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ROOF SLABS IN LOW COST HOUSES

Part 2.—Vault Roofs with Uniform and Varying Arch Thickness

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The construction, deflection testing, movement due to diurnal variations and ultimate strength of plain concrete vault roofs have been described. The roofs with varying and uniform arch thickness were laid on two separate rooms measuring 10 × 10′ each and tested under a uniformly varying superimposed load of sand bags. The results indicate the suitability of these types for larger spans in shell roof constructions.

Introduction

In a preliminary[1] study of the design, construction and testing under uniformly distributed loads of plain concrete vault roof, it was observed that varying arch thickness gave better strength, 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. The increased strength was attributed partly to the quick method of testing and partly to the absence of the cantilever action in the frame. Two roofs (Fig. 1) with $4\frac{1}{2}'' \times 10''$ frames were, therefore, laid and tested under similar conditions to study the effect of increased thickness of the arch section at ends. The present paper describes the deflection testing, movement due to diurnal variations and the effect of varying arch thickness on the ultimate strength of the plain concrete vault roofs.

Construction

The centring, as reported in the previous communication,[1] was erected and the roofs on the two experimental rooms (10′–0″ × 10′–0″ inside dimensions) were laid in a mix composed of Dalmia Portland 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. The curing of the concrete was done in the usual way and the centring was removed after 14 days. The roofs were then plastered on both sides with $\frac{1}{2}$ inch thick 1:6 (Dalmia Portland cement and Malir sand) cement mortar.

Deflection Testing

British Standard[2] has recommended a test load equal to $1\frac{1}{4}$ times the designed superimposed load to be maintained for 24 hours on the completed structure. The loads of $1\frac{1}{4} \times 30$ and $1\frac{1}{4} \times 50$ lbs. per sq. ft. (measured on plan) were therefore imposed separately on the curved surface of the plain concrete vault roof with uniform arch thickness of 2 inches and the deflections recorded in Table 1. The loads were imposed or removed just after obtaining the gauge readings at 3-0 p.m. and the readings at 3-45 p.m. were recorded immediately after loading or unloading the roof. The recovery of deflection upon removal of the test loads was cent percent within the specified period of 24 hours in both the cases and the structure did not show any sign of weakness or faulty construction. Similar deflection testing for increased superimposed loads was not considered necessary, as British Standard[3] specifies only an imposed load of 15 lbs./sq. ft. for the roofs with no access provided other than that which is necessary for cleaning and repair.

The Movement of Vault Roofs under No Imposed Load

The effect of diurnal variations on upward and downward movement was studied by fixing a gauge at centre of the vault roof with varying arch thickness on the underside of the curved surface. The gauge readings were recorded at different times in the day and night nearly

