A DISCUSSION OF SEVERAL DESIGNS FOR THE LARGE SCALE PRODUCTION OF LOW-COST ROOFING IN SMALL HOUSES

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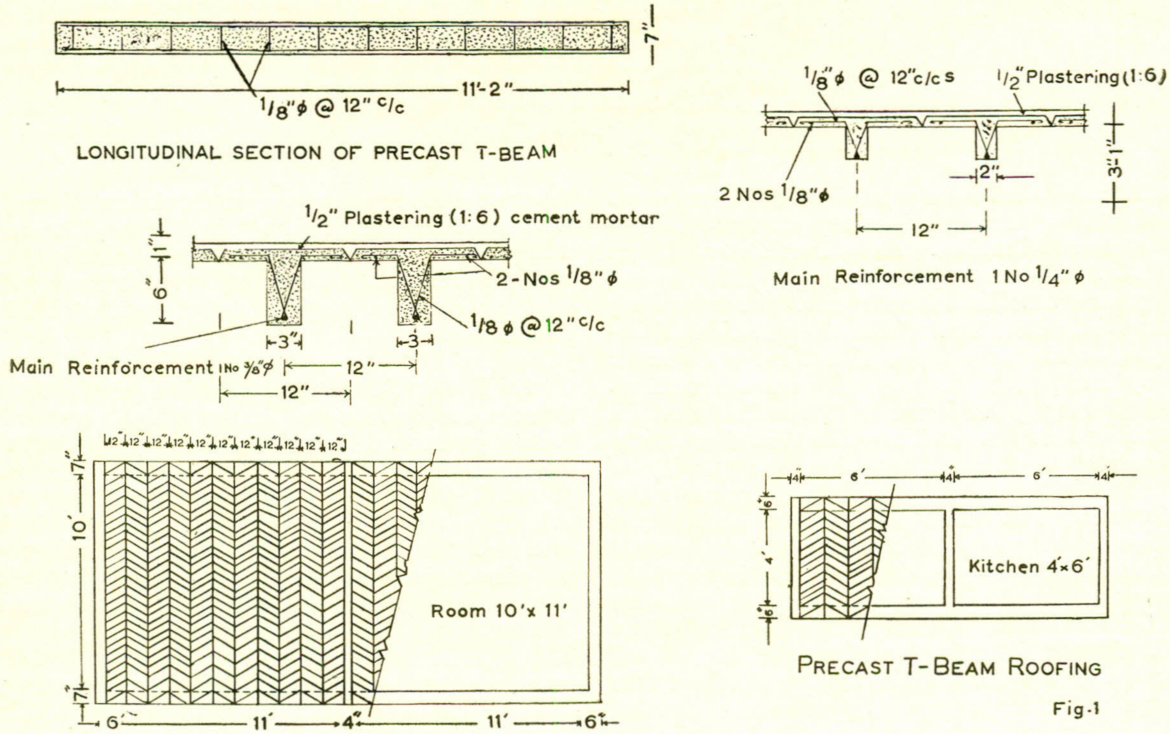
The large scale construction of low-cost houses is of vital significance especially with reference to refugee rehabilitation. Experiments carried out by Mr. Middleton (housing expert) in the use of cement stabilised blocks have not been very successful, since, apart from the question of strength, it has been found that these walls scour away easily and develop pits on the surface. This is largely attributable to the fact that the conditions in Karachi are different from those elsewhere as the concentration and quality of alumina in the local soil does not appear to be adequate. The walls of quarters constructed with soil cement blocks are now being plastered with in order to prevent this scouring, which, however, means that there is very little economy in the total cost. Although this does not mean that further investigations into the use of soil cement blocks have been finally dropped, the best alternative, at present, appears to be the use of bajri (gravel) concrete, but with a little less cement in order to effect economy. At present cement and bajri are used in the ratio of 1:9, but a number of private houses have been constructed (many of them two storeyed) with a mix as lean as 1:18 to 1:15. However, for a quick rate of construction, it would not be desirable to use a mix leaner than 1:12.

