Mud Brick Roofs

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In a land where time seems to have stood still for six thousand years, there exists today structures of sun-dried mud brick which show every stage of development in this type of construction from 4,000 B. C. to the present. In Upper Egypt one still sees the fellahin, the peasants, living and working just as they have since earliest recorded time. Every detail of the life of the fellah, along with that of the Pharoah and the nobles of his court, has been pictured in the tombs in the Valley of the Kings, the Valley of the Nobles, and the Valley of the Queens. The record in bas-relief on the walls of Medinet-Habu show bricks being made some six thousand years ago with moulds identical to those used today by village masons in that area.

The first use of mud brick for vaulted roof construction in Egypt is believed by archeologists to be in some early graves thought to date back more than six thousand years. While the span of these vaults is less than 30 inches, in them was perfected the method used in all later vault construction.

In the funerary temple complex of Rameses II still stand mud brick granaries dating back to at least 2,000 B. C. Vaults of the Rameseum were covered with earth for further protection against the sun's heat.

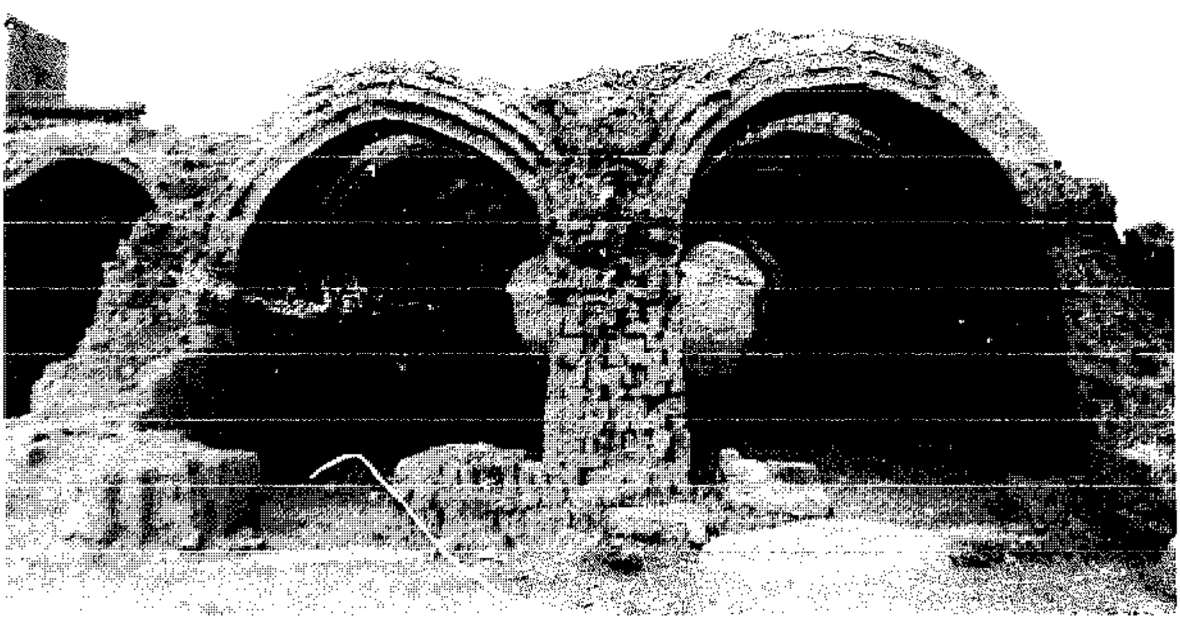


FIGURE 1. Mud brick granaries dating back to at least 2000 B. C.

A fine illustration of the more ambitious use of mud brick vaults is found in a monastery built about 890 A. D. near Asswan. This monastery is believed by some archeologists to be the first mud brick structure to use the vault to support an upper floor. Whether or not it was actually the first is less important to us than the fact that here we see vault construction used for a large important structure two (and in some portions three) stories high which still stands today. An interesting thing about this monastery is the use of small vaults on each side of the main vault. The walls in this area are about three feet thick. In another part of the monastery which was built for a fortress the roof is made of cedar logs (apparently imported from Lebanon) and mud; here the walls are almost four feet thick. This part of the structure is three stories high but the ceiling height is only about six and one half feet as compared to about 14 feet in the vaulted portion.

