SUN DRIED MUD BRICK CONSTRUCTION.

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1953

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SCHOOL OF ENGINEERING

PROJECT REPORT

UNIVERSITY OF BEIRUT

R E P O R T

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S U N - D R I E D M U D B R I C K

C O N S T R U C T I O N

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S A L A H Y A M O U T

June 1953

MUD CONSTRUCTION

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INTRODUCTION

MUD IS THE SIMPLEST AND MOST ACCESSIBLE MATERIAL FOR BUILDING PURPOSES. ANIMALS LIKE THE BEAVER USE IT TO BUILD THEIR HOUSES. BIRDS USE IT TO BUILD THEIR NESTS.

MAN USED MUD AS A BUILDING MATERIAL FIRST IN SIMPLE SUN-DRIED FORM AND LATER LEARNED TO BURN IT INTO BRICKS AND POTTERY. CERAMIC INDUSTRY AND CHINAWARE IS A REFINED MUD PRODUCT. BUT STILL SIMPLE SUN-DRIED BRICKS ARE BEING USED IN VILLAGES AND TOWNS BECAUSE OF CHEAPNESS ACCESSIBILITY AND THE SATISFACTORY RESULTS OBTAINED FROM SUCH CONSTRUCTION. THIS ESSAY IS INTENDED TO GIVE THE ENGINEER SUFFICIENT INFORMATION TO BE ABLE TO DESIGN AND EXECUTE MUD BRICK HUTS AND HOUSES.

I ESSENTIAL ELEMENTS OF MUD CONSTRUCTION.

A. Cohesive impermiable soil.

Any type of soil will do so long as it has enough cohesive force to make a brick that can be handled without breaking. Such bricks brought to test (in A.U.B. Lab.), revealed an ultimate strength of 185 lbs per square inch, which means with a factor of safety of 4, can build a wall carrying its own weight of 100 feet. (weight of mud 75 lbs per cubic feet.)

The next property required is a certain degree of impermeability to water. Some soils are cohesive but contain some coarse material to make it porous where water will penetrate into the bricks.

On asking an experienced mason what kind of mud will do for the bricks, they all said any mud except that which is good for plant growing and they point out to the dark soil of the field, saying this will break on getting water. A simple examination of such soil revealed to me that the porosity necessary for plant growing is not required for brick making. Then I inquired with these masons whether an addition of marl to such soil will make it better. The answer was yes. This is because marl will fill the pores of such soil and make it impermeable to water.

B. Water for mud bricks must be potable water. Sea water will not do because of the salt in the water. After the water have dried it will be a source of getting more water and weakening the bricks. (The hygroscopic property of salts.)

C. A 40 days of dry weather.

Bricks have to be dried keeping in the bricks only the necessary water for binding the soil. This is called by present soil science "optimum moisture content". It is about 8% by weight of the soil and takes between 15-20 days of sun drying. The mason must make sure that no rain take place during building. That means a spell of at least 40 days dry weather. For this reason there is a dead line limit after which no use of making bricks and building. This is about 40 days before the coming of rainfall. Rain starts in October in this part of the world. So about Mid September is the dead line limit.

It is interesting to note here how this water in the mud links masonry with astronomy. The Arab calendar is lunar. It does not indicate the season. So they have to rely on stars for telling the seasonal changes. The star well-known to all Arab Bedwins and Semi-Bedwins is the "Souhail" (Almanac name Suhil), which indicates the coming of winter. When the Souhail star begins to appear as a mourning star, it is an indication of the coming of winter rain and cold weather. When the Sheik of the village announces the rise of the Souhail, it is a note to farmers to start tilling the soil. To our mason it is the dead line limit to his building work. "Did the Souhail rise?" This is the question in the mouth of every villager in September. It is to the interest of the farmer, the Bedwin and the mason to know.

D. Straw.

The cost of straw is the determining factor whether to build a wall of stone or mud.

In Syria I noticed that where Tibn is abundant, mud huts are the rule. For if the straw is dear, stone is cheaper to build with. In a village like Tel-Bisse near Homs where Tibn is abundant, it costs 30 pounds every thousand bricks. 10 pounds the cost of Tibn, and 20 for mud and workmanship. What function does the straw serve in the mud? Is it absolutely necessary?

1) Functions of straw in mud bricks.

1) Mud bricks crack after becoming dry and straw helps to keep the bricks together. This applies to mud that is most commonly used. It is unselected poor binding, deficient in fines of the size of marl particles, moreover too much water in the mix will make the mud liable to more cracking. One can see that pottery mud, which is caly and marl put together in certain proportion, does not crack after being put to shape. This is because it is put to shape in the plastic limit in which case it does not crack. While if the mud is put to a form in the liquid limit it will definitely crack. In other words putting straw in the mud is to guard against poor selection of the soil and poor handling with water.

2) Straw serves as a sort of tension reinforcement.

For bricks of the size used 40cm X 20cm X 10cm is subject to tension in handling and mud cannot hold tension without the straw. Of course this is true of the very poor quality of mud in use, and it is not necessary for mud of high cohesive force.

3. For the same poor quality of mud straw helps to make brick stronger in compression. This can be proved experimentally. Still a discussion of the resistance of material will show that it is true.

Materials under compression fails by tension or shear in planes making an angle with the acting force, and since straw increases the shear and tension strngth of mud, therefore it will increase the compression strngth.

Another way of looking at it is this. By adding straw you increase the tension resistance of the mud and by increasing the tension resistance you increase the elastic limit of the maerial. Some mathematical relation must exist between the compressive strngth of material and the elasticity.

In all the above discussion on the use of straw in mud it is applicable to poor quality mud. But for mud plaster, straw is a necessary especially external plastering, because on being subject to rain plaster cracks or peels off from the main body of the wall and straw is necessary to keep the plaster bound to the main body of the wall.

Kind size and quantity of straw.

Subject a straw in a mud brick to tension, it will either break or slip off, if there is not enough bond stress between the straw and the mud. So the following points have to be observed:

(1) The straw must be long enough to establish a bond stress equal to its tensile stress.

(2) To increase the tensile stress of a brick, increase the sectional area of the straws used.

<u>a) Kind of straw.</u> Straw must be dry or else becteria or vermin may grow in it. It also must be strong to hold tension.

<u>b) Size of straw.</u> The following mathematical analysis may help to give a picture of the sizes required.

Let: Fs= allowable unit tensile stress of straw / cm^2.

V= allowable mnit bond stress / cm^2 between mud and straw.

L Length of straw.

R diameter of straw (take it round)

Tensile stress in straw will be $\pi R^2 Fs$.

Bond stress $2\pi RLV$.