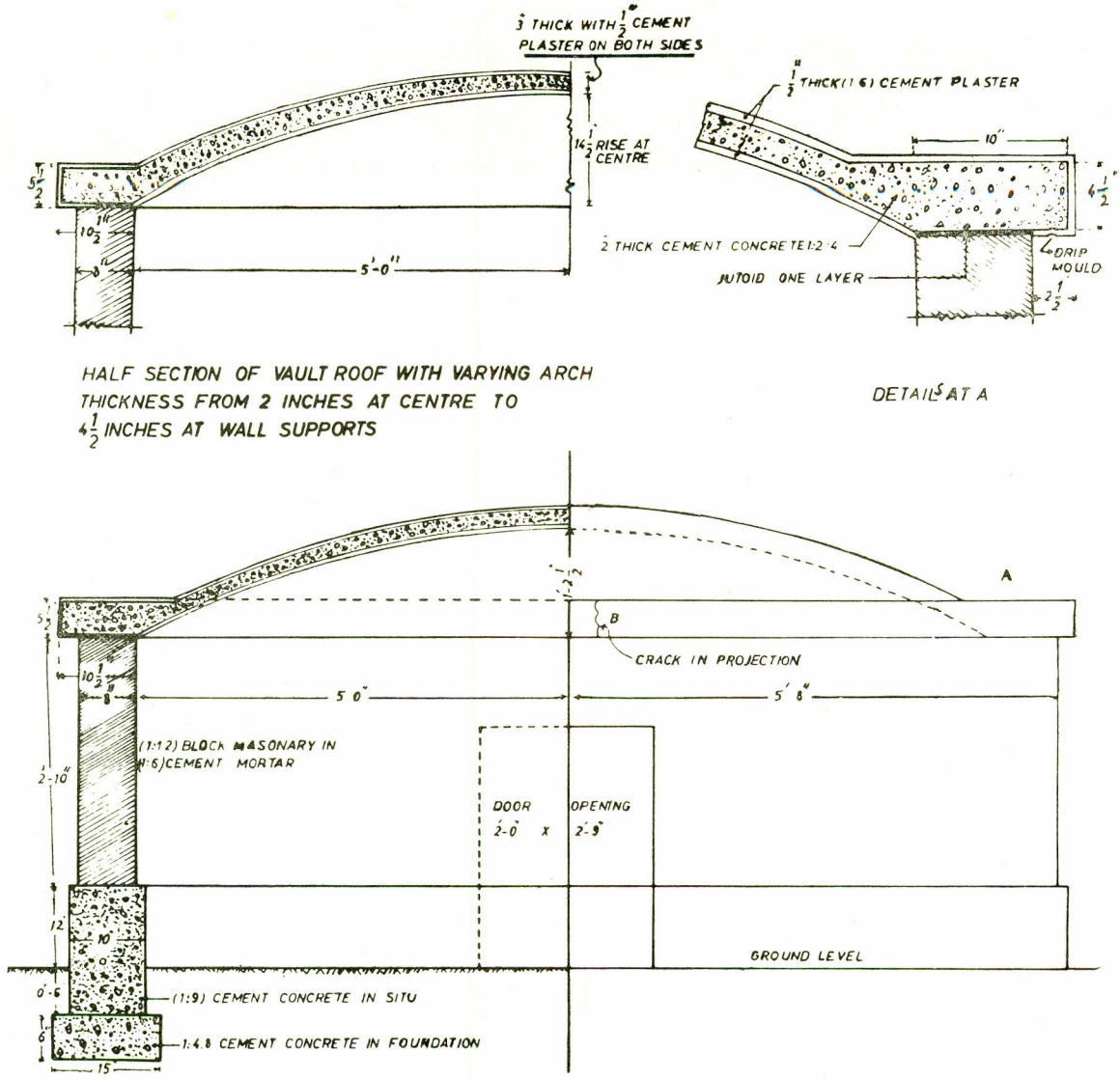

Fig. 1.—The Construction Details of the Experimental Rooms with Vault Roofs of Uniform and Varying Arch Thickness.

during all the varying seasons from January to June 1963. The temperatures of inside and outside concrete surfaces at centre of the roof were also measured and some of the gauge and temperature readings are shown in Table 2. The movement in the roof with uniform arch thickness was almost the same.

The maximum upward movement was observed at 12-30 (noon) and maximum downward movement or deflection was recorded at 10 p.m., though maximum and minimum temperatures of concrete

TABLE 1.—DEFLECTION TESTING OF THE VAULT ROOF WITH A UNIFORM ARCH THICKNESS OF 2″ AND A RISE OF 15″ AT CENTRE.

Date	Superimposed load in lbs. per. sq. ft. (measured on plan)	Gauge readings in inch at			
		10 a.m.	3 p.m.	3-45 p.m.	8 p.m.
6-1-63	Nil	0.083	0.080	—	0.091
7-1-63	,,	0.082	0.078	—	—
,,	1.25×30	—	—	0.084	0.085
8-1-63	,,	0.087	0.094	—	—
,,	Nil	—	—	0.092	0.091
9-1-63	,,	0.082	0.078	—	—
,,	1.25×50	—	—	0.086	0.087
10-1-63	,,	0.087	0.095	—	—
,,	Nil	—	—	0.092	0.092
11-1-63	,,	—	0.077	—	0.090
12-1-63	,,	0.080	0.077	—	0.091

surfaces were obtained at 3 p.m. and 7-30 a.m., respectively. The outside concrete surface of the slab became warmer than that of the inside in day time while it remained cooler from evening at about 4 p.m. to the morning at about 8 a.m. This movement of roof, without any superimposed load on it, may be related to the temperatures of concrete surface, the rate of increase or decrease of temperatures and the relative humidity at that time.

The combined effect of diurnal variations and different surface treatments on movement of a similar vault roof with varying arch thickness but with a rise of 21 inches at centre is shown in Table 3. The bitumen painting on the exposed surface of the slab and white washing on ceiling increased the rate of deflection or upward movement. It was also noticed that the increased rise at centre of the vault roof and the insulation layers on top surface considerably reduced the movement due to diurnal variations.

Ultimate Strength of the Vault Roofs with Uniform and Varying Arch Thickness

The superimposed loads of sand bags were gradually increased on the curved surfaces of the plain concrete vault roofs with uniform and varying arch thickness separately and measured in lbs. per sq. ft. on plan area of the rooms. The uniformly distributed load was varied from 100 to 300 lbs. per sq. ft. on the slab with uniform arch thickness and deflection recorded. Table 4 shows the gauge readings before and after increasing the imposed loads and the maximum during a particular load. On 4-2-63, the test load was increased from 260 to 300 lbs. per sq. ft. and a crack on the roof projection at B (Fig. 1) over the door opening appeared on 5-2-63. Under this load, the deflection increased constantly and slight increase in the length of crack was also observed toward the centre of the vault. The load was removed on 5-3-63.