THE VILLAGE OF NEW GOURNA

For anyone interested in roofs of earth, the mud brick dome-and-vault houses and community buildings at the Village of New Gourna in Upper Egypt provide recent examples of this type of construction. New Gourna Village, across the Nile from Luxor, was built to house the people of nearby Old Gourna in the vicinity of the Valley of the Nobles and the tombs of the ancient Pharaohs. Many of the tombs are in the depths of the earth beneath Old Gourna and the old village is scheduled to be demolished by the Egyptian Government as the entire area has been set aside for a national park.

FIGURE 2. Mud brick vaults used in a Monastery built about 890 A. D. near Asswan.

In designing the houses themselves, Dr. Fathy took into consideration the village people's needs and customs, then tried to introduce as much improvement as he felt they could absorb at one time. Among his innovations are: built-in beds with channeled indentations for scorpion barriers; a drainage system which prevents formation of mudholes; locally-made pottery reservoirs for household water; locally-made floor-level latrine slabs; built-in furnaces of mud brick to provide heat when necessary; (Main baking ovens are always in the courtyard for coolness); built-in evaporative coolers;[1] and a laundry basin in each courtyard with a scrubbing disk of a size and height most useful. The laundry basin is also used by the family for personal bathing. Then water is later piped into the houses it will be installed there.

All in all, Dr. Fathy has designed for a way of life which grows out of the traditional life of the people which he feels is an improvement over what they have had and one which can change further with the time and the need. He has kept alive a method of building developed thousands of years ago and while improving on it has preserved its simplicity.

MUD BRICKS

Mud bricks, as used in New Gourna, are a good building material in an arid climate like that of Upper Egypt. The bricks are cheap, light, and insect and fire resistant. From the appearance of the finished product, one might think the brickmaking is done rather casually but this is not the case. A great deal of planning, testing, and careful mixing has gone into the making of the bricks.

The way mud bricks were made for use in New Gourna is described in the Appendix. It must be emphasized that the proportioning of materials and even the methods of manufacture were developed in connection with the use of the particular soils available. It would be a rare coincidence if they would be suitable elsewhere without modification. The reader is referred to publications[2] on soil technology for tests and techniques to determine optimum procedures for use in other areas. Bricks for wall construction are about 9" long, $4\frac{1}{2}$" wide, and $2\frac{3}{4}$" thick. Bricks for dome and vault construction are approximately 10" long, 6" wide, and 2" thick. Dimensions are of the finished bricks after drying and shrinkage. Bricks for wall construction are generally used for arches instead of the bricks designed especially for dome and vault.

In all bricks for dome or vault construction the maker forms grooves on one face. At the time the brick is made and while still in the mold the maker with his first three fingers gouges three grooves in the top face of the bricks. These grooves are about 5 to 6 inches long and about one-fourth to one-half inch deep. They act as keys when the brick is laid and will help hold the brick in place. They may be seen as swirls on the ninth century bricks shown in Figure 2, and as diagonal traces in the modern bricks seen in Figures 11, 12, 13, and 14. In laying up mud bricks in dome or vault construction the Egyptians use a mortar made in the same combination of materials as was used to make the bricks.

[1] See: IME No. 41.

[2] IME No. 22 contains a bibliography.