An analysis of the costs of previous constructions shows that the expenditure on the construction of walls of the refugee quarters in the Malir and Landhi colonies of Karachi is about 35% of the total cost. Some saving can indeed be made in this cost by using a leaner mix, as suggested above, without affecting the durability of the walls and the strength would be upto the specification. However the most important item on which economies are required and can be effected is the roofing which accounts for nearly half the total cost of construction. The present system of constructing the houses with R.C.C slabs is time-consuming and requires a heavy use of centring, cement and steel. The time required for fixing the shuttering and laying the slabs, and the period of curing and removal of shuttering makes it difficult to use the same shuttering more than 2 or 3 times a month. This greatly cuts down the speed of construction and at the same time increases the cost of the work. Attempts have therefore been made to design and test several types of roofing that can cut down the cost and expedite the construction of small houses. Five such designs are discussed below, and Table 1 gives a comparative statement of materials required for the important items in the construction of a single room of 10'x11' inside dimensions.

1. *Precast T-Beams Slab*.—This type of roofing reduces the quantity of concrete from approximately 50 cu.ft. required for one room (10' x 11' inside) and one kitchen (4'x6' inside) to about 30 cu. ft. and that of steel from 1.7 cwt. to approximately 0.7 cwt. per refugee quarter. It is seen that this proposal will reduce not only the use of materials which are in short supply but will also cut down the time required for the construction as the problem of shuttering will be obviated. This type of roofing (Fig.1) is similar to R.C.C. precast battens and unreinforced tiles for roofing. Some of the quarters constructed in the Baldia Colony of Karachi have incorporated this type of construction. The disadvantages of this type of work are that a proper water proofing layer has to be provided on top, and that the ceiling surface at the bottom is somewhat unsightly. Experiments were also carried out using only one bar of 3/8" in the T precast for the main room spanning 10' clear. This type further reduces the quantity of steel required from 0.7 cwt. to 0.5 cwt. including wastage, but the handling becomes more difficult and even slight negligence of the labour in handling causes breakage of the flanges. After joining these Ts as shown in Fig. 1, this roofing gave a satisfactory result on a load test of 30 lbs. per sq. ft.

2. *Hollow Clay Block Slab*.—One of the disadvantages of the precast T-beam roofing, namely the ugly appearance of the ceiling, can be obviated by placing hollow tiles (Fig. 2) in the gaps created by T-beams placed at intervals. This is a ribbed slab construction with hollow clay blocks between the ribs instead of a solid slab, and is equivalent to providing a highly heat insulating false ceiling. It can be adopted for the middle and better classes of accommodations. Generally, the tiles are held in position by supports and the roofs are laid in situ. This type of work increases the cost of the slab as compared with the previous method, because shuttering and blocks are required. The second disadvantage of the precast roofing, *i.e.* leakage, is also