TABLE 2.—THE EFFECT OF DIURNAL VARIATIONS ON THE DEFLECTION OF THE VAULT ROOF WITH VARYING ARCH THICKNESS AND A RISE OF 15″ AT CENTRE.

Date	Time	Concrete temperatures in °C. at centre of the vault roof		Gauge reading at centre (inch)	Deflection or upward movement at centre (inch)
		Inside	Outside		
25-1-63	12-30 (noon)	27.8	30.2	0.122	0.000
	3-00 p.m.	32.5	33.8	0.124	+0.002
	5-30 ,,	30.8	28.8	0.129	+0.007
	8-00 ,,	25.0	23.4	0.132	+0.010
	10-00 ,,	21.8	20.6	0.133	+0.011
26-1-63	12-00 (mid. night)	20.4	18.6	0.132	+0.010
	2.00 a.m.	19.4	18.2	0.131	+0.009
	5-00 ,,	18.0	16.8	0.130	+0.008
	7-30 ,,	16.8	15.6	0.130	+0.008
	10-00 ,,	20.4	26.4	0.126	+0.004
25-2-63	10-00 a.m.	22.9	28.2	0.118	−0.004
	12-30 (noon)	35.4	38.0	0.111	−0.011
	5-30 p.m.	37.9	36.6	0.122	0.000
	8-00 ,,	28.8	25.8	0.126	+0.004
	10-00 ,,	24.8	22.4	0.126	+0.004
25-3-63	10-00 a.m.	26.4	34.6	0.110	−0.012
	12-30 (noon)	38.2	43.4	0.105	−0.017
	5-30 p.m.	38.0	32.9	0.117	−0.005
	8.00 ,,	28.4	26.2	0.121	−0.001
22-4-63	10-00 a.m.	31.4	35.4	0.110	−0.012
	12-30 (noon)	40.4	40.9	0.107	−0.015
	5-30 p.m.	38.6	34.0	0.118	−0.004
	8-00 ,,	31.9	28.2	0.121	−0.001
21-5-63	10-00 a.m.	33.2	36.8	0.110	−0.012
	12-30 (noon)	44.7	45.0	0.105	−0.017
	5-30 p.m.	44.0	39.0	0.117	−0.005
	8-00 ,,	35.6	31.6	0.121	−0.001
17-6-63	10-00 a.m.	32.8	33.6	0.111	−0.011
	12-30 (noon)	36.7	37.0	0.110	−0.012
	5-30 p.m.	38.4	35.4	0.115	−0.007
	8-00 ,,	32.8	30.0	0.118	−0.004

The results of the roof with varying arch thickness are shown in Table 5. The uniformly distributed load was increased just after obtaining the readings at 3-0 p.m. and the readings at 3-45 p.m. were recorded immediately after increasing the load on the curved surface. The rain shower on 1-8-63 slightly increased the imposed load on the roof. No separation crack between wall and slab was observed under any imposed load. The test load was increased from 300 to 340 lbs. per sq. ft. on 2-9-63 and a crack appeared on 3-9-63 in the roof projection at a similar point as in the case of roof with uniform arch thickness of 2 inches.

Conclusion

On the basis of the foregoing results, the plain concrete vault roofs with uniform and varying arch thickness can be used for single-storey low cost houses. The increased rise at centre of the slab

TABLE 3.—THE COMBINED EFFECT OF DIURNAL VARIATIONS AND DIFFERENT SURFACE TREATMENTS ON DEFLECTION OF THE ROOF WITH VARYING ARCH THICKNESS AND A RISE OF 21 INCHES AT CENTRE.

Date	Time	Gauge reading (inch)	Maximum variation (inch)	Remarks
7-1-63	10 a.m.	0.007		1. The maximum variation in vault roof with varying arch thickness and 15 inches rise was observed as 0.011 inch on 7-1-63.
	3 p.m.	0.004	0.007	
	8 ,,	0.011		
9-1-63	10 a.m.	0.007		1. The exposed surface of the roof was covered with jute bags.
	3 p.m.	0.004	0.003	
	8 ,,	0.007		
19-1-63	10 a.m.	0.001		1. Jute bags removed and
	3 p.m.	0.000	0.004	2. The top surface was given a white wash with lime.
	8 ,,	0.005		
21-1-63	10 a.m.	0.001		1. Bottom surface or the ceiling of the roof was also given white wash.
	3 p.m.	0.001	0.003	
	8 ,,	0.004		
27-1-63	10 a.m.	0.001		1. White wash removed from top surface only.
	3 p.m.	−0.004	0.010	
	8 ,,	0.006		
31-1-63	10 a.m.	−0.002		1. Top surface painted black with bituminous paint and bottom remained white washed.
	3 p.m.	−0.008	0.015	
	8 ,,	0.006		
	10 ,,	0.007		2. The maximum variation of the roof with varying arch thickness and a rise of 15 inches at centre was 0.015 inch on 25-2-63 (without any surface treatment).
25-2-63	10 a.m.	−0.005		
	12-30 (noon)	−0.009	0.014	
	10 p.m.	0.005		