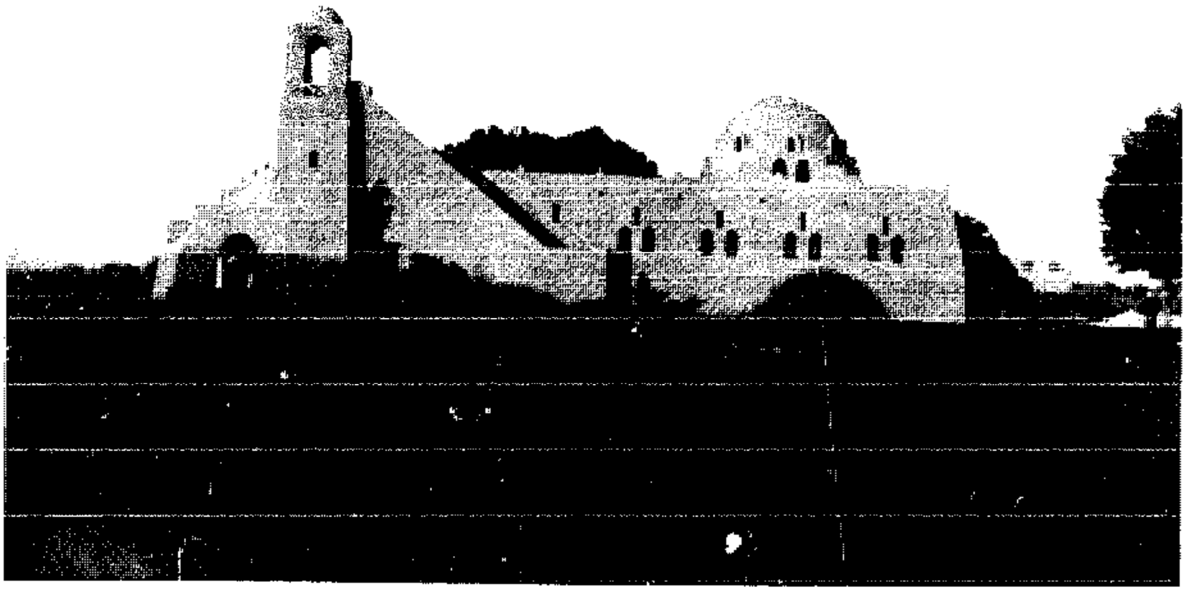
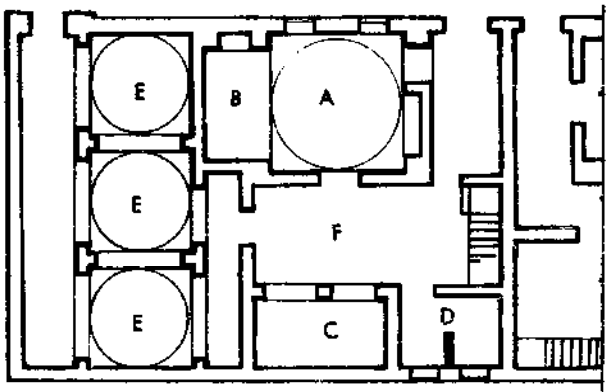


FIGURE 3. The Mosque at the Village of New Gourna, showing the main entrance and the dome. The dome is said to be the largest mud brick dome in existence.

The recent construction at New Gourna Village was completed in 1954. Additional building was scheduled to begin in December 1956. The first unit of the village contained approximately 150 one-story and two-story homes, a large market place with shops and craft works, an open air theatre, a large recreation area, an administration building and town hall, two large 12-classroom schools, a craft school and workshops, a community building, and a very fine Mosque. The Mosque has the largest known mud brick dome, about 20-feet in diameter. New Gourna Village when completed will provide housing, business, and schooling for between 5,000 and 6,000 people. It was built entirely of locally-made, sun-dried mud brick by the Government of Egypt with some financial help from abroad. Dr. Hassan Fathy, Architect and Archeologist, designed it and supervised all the construction.

In planning this community, Dr. Fathy took into consideration the psychological as well as the sociological character of the people who would live in New Gourna. He designed New Gourna to be an improvement over Old Gourna, yet he retained enough of the characteristics of the old village so that the people making the transition could accept the changes as a natural thing. He maintained a grouping of people in the new village similar to that in the old. While the streets of New Gourna which separate the five main quarters are fairly wide, the streets within each quarter are narrow and angular, though free ingress and egress have been provided for ambulances and fire-fighting equipment.

First Floor Plan



Second Floor Plan

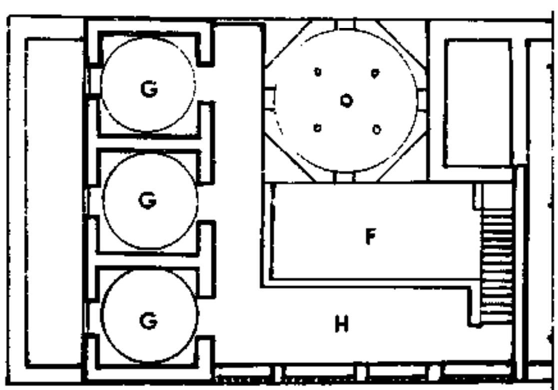


FIGURE 4. Plan of typical mud brick house-New Gourna, Egypt.