Tensile stress must equal to bond stress

$$2\pi RLV = \pi R^2 Fs$$

$$2LV = RFs$$

$$L = \frac{2Fs.\ R}{2V}$$

This equation makes the following clear:

(1) For a given quality of mud and straw (V is constant and Fs is also constant) The length is proportional to the radius of the straw.

If a straw with a diameter of 3mm and a length of 60mm. satisfy this equation, a straw with 1/10 mm. (that is hairlike) need to have a length of 2mm.

So if we put fine and short fibers will do just as good as the long and thick straw. In fact it is much easier to work mud with fine fibers of 2mm. and 1/10m than with long and thick. Jute fiber would be ideal for the job but it is uneconomic to use. They usually use straw of the size of 1cm to 6cm and diameter from 1mm to 3mm.

c) Quantity of straw.

To increase the tensile stress of the mud, you have to increase the number of straw. But there is a limit to it. One limit is economic. For straw is comparatively dear and putting too much straw will be uneconomic. Another limit is too much crowding of the straw will not give every straw enough mud surface to develop to complete bond stress.

Experience of the masons in Syria give the following figures: For a thousand bricks of the size of 40cm X 20cm X 10cm, a jute bag of tibn (hay) is required (about 10 kgs)

II STRUCTURAL VALUE OF MUD BRICKS

Tests have shown that for the weakest straw mixed mud the ultimate strength is 185lb per square inch, so with a factor of safety of 4 a wall of 100 feet can be built with it. But muds of much higher resistance is abundant in all parts of the world. It's ultimate strength may be as big as

350-400lbs per square inch. So with a factor of safety of 4 say a working stress of 85lbs, with this working stress you can build a wall 170 feet high carrying its own weight. I have seen in Riaad and Al Hofuf in Saudi Arabia fortress walls as high as 150 feet. Specification from "minimum requirements for masonry wall construction report of Building code Committee of U.S. Department of Commerce 1925", specify for a three story building a minimum of 80lbs. So by our brick we can build building three story high. In Hadramuth, Southern Arabia, I have seen pictures of buildings 15 story high, out of mud bricks, but probably they use gypsum with the mud.

III MUD BOUND STONES.

The presence of small shells and sand in abundance in the Persian Gulf, suggested to me making Hollowed Cement blocks (Knapkin), with mud as a mortar. If the power of the mortar is 300lbs breaking strength, the stone should have the same strength. But the problem is to waterproof the stone, for if water creeps into the pores of the stone, it will disintegrate it. So some method of water proofing have to be devised. The following three methods have been suggested.

1) A thick layer of mud and straw 1 inch to be plasted on the surface of the wall. Mud being impermiable to water when wet, will make the wall waterproof.

2) A cement plaster be used to coat the wall. Although there is mud in the stone, but the presence of the shell will "key"

the cement to the bricks.

2) Stabilized soil bricks.

Treating soils with cement is a subject dealt with under the title of soil stabilization in road work, and air fields. It is mostly used for forming a base course for thin bituminous pavements. However, if the proper strength and the waterprofing property be made economically, it can as well be used for making cheap bricks. The procedure established in treating a soil is as follows:

Given a soil with various sizes and percentage content, a graph is made of size against percentage content. To give good results this graph must fall in an established range. If not, fines or coarse materials have to be added or deducted. Then after establishing the proper proportion, laboratory tests are made with different percentages of cement until the proper mix is found.

Another problem arises in mixing these contents. For mud if dry is in the form of small stones and it would take a lot of mixing to break it with water and distribute it evenly in the mix. In fact what we have saved in the amount of cement we would put it in more labor work for mixing. If the mud is plastic it will remain in lumps when mixing.

The best results were obtained by putting the mud in the water and instead of pouring water to the mix we pour this liquid mud.

From the table of tests on page 8 we can see that mix 1 in 29 that is with 3.5% cement strength and waterprofing property is satisfactory.

But comparing results from economic point of view, the following table is shown. The two mixes compared are a 10% mix of pure cement, which the minimum cement used in brick work, and a 3.5% mix of cement and mud.

The follwoing are the cost of making a hollowed cement brick of the size of 18" X 9" X 8" in Lebanese piasters in Saudi Arabia.

	Cement brick	Cement mud brick
Cost of sand and gravel	30	30
Cement	70	23
Mud	00	10
Labor	20	25
Total cost of a brick	120	88

It can be clearly observed that we reduced cement to 1/3 and the price of the brick dropped only $\frac{32}{120}$ X 100 25%.

TESTS ON VARIOUS MIXES OF MUD, SAND, SHELLS AND CEMENT

CEMENT MIX	00	1/115	1/57	1/38	1/29	1/14.3
CEMENT CONT. % BY VOL.	0.00	0.87	1.75	2.62	3.50	7.00
MUD CONT. % BY VOL.	35.00	34.10	33.25	32.37	31.50	28.00
SHELLS CONT. % BY VOL.	46.02	48.70	48.70	48.75	48.70	48.70
SAND CONT. % BY VOL.	16.25	16.25	16.25	16.25	16.25	16.25
CRUSHING AT 10DAYS	166	171	193	224	293	380
CRUSHING AT 28 DAYS	213	239	231	276	305	485
CRUSHING AFTER SOAKING IN WATER FOR 48 HOURS	---	---	209	254	437	644
SLUFFING AFTER 48 HOURS IN WATER	100 %	100%	7.8%	3.0%	1.22	0.00

NOTES

(1) The above figures are in pounds per square inch.

(2) Mix 1/29 makes the brick nearly waterproof. It increased the strength from 213 lbs/sq. in. to 437 lbs/sq. in., that is about twice.

(3) It is interesting to note in Mix 1 in 14.3, the difference between the soaked and the unsoaked brick from 485 to 644 an increase of 159 pounds.

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IV MUD ROOFS.

A. Flat Roofs.

Mud slabs supported on timber joists was the prevailing flat roof of all Arab towns and villages before the coming of cement.

In the case of roofing, impermiability of the material rather than strength is the main property looked for. For this reason roofing mud is usually of a finer texture than that of mud bricks. Marl is the substance used in Syria and Lebanon. It is sometimes mixed with sand and coarse aggregate of the size of 1 inch and below. Usually the material is poured on the roof in a semi-liquid state, so that after drying cracks appear. The usual remedy for such cracks is to keep the roof for 20 days or more without touching until it is completely dry and all the cracks appear. Then these cracks are grouted with mud.

a) A seal coat is usually made to this roofing. The cheapest and simplest seal coat is another layer of mud, reinforced with straw. The object of the straw is to keep the surface layer bound to the main body of the roof. For during winter after a spell of rain and then sunshine, that surface layer dries and cracks or peels off the roof. The straw is to keep it tied to the main slab, so that when another rain comes again it is bounded again to the roof.

