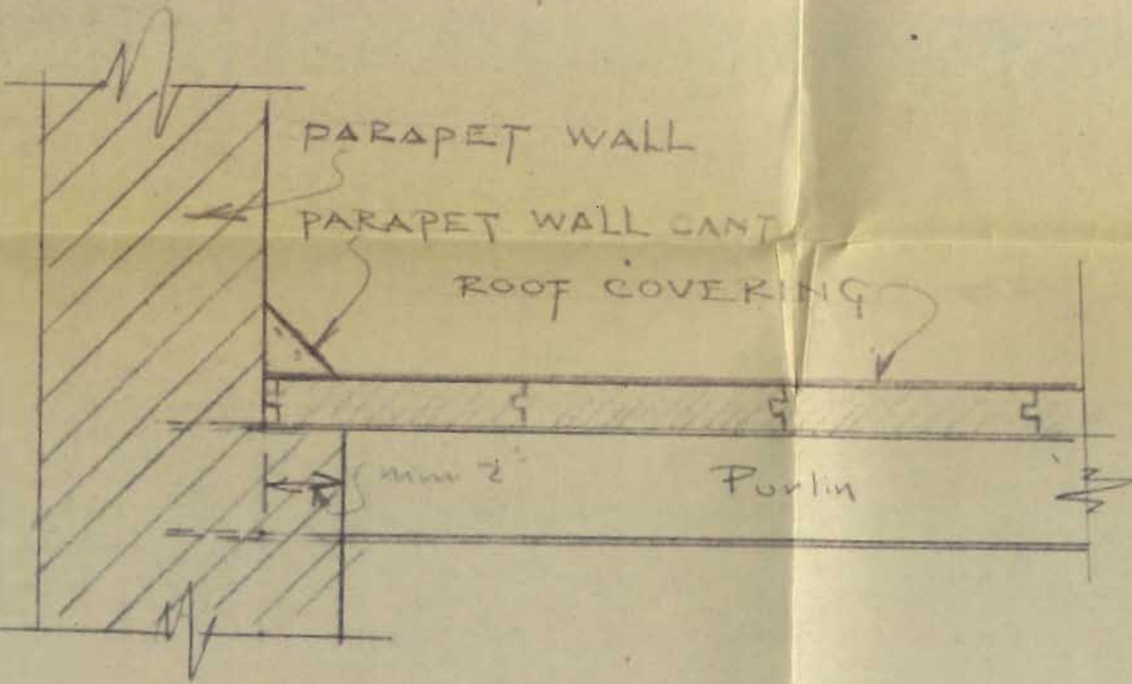
WELTED JOINTS

FIG 8e



FLAT LONG SPAN SLABS

FIG 10 a



FLAT GYPSUM PLANK
FIG 10b.

SHEETROCK & PYROFILL GYPSUM SLAB.
FIG 10c

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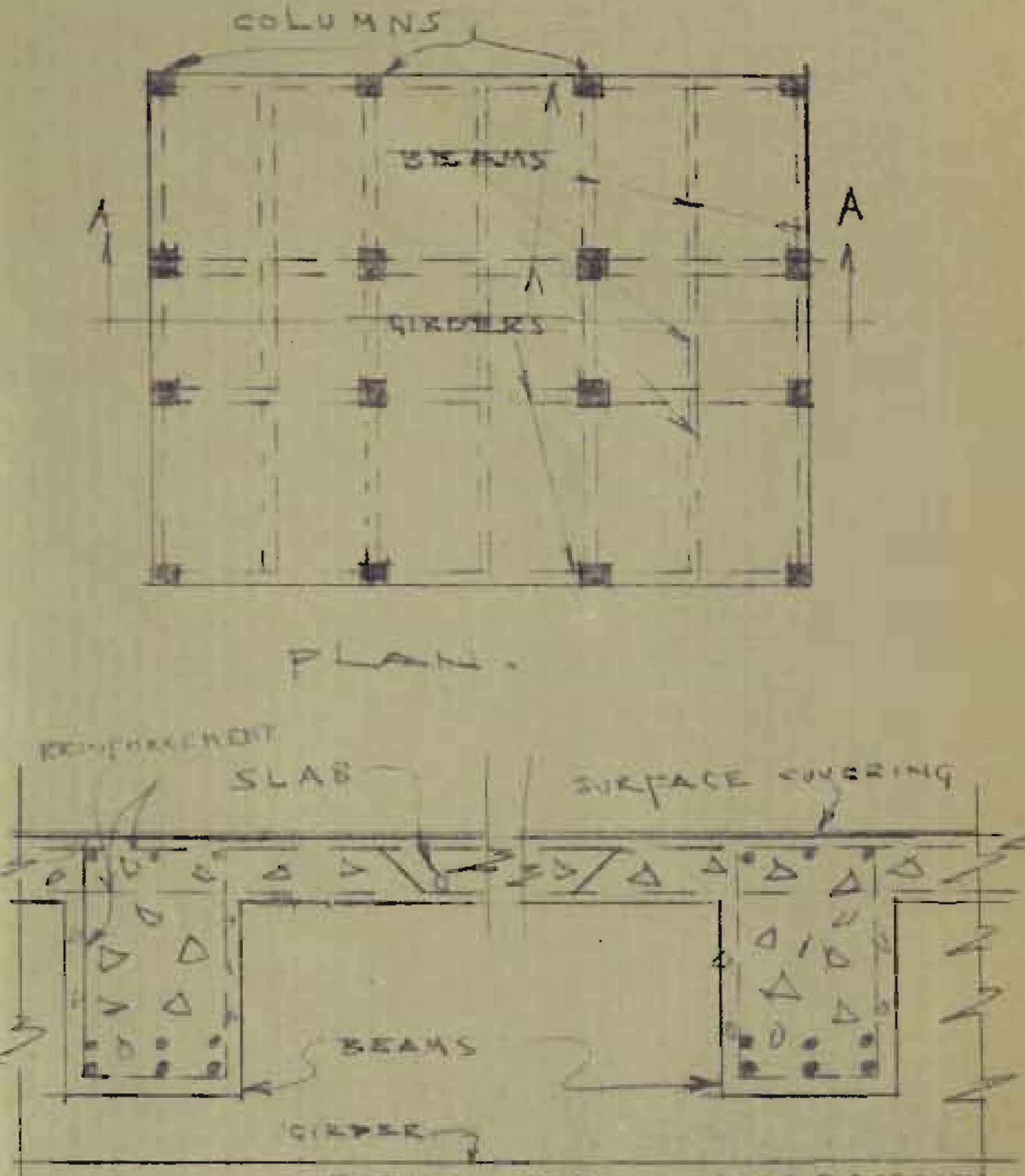
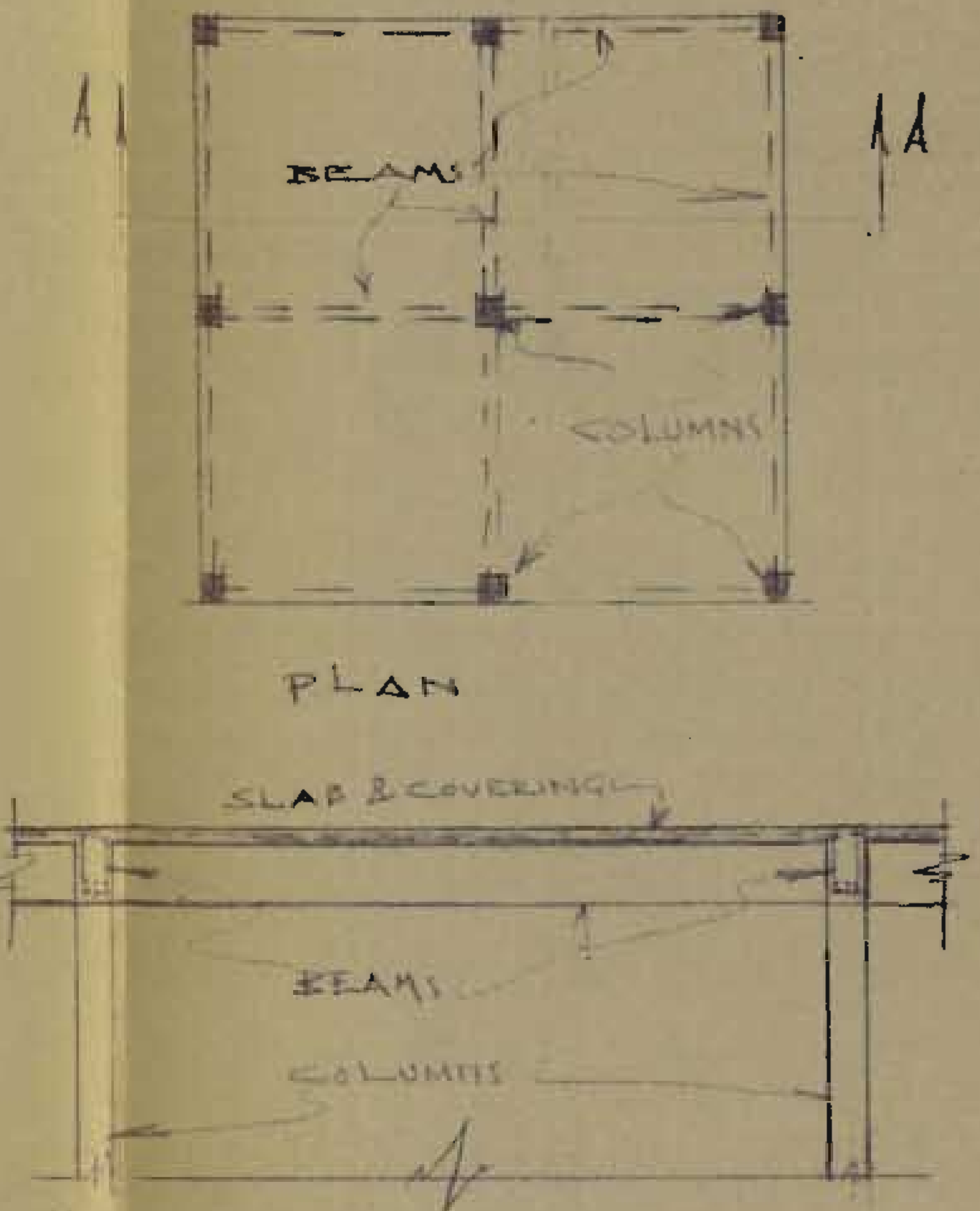
PROJECT : ROOFS AND ROOFING.
ILLUSTRATIVE DIAGRAMS.
DESIGNED BY SUHAYL HABIB.
DATE: JUNE 1, 1953 NOT TO SCALE SHEET 1



