International Journal of Engineering & Technology

Research paper

Application of Ancient Principles of Architecture in Modern Practice

Marshal DG[1], Prakash A[2], Venkatasubramanian C[3], Muthu D[4], Madhan Vignesh M[5]

School of Civil Engineering, SASTRA Deemed University, Thanjavur, Tamil Nadu, India
*Corresponding Author Email: [1]marshaldg97@gmail.com

Abstract

Before the advent of reinforced cement concrete and steel structures in the 20th century, structures like Arches, domes and vaults were being widely used worldwide. Arches were mainly used in span openings replacing beams. This was done based on the erstwhile cultural aesthetics and technical development in the prevailing construction methodologies. Nowadays, about 35 to 40 percentage of the total construction cost is being consumed by steel and concrete and therefore constructing a building without steel and concrete contributes to reduction in cost. Vaults and arches do not require concrete and steel but use only bricks and hence environment friendly. This paper deals with the design and construction procedure for structural members including the vault and buttress wall. It also highlights the reduction in cost when adopting vault method over conventional methods, in a residential building. The Vault prototype has been made with the studied design and concepts. The idea is to introduce this technique as a cost reduction approach and to preserve this ancient construction technique. Also, this method will be economical for construction of low cost houses up to two storeys.

1. Introduction

Vault is an ancient construction technique used largely in ancient temples whose use is greatly reduced after the introduction of steel and concrete. In a structure, steel and concrete occupies 35 to 40 percentage of the total cost, therefore construction a building without steel and concrete would reduce the cost of construction. People are unaware of the benefits of this construction technique. Vault structures are environment friendly since they use clay bricks. The reduction in cost when adopting vault method is arrived through estimation. The complete procedure for construction of the structural members has been studied and a prototype was made.

2. Literature Review

1 Vaulted systems for low-cost construction in Africa. Philippe Block, et al. ATDF JOURNAL, Volume 7, Issue 1/2 2010 – This paper deals about using vaulted structural systems to provide sustainable and low-cost construction for Africa, based on experiences both in and practice.
2 Traditional vault construction without formwork: Masonry pattern and vault shape in historical technical literature and in experimental studies David Wenland. International Journal of

Architectural heritage, Volume 1, Issue 4,2007. This article aims in a better understanding of the traditional technique and to provide the base of the design process. Beyond that, an accurate surface model for vaults is proposed to be helpful for the numerical modeling of their structural behavior.

3. Methodology

The design and construction process of the structural members such as vault, buttress wall for a residential building is studied and the detailed estimate is worked out to find the cost reduction.

4. Design Procedure

Floor Plan

A plan for 2 BHK house with dimensions 22.25 x 42.25 ft. have been prepared. The house has been designed for ground floor only and it is divided into two segments so that it has two vaults. The thickness of the wall adopted is 230 mm and the wall height is 2.1 m. Vault structures have buttress walls instead of columns. The total plinth area including verandah is940 sq.ft. (refer FIG.4.1)
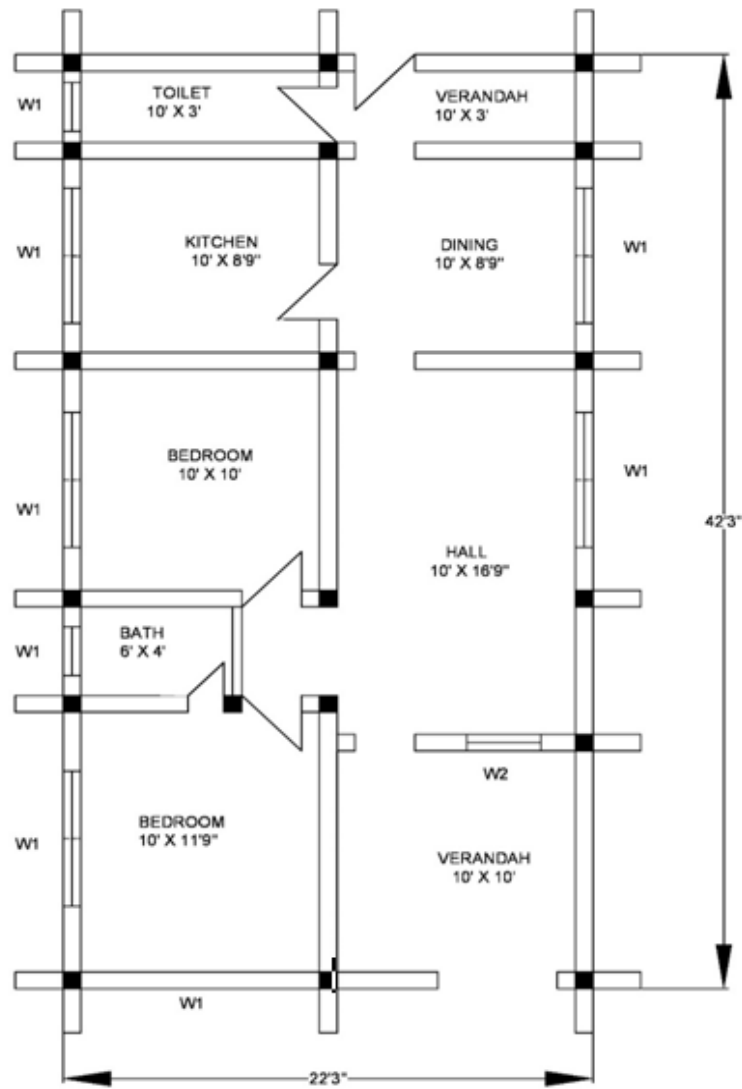
Fig. 1: Floor plan for a two-bedroom house