In such kind of roofing a hand roller is kept on the roof and before the coming of wet weather it is sprayed and rolled. This is because during summer the mud may have cracked and rolling seals it. Moreover such roofs usually deflect so much on walking on it that the mud cracks and rolling is always necessary to seal that crack.

Another type of sealing coat used in town is an one inch layer of lime mortar, also such layer cracks because of deflection of the roof so that before the coming of wet weather the roof has to be checked and the cracks sealed.

b) Thickness of the layer. The thickness of the layer should be enough to insure impermeability and not thick enough to require big and costly joist. The established thickness has been found to run between 5 to 10 inches. In a hot country a thick roof is preferred.

c) Roof supports and sheathing. Some kind of sheathing to hold the mud is required and joist to support the roof. Drawing No...6... shows the various types of roof supports and sheathing used in Syria, Lebanon, Iraq and Saudi Arabia. One thing to be noted about these supports is that the size and spacing has been determined by strength rather than by the maximum deflections. This is because as mentioned before cracks are expected in the mud, so if one can save timber in the design on the expense of more cracks, reasonably enough, it is allowed. The present tendency in modern design it to design the rafter or joists in plastered ceiling for a Maximum deflection of $\frac{1}{360}$ of the span.

<u>B. An all mud Dome Roofing House.</u>

In Syria, Mesopotamia and Turkey an all mud house is still being made in villages. Unbeaten simplicity, cheapness and comfortable in all weather, are the cause of the maintanance of such construction. Mud is available and cheap, construction simple, walls are made thick so that they are a good insulator against cold and hot weather. The mud lends itself to liquid and semi liquid coating such as a white wash or a coloured distemper which will give the interior of the house a clean neat appearance. No need for any other material such as timber, sheets, matting or any other things except doors and windows. In my opinion it is an ideal house for villages.

Walls. These huts are made of mud walls to a height 8-9 feet. Then a mud dome shaped roof is built, giving the house a picturesque sky line.

The dome. The dome is a remarkably stable structure. It can be shown analytically to be stable with a uniform thickness of 23/1000 of the span, which is less than 1/3 of the necessary thickness of a masonry arch of uniform thickness carrying only its own weight.

If the thickness of the shell is tapered from the springing joint toward the summit, it need only to have a volume of 9/16 of the thinnest uniform dome of the same span. That is a dome having a span of 4 meters must have a uniform thickness equal to 23/1000 X 4000 = 9cm to carry its own weight say 4 inches. The thickness of the mud domes made are 16 inches i.e. four times the strength requirement.

What fixes the various dimensions of the house is the size of the brick used therefore it is necessary to establish the size of the brick. The following points have to be concidered

1) Bricks must not be too big to be heavy and clumsy in handling.

2) Thickness and length are governed by the weakness or strength of mud.

3) Too long and thin will break on handling.

4) It must not be too small.

5) Length width and thickness must be whole multible of each other; this to help in the coursing and bonding of the construction.

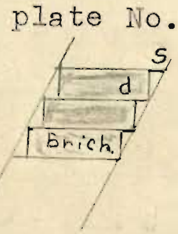
Once the length is fixed the other dimensions are whole multiples. The ratio of thickness breadth and length is 1:2:4. The size of the mud bricks established in Northern Syria, with the present mud used (ultimate strength 185lbs per square inch) is 40cm X 20cm X 10cm. Now that the size of the brick is established, the various dimensions of the house area multiple of it, and the masons measure things in multiples of the brick. The dome cannot be thinner than the width of a brick so the thinnest dome is 20cm or 8". But with ordinary spans of 10-15 feet for rooms, the brick is put lengthwise and the thickness of the dome is 40cm=16in. The wall supporting the dome, being a bearing wall is given a thickness of 60cm=2 feet which is the size of one brick lengthwise and one breadthwise put together. For the foundation, no need for the footing of the wall to be wider than the wall 2 feet, for it is carrying a load equivalent to a mud wall 20 feet high, which gives a required bearing of 10lbs per square inch. The foundation which is about 2 feet of the wall being underground and subject to run off water is made of random rubble stone. Lime mortar is preferable but mud mortar will do as well if some stones are big enough to span the whole breadth of the wall. This random rubble construction is extended 6 inches above the surface.

Dome construction. The dome is constructed by making the mud brick courses run helically up. This is accomplished by gradually increasing the mortar bed in the first course until the last brick meets the first in the circle one on top the other. Then the helical movement of the coursing will take care of itself, simply by laying the courses as you go on putting the top brick always nearer to the center a certain constant distance. This screw ~~moment~~ movement will close the dome at the top. The shape of the dome is a cone of revolution generated by turning a line making an angle with another vertical line, around the vertical line as an axis.

The established slope of the line to the vertical is 2.

Therefore a room with a span of 4 meters must have a dome with a height of 4 meters. The plan of the room must be a square in order to have the 4 sides of the dome supported on walls (as shown on plate No.2). As walls form a square and the dome a circle, corners have to have special construction known to the masons in Syria as the "talabeh" (as shown in plate No. 4).

Size and shape of the dome.



Let s be a shown in figure

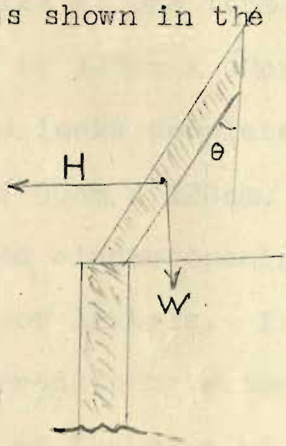
d thickness of brick.

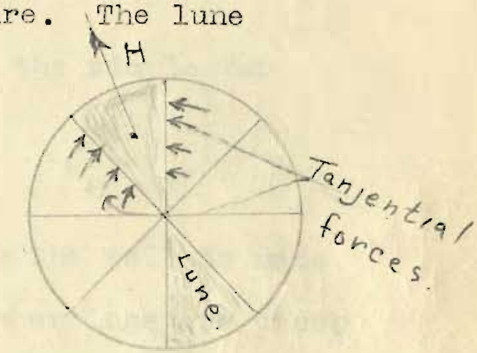
Therefore $\frac{s}{d}$ is the ~~curve of the dome~~ slope. If s is made constant, since d is constant then the slope of the curve is constant that is a straight line, and the solid generated by revolving the the curve around its vertical axis is a cone of revolution. It is clear that it is in the hands of the mason if he wants a cone shape dome he makes his s constant all through out. The magnitude of s determines the steepness of the slope. It has been found that s equals $\frac{1}{2}$ d gives a well stable cone shaped dome. This meant that the mason takes $\frac{1}{2}$ the thickness of the bricks as a measure of the increase per course. So a room 4 meters wide has to have a dome 4 meters high. The dome is built on a wall 300 meters high. So this gives a total of 7 meters for each room from ground level to the top of the cone. In pressure it is equivalent to a wall 3 ~~and~~ + $1\frac{1}{2}$ equals $4\frac{1}{2}$ meter high. i.e. 15 feet high roughly giving a pressure of 8lbs per square inch. Since the bearing is about 50, so it is quite safe and one can build even 5 times as high.