PRECAST T-BEAM ROOFING

Fig-1

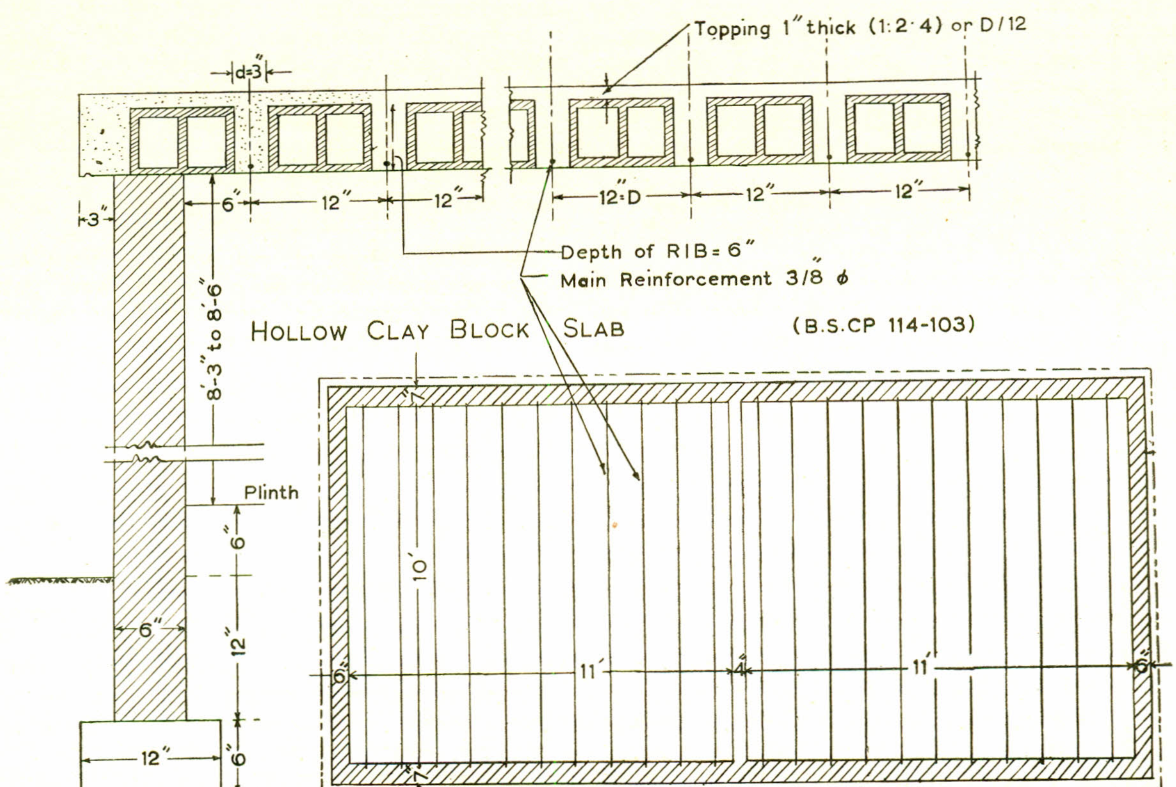


FIG-2

TABLE 1

Design	Type of roofing	Concrete (1:2:4) cu. ft.	Mild steel As per drawing lbs.	Mild steel i/c 10% washing lbs.	Centring sq. ft.	Block masonry in (1:9) cement concrete block cu. ft.	Cost Rs.	Remarks
	Standard R.C.C. slab	40	155	170	110	190	600	Quarters under construction at Malir, Landhi, & Drigh Village have been provided with solid R.C.C. slab.
I	Precast T-beams	26	68	75	nil	170	460	Moulds for precasting will be required.
II	Hollow clay blocks	26	46	51	50	170	500	The clay or hollow concrete blocks are required. No temperature reinforcement has been provided (Fig. 2).
III	(A) Cast-in-situ	26	78	86	110	170	480	If temperature reinforcement is not provided, the steel required will be same as in II.
	(B) Cast-in-situ	22	80	88	110	170	470	IIIA is better as the centring is easier than III B.
V	Vault plain concrete	40	nil	nil	110	193	520	No reinforcement has been provided.

Note.—Estimates of design IV have been omitted because of its limited applications in West Pakistan.