Vault Design

Vault is a three-dimensional configuration of arch. The span of room is 3m. Since the span is very less, semi-circular vault has been adopted. The semicircular vault transfers only the vertical forces and not the lateral forces. The thickness of the vault is proportional to its span.

Design Parameters:

Rise in the center of vault = span/2

$\qquad\qquad\qquad\qquad = 1.5$ m

Thickness of the vault = span/12

$\qquad\qquad\qquad\qquad = 250$ mm

Therefore, the total height of the room becomes 3.6 m at the center. Lintels above the doors and windows are replaced with semicircular arches. The skewback is made up of chiseled bricks, because the compressive strength of brick is more than that of cement. The skewback is also provided where the two vaults meet.

5. Construction Procedure

Sub Structure

The foundation consists of alternate layers of stone and brick masonry for a depth of 0.75 m. Sand filling for 150 mm has to be done. Over that a layer of stone block with the thickness of 150 mm is placed and it is an alternate for conventional PCC. Above that a 450 mm thick layer of random rubble masonry is to be laid which forms the major part of foundation, then brick masonry for 300 mm height is constructed following this a stone block of 100

mm thickness is used as the plinth beam as an alternative for conventional RCC beams.

Super Structure

The wall is designed for a thickness of 230 mm and has to be constructed for a height of 2.1 m using brick masonry. The Vault is raised over the wall structure. Thus, making the roof dome shaped.

Buttress Wall

Buttress wall is provided to support the brick wall as it counteracts the forces and moments created due to the dead and live loads from the vault. These are not mandatory at the front and back side of the building but at the sides they play a major role by supporting the main wall.

The foundation, thickness and height of the buttress wall is same as that of the main wall. The length of the buttress wall at top and bottom is 230 mm and 600 mm respectively.

Vault

The formwork for the construction of vault consists of wooden or steel planks which are supported by shoring. Over this, bricks along with mud mortar is placed by threading technique to obtain the curvature.

Once the formwork is completed, bricks are laid simultaneously from both the sides with the help of thread, such that the center of the thread should be in the center of the brick that is being laid. To maintain the radius the cement mortar on the outer edge should be greater when compared to the inner edge.

The skewback in the place where the two vaults meet should be formed with chiseled bricks. Care should be taken that the skewback has more bricks than cement mortar. Once the vault is finished, the formwork can be removed within a week and a proper water draining arrangements should be made to prevent infiltration of rain water into the vault.[1]

6. Cost Comparison

The cost reduction achieved is arrived by comparing the construction of a two-bedroom house by conventional and vault methods.

Conventional Technique

- This method involves the usage of steel and concrete.
- The foundation involves sand filling, P.C.C and R.C.C.
- The flooring is again P.C.C.
- Plastering is necessary for the roof and for both sides of the walls.
- White washing is necessary.

Vault Technique

- This method does not need steel and concrete.
- The foundation consists of sand filling, stone and brick masonry.
- Brick flooring can be adopted
- Plastering is not mandatory.

These are the regions where the difference in construction methods can be observed and also, this is where the cost reduction can be acquired.

Table 1: Conventional Technique

S. No.	Particulars	Quantity	Unit	Rate	per	Amount
1	Earthwork excavation in foundation	77.796	m³	220	m³	17,115
2	Earthwork Refilling	23.939	m²	80	m²	1,915
3	Sand filling in foundation	10.26	m³	2824	m³	28,974
4	Cement concrete 1:1.5:3 in foundation	1.647	m³	5400	m³	8,894
5	R.C.C work 1:1.5:3	30.47	m³	7000	m³	213,290
6	Mild steel reinforcements	2124.8	kg	65	kg	138,112
7	First class B.W in CM 1:6	42.56	m³	5400	m³	229,824
8	Half brick masonry	18.178	m³	800	m³	14,542
9	P.C.C. flooring	9.274	m³	4200	m³	38,951
10	Grano finish on the top	61.83	m²	600	m²	37,098
11	Teakwood (Frame)	2.4	m³	1,20,775	m³	289,860
12	Teakwood (Shutter)	1.5	m³	1,20,775	m³	181,163
13	Plastering	486.5	m²	400	m²	194,600
14	White washing	486.5	m²	20	m²	103,760
15	Color washing	412	m²	30	m²	133,020
	Total					1,631,118
	Add 2% for sump					32,622
	Add 2% for septic tank					32,622
	Add 3% for contingencies					3,991
	Add 2% for work charge establishment					2,660
	Add 7% electrical works					9,311
	Add 10% plumbing					13,302
	Total					1,858,648