Angle of the cone.

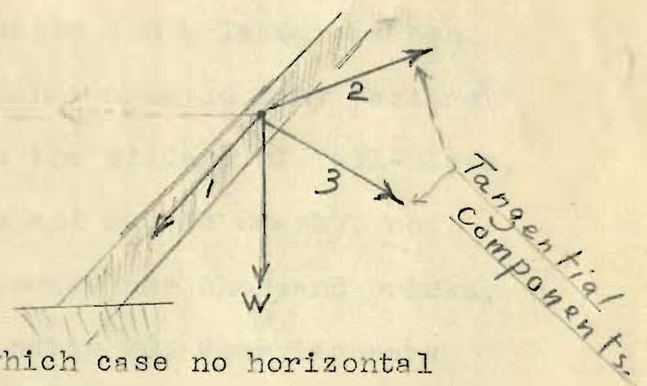
How flat a cone can we use? (i.e. size of the angle.) This depends upon the effect of the horizontal thrust, which we shall discuss.

1) Cut the cone into lunes as shown in the figure. The lune is made stable by a horizontal force H to counteract the weight. It is equal to W tan.θ





2) This horizontal force is supplied by 3 components: 2 tangential from adjacent lunes and one downward along the lune to the supporting wall. How much will reach the wall will depend how much taken by the other two tangential components. If all the horizontal force is taken by the tangential components, no horizontal thrust is on the wall. In this case the dome can be considered as a solid cap, in which case no horizontal thrust is on the wall. How this force is distributed along these three components, is a ~~complex~~ mathematics involving elasticity. The best way to find the biggest angle of the cone with a given material such as mud, is to try experimentally. Experience of the masons have revealed that an angle whose tangent is around 0.5 with a thickness of the dome of 40 cm, gave satisfactory results.



V BILL OF QUANTITIES

AND COSTING FOR A ROOM

4m X 4m WITH A DOME ROOFING

MUD: $40m^3$ or 5000 bricks of the size of 40cm X 20cm X 10cm.

RUBBLE:STONE: $5m^3$ of the size of one foot.

DOOR: One door of the size of 180cm X 80cm of the simple two panels type with hinger and locks complete.

WINDOW: One number, size of 90cm X 120cm.

TIMBER LOGS: If the door and window opening in the wall is made of the arch type, no need for lintels. If timber logs are cheap and available, it is preferred to have the door and window lintel of 3 Nos timber logs each, of the size of 120cm each diameter 3 inches. For it may take time in building an arch over the door and the window and it may be cheaper to get wooden logs instead, or else an arch will do.

Men hours of work and costing. One mason and 4 labourers can build a room in 5 days. The cost depends upon so many factors but for illustrative purpose I shall take the village of Tell-Bisse, Syria as a sample. There water, tibn and mud is nearby, no transport is required. It costs 30 pounds per thousand bricks, the cost of tibn 10 pounds and workmanship 20. Four laborers and 9 masons take 16 pounds daily. In five days they take 90. The total cost of a room 4m X 4m with a dome would amount to the following:

Bricks	120	cost of 4000 bricks
Labor	90	one mason at 6 pounds, 4 laborers at 2.5 for 5 days.
Door	30	
Window	20	
Rubble store	20	cost of $5mm^3$
Finish	15	
	295	say 300

How the mud bricks are made.

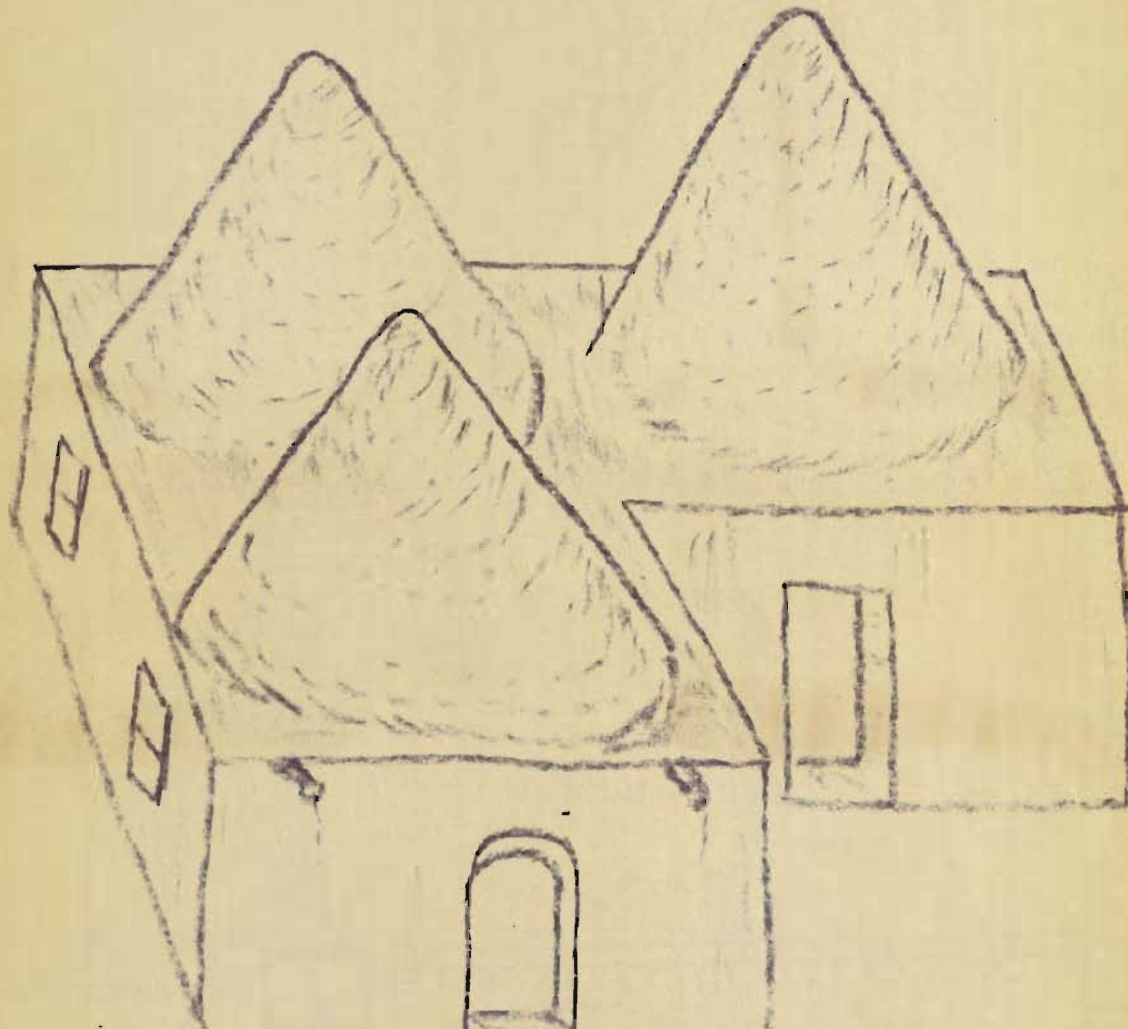
Mud is put in a borrow pit where it is mixed with water and tibn, by means of shovels and feet. It is then left for 24 hours. The mud is then put in timber moulds on a flat ground and left to dry for a few days until it can be taken off the moulds. Then it is left to dry for another 10 days.