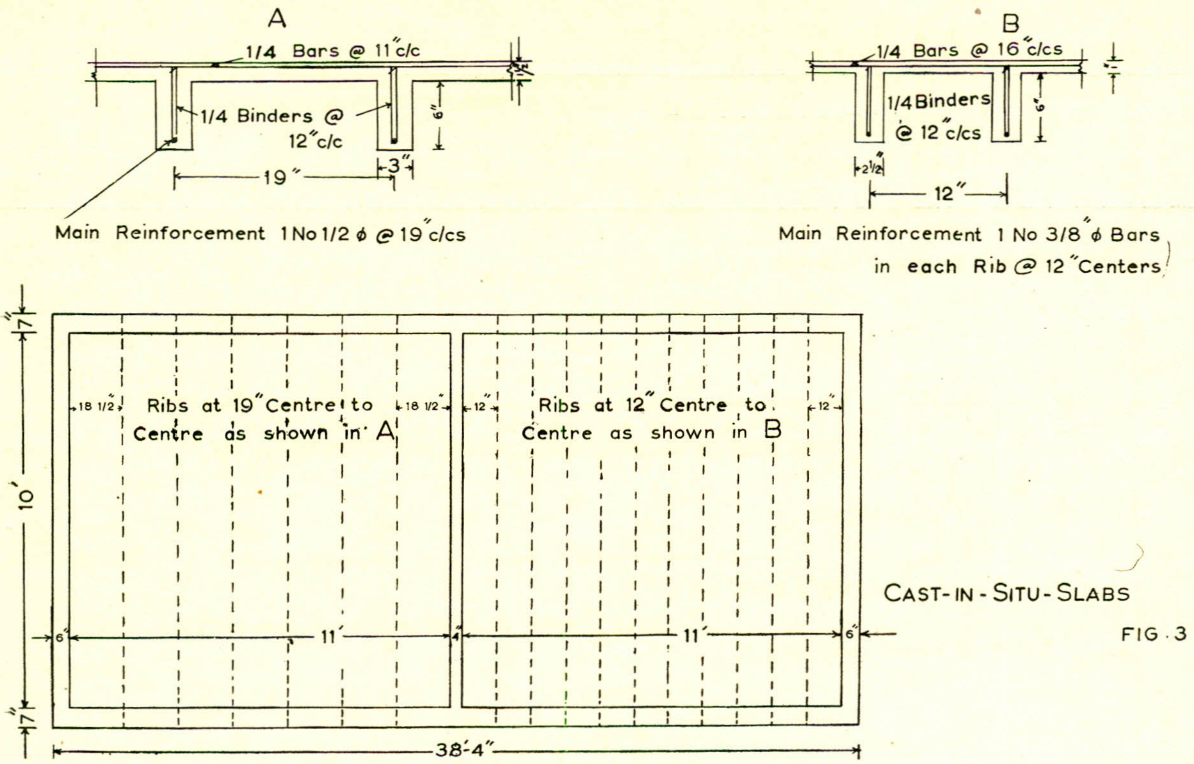
avoided as the slab is cast in situ. Hollow concrete blocks may also be used in place of clay blocks.

3. *Cast-in-Situ Slab.*—Hollow clay tiles are not readily available in quantities in Karachi, and in any case they add to the cost of construction. Therefore, it would be advantageous to lay the slab in situ without these blocks in houses constructed for refugees. The centring now becomes a bit expensive, but there is still an overall saving. A temperature reinforcement has also been provided in the slab portion (Fig. 3) to avoid cracks or leaking during the rainy season. If steel is available in the required quantity, this method will be the cheapest and the best as it avoids leakage.

