ROOF SLABS IN LOW COST HOUSES

Part I.—Plain Concrete Vault Roofs

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The construction and testing of plain concrete slabs have been described. Two types of vault roofs with uniform and varying arch thickness were laid on rooms (10′–3″ × 11′–7″ inside dimensions) and tested under a uniformly varying superimposed load of sand bags. The low deflection under a high test load indicates the suitability of the design for single storey-houses.

Introduction

In an earlier communication,[1] the design and construction of vault roofs were briefly discussed. Without any re-inforcement, this construction needs the same amount of cement concerte as in the conventional reinforced cement concerte slabs. The mild steel used as reinforcing material is an imported item at present. Because of its shape, there is no possibility of water accumulating on a vaulted roof, and therefore, no water-proofing is required. Water-proofing felt is not only expensive but needs replacement, as its life is generally limited to a period of 5 to 10 years.

Natural ventilation, another very important factor in tropical climates, largely depends on wind force and temperature difference (stack effect). The stack effect in a room is directly proportional to the square root of the difference in the height of outlet and inlet openings. The increased ceiling height can only improve ventilation if the inlet and outlet openings are respectively at floor and ceiling levels. The vault roof is thus advantageous as the rate of air flow can be considerably increased by providing a ventilation shaft (Fig. 1) on the top of the roof. The stack effect can be increased without increasing the height of the walls and taking the ventilators to the ceiling height. The additoinal comfort can, therefore, be obtained without any increase in expenditure.

Design and Construction

Previously a vault roof with a uniform arch thickness of 2″ was designed for a clear span of 10 ft. with a rise of 15 inches at the centre, and the size of the end frames was calculated at 5″ × 18″. The same design was adopted for the roof with two curved surfaces covering two adjacent rooms measuring 11′–7″ × 10′–3″ each. The curved portion of the roof over each room measured 10′–3″ × 8′–11″ as shown in Fig. 1.

The roof was designed as a circular dome and the vault was composed of several circular segments. As the rise at the centre of each room was constant at 15″, the radius of curvature for each segment varied with the length of the chord. Full-size circular curves were marked on a cement concrete platform and mild steel bars were bent and welded to form the shape of the lower surface of the roof (cf. Fig. 3). Ordinary centring with rough wooden planks was erected and the steel bar frame was placed on it. Earth was filled in between the centring and the frame and levelled to the exact shape of steel bar frame. The mild steel frame was removed for re-use. The earth form of the centring was coated with a weak cement plaster of (1:20) Dalmia cement and Malir sand to prevent the contact of cement concrete of the roof with earth. Similar centring was used for the roof with varying arch thickness (cf. Fig. 2). For large scale production, steel sheet centring should prove economical.

Water was sprinkled on the centring described above and the roof on the two experimental rooms was laid in a mix composed of Dalmia cement, Malir sand and double-screened coarse aggregate from the Malir river-bed in the ratio of 1:2:4 by volume. The water-cement ratio (which was inclusive of the water absorbed by the dry aggregate) was kept at 0.7. This ratio gives the best flexural strength in the above mix in the absence of mechanical compaction of the concrete. The work on the flexural and other strengths of cement concrete with varying water-cement ratios will be reported separately. The curing of the concrete was done in the usual way and the centring was removed after 14 days. The roof was then plastered with ½″ thick (1:6) cement mortar (Dalmia cement and Malir sand). Cemto, a water-proofing agent developed at our labora-