The question of the amount of water affects the amount of shrinkage and cracking in the bricks. If the mud is too plastic (semi liquid) a lot of cracks appear and the bricks are useless. It too little water is put it would be unworkable. In general minimum amount of water is to be put as much as "workability allows."

The question of cracking and shrinkage of mud bricks has been the subject of study for the ceramic industry. The conclusion reached is that there is a shrinkage limit after which a reduction of water in the soil will not reduce the volume. This limits passes the plastic limit of the material to the dry limit. So it cannot be used as a limit in mud bricks for in that stage it is too dry.

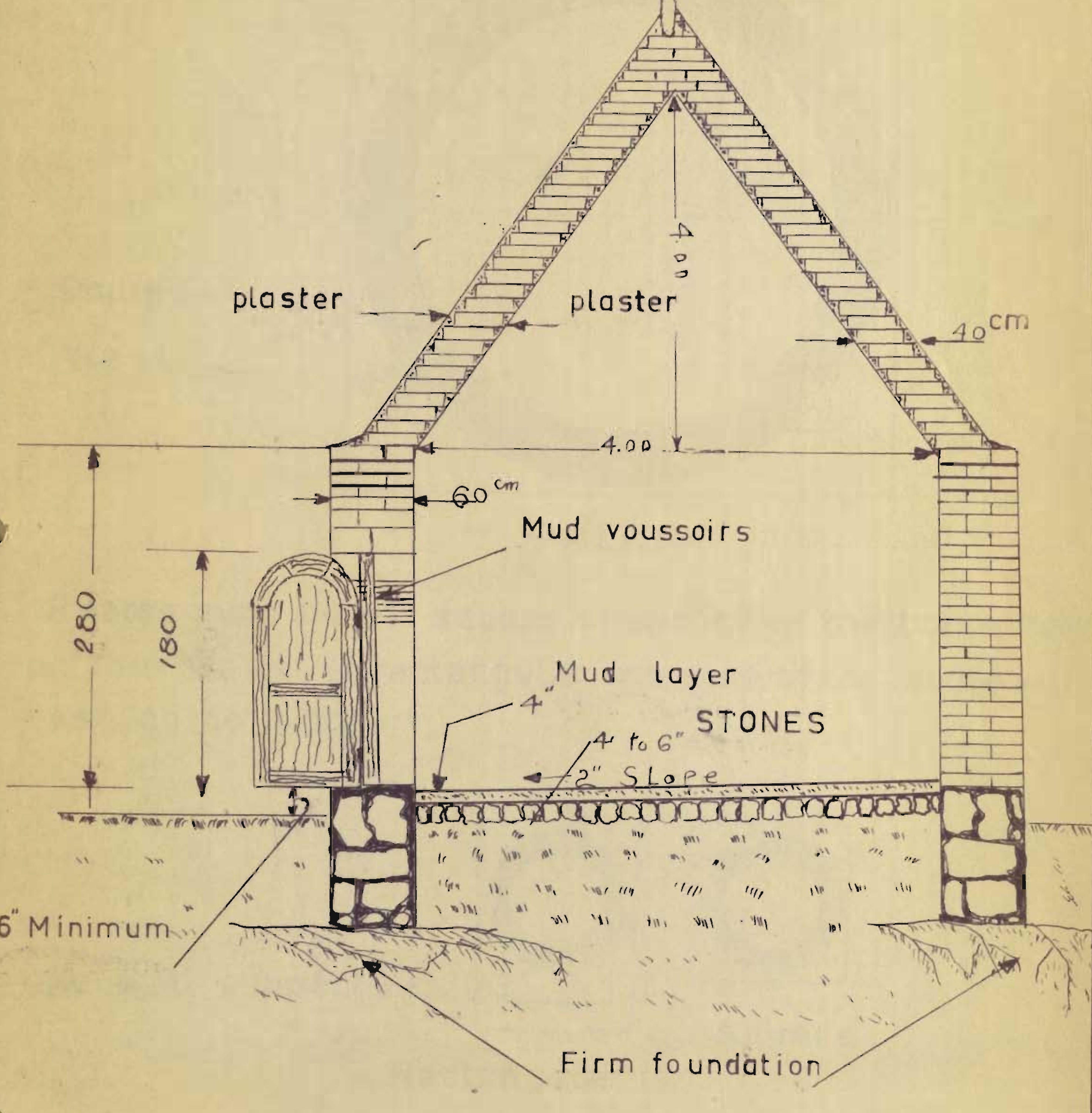



PLATE _ 1