A. Main Living Room
B. Guest Bedroom
C. Family Room
D. Bath and Latrine
E. Stables
F. Reception
G. Bedrooms
H. Terrace

ROOF CONSTRUCTION IN NEW GOURNA

In Egypt as in so many places roofs framed in durable wood or concrete are expensive since imported materials must be used. Architect Hassen Fathy, therefore, selected mud brick dome and vault roof construction. He introduced some improvements in techniques but developed his plans to accommodate that system of roof construction indicated in Figure 4.

MUD BRICK VAULT CONSTRUCTION

For practical purposes, spans for mud brick vaults in Egypt are limited to from 12 to 13 feet. It is possible to go to greater spans but height then tends to become excessive for residential use.

Vault construction is really quite simple. Construction is usually started against end walls and built toward the center. In certain instances, as shown in the photograph on the cover of this publication, construction is started at one end and carried through to completion in one continuous operation. The cross sections of the vaults take the form of a hyperbola rather than a half circle as one might expect. Construction is started by applying mud plaster about one inch thick against the end wall in the desired shape. Bricks are then laid against the mortar as described below.

About one lineal yard of vault can be safely laid each day. At New Gourna drying overnight gives sufficient strength to allow additional construction each day. The masons, as a rule, work at one end of the vault one day and at the other end the next day. This method of construction of mud brick vaults without centering is shown in detail in figures 5 through 14 inclusive.

FIGURE 5. Two masons are seen applying the mud guide ring which will tie the vault to the end wall. The end wall has been built above the limits of the proposed vault and has had sufficient time to dry and reach its maximum stability. It is now ready to receive the thrust of the vault. Before Gourna Village was started the masons would make this mud ring guide by guess work and by eye. Dr. Hassan Fathy speeded up construction time by making a wood template in the shape of the under side of the vault and using this template as a guide for this mud ring. A more uniform vault was the result, plus a saving in time. In addition, at New Gourna, two masons, rather than one, work on the vault. One helper can supply material for both masons.

FIGURE 6. A mason is placing the first brick. This first brick is very important, as it sets the cant of the remaining brick courses in the vault. The mason has placed this brick almost flat against the end wall. The base which is resting on the side wall is about one inch from the end wall. The top of the brick rests against the end wall. This gives a slope to the brick courses of about 1 to 10. This brick is held in place by mud mortar and friction developed by small grooves on the back face of the brick. It has its main thrust downward which is carried by the side wall. The brick also has some horizontal thrust which is taken by the end wall.

FIGURE 7. The mason is placing the second brick and also the second brick course. Since the mason used a whole brick on the first course, he used a half brick to start the second in order to stagger the joints between brick courses. As a general rule, the mason will alternate starting courses with whole and half bricks.

FIGURE 8. The mason is placing the second and last brick in the second course. While this photo only shows one side the mason is doing the same thing on the other side of the vault.

FIGURE 9. The mason is tapping the third and final brick in the third course. The cant of the vault is now beginning to be noticeable.

FIGURE 10. The mason is applying the mud mortar for the next course. Some masons have trowels, but most of the masons in upper Egypt use their hands as trowels.

FIGURE 11. The fourth brick course has been completed. Also in this photo the grooves can be seen, especially in the top brick.

FIGURE 12. The mason is placing the last brick in the fifth course. The cant of the courses is now well established.

FIGURE 13. The vault is starting to take form. The courses have now met and are continuous from side wall to side wall. The mason is shown tapping into place a stone in the soft mud mortar between the bricks. Because the bricks are rectangular in shape and are being placed to form a curve with inner edges touching, the outer edges are separated by a wedge shaped gap. Mud mortar has filled this gap and the mason is tapping a small stone into place at the outer edge. With the insertion of this small stone, the downward thrust is divided equally between interior and exterior edges of the brick. The grooves are also very noticeable in this photo. A two colored angular shapped guide has been placed in this photo to indicate the slope at a point half way between the top and the bottom of the vault.