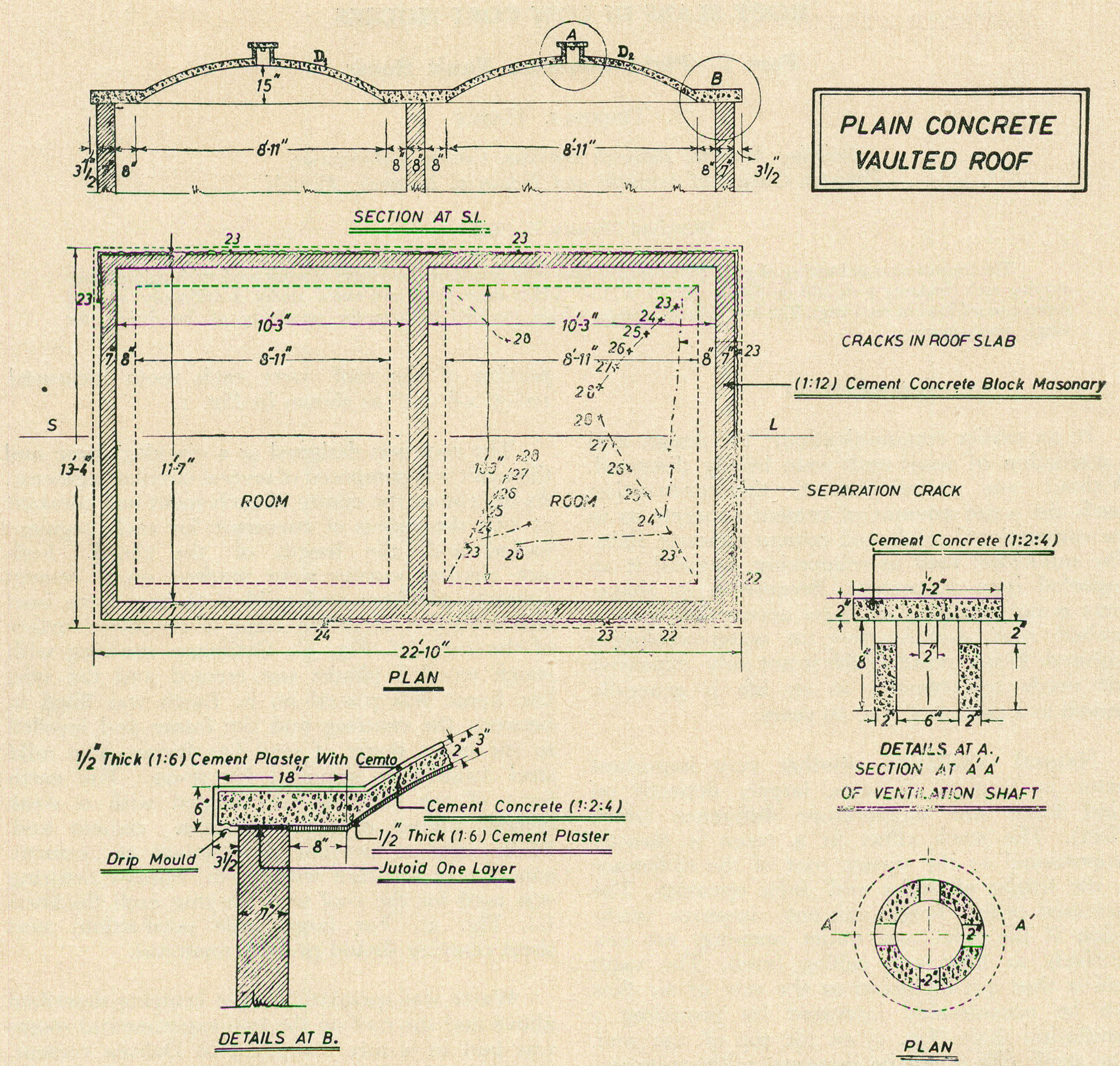

Fig. 1.—The construction and testing details of the experimental rooms with vault roof of uniform arch thickness. Test load: 210 lbs./sq. ft. on the curved surface of the roof.

tories, though not essential in a vault roof, was also added at the rate of 3% by weight of the cement in the exterior plaster. The precast ventilation shaft can be placed in position before pouring the concrete in the roof slab. It was not provided in the experimental roof, because it would have been an obstruction while proving to be a source of superimposed load.

Another roof was laid (cf. Fig. 2) using the above specifications of the cement concrete and plaster. The thickness of the arch was $1\frac{1}{2}''$ at centre and $4\frac{1}{2}''$ at ends. The size of the frame was reduced to $4\frac{1}{2}'' \times 10''$ and the same rise of 15″ was given at centre of the room (10′–3″ × 11′–7″ inside dimensions.) The average dry compressive strength of the concrete used in the roof was measured as 1178 lbs. per sq. inch after 7 days in the laboratory.