SECTION AA   SCALE EXAGGERATED

BEAM AND GIRDER ROOF

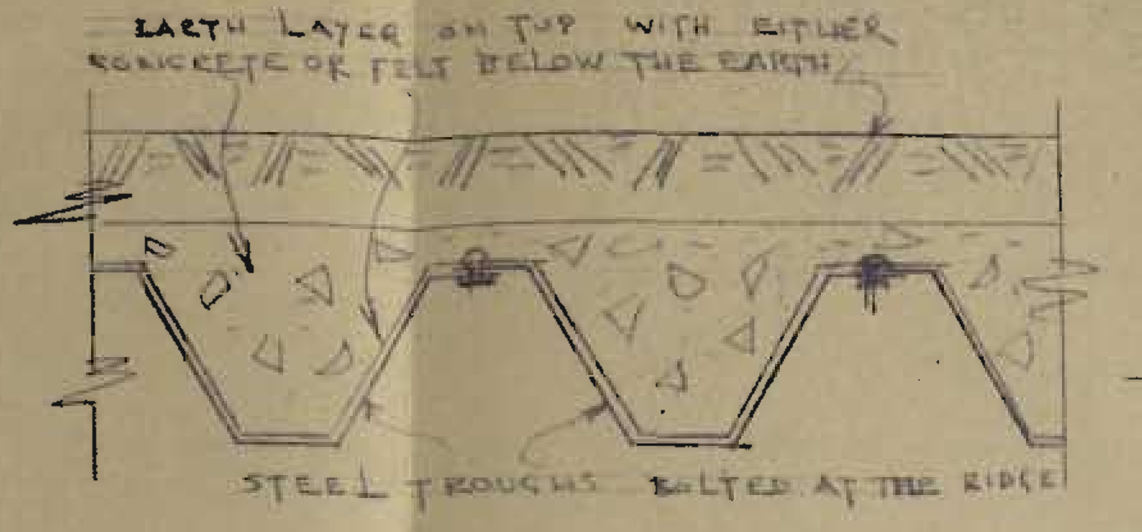
FIG 12a



SECTION AA

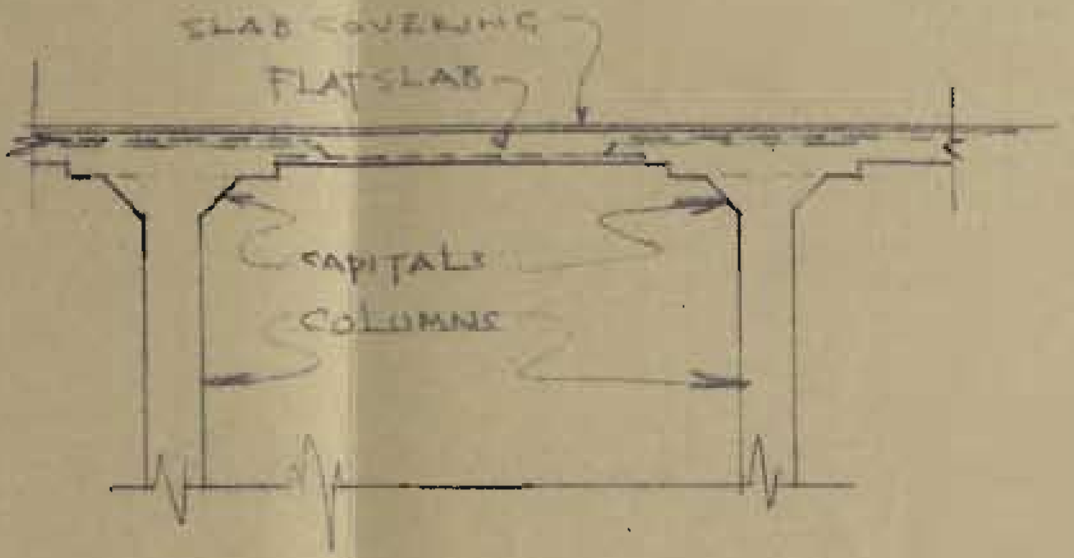
BEAM AND SLAB ROOF

FIG 12 b



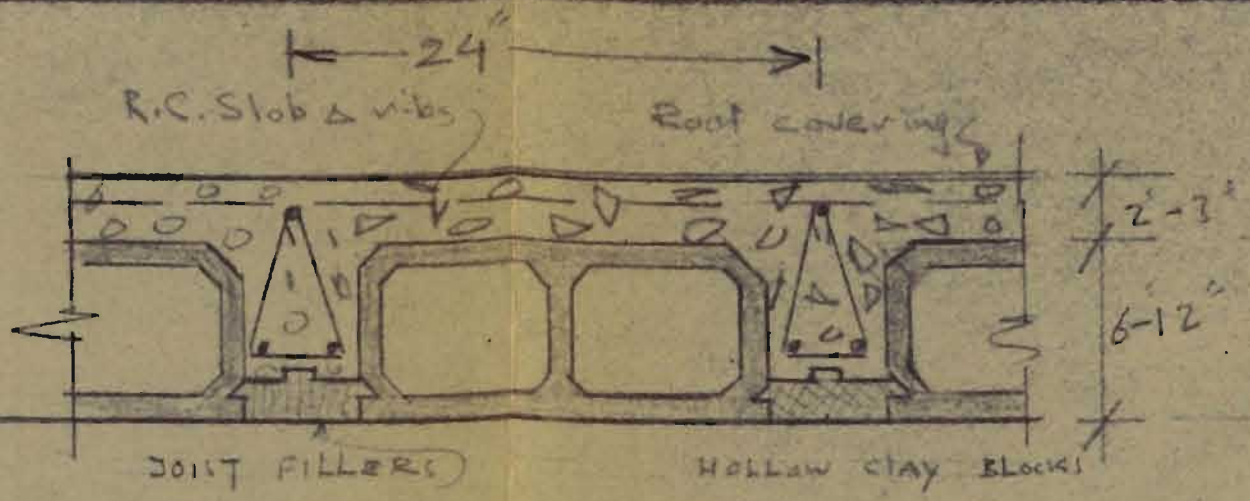
SECTION THROUGH STEEL TROUGHS ROOF.

FIG 11.



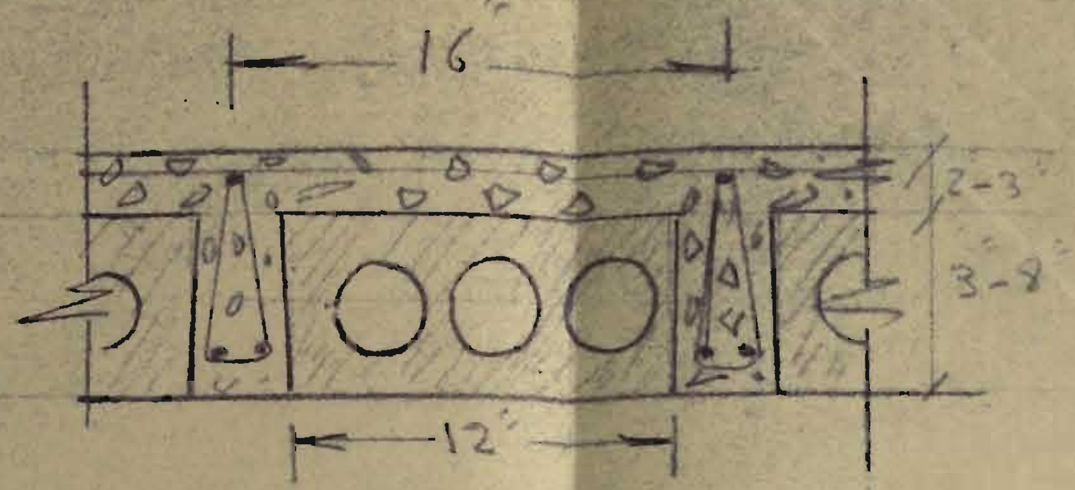
SECTION THROUGH FLAT SLAB ROOF.

FIG 12C.



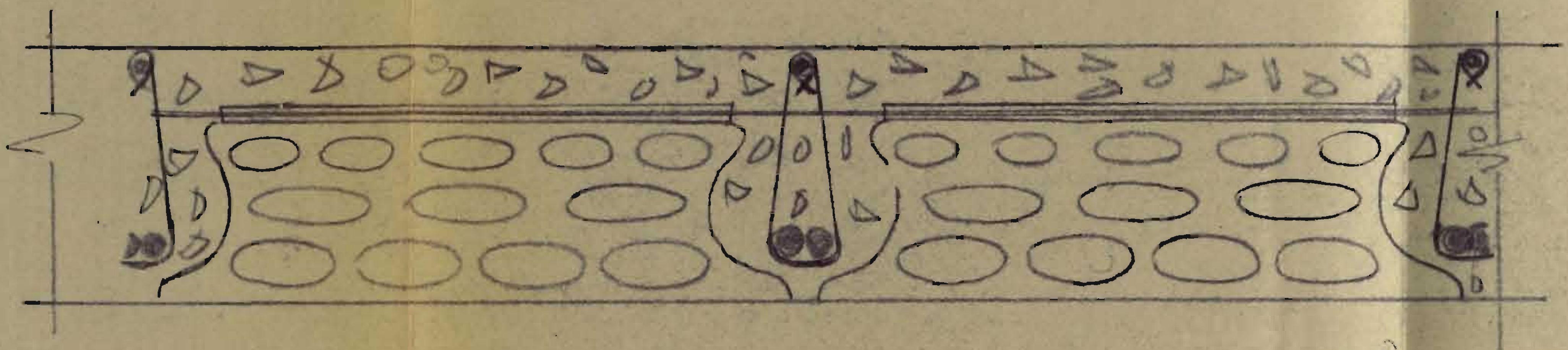
SECTION THRU RIBBED ROOF WITH HOLLOW CLAY BLOCKS

FIG 13a



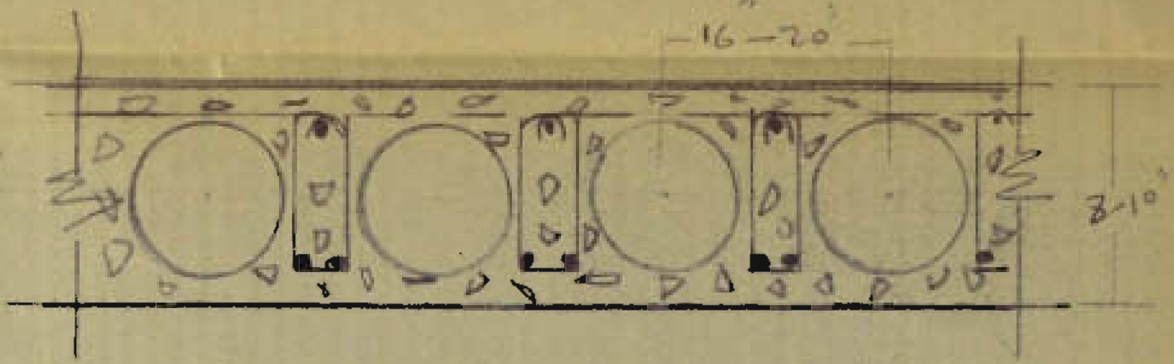
SECTION THROUGH RIBBED ROOF WITH GYPSUM HOLLOW BLOCKS

FIG 13C



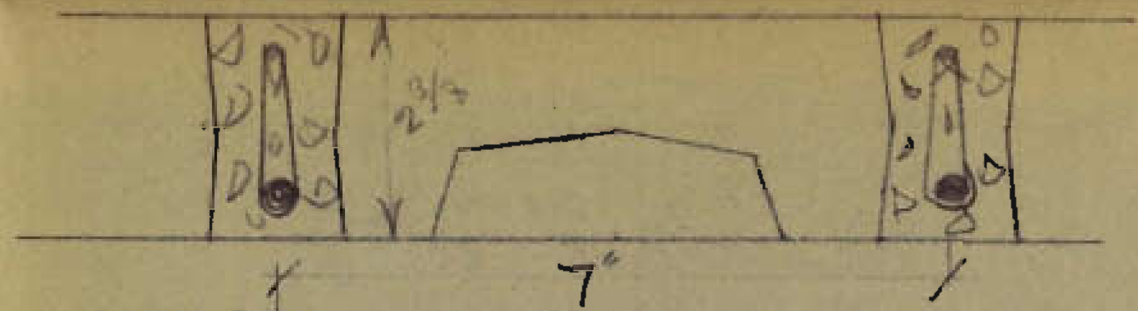
A SECTION THRU RIBBED ROOF WITH CONCRETE BLOCKS

FIG 13b.