4. *Precast Beams and Tiles with a Mud Topping.*-A United Nations expert, Dr. O.H. Koenigsberger, who recently visited Pakistan suggested that, for houses built in West Pakistan, a 4″ earth topping is desirable to keep them cool in summer and warm in winter.

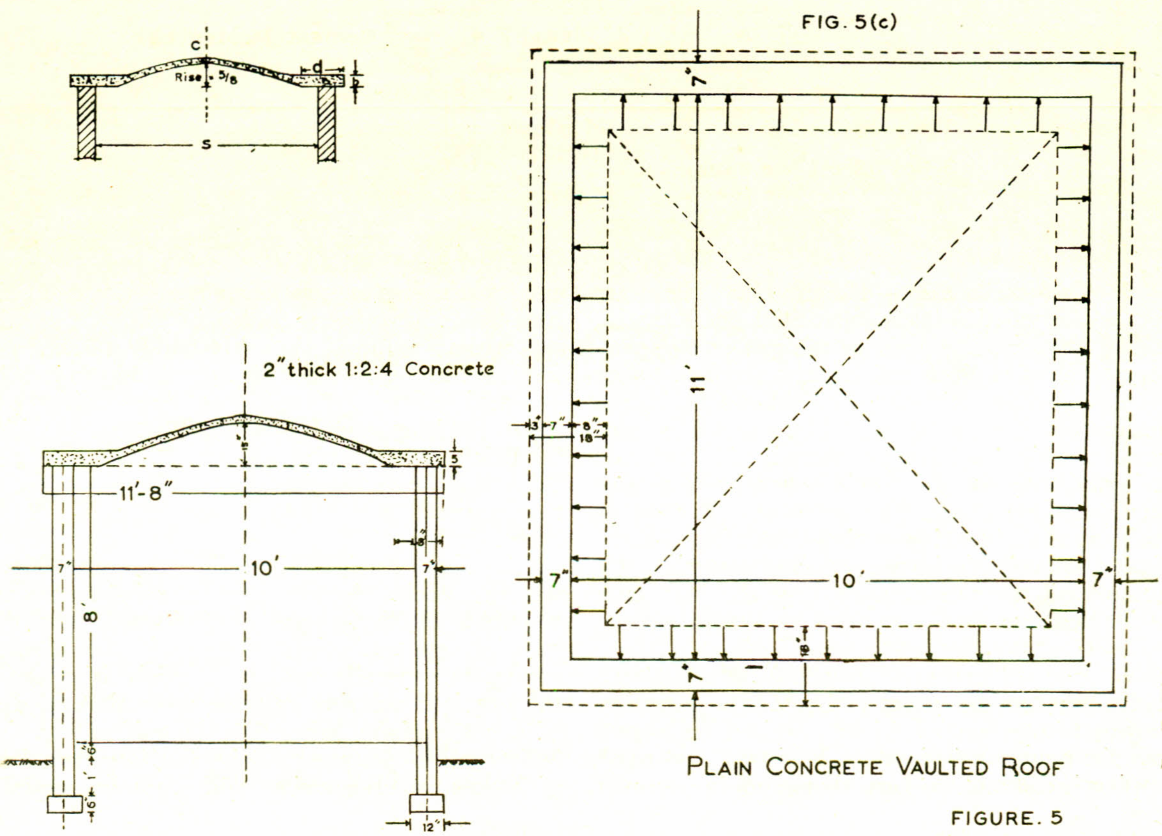
Different types of sections have been tried with 4″ mud mixed with 'bhusa' and 'gobri' mud plastering on top. Sketches of the two suitable types have been shown in Fig. 4, but the quantities required in this method are not included in Table 1 as it is not recommended for Karachi. The superstructure, according to West Pakistan conditions, shall be in 9″ thick B. Brick masonry for outer walls and 4 1/2″ thick B.B. masonry for inner walls in a set of two rooms.