FIGURE 14. This shows different stages of vault construction over three adjoining rooms. The small square block at the center of each vault, located on the end wall, is a guide for the masons in keeping the center of the vault in line and level. A trowel is seen in use but actually the mason only uses it to stir up the mud mortar.

MUD BRICK DOME CONSTRUCTION

The first dome roofs built in Egypt were constructed over circular shaped rooms. The domes were much higher than those built today. They were built in the form of a hyperbola similar to the cross sectional shape of the early vaults. They are called "Beehive" domes. In some of the early domes the height exceeded the width several times. In the modern adaptation the designers have lowered the height of the dome.

Apparently, dome construction was limited to circular shaped rooms for many years. It is the opinion of Dr. Hassan Fathy that the first change occurred when a builder built an octagonal shaped room with walls thick enough to provide a base upon which the circular dome would rest. Later devices were developed to permit dome construction over square rooms.

HIGH DOMES

In modern high dome design, the dome or half sphere whose inside diameter is the interior width of the room rests on the room walls at their center point or on a vertical ring beam which in turn rests on the room walls at their center point. Since the dome or ring beam is supported directly only at the mid points of the four walls, the remaining portion of either the dome or ring beam must be carried at other points by means of pendentives--triangular pieces of vaulting which spring from the corners of a rectangular plan and serve to allow the room enclosing it to be covered by a rounded plane or a dome.

FIGURE 15. The mason is just beginning the construction of the vaulting in the corner of a room. The guide stick to insure that each course is circular is in use. In the foreground may be seen the vaulting, the pendentives, completed. A hemispherical dome will complete the roof structure.

LOW DOMES

In low dome design, the interior radius of the dome is one-half of the interior diagonal distance of the room. The dome starts out as four pendentives which gradually merge into a complete dome. In this design, generally, where an opening is located in the center of a room wall the height of the wall above the opening which must allow sufficient bridging of the span, determines the minimum height for a low dome. Pendentives springing from each corner will meet at the height of this minimum at the center of each wall of the room as may be seen in Figures 15 and 16.

CONSTRUCTION OF THE PENDENTIVES

In actual construction, the mason will build the four walls of the room, usually of two and one-half bricks thick (22 inches), up to the point where the pendentives begin. Wall construction continues beyond this point in an arched form as may be seen in the room in the background of Figure 15. On top of this construction on each of the four walls a course of bricks is laid flat as a starting point for the pendentives. This semicircular course may also be seen in Figures 15 and 16.

The mason then begins to build the pendentives in each corner as shown in the background of Figure 15 until he has completed them, Figure 16. As he builds them he continues the construction of the exterior corner of the wall behind them, filling in the increasing space between the corner and the face of the pendentive with rubble masonry. The

FIGURE 16. Low dome construction in mud brick without centering. The minimum height of the house is established by the supporting structure above the opening. The triangular vaulting in each corner carries the dome.

pendentive is laid only one brick thick with the end of the brick exposed to the room.

In building the pendentives, the mason uses a guide stick to help him establish the spherical shape. As he progresses in laying each course, he works toward the center of the pendentive finishing with a wedge shaped brick in the center, up to courses involving ten bricks each. Later he inserts the wedge shapes at intervals of six or seven bricks in each course. The wedge shapes never quite "catch up" so that a brick never is quite parallel to the long axis of the guide stick. Therefore, each brick in the pendentive and later in the dome proper is supported in two directions. Its vertical bearing is on the previously laid course. Horizontally, it is resting against previously laid bricks in the same course or against the edge in the case of the first hard brick in each course. The grooves in the face of the brick act as keys to assist in keeping the brick in place without the use of centering.

The slope from horizontal begins with the first course laid in the pendentive and is slightly over 10 degrees. The last course in the pendentive, illustrated in Figure 16, is inclined about 25 degrees from the horizontal. The last course in the top of the dome will be inclined about 75 degrees, the maximum possible.