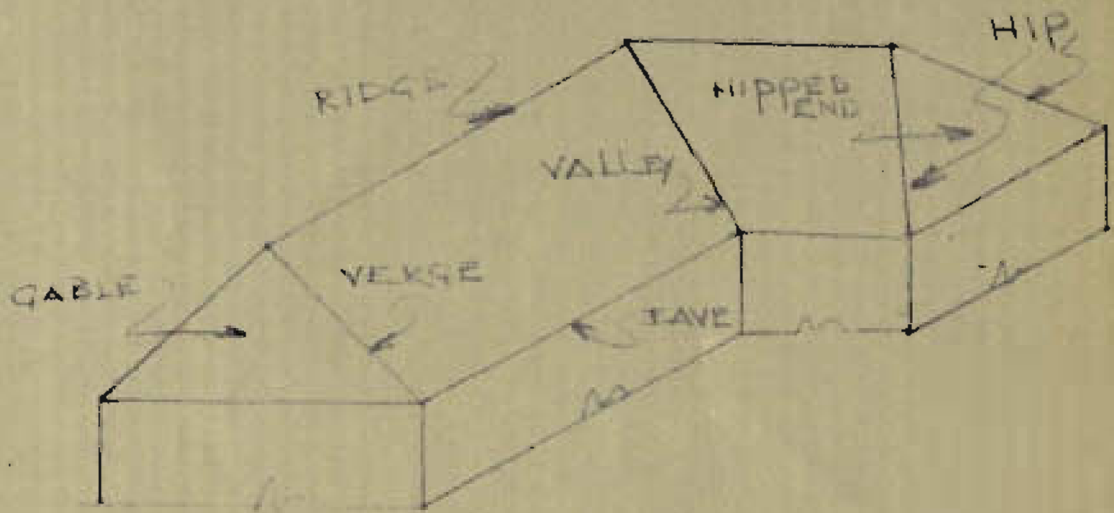
SECTION THROUGH HOLLOW SLAB

FIG 13 d



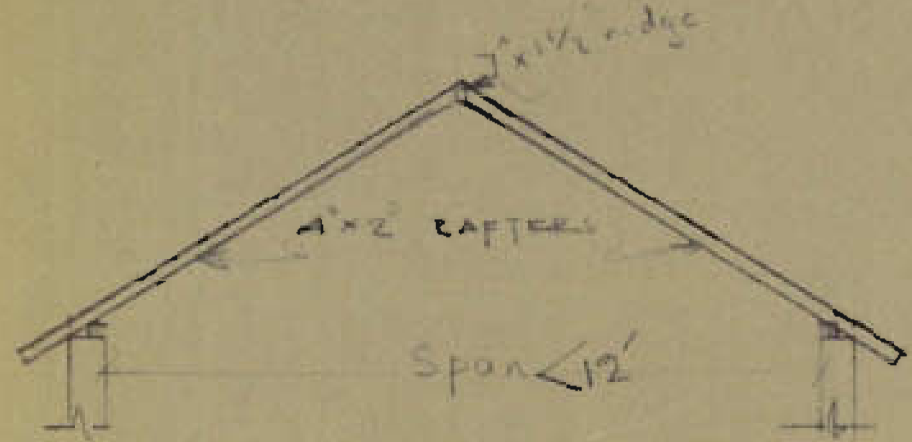
RIBBED ROOF WITH GLASS BLOCKS

FIG 13 e



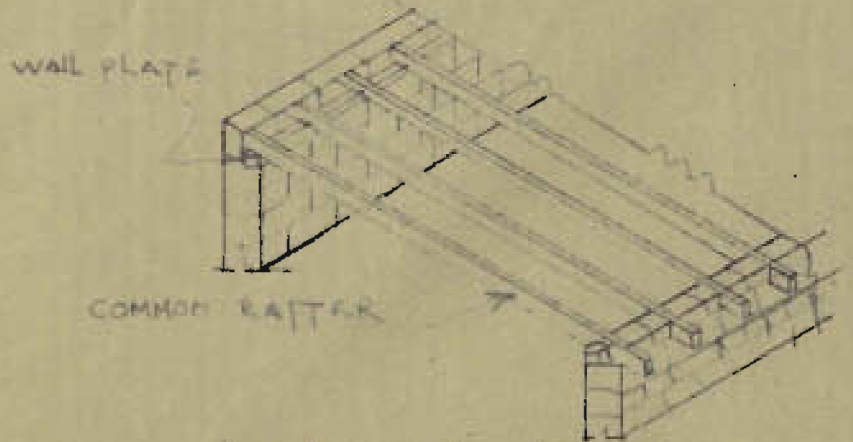
TYPICAL PITCHED ROOF

FIG 15



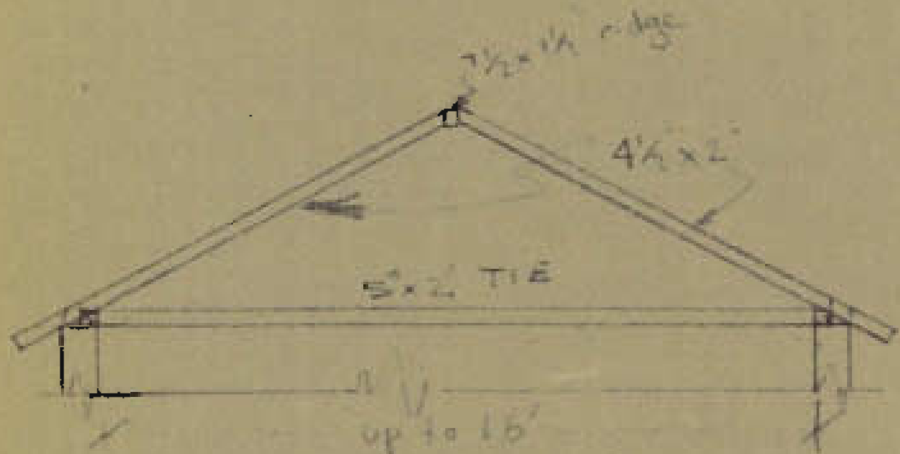
COUPLE ROOF

FIG 16 b.



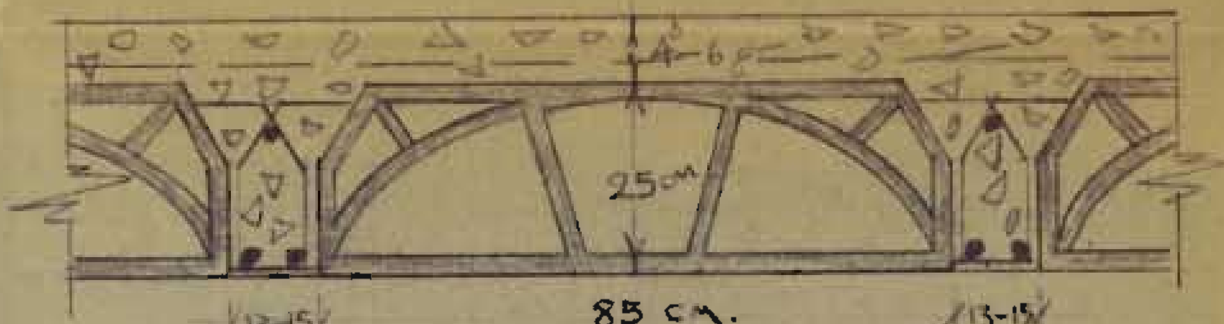
LEAN-TO ROOF

FIG 16a



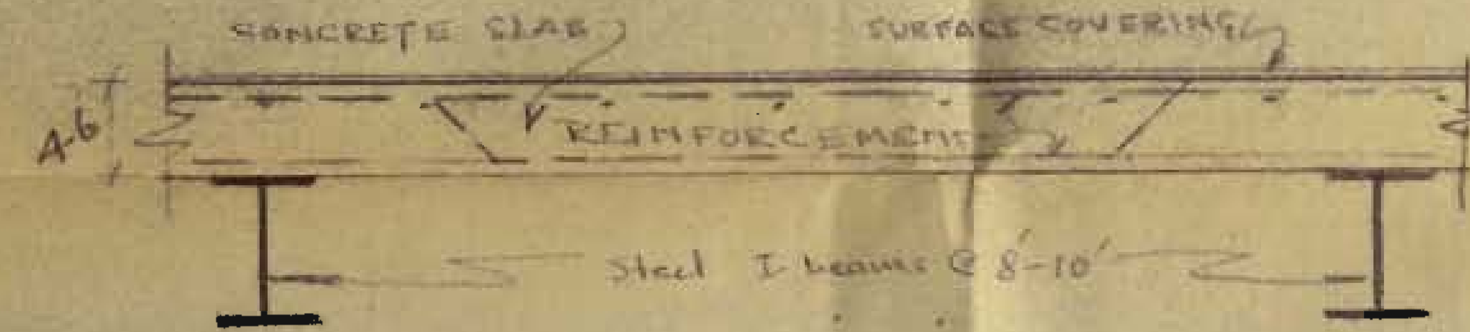
COUPLE CLOSED ROOF

FIG 16 c



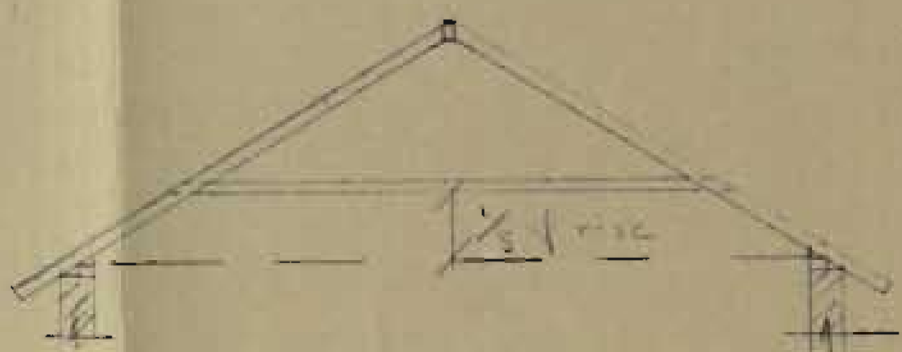
PRECAST CONCRETE TRUSSES AS FILLER BETWEEN RIBS.

FIG 13 f.



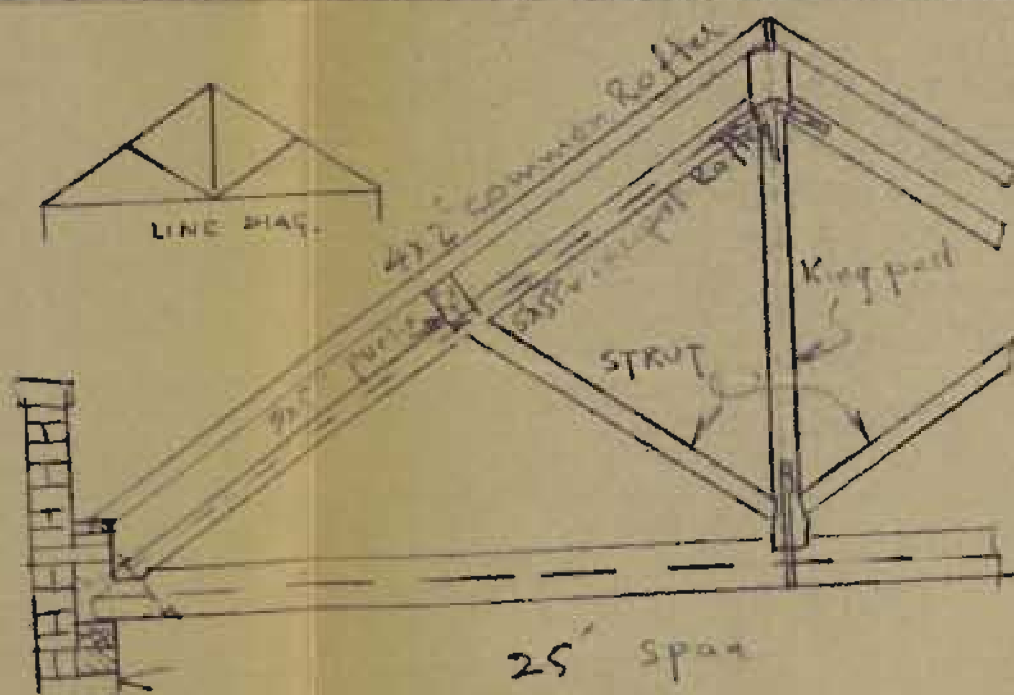
CONCRETE SLAB ON STEEL BEAMS

FIG 14



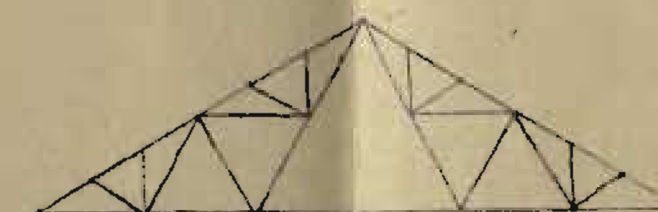
COLLAR ROOF

FIG 16 d



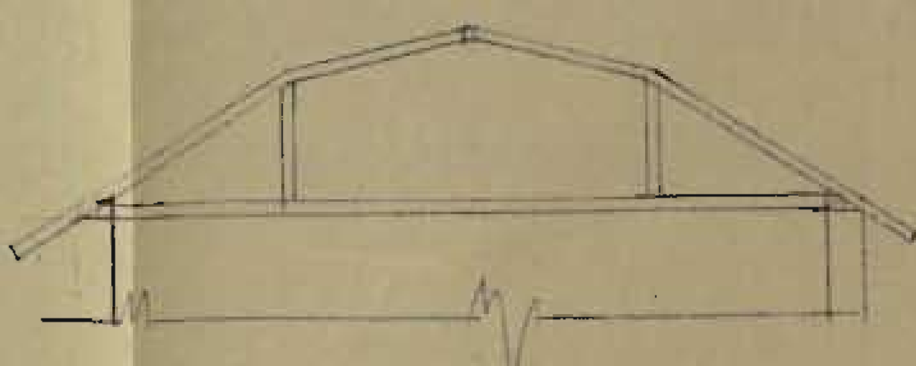
KING POST TRUSS

Fig 17a



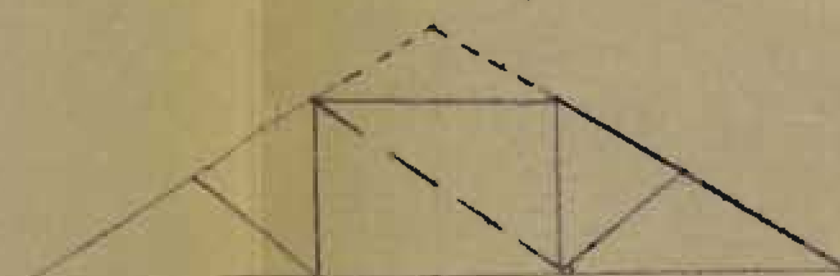
LINE DIAGRAM OF A FINK TRUSS

FIG 18a.