5. *Vault Roof.*—This design shown in Fig. 5 has the special feature that no reinforcement is required. It is generally considered that this type involves costly shuttering, but if the "dhola" system as generally used in Punjab is adopted the required centring costs no more than in case of a conventional type of roofing if only a few houses are to be constructed. For large numbers of houses, steel centring will also be equally



CAST-IN-SITU-SLABS

FIG. 3



PLAIN CONCRETE VAULTED ROOF

FIGURE. 5

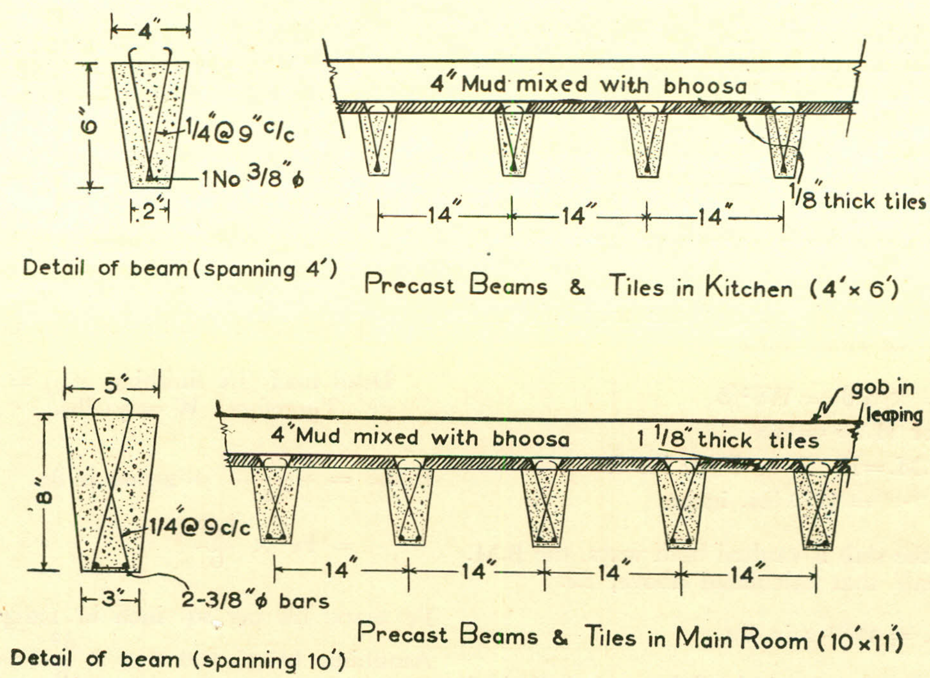


FIG. 4.a

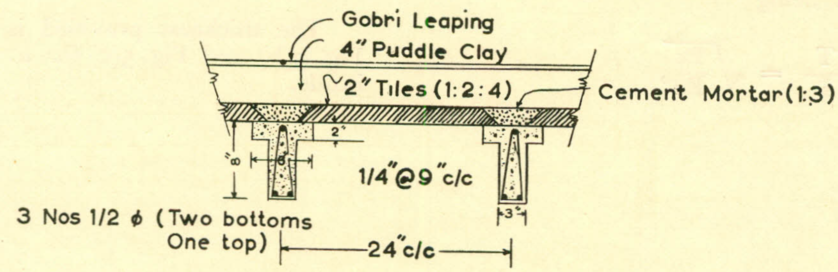


FIG.4.b

FIG 4

PRECAST ROOFING FOR WEST PAKISTAN

economical.

Mr. Chandulal C. Dangoria, Divisional Engineer, Hyderabad Improvement Board, is probably the first engineer to introduce plain cement concrete vaulted roofs to replace costly methods of construction such as R.C.C. solid slab. Later on, it was pointed out by Mr. R.G. Gokhale, Assistant Executive Engineer, C.P. W.D., that Mr. Dangoria has made some incorect assumptions in designing the vaulted roof and that this type of roofing would be unsafe and uneconomical. The following analysis however is found to lead to a workable design for a vault roof, taking our conditions into consideration, which are:

(1) Refugee quarters are to be designed for single storey.

(2) The superimposed load can be assumed to be 20 lbs. per sq. ft. as the roofs are inaccessible.

As the quarters are to be single storeyed, a 15" rise at centre has been adopted, which is not only required for reducing the thrust, but also increases, the headway. Therefore, in this type of roofing 8' high walls (above the plinth level) will give a better appearance and greater comfort than 8′-3″ high walls in case of the refugee houses constructed with solid R.C.C. slabs.

Let A and B be a rigid frame and C an arch inside frames (Fig. 5a). Let S be the span and S/8 the rise, W be the load per sq. ft., and H.T. be the horizontal thrust and B.M. the bending moment.

(*i*) If the slab is vaulted one way only and is rigid at the ends, then

$$\text{H.T.} \times S/8 = WS^2/8$$

$$\text{or H.T.} = WS$$

$$\text{and B.M.} = \text{H. T.} \times S^2/12 \text{ lbs ft.}$$

$$= WS^3 \text{ lbs. inches}$$

(*ii*) If the slab is vaulted both ways, the B.M. will be half that calculated above, *i.e.*

$$\text{B.M.} = WS^3/2 \text{ in lbs.}$$

Thickness of arch width of the vault is limited by the modulus of elasticity of plain cement concrete, as in case of pipes under external pressure, the formula being

$$\frac{T}{S} = \sqrt{\frac{Fc}{Ec}},$$

T = Thickness of arch at crown, S=span of arch, Fc=Safe compressure stress of concrete 600 lbs. per sq. inch, Ec=20,00,000 lbs. per sq. inch.

$$\text{Thus } \frac{T}{S} = \sqrt{\frac{600}{2 \times 10^6}} = \frac{1}{56}, \text{ or say } \frac{1}{60}$$

Therefore, a 2″ thickness is adopted in the present case.

Superimposed load = 20 lbs. per sq. ft.

Dead load (i/c finishing etc.) = 30 lbs.
Therefore W = 50 lbs.

$$\text{B.M.} = \frac{50 \times 10^3}{2} = 25000 \text{ in lbs.}$$

$$= Fc \times \frac{bd^2}{6}$$

Fc = 100 lbs per sq. inch in 1:2:4 concrete

$$\text{Assuming } b = 5'', \ 100 \times 5 \times \frac{d^2}{6} = 25000$$

$$\therefore \quad d^2 = 300$$

$$\text{or} \quad d = 17{\cdot}3''$$

The thickness provided is 18″ as shown in Fig. 5(b) and Fig. 5(c) for a room of 10′ × 11′ inside.