Table 2: Vault Technique

S.No.	Particulars	Quantity	Unit	Rate	per	Amount
1	Earthwork excavation in foundation	27.718	m³	220	m³	6098
2	Earthwork refilling	23.939	m²	80	m²	1915
3	Sand filling in foundation	4.732	m³	2824	m³	13363
4	Stone block in foundation	4.732	m³	4000	m³	18928
5	Random rubble masonry in foundation	16.226	m³	4000	m³	64904
6	Brick masonry above G.L	8.497	m³	4850	m³	41210
7	Stone masonry in Plinth	2.829	m³	4360	m³	12334
8	Brick Masonry in super structure	39.589	m³	5800	m³	229616
9	Brick work in vault	32.64	m³	6000	m³	195840
10	Quantity of filling in Vault	11.24	m³	300	m³	3372
11	Centring for Vaults	202.37	m²	200	m²	40474
12	Brick flooring	61.83	m²	400	m²	24732
13	Grano finish	61.83	m²	600	m²	37098
14	Teakwood (Frame)	2.4	m³	1,20,775	m³	289860
15	Teakwood (Shutter)	1.5	m³	1,20,775	m³	181163
16	Plastering (inside)	363	m²	400	m²	145200
17	White washing	363	m²	20	m²	7260
18	Color washing	293	m²	30	m²	8790
	Total					1322158
	Add 2% for sump					26443
	Add 2% for septic tank					26443
	Add 3% for contingencies					39665
	Add 2% for work charge establishment					26443
	Add 7% electrical works					92551
	Add 10% plumbing					132216
	Total					1665920

Cost Reduction

The total cost using conventional technique = 18,60,000 (approx.)
The total cost using vault technique   = 16,66,000 (approx.)
Cost reduction   = 1,94,000.
Percentage   = 10.4%
Therefore, a cost reduction of 10.4% is achieved using vault technique and it can be used for low cost construction.[4]

7. Prototype Construction

To understand the construction process of the vault clearly a prototype is built. The main motive is to show the feasibility of vault structures.

Base Making

A concrete base with reinforcement of 8 mm diameter bars and 6 mm diameter stirrups is made over which the vault will be built. Wooden planks are used as formwork for concreting. The base makes the prototype portable.

Vault Making

The bricks of dimension 5x3x1 inch is used for the model. The form work is made with bricks and mud mortar. The radius is maintained with the help of thread and rods. Bricks are placed simultaneously from both the ends. In order to maintain the curvature threading technique is used. The key block is placed finally, which makes the vault a complete structure. The formwork is removed once the vault has been built.[6]

Fig. 2: Reinforcement for base

Fig. 3: Base after Concreting

Fig. 4: Formwork

Fig. 5: Bricks Arrangement

Fig. 6: Finished Vault

Fig. 7: Vault after removal of formwork

8. Conclusion

- Introducing vault in building construction is a cost reduction approach.
- It is environment friendly as the vault construction involves bricks only.
- Vault is limited to G+1 floor only. This is one of the major limitations in vault structures.   But introducing concrete in the structure will enable more number of floors in the building.
- Erection and removal of formwork is a difficult task. The formwork involves mud mortar and bricks other than steel props which takes more time to complete and set. Unlike the removal of steel props, removal of mud mortar takes more time.
- Skilled masons are required for vault construction. Since this is an ancient technique masons are not well versed in arch or vault construction now-a-days.
- Vaults cannot be practiced in urban areas. Ramming of piles in nearby areas may tremble the vault structures. Therefor vault structures are recommended only in rural areas as low-cost housing.

References

[1] www.earth-auroville.com,Building with earth, Vaulted Structures.

[2] Philippe Block, Matthew DeJong, Lara Davis, John Ochsendorf, Tile Vaulted Systems for Low-cost Construction in Africa, ATDF Journal, Volume 7, Issue 1/2, (2010).

[3] Traditional Vault Construction Without Formwork: Masonry Pattern and Vault Shape in the Historical Technical Literature and in Experimental Studies, David Wenland, International Journal of Architectural Heritage, Volume 1, Issue 4, (2007).