MANSARD ROOF

FIG 16e



QUEEN POST TRUSS

FIG 17 b

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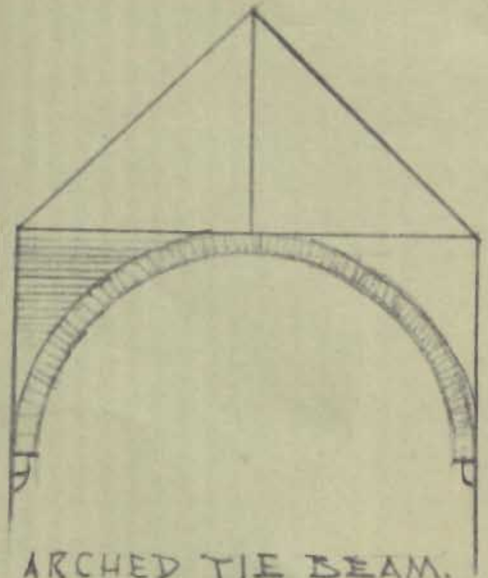
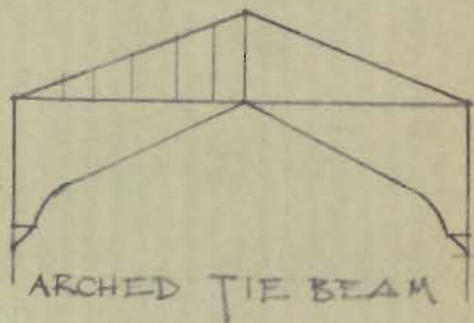
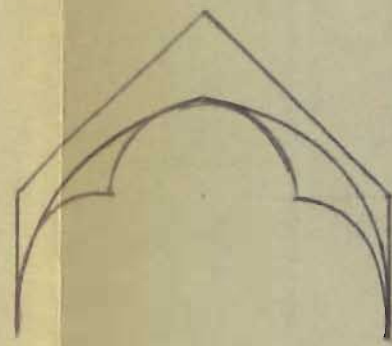


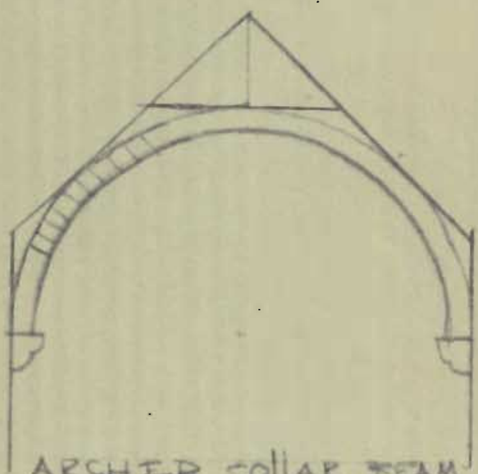
ARCHED TIE BEAM.



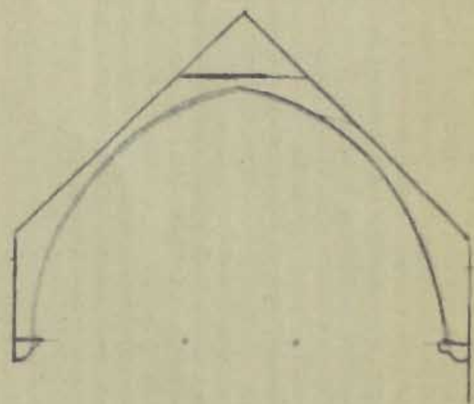
ARCHED TIE BEAM



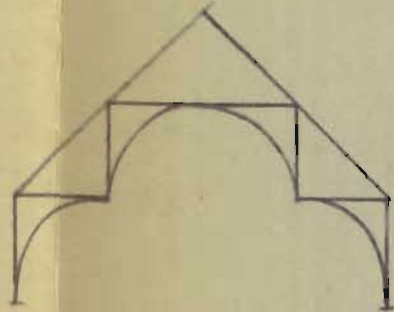
ARCHED HAMMER BEAM



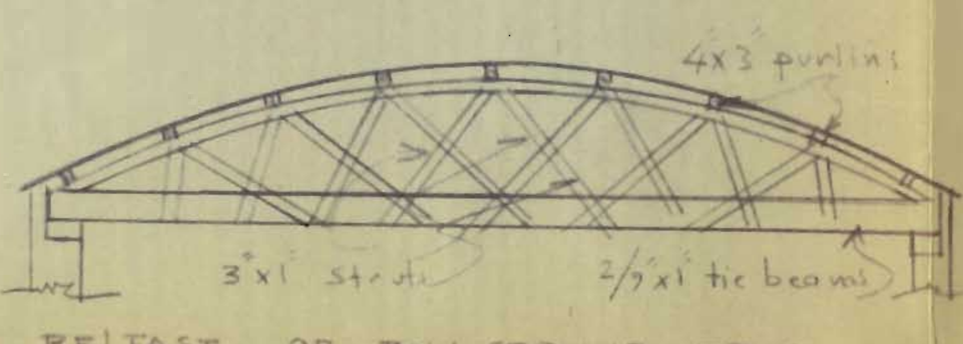
ARCHED COLLAR BEAM



ARCHED COLLAR BEAM

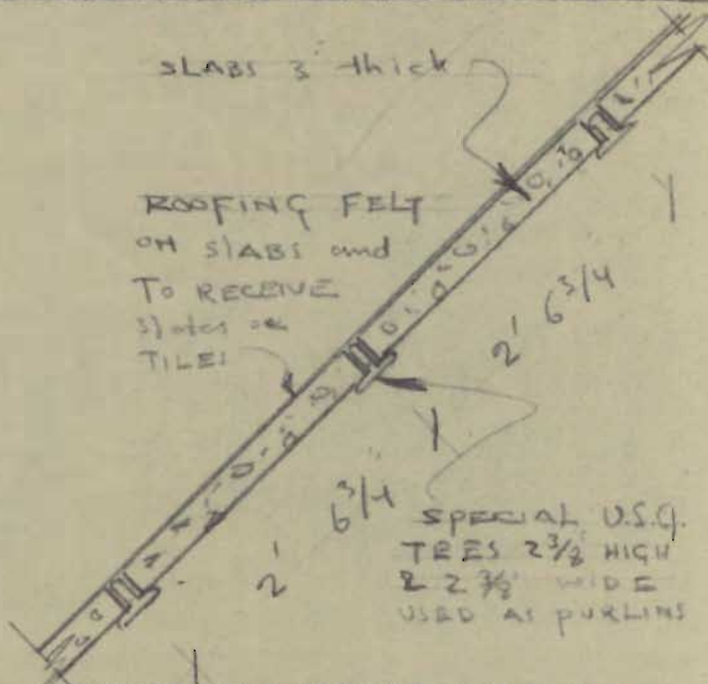


BRACKETED HAMMER BEAM

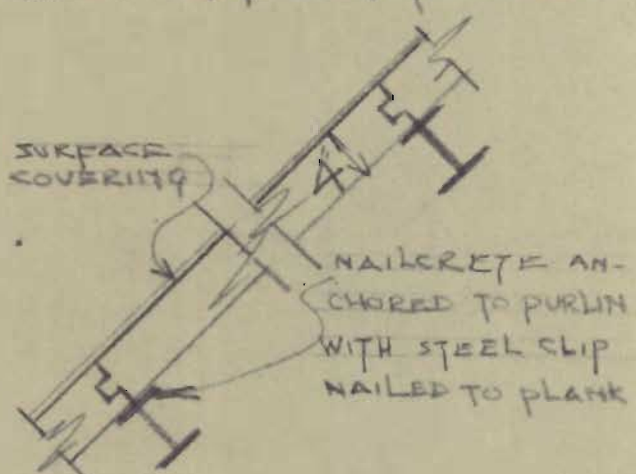


BELFAST OR BOW STRUNG TRUSS

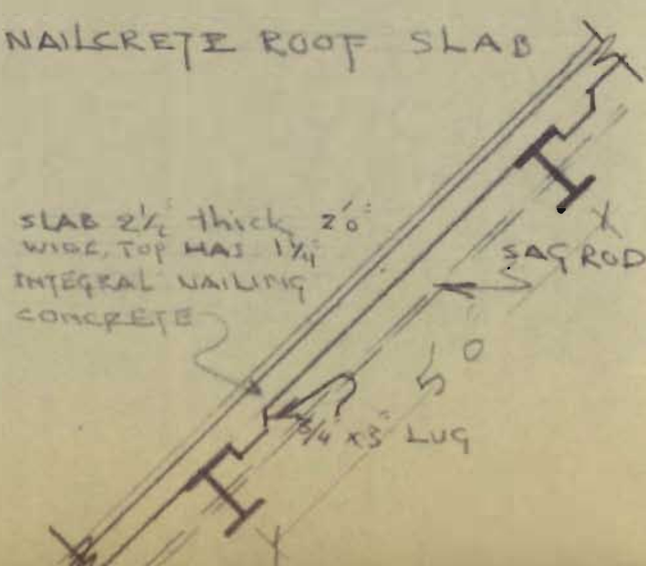
FIG 17C OPEN TIMBER TRUSSES



SHORT SPAN PRECAST CONCRETE OR GYPSUM LIGHT WEIGHT SLABS



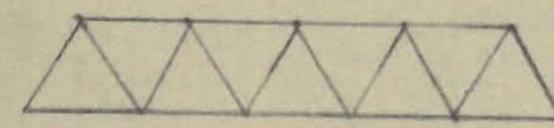
NAILCRETE ROOF SLAB



FEATHERWEIGHT CONCRETE INSULATING ROOF SLAB

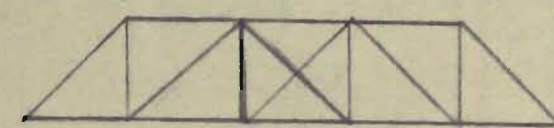
DIFFERENT CONCRETE TILES ON STEEL TRUSSES

FIG 18 b



WARREN TRUSS

FIG 19a



HOWE TRUSS

FIG 19 c

PRATT TRUSS

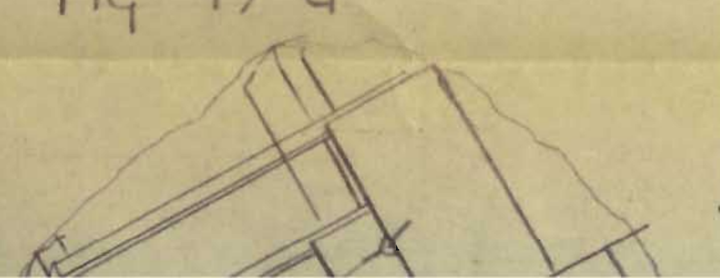
FIG 19 b

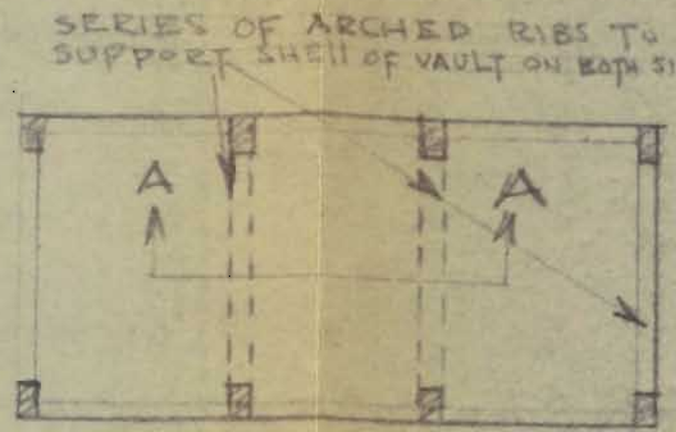
PRATT TRUSS & HOWE TRUSS WITH PITCHED TOP