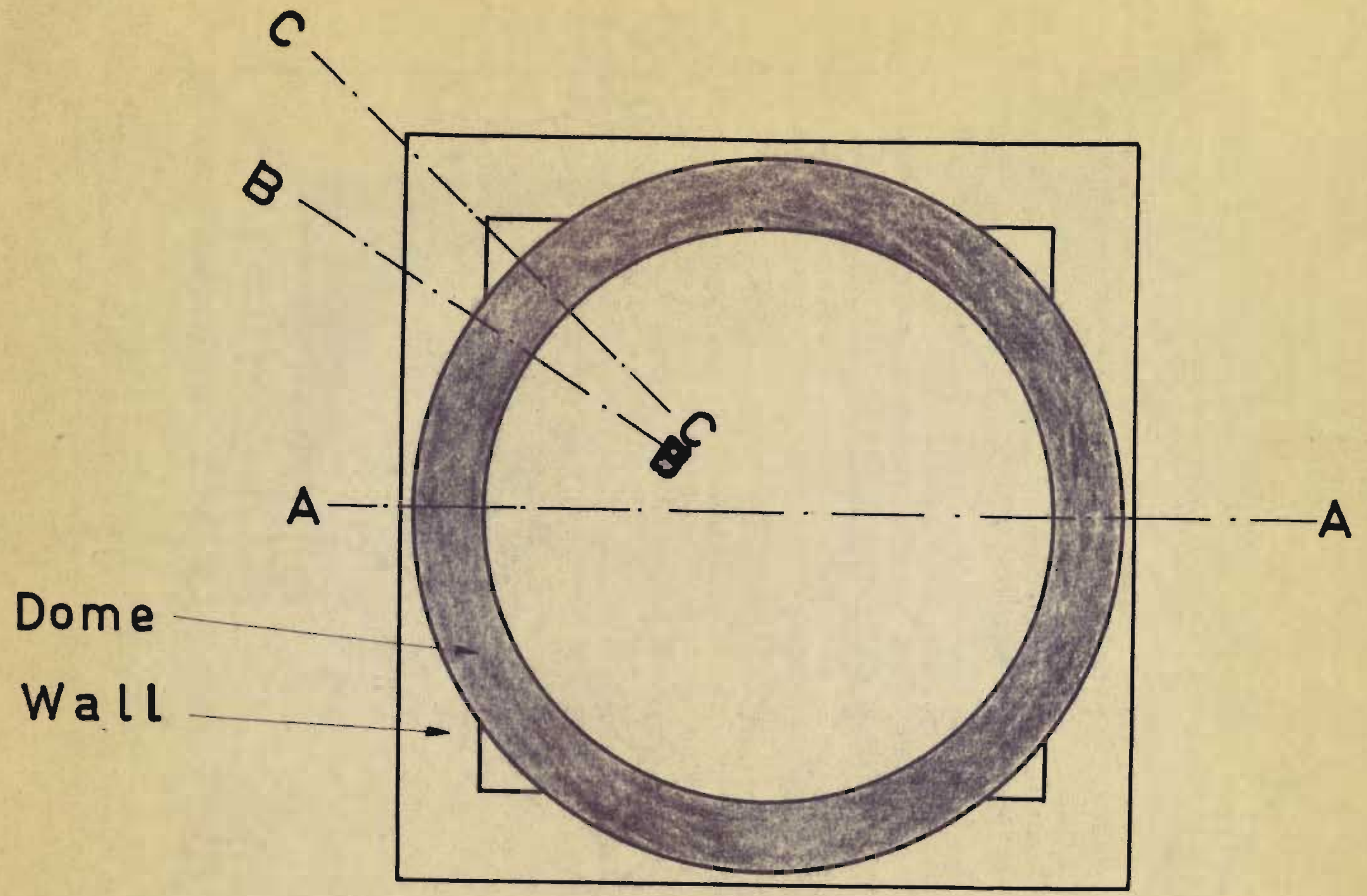


3 ROOM HOUSE

PLATE 2

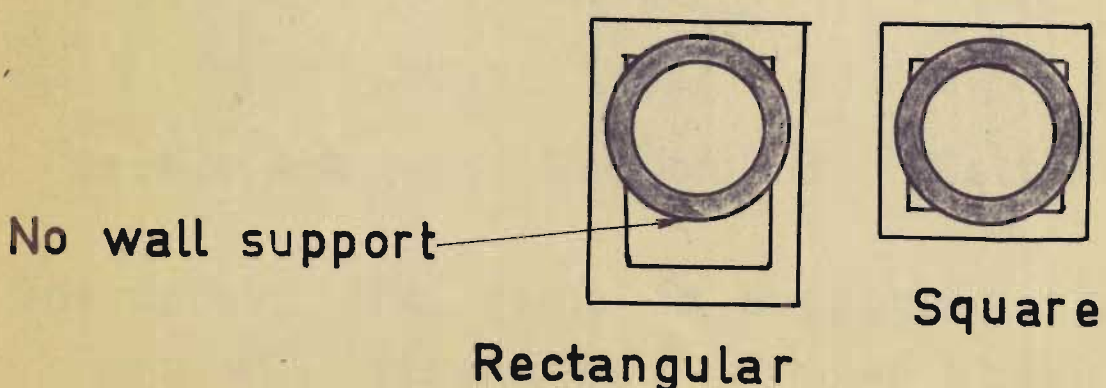


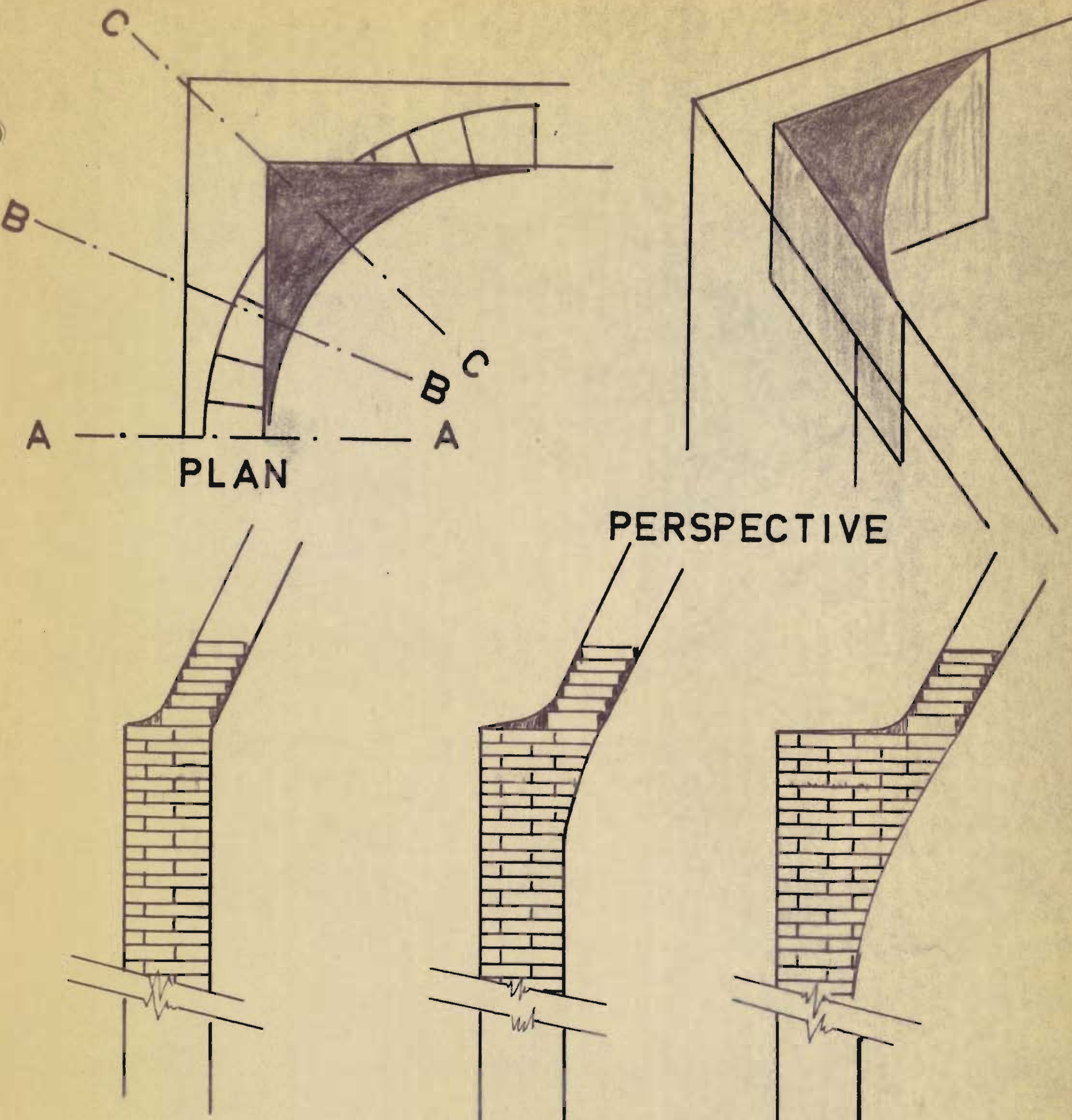
SECTION A A



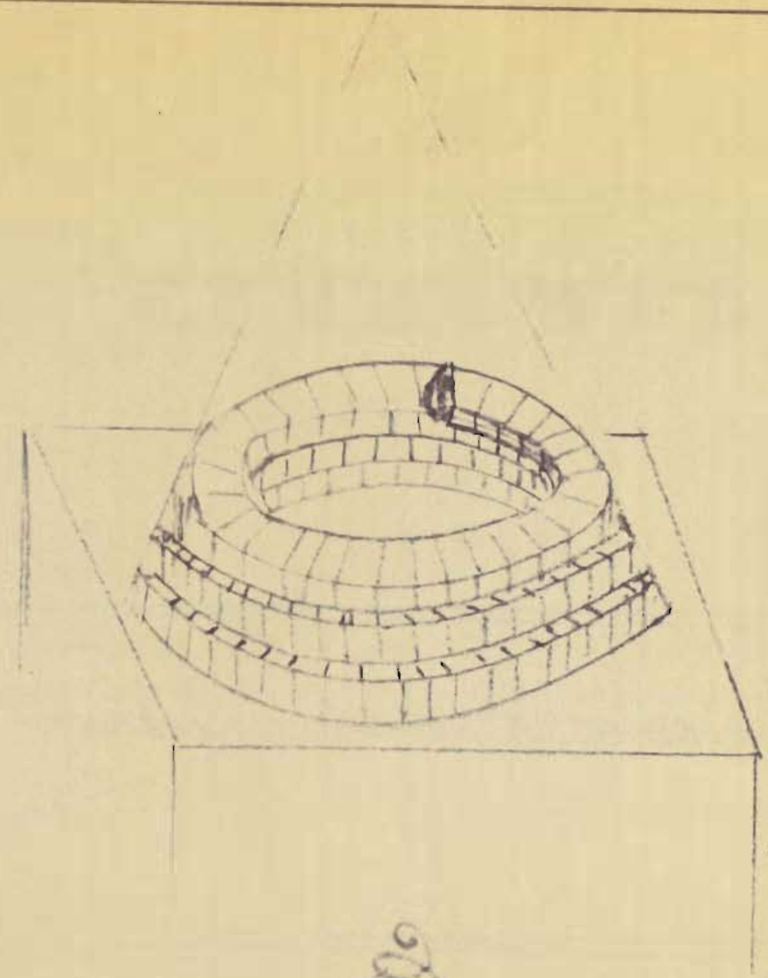
PLAN

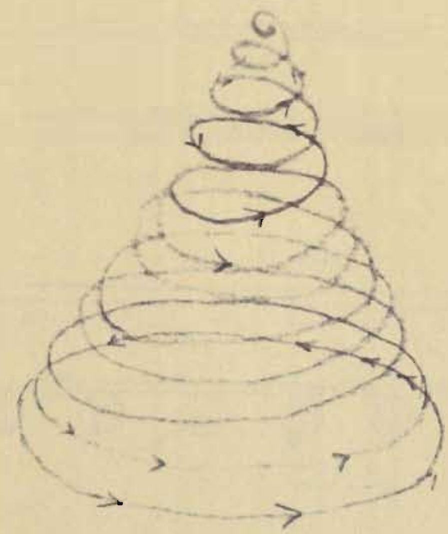
Rooms must be of square shape to have the dome rest on four walls. If rectangular one side of the dome will rest on no support