Up to the completion of the pendentives, construction is similar for a low dome, a high dome, or a high dome on a vertical ring beam. The ring beam may or may not be pierced. Figure 17 shows a low dome in the foreground and a high dome with a ring beam behind it.

FIGURE 17. The roof of a house at New Gourna. A low dome may be seen in the foreground. A high dome is behind it.

LOW DOME CONSTRUCTION

In low dome construction, the remaining portion of the roof is a segment of half a sphere, the pivot point for the guide stick being in the center of the room at the level of the bottom of the pendentives in the corners. The length of the guide stick is one-half of the diagonal distance from corner to corner of the room.

Some masons will start the dome construction and will spiral the brick courses while others will complete each course and start another course and so on until the dome is completed. In either method the mason will lay the brick close against the previously laid brick for about 6 to 8 bricks then will insert a wedge-shaped brick which will have its exposed side nearly parallel to the long axis of the guide stick in a manner previously described for the construction of the pendentives. No brick is actually placed parallel to the axis of the guide stick. All bricks are sloped both horizontally and vertically, the horizontal slope veering from almost parallel at the wedge shaped brick to a maximum after about 6 to 8 bricks, where the wedge shaped brick brings the horizontal slope back to almost parallel again. This horizontal slope is increased slightly as construction nears completion of the dome.

The low dome is considered especially suitable for two-story construction or where, by filling in above the domes, a flat roof is to be obtained.

HIGH DOME CONSTRUCTION

Techniques used in laying the brick in high dome construction are similar to those described just above. The high dome is built either on top of the completed pendentives as shown in Figure 16 or on top of a ring wall which rests upon the pendentives. The high dome is one-half of a sphere. It is formed by using a guide stick pivoted in the center of the room on a level with the top of completed pendentives or the guide ring as the case may be. The radius is one-half of the horizontal diameter of the base upon which the high dome rests. The first, or lower, course of brick in the construction of the high dome is inclined from the horizontal about 15 degrees with the high end of the brick on the outside. The inclination from the horizontal, as in the case of the low dome, never exceeds 75 degrees at the top of the dome.

In designing New Gourna Dr. Fathy used both the high and low domes seen in Figures 15, 16, and 17. Further examples may be seen in Figure 18, a reproduction of a photograph taken from a point above the roofs of the Administration Building and the Theater. As a general rule, the high dome type of construction is favored in one-story buildings, or where a maximum of light is needed.

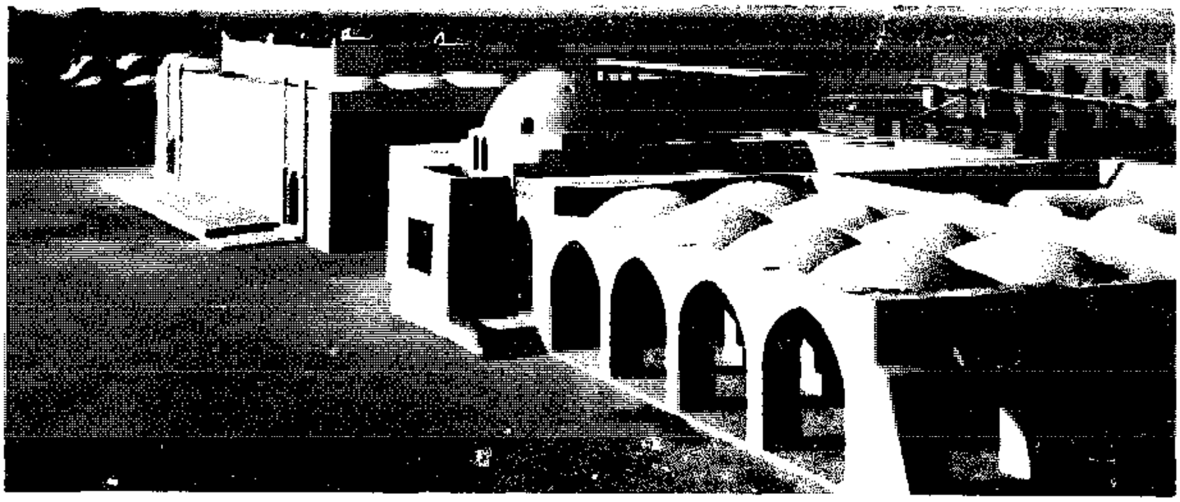


FIGURE 18. The Administration Building at New Gourna shows both the low and high dome types of construction. To the left and in the rear of the Administration Building is the Theater. In the right background are residences under construction.