FIG 19 e

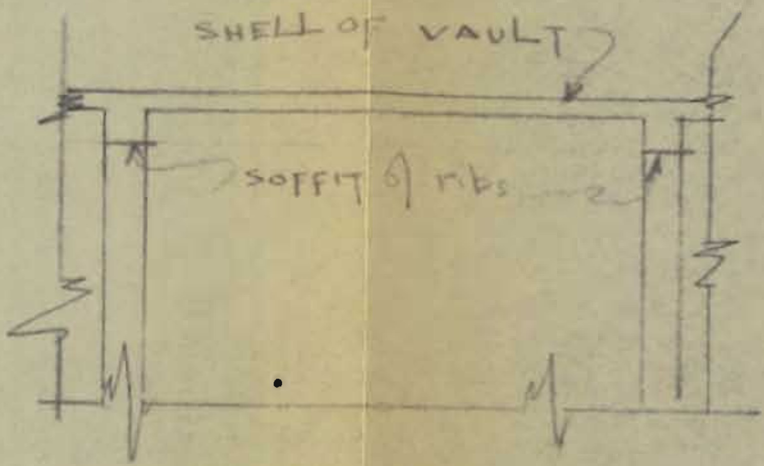
SAWTEETH TRUSS

FIG 19 d





PLAN



SECTION A-A

RIBBED VAULT
FIG 20

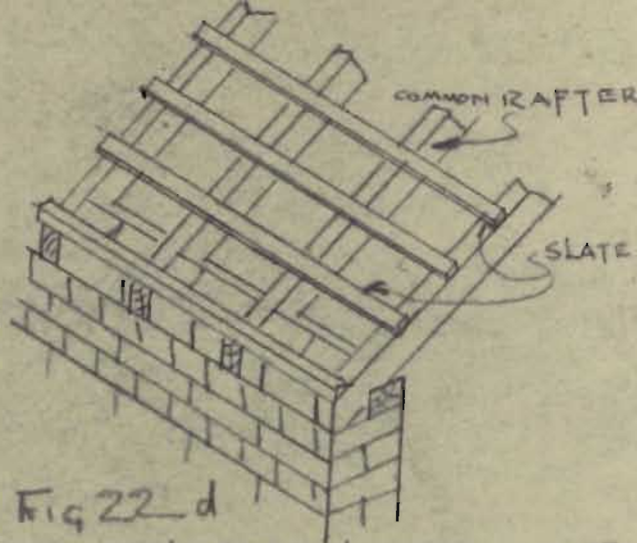


Fig 22 d
TIMBER, FELT & TWO LAYERS OF BATTENS

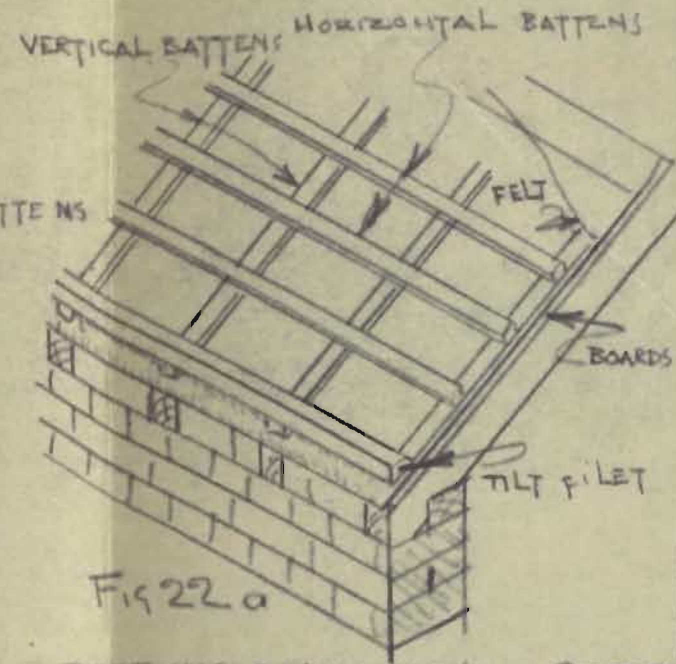
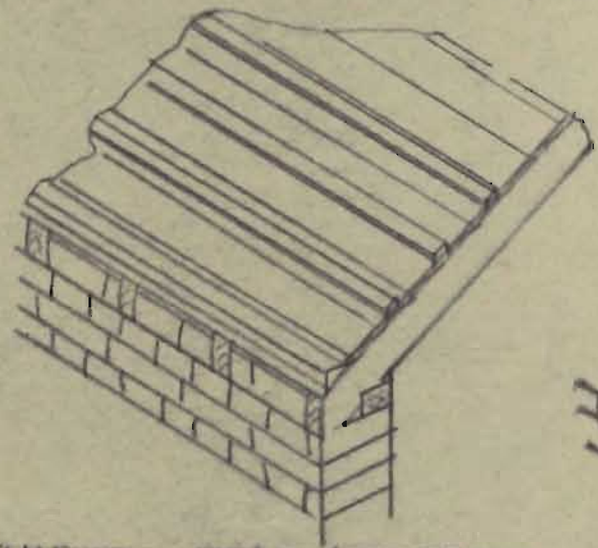
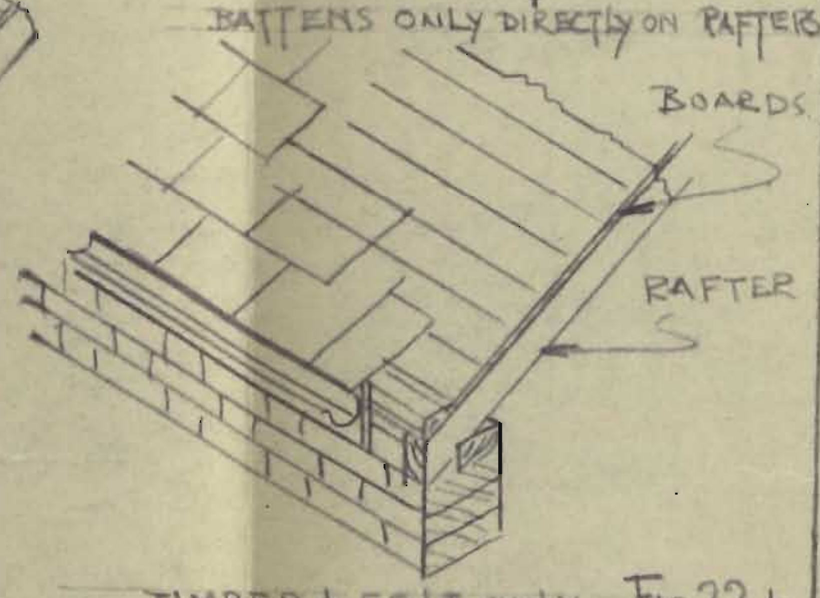


Fig 22 a
BATTENS ONLY DIRECTLY ON RAFTERS.



TIMBER, FELT & BATTENS
FIG 22 C

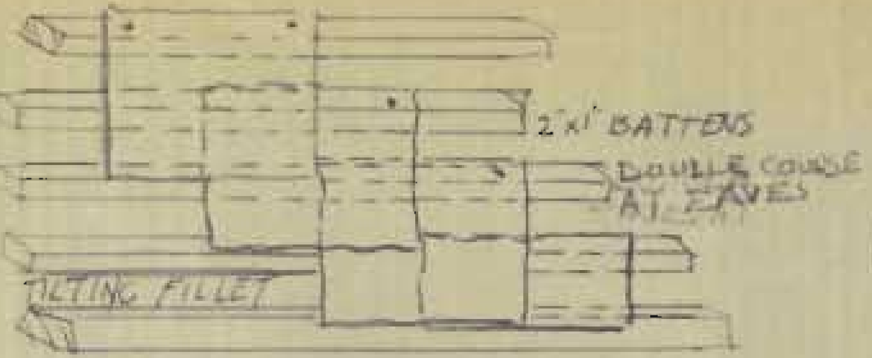


TIMBER & FELT ONLY Fig 22 b

DIFFERENT WAYS OF SHEATHIHG ON RAFTERS.
FIGs 22 a, b, c & d.

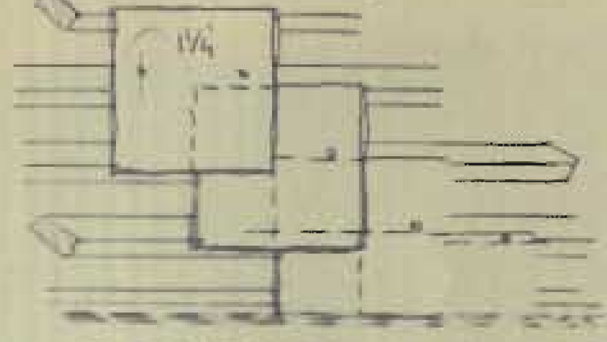
DIFFERENT CONCRETE TILES ON STEEL TRUSSES

FIG 18 b



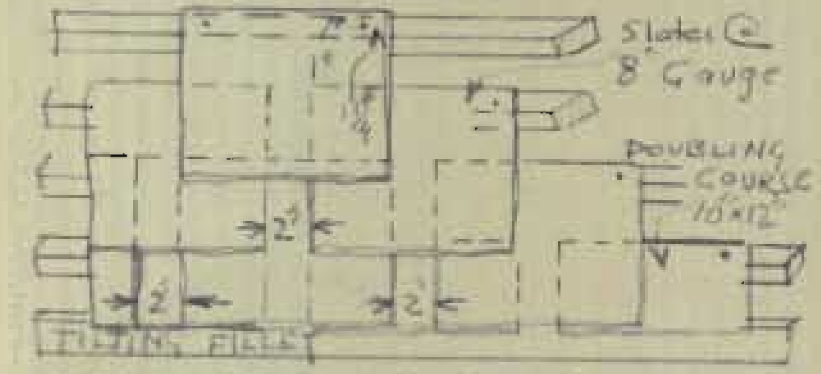
HEAD NAILING TO SLATES

Fig 22e



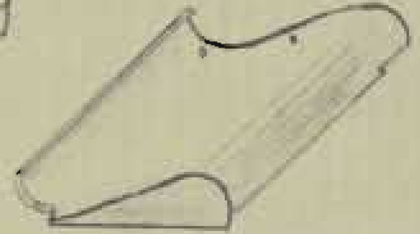
CENTRE NAILING TO SLATES

FIG 22f



OPEN SLATING NAILED NEAR HEAD.

Fig 22g



SPECIAL TILES WITH BLOCKED ENDS FOR USE ON EDGES.

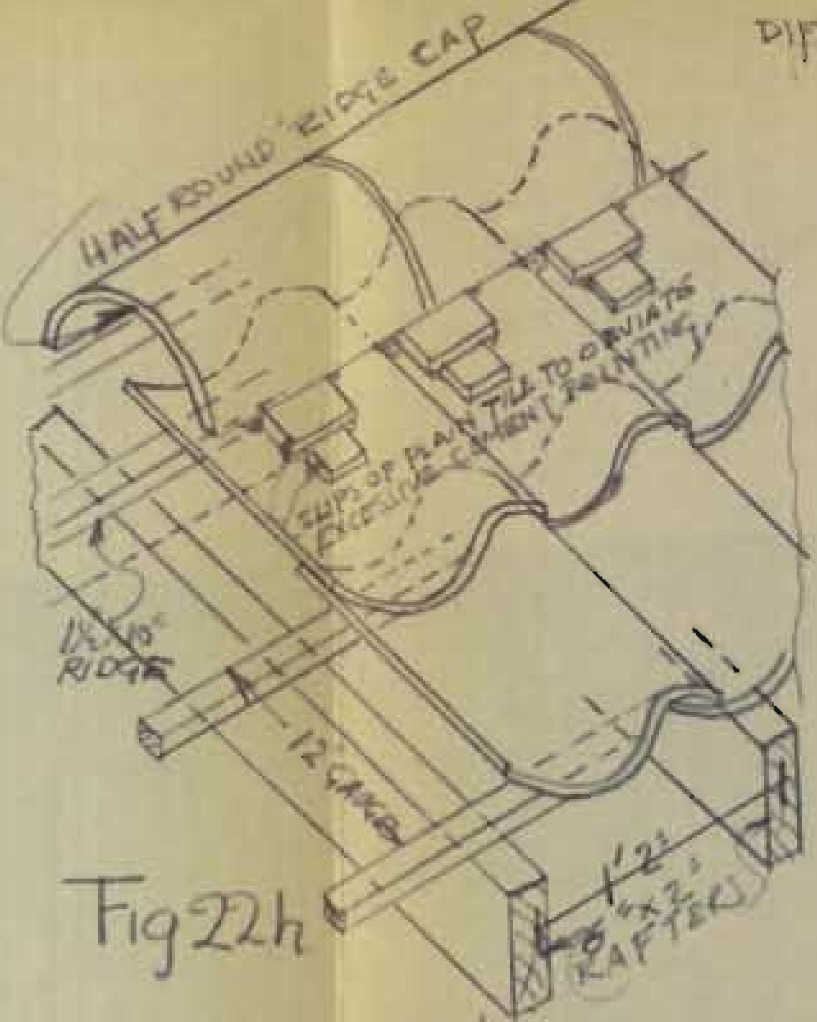
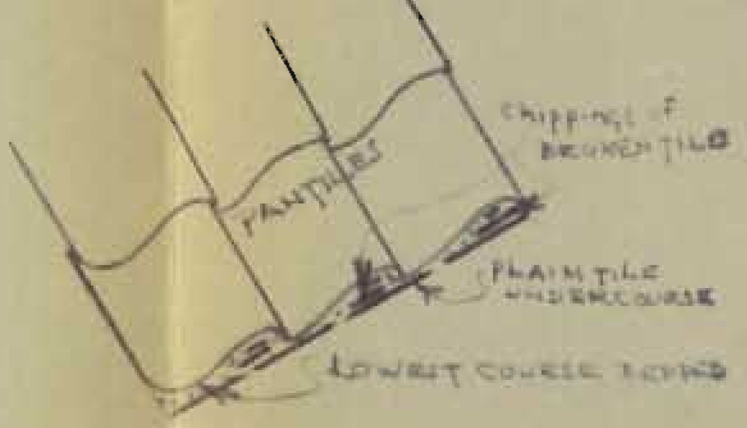


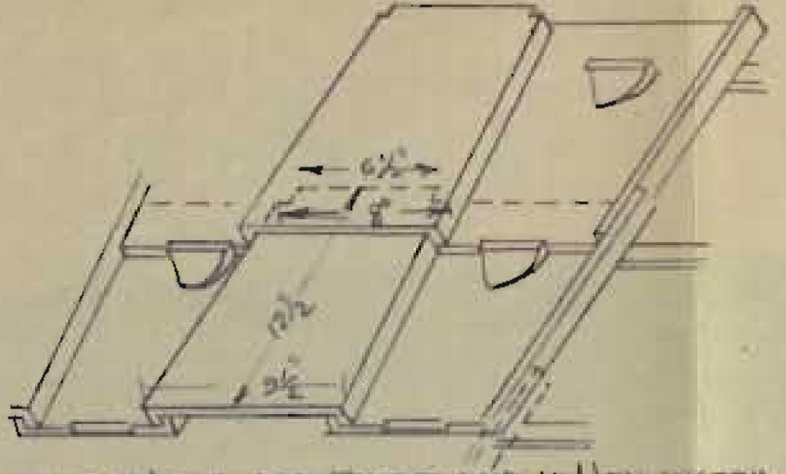
Fig 22h

RIDGE TILING.