Testing Under Uniformly Distributed Load

Fifty-six days after pouring the roof slab with uniform arch thickness (Fig. 1) was loaded on

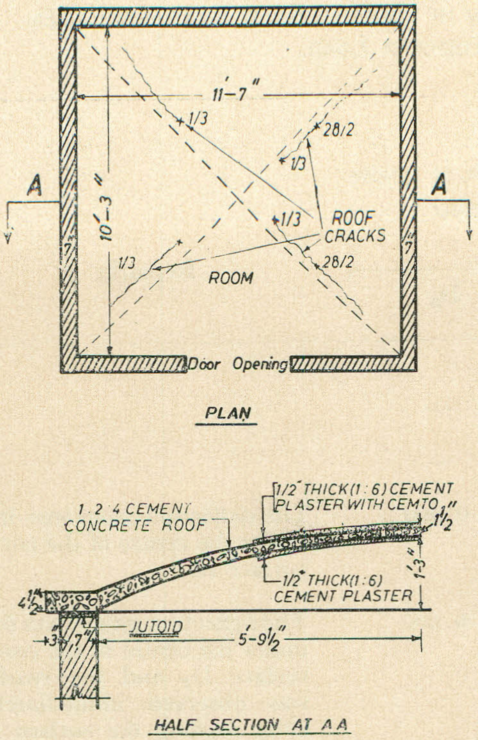

Fig. 2.—The construction and testing details of a room with vault roof of varying arch thickness. Test load: 270 lbs./sq. ft. on the curved surface of the roof.

29th August, 1960 with sand bags on the curved portions (cf. Fig 4). This superimposed load was gradually increased and deflection recorded (Table 1) under the roof at the centres of the curved portions D_1 and D_2. The separation crack between wall and slab appeared on 22nd September, 1960 on the exterior side at a superimposed load of 180 lbs. per sq. ft. This extended in length on 23rd and 24th September. The first crack in the slab (ceiling side) appeared on 23rd September at a superimposed load of 210 lbs. per sq. ft. Further loading on the curved surface D_2 was discontinued and the position of the extended cracks observed (Fig. 1). The superimposed load of 210 lbs. per sq. ft. remained on the curved surface D_2 for about 6 days. The rate of deflection rapidly increased from 0.0018" in the first 24 hours to 0.0750" in the last 24 hours. The deflection reading under the surface D_1 became constant as the concrete in the roof portion D_2 approached the failure stage, otherwise it was constantly decreasing under the increased load on surface D_2 of the roof. Final recorded deflection under the centre of D_2 portion was 0.1765" on 28th September at 10.00 a.m. and after 3 hours, the same day, D_2 portion of the slab fell with the side walls. The middle 8" thick wall was also affected due to the thrust at failure, but the D_1 portion of the slab is still in position without any cracks.

The roof with varying arch thickness (Fig. 2) was also loaded with sand bags on 27th February, 1961 after 3 months of its laying. The superimposed load was gradually increased during 4 hours till it reached 165 lbs. per sq. ft. At a load of 120 lbs. per sq. ft. on the curved surface of the roof, separation cracks between walls and roof slab appeared on the exterior side. These became quite prominent at 135 lbs. per sq. ft. and were visible right round under the projection of the slab. Separation cracks in the angular interior corners also appeared at 135 lbs. per sq. ft. The next day the loading was increased from 165 lbs. to 270 lbs. per sq. ft. Cracks appeared in the roof slab on the same day at the final superimposed load of 270 lbs. per sq. ft. and further loading was stopped. These cracks extended in length (Fig. 2) and the roof fell on 1st March, 1962 at 6-30 p.m. together with all the four walls of the room. The total load taken by this roof was