THE VAULT AND DOME COMBINED

Interesting treatments for rectangular rooms may be obtained by combining the vault and the dome. At times the rooms may be finished with one semi-circular end, if a dome is to be used above it. However, the end could be square with pendentives in the two corners below the half-dome.

Construction procedures for a combined vault and dome roof are similar to those described previously. The vault is built first, starting from the end opposite the location of the dome. After the construction of the vault is completed, the half-dome is built. Rather than being a segment of a sphere, a cross section of the dome becomes a hyperbola to meet the already completed vault. Each separate horizontal brick course in the dome remains in semi-circular form. The guide stick, pivoted as usual, must be extensible to adapt itself to the hyperbolic cross section of the dome.

CONCLUSION

The approach which Dr. Hassan Fathy took in the general design of New Gourna, his extended use of earth throughout the structures, and his incorporation of vaults and domes into the roof construction all represent a method to improve village construction under one particular set of conditions using local materials and, in this case, almost forgotten techniques. As such, the story of New Gourna may provide inspiration to others faced with the same basic problem even though local conditions, materials, and problems may be entirely different from those Dr. Fathy confronted.

APPENDIX-methods of making mud brick roofs

The description of the methods of making mud bricks in Egypt, with particular reference to those made for use in New Gourna, results from observations on the site.

The proportioning of the materials and even the methods of manufacture were developed for use with the available soils. It would be a rare coincidence if they would be suitable elsewhere without modification. The reader is referred to publications[1] on soil technology for tests and techniques to determine optimum procedures for use in other areas.

In Egypt sun dried mud bricks are prepared from clay soil, sand, and straw. Almost any soil with a clay content is useable for brick making in Upper Egypt. The firmest bricks are made from soil with the highest clay content in that area. White calciferous sand is the best material for brick making, but almost any sand will do. However, the sand from the desert is so worn and round that a much higher clay content is needed in the soil to make a good brick. At times sandy loam or river silt is used for brick making.

Regardless of what material is available it first must be tested for brick making qualities. The proper percentage of materials must be determined. In Egypt fresh straw, dry weed brush, cotton stalks, and sometimes cane husks are used for the binder.

In preparing the material for brick-making, the introduction of the proper percentage of each of the ingredients is important. Tests should be made in advance to determine the proper proportions.

In Upper Egypt, a generally satisfactory mixture for hand-made bricks contains one cubic meter of good clay soil, 1/3 cubic meter of white calciferous sand, and about 45 pounds of fresh straw chaff. This amount will make about 660 bricks.

For making bricks, a pit is dug about $\frac{1}{2}$ meter deep, 2 meters wide, and from 3 to 4 meters long. The materials are dumped into this pit and mixed by hand until they are blended into an homogeneous mass. Water is then added and after the mixture has absorbed all the water it is allowed to "cure" as in the process of slaking lime. When the mixture is sufficiently "cured" and is in a plastic state indicating less than 10 percent slump by test, the mud is ready to be made into bricks. Generally, only one day's supply is mixed at a time. This can be estimated fairly accurately since, in Egypt, a brickmaker will make from 600 to 700 bricks a day.

[1] IME No. 22 contains bibliography.

The mould for forming mud bricks is a four-sided "box" with no bottom or top. Before each brick is molded, the mould is immersed in water and covered with dry sand. When the mould is lifted, a small amount of sand adheres to the wet walls. The mould is then filled by throwing mud into the mould and striking off the top excess with the hand or a stick.

After bricks are taken out of the moulds, they must be cured in the sun for at least two weeks. During the curing period, they are turned over every other day to allow proper drying. The first few days, the bricks are dampened by sprinkling.

Shrinkage in hand-made bricks can be as much as 37 percent. Moulds for the bricks must be made in such a way as to allow for this shrinkage. The amount of shrinkage depends largely upon the character of the ingredients used.