TABLE 4.—TESTING OF THE PLAIN CONCRETE VAULT ROOF WITH UNIFORM ARCH THICKNESS AND A RISE OF 15 INCHES AT CENTRE UNDER UNIFORMLY DISTRIBUTED LOADS OF SAND BAGS.

Superimposed load on the curved surface			Gauge reading in inch		
Load in lbs./sq. ft. measured on plan	maintained on roof from	to	before loading	after loading	maximum during the imposed load
100	13-1-63	17-1-63	0.077	0.087	0.096
140	17-1-63	21-1-63	0.095	0.098	0.098
180	21-1-63	28-1-63	0.095	0.096	0.098
220	28-1-63	31-1-63	0.098	0.098	0.100
260	31-1-63	4-2-63	0.100	0.100	0.102
300	4-2-63	5-3-63	0.102	0.106	0.152

and insulation layer on exposed concrete surface reduce the movements due to diurnal variations which may consequently increase the durability of the structure. The bitumen painting, which generally improves the water proofing properties of concrete surfaces, increases thermal stresses but no water proofing is required in this type of construction because of the vault roof shape. The increased thickness of the arch section in the vault roof with varying arch thickness imparts

TABLE 5.—TESTING OF PLAIN CONCRETE VAULT ROOF WITH VARYING ARCH THICKNESS AND A RISE OF 15 INCHES AT CENTRE UNDER UNIFORMLY DISTRIBUTED LOADS OF SAND BAGS.

Date	The superimposed load on the curved surface in lbs. per sq. ft. (measured on plan)	Gauge readings in inch at			
		10 a.m.	3 p.m.	3-45 p.m.	8 p.m.
20-6-63	20	—	0.110	0.111	0.114
21-6-63	,,	0.117	0.121	—	0.116
22-6-63	,,	0.119	0.120	—	0.116
24-6-63	60	0.118	0.119	0.121	0.120
25-6-63	,,	0.121	0.128	—	0.121
1-7-63	,,	0.120	0.126	—	0.121
2-7-63	100	0.120	0.125	0.127	0.123
4-7-63	,,	0.122	0.128	—	0.124
7-7-63	,,	0.121	0.127	—	0.123
10-7-63	140	0.122	0.127	0.129	0.126
11-7-63	,,	0.127	0.130	—	0.127
15-7-63	,,	0.128	0.131	—	0.129
16-7-63	180	0.127	0.132	0.134	0.136
17-7-63	,,	0.129	0.128	—	0.131
19-7-63	,,	0.131	0.134	—	0.131
23-7-63	,,	0.135	0.139	—	0.135
24-7-63	220	0.134	0.139	0.141	0.137
25-7-63	,,	0.135	0.139	—	0.136
30-7-63	,,	0.136	0.139	—	0.137
31-7-63	260	0.136	0.139	0.141	0.141
1-8-63	,,	0.140	0.145	—	0.143
2-8-63	,,	0.146	0.150	—	0.149
15-8-63	,,	0.155	0.158	—	0.155
17-8-63	300	0.155	0.158	0.160	0.159
18-8-63	,,	0.157	0.161	—	0.159
26-8-63	,,	0.159	0.161	—	0.159
27-8-63	320	0.159	0.162	0.163	0.161
30-8-63	,,	0.161	0.162	—	0.160
31-8-63	,,	0.161	0.164	—	0.188
1-9-63	,,	0.187	0.189	—	0.187
2-9-63	340	0.184	0.185	0.187	0.186
3-9-63	,,	0.186	0.189	—	0.186
6-9-63	,,	0.189	0.194	—	0.191
8-9-63	,,	0.192	0.195	—	0.194
10-9-63	,,	0.194	0.197	—	0.195
15-9-63	,,	0.197	0.200	—	0.199

better rigidity and this roof deflects much less than the roof with uniform arch thickness when tested under the same imposed load. To examine the suitability of this design for shell roof constructions of much larger spans, further work is in progress.

References

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