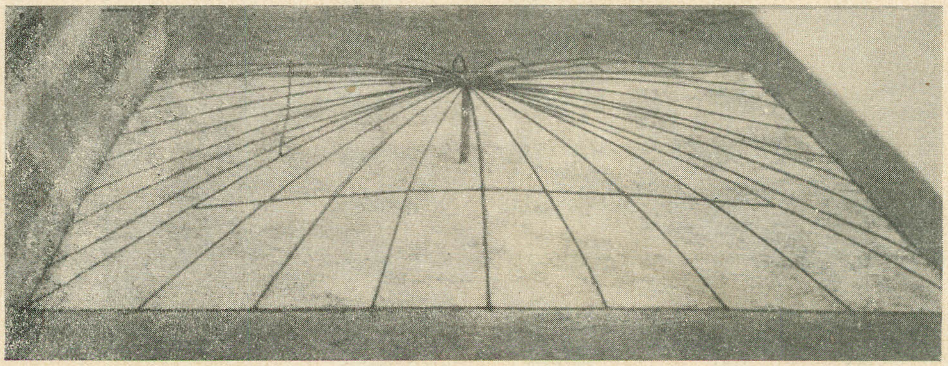

Fig. 3.—Welded mild steel bar frame for forming the centring of the vault roof.

Table 1.—Deflection Testing of the Designed Roof of Uniform Arch Thickness Under Unifromly Varying Superimposed Load.

Date	Total superimposed load in lbs. per sq. ft. on the curved surface of the roof		Deflection in inches at centre of the curved surface		Remarks
	D_1	D_2	D_1	D_2	
29-8-1960	30	—	—	—	
1-9-1960	60	—	—	—	
3-9-1960	60	—	0.0000	0.000	The deflection gauge was fixed under the centre of the curved surface D_1.
3-9-1960	60	30	0.0000	0.000	The deflection gauge was fixed under the centre of the curved surface D_2 and the reading was observed immediately after loading the surface D_2.
6-9-1960	90	30	0.0850	0.0010	The reading in the gauge under the surface D_1 was adjusted immediately after the load was increased on the surface as the deflection gauge was disturbed.
7-9-1960	90	30	0.0800	0.0010	
8-9-1960	90	30	0.0760	0.0010	
9-9-1960	90	60	0.0720	0.0147	
10-9-1960	90	60	0.0680	0.0157	
11-9-1960	90	60	0.0640	0.0157	
12-9-1960	90	90	0.0620	0.0237	
13-9-1960	90	90	0.0600	0.0245	
14-9-1960	90	90	0.0490	0.0245	
15-9-1960	90	90	0.0490	0.0245	
16-9-1960	60	120	0.0450	0.0255	
17-9-1960	30	150	.00450	0.0280	
19-9-1960	30	150	0.0350	0.0324	

20-9-1960	—	180	0.0350	0.0338	
21-9-1960	—	180	0.0250	0.0350	
22-9-1960	—	210	0.0230	0.0397	The separation cracks between walls and roof slab appeared at a superimposed load of 180 lbs. sq. ft. (Fig. 1) on 22-9-1960.
23-9-1960	—	210	0.0230	0.0415	The cracks in the slab of the roof appeared at corners at a load of 210 lbs. sq. ft. (Fig. 1) on 23-9-1960.
24-9-1960	—	210	0.0160	0.0445	
25-9-1960	—	210	0.0130	0.0505	
26-9-1960	—	210	0.0130	0.0575	The vertical crack in the wall appeared at about 7″ bleow the roof level.
27-9-1960	—	210	0.0130	0.1015	
28-9-1960	—	210	0.0130	0.1765	D_2 portion of the roof fell at about 1.00 p.m. The reading of deflection gauge was observed at 10.00 a.m.

much more than that by the previous one. In both cases only the curved portions were loaded with sand bags. The increased strength in the case of this roof might be due to the quick method of testing, the absence of the cantilever action in the frames and the provision of the thickened arch at ends. There is a possibility of the bending stresses also in the arch portion as the whole roof is not exactly like a circular dome. The theoretical aspects will be discussed later on when the work in hand about this type of roofing is completed.

Conclusion

The test loads of 210 and 270 lbs. per sq. ft. indicate that this tpye of construction can be safely used for roofs of single-storey houses. The British Standard[2] specifies only an imposed load of 15 lbs. per sq. ft. measured on plan for flat and sloping roofs upto 30° with no access provided to the roof other than that which is necessary for cleaning and repair. The vault roof with a varying arch thickness gave better results, though the size of the frame used was $4\frac{1}{2}'' \times 10''$ instead of $5'' \times 18''$ in the case of the slab with uniform arch thickness. Further experiments aimed at studying the effect of the increased thickness of the arch section at ends and increased rise at centre of the roof are being carried out.

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References

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