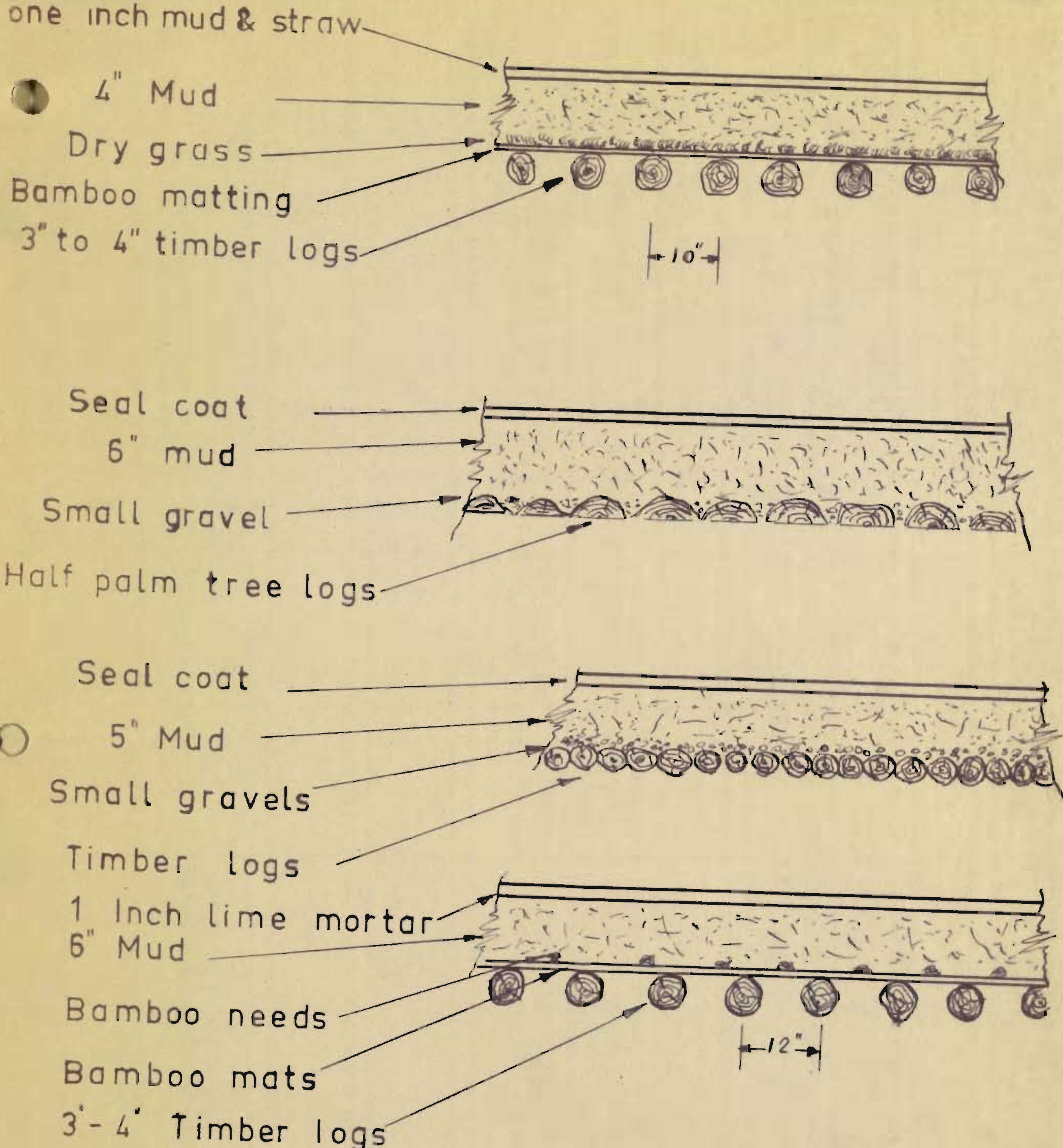
In the corner the dome is supported on a special structure (shown above)





LINE OF COURSING

COURSING IS HELICAL



SECTIONS OF MUD ROOFS

STRESS STRAIN DIAGRAM

For a mud brick 8" X 8" = 64 □" area

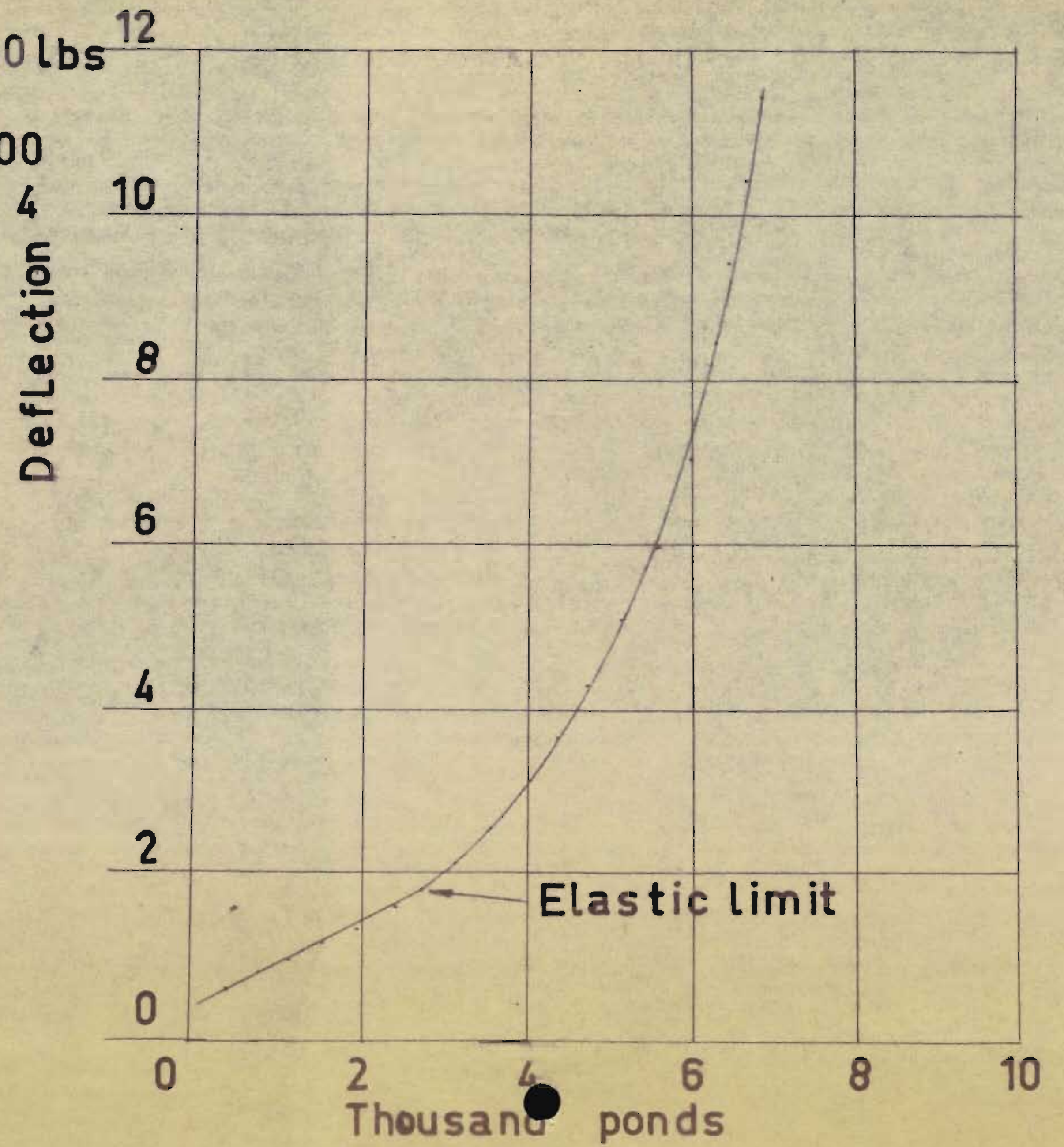
Crushing at 11700 lbs

Elastic limit 2800

Safety factor 4

Working stress

47 lbs/ sq.in



Pounds	Deflection
400	40
800	75
1200	95
1600	110
2000	126
2400	150
2800	170
3200	200
3600	225
4000	270
4400	320
4800	380
5200	440
5600	520
6000	600
6400	880