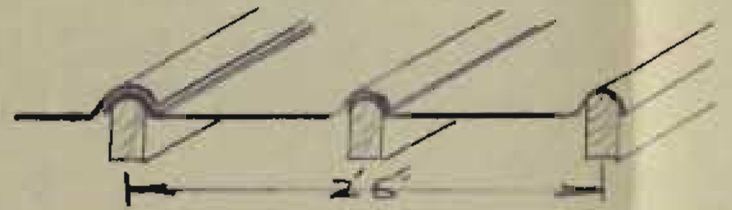
PANTILES BLOCKED GAP AT EAVES AND HIPS WITH CHIPPINGS & MORTAR

FIG 23a



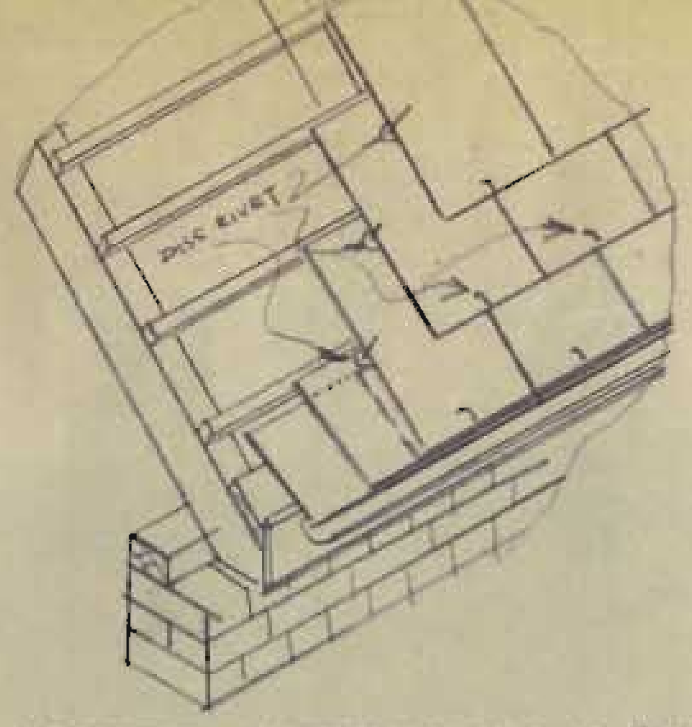
PANTILES ON RIDGE AND VALLEY SYSTEM

FIG 23 B



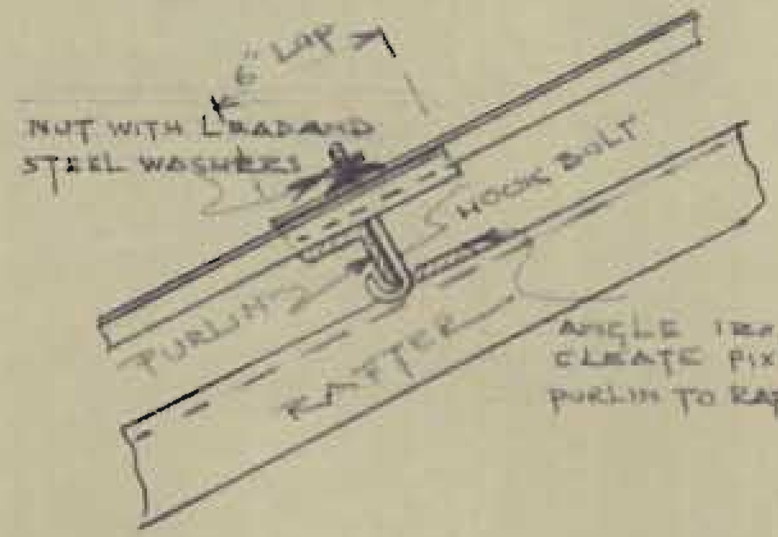
CORRUGATED ZINC SHEETS ON TIMBER ROUNDED TOP RAFTERS.

FIG 24a



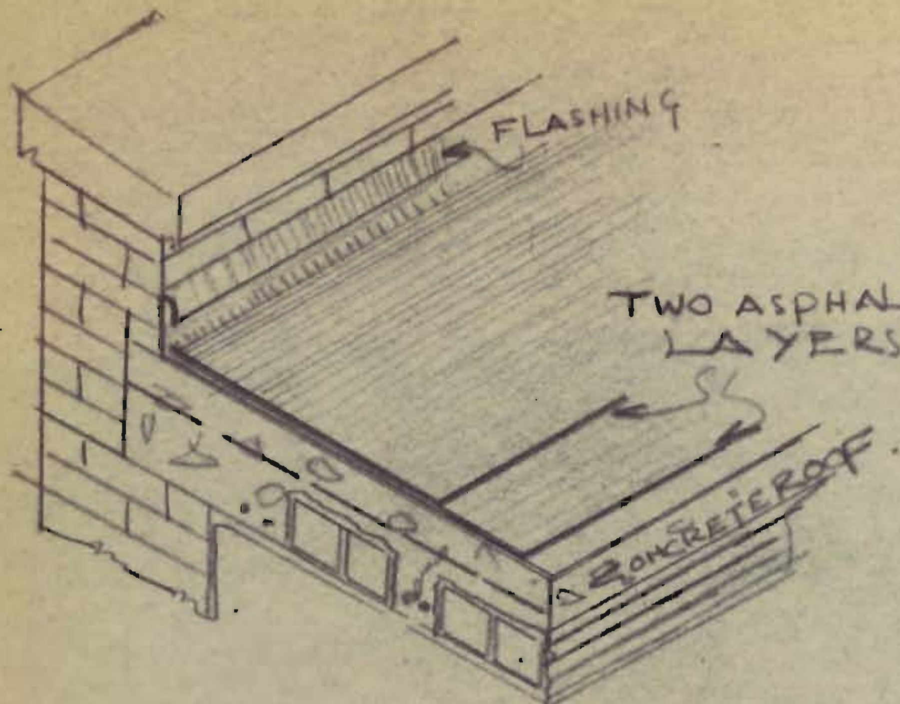
ASBESTOS SHEETS WITH DISC RIVETS

FIG 25



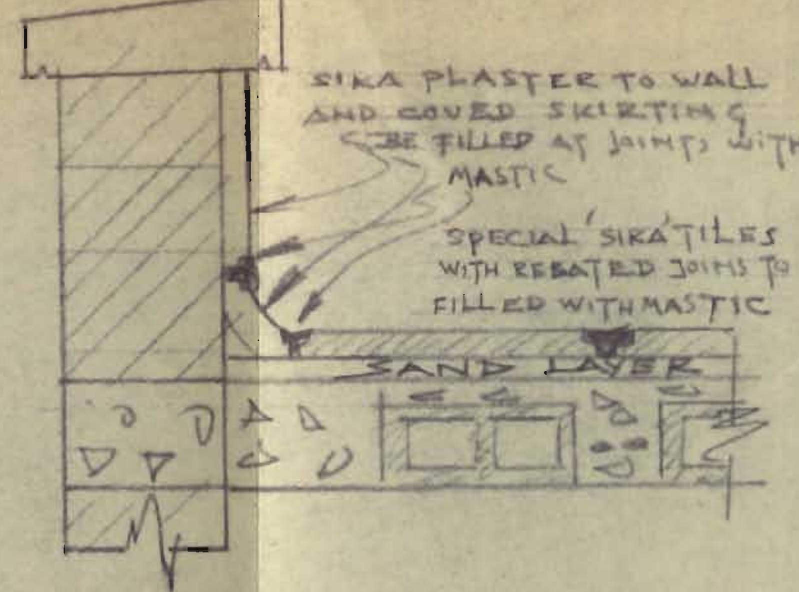
FIXING CORRUGATED SHEETS TO PURLINS

FIG 26



ASPHALT ROOFING

FIG 27



WATERPROOFING TILES ON ROOFS

FIG 28

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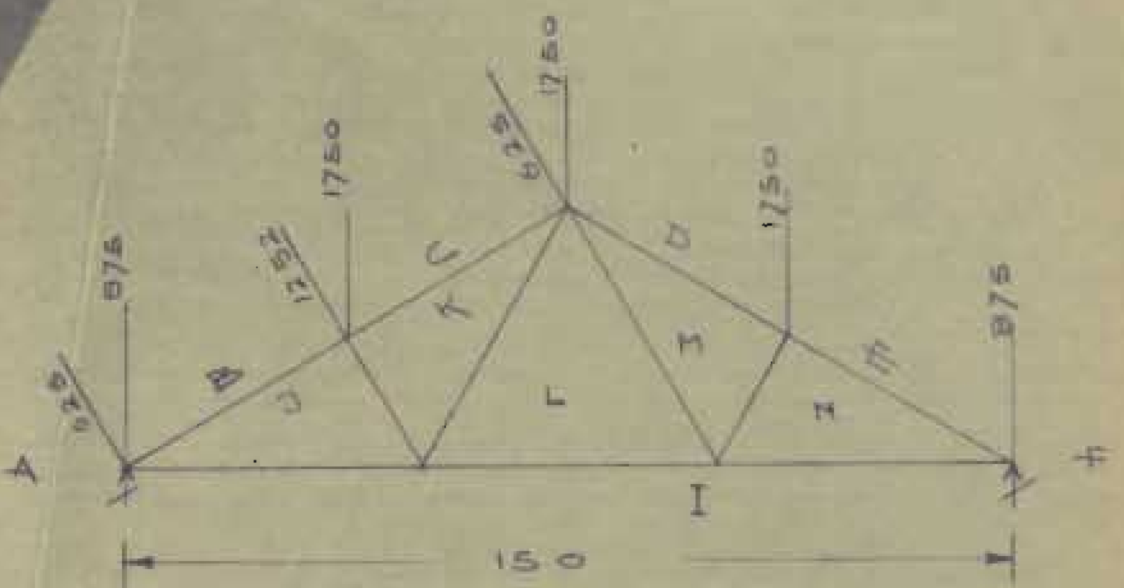
PROJECT : ROOFS AND ROOFING

ILLUSTRATIVE DIAGRAMS

DESIGNED BY : SUHAYL HABIB

DATE : JUNE 1, 1953 NOT TO SCALE SHEET 3



As shop is similar to the 30' span, and weights etc with same ratio as spans, the stresses in each member is half the stress in the corresponding member in the 30' span.

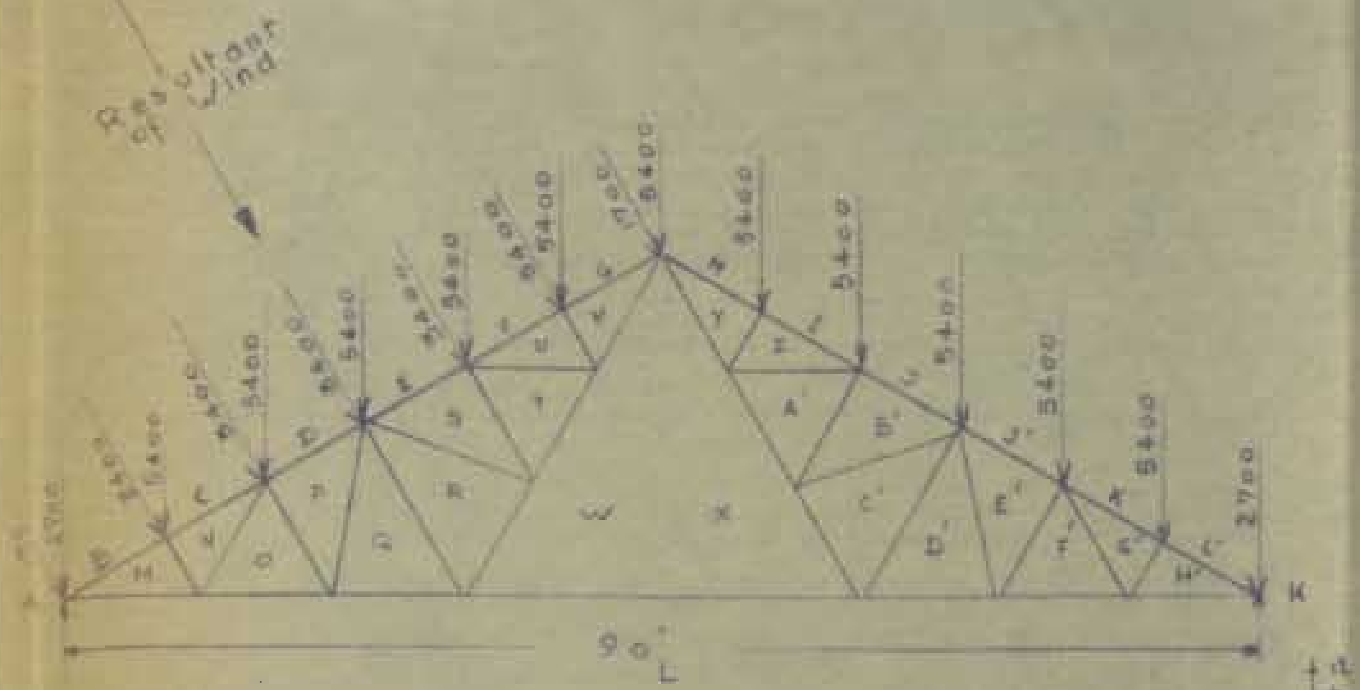
Member	Wind Stress Kips	D.L Load Kips	Total Stress Kips	Selected section	Weight #/'	Length '	Weight #
BJ	-1800	-5200	-7,000	2L - 2½"x2"x 3/16	5.8	4.33	23.6
CK	-1.800	-4.400	-6.2	" "	"	"	"
DM	-1.500	-4.400	-5.9	" "	"	"	"
EN	-1.500	-5200	-6.7	" "	"	"	"
JI	+0.850	+4.500	+5.35	" "	"	5.0	27.5
LI	+0.850	+3.000	+3.85	" "	"	"	"
NI	+0.850	+4.500	+5.35	" "	"	"	"
JK	-1.250	-1.500	-2.75	L - " "	2.8	"	14
KL	+1.250	+1,500	+2.75	" " "	2.8	"	"
LM	—	+1,500	+1.5	" " "	2.8	2.5	7
MN	—	-1.500	-1.5	" " "	2.8	"	"
				total			219

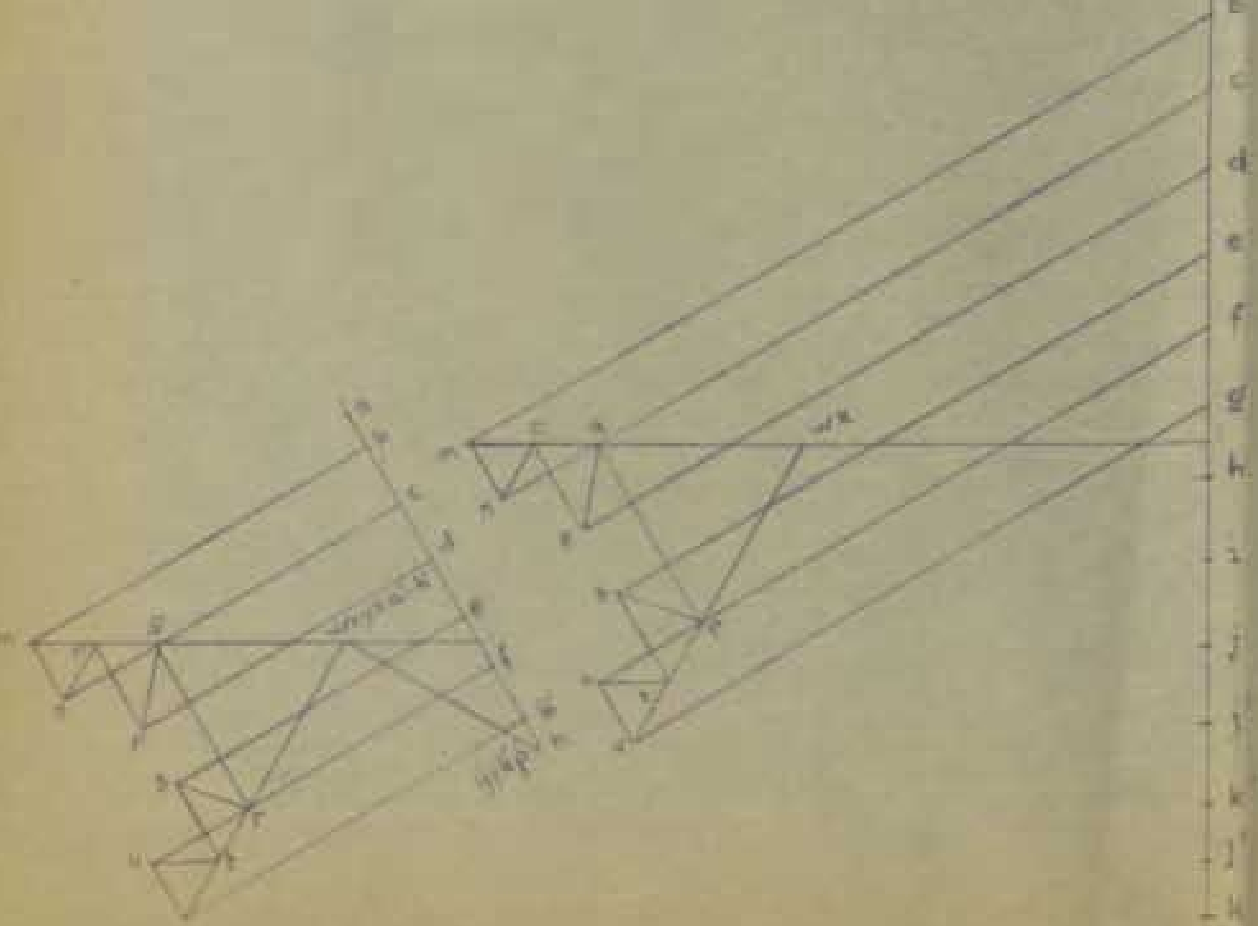
DESIGN OF COLUMNS 12'0" HIGH

Span	Area sq. ft	Equiv load.	Total weight	Selected column	Wt./F.R	Total weight
15	180	45	8.1	6"x4" I - col	12	144
30	360	45	16.2	" " "	"	"
60	900	48.25	43.4	6"x6" - I col	15.5	186
90	1440	51	73.5	" " "	20	240

SUMMARY OF WEIGHT

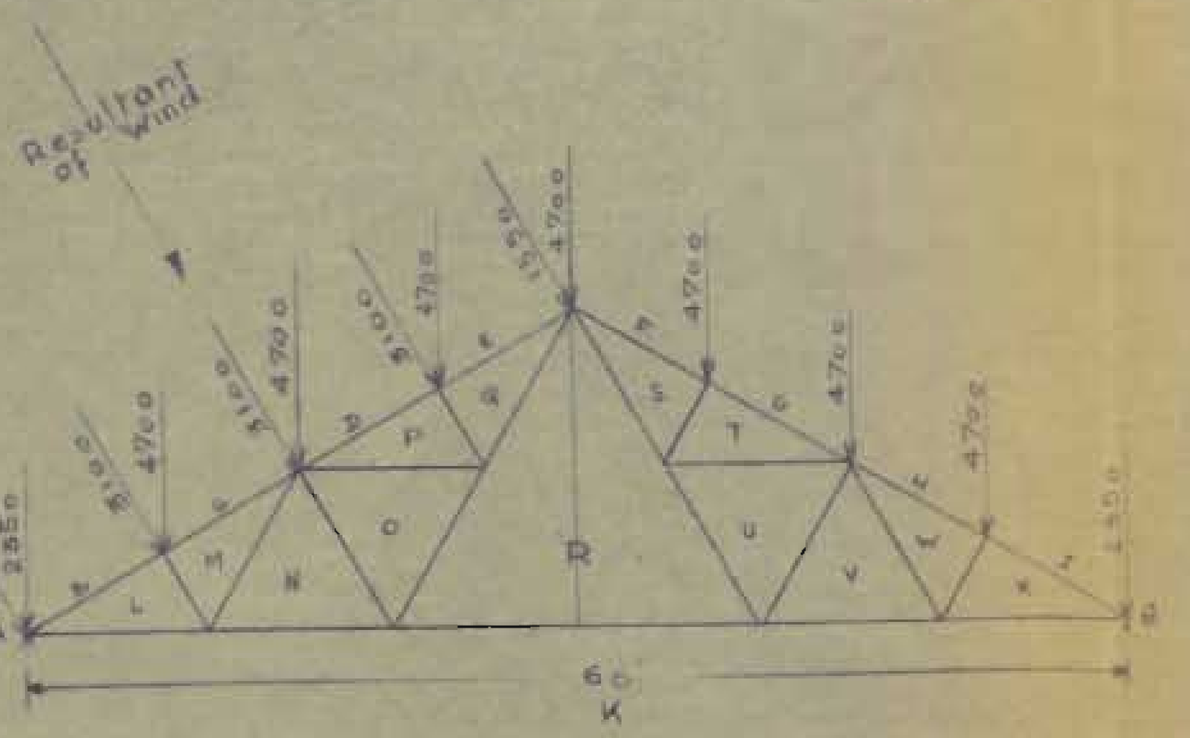
Span	Area	Weight col. K	Weight of truss K	Total Wght K	+ 33% for bolts gussets & bracing	Weight of truss & col. /□	Weight of purlins /□	Total weight of frame /□
15	108	0.144	0.219	0.363	0.484	2.7	3.0	5.70
30	360	0.144	0.614	0.758	1.011	2.8	3.04	5.84
60	900	0.186	2.593	2.779	3.705	4.1	3.3	7.4
90	1440	0.240	5.950	6.190	8.250	5.7	4.0	9.7

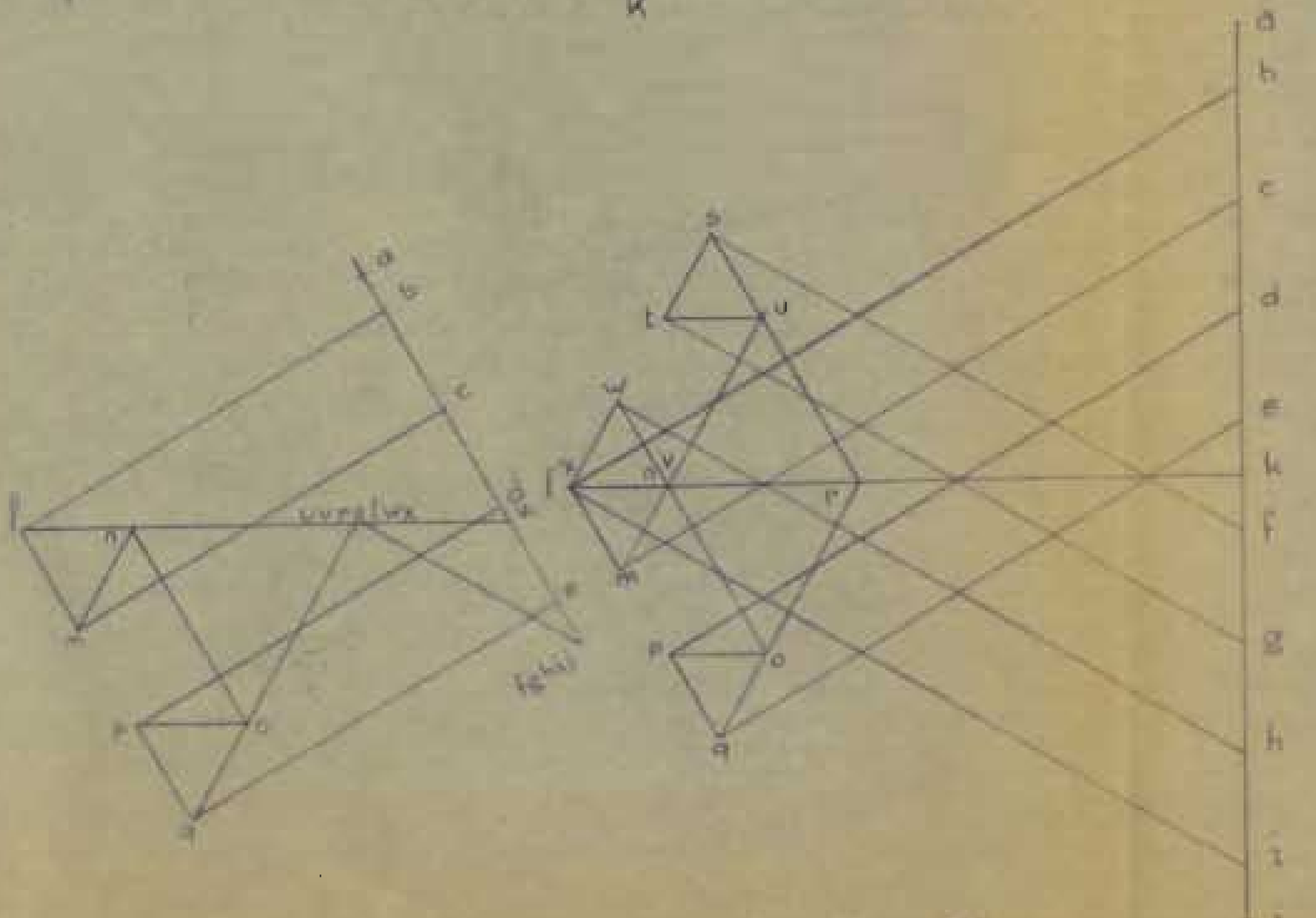




1 in = 4 ft

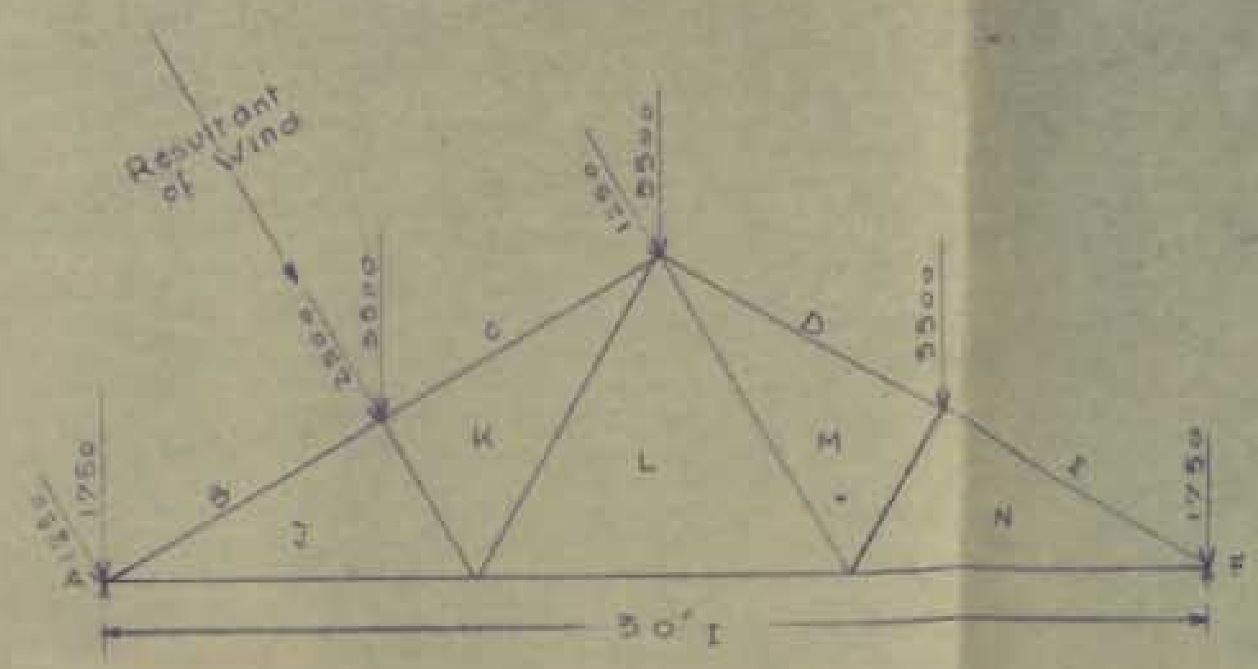
Member	Wind Stress Kips	D.L. Stress Kips	Total Stress Kips	Selected Section	Weight #/'	Length '	Weight #
BM	-21.0	-58.0	-79.0	2L - 5"x3½x7/16	24.0	8.67	208.0
CN	-21.0	-56.0	-77.0	" "	"	8.67	208.0
DP	-18.0	-47.0	-67.0	" - 5"x3½x3/8	20.8	"	180.0
ES	-18.0	-47.0	-65.0	" " " "	"	"	180.0
FU	-21.0	-48.0	-69.0	" " " "	"	"	180.0
GV	-21.0	-45.5	-66.5	" " " "	"	"	180.0
HY	-12.0	-45.5	-57.5	2L - 5x3½x5/16	17.4	"	151.0
IZ	-12.0	-48.0	-60.0	" " " "	"	"	151.0
JB'	-12.0	-47.0	-59.0	" " " "	"	"	151.0
[illegible]	-12.0	-49.0	-61.0	" " " "	"	"	151.0
KD'	-12.0	-56.0	-68.0	2L - 5x3½x3/8	20.8	"	180.0
[illegible]	-12.0	-58.0	-70.0	" " " "	20.8	"	180.0
ML	+25.0	+50.0	+75.0	2L - 5"x3½x½"	27.2	10.0	272.0
OL	+21.0	+46.0	+67.0	2L - 5"x3½x7/16	24.0	"	240.0
QL	+17.5	+41.5	+59.0	2L - 5"x3½x3/8	20.8	"	208.0
[illegible]	+7.0	+41.5	+48.5	2L - 5x3½x5/16	17.4	"	174.0
[illegible]	+7.0	+46.0	+53.0	" " " "	17.4	"	174.0
[illegible]	+7.0	+50.0	+57.0	2L - 5"x3½x3/8	20.8	"	208.0
WL	+7.0	+27.5	+34.5	" " " "	"	15.0	312.0
XL	+7.0	+27.5	+34.5	" " " "	"	"	312.0
[illegible]	—	0	—	L - 5"x3½x3/8	10.4	26.0	270.0
MN	-3.5	-4.5	-8.0	L - 2½x2x3/16	2.8	5.0	14.0
NO	+3.5	+4.5	+8.0	2L - 2½x2x5/16	5.5	10.0	55.0
OP	-5.2	-6.5	-11.7	" " " "	"	10.0	55.0
PQ	+4.5	+6.0	+10.5	2L - 3x2½x¼	9.0	13.25	119.2
QR	-10.0	-14.0	-24.0	2L - 3½x2½x5/16	12.2	15.0	185.0
RS	+4.5	+6.0	+10.5	2L - 3x2½x¼	9.0	13.25	119.2
ST	-5.2	-7.0	-12.2	2L - 2½x2x5/16	5.5	10.0	55.0
TU	+3.5	+4.5	+8.0	" " " "	5.5	10.0	55.0
UV	-3.5	-4.5	-8.0	L " " " "	2.8	5.0	14.0
VW	+17.0	+25.5	+42.0	2L - 3x2½x5/16	15.2	10.0	152.0
[illegible]	-15.5	+19.0	+31.5	2L - 3½x2½x¼	9.8	"	98.0
[illegible]	+10.0	+14.5	+24.5	2L - 3x2½x¼	9.0	"	90.0
YX	+ —	+23.5	+23.5	" " " "	"	"	90.0
[illegible]	+ —	+19.0	+19.0	" " " "	"	"	90.0
[illegible]	+ —	+14.5	+14.5	" " " "	"	"	90.0
YZ	—	-4.5	-4.5	L - 2½x2x3/16	2.8	5.0	14.0
ZA'	+ —	+4.5	+4.5	" " " "	"	10.0	28.0
A'B'	—	-7.0	-7.0	" " " "	"	10.0	28.0
B'C'	+ —	+6.0	+6.0	L - 3x2½x¼	4.5	13.25	60.0
C'D'	—	-14.0	-14.0	2L - 3½x2½x¼	9.8	15.0	137.0
D'E'	+ —	+6.0	+6.0	L - 3x2½x¼	4.5	13.25	60.0
E'F'	—	-6.5	-6.5	L - 2½x2x3/16	2.8	10.0	28.0
F'G'	+ —	+4.5	+4.5	" " " "	"	10.0	28.0
G'H'	—	-4.5	-4.5	" " " "	"	5.0	14.0
				total			5946.4

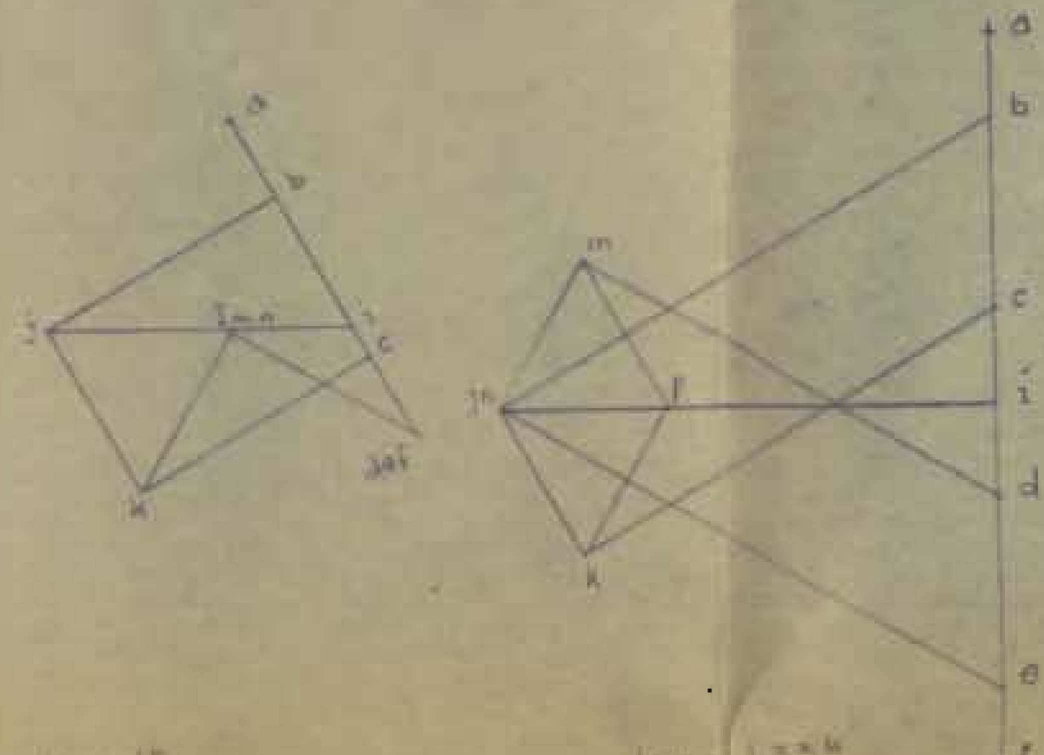




1 cm = 2 k   1 cm = 5 k

MEMBER	WIND STRESS KIPS	D.L. STRESS KIPS	TOTAL STRESS KIPS	SELECTED SECTION	WEIGHT #/	LENGTH '	TOTAL WEIGHT #
BL	-12.0	-33.0	-45.0	2L-3½x2½x3/8	14.4	8.67	125.0
CM	-12.0	-31.0	-43.0	" "	"	8.67	125.0
DP	-12.0	-28.0	-40.0	" "	"	"	125.0
EQ	-12.0	-26.0	-38.0	" "	"	"	125.0
FS	-7.0	-26.0	-33.0	" "	"	"	125.0
GT	-7.0	-28.0	-35.0	" "	"	"	125.0
HW	-7.0	-31.0	-38.0	" "	"	"	125.0
IX	-7.0	-33.0	-40.0	" "	"	"	125.0
LK	+14.0	+28.0	+42.0	2L-3½x2½x3/8	14.4	10.0	144.0
HK	+10.5	+24.0	+34.5	" "	"	10.0	144.0
RK	+4.0	+16.0	+20.0	" "	"	20.0	288.0
VK	+4.0	+24.0	+28.0	2L-3½x2½x3/8	"	10.0	144.0
XK	+4.0	+28.0	+32.0	" "	"	10.0	144.0
LM	-3.0	-4.0	-7.0	2L-2½x2x3/16	"	5.0	27.5
PQ	-3.0	-4.0	-7.0	" "	"	5.0	27.5
ST	—	-4.0	-4.0	" "	"	5.0	27.5
WX	—	-4.0	-4.0	" "	"	5.0	27.5
MN	+3.0	+4.0	+7.0	" "	"	10.0	55.0
NO	-6.0	-8.0	-14.0	2L-2½x2x¼	7.2	"	72.0
OR	+6.0	+8.0	+14.0	" "	"	"	72.0
RQ	+9.0	+12.0	+21.0	2L-3x2½x¼	2.0	"	90.0
WV	+ —	+4.0	+4.0	2L-2½x2x3/16	5.5	"	55.0
VU	—	-8.0	-8.0	2L-2½x2x3/16	5.5	"	55.0
UR	+ —	+8.0	+8.0	" "	"	"	55.0
RS	+ —	+12.0	+12.0	" "	"	"	55.0
OP	+3.0	+4.0	+7.0	" "	"	"	55.0
TU	+ —	+4.0	+4.0	2L-2½x2x3/16	2.8	"	55.0
				total			2593 #





1 cm = 1 k   1 cm = 1.33 k

MEMBER	WIND STRESS	D.L. STRESS	TOTAL STRESS	SELECTED SECTION	WEIGHT /'	LENGTH '	WEIGHT OF MEMBER
BJ	-3600#	+10.400#	-14.000#	2L-2½x2x¼	7.2	8.66	62.5
CK	-3600	-8.800	-12.400	" "	"	"	62.5
DM	-3000	-8.800	-11.800	" "	"	"	62.5
EN	-3000	-10.400	-13.400	" "	"	"	62.5
JI	+1700	+9.000	+10.700	2L-2½x2x3/16	5.5	10.0	55.0
LI	+1700	+6.000	+7.700	" "	"	"	55.0
NI	+1700	+9.000	+10.700	" "	"	"	55.0
JK	-2500	-3.000	-5.500	1L-2½x2x¼	7.2	10.0	72.0
KL	+2500	+3.000	+5.500	" "	7.2	10.0	72.0
LM	+ 0	+3.000	+3.000	1L-2½x2x3/16	5.5	5.0	55.0
MN	- 0	-3.000	-3.000	" "	5.5	5.0	55.0
				total			614.0 #

SCHOOL OF ENGINEERING A.U.B.
PROJECT ROOFS AND ROOFING
DESIGN OF STEEL TRUSSES
DESIGNED by SUHAYL HABIB
DATE JUNE 30 1953 NOT TO SCALE SHEET 4