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# Construction and Analysis of Brick Masonry Dome in Lime Mortar without Form Work

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***Abstract***
*Dome is a large hemispherical roof, which is an ancient roofing technique used for large span structures without intermediate fixed support. And it's a technique where there is no need of any kind of support or formwork at the time of construction. Many stone masonry domes built few hundred years ago are serving in best working conditions and are aesthetically more appealing than domes built using any other material. The temples, mosques and churches built using stone masonry are still standing with minimum maintenance. The feeling of tranquility in these structures cannot be compared with structures built using reinforced cement concrete or steel. It gives astonishing results if we use naturally available materials viz., stone, mud, haze, etc. In this paper construction technique of domes without form-work have been discussed. This paper talks about the results of experimental study on construction and analysis of masonry dome in lime mortar without using formwork.*

***Keywords:*** *Formwork, funicular analysis, lime mortar, loading, masonry dome*

## INTRODUCTION

We see around us many heritage structures, most of them built using masonry, are standing for centuries. Many stone masonry domes built few hundred years ago are serving in best working conditions and are aesthetically more appealing than domes built using any other material. The temples, mosques and churches built using stone masonry are still standing with minimum maintenance. The feeling of tranquility in these structures cannot be compared with structures built using reinforced cement concrete or steel. These masonry structures have proven its durability over hundreds or even thousands of the years. In terms of durability and tranquility reinforce concrete and steel structures cannot be compared with masonry structures. These heritage structures built by our forefather are standing for generations, but the structures we are constructing using reinforced concrete and steel will not survive for our grandchildren. Hence to maintain these valuable heritages and to re-consider our choices of material for many new structures, it becomes imperative to understand the structural behavior of masonry structures.

The maintenance of heritage masonry structures and it's assessment for stability need the appropriate method of structural analysis. The stability parameter of these heritage structures is still haze to the engineers. It is easy to find the document related to history and art of these monuments, but it is very hard to find any structural analysis or drawing related to these structures. It is imperative to understand the structural actions of these structures not only to maintain its integrity but also to create heritage by ourselves for our grandchildren.

 

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The masonry dome structure of Taj-Mahal is one of the very impressive heritage structures exists in India. The key for durability of masonry structures lies in its material properties and in its structural action. The structural profile of these heritage building was always maintained in compression by ancient builders. The property of masonry is good in resisting compression, whereas it fails to resist any tension. These masonry dome structures are designed mainly using understanding of geometrical stable shapes, or by using simple graphical methods like thrust line method. The application of this approach was remained limited to the arch problem only, and so masonry dome are historically analyzed as arch or by orange slice methods. This approach has ignored the strength available due to hoop compressive forces and at the same time ignored the ill effect due to hoop tension forces. Almost all masonry dome structures suffer the cracks due to these hoop tension forces. The domes constructed under Islamic architecture like Gol-gumbaz of Bijapur and Taj-mahal of Agra were not provided with any tension resisting mechanism, wherein the domes constructed in Europe like Pantheon and St. Peter cathedral of Rome were provided with metal chains in the thickness of these domes. The effect of existence or non-existence of these tensions resisting mechanism on stability of the dome needs to comprehend. Finite element analysis can quantify these hoop forces. But the engineers face some difficulties in finite element analysis of these structures due to non-availability of data for mechanical properties of the heritage structures. Even in new construction, the assessment and control of these mechanical properties is challenging task due to uncertainty associated with texture (pattern of placement of stone and matrix) of masonry [1-5].

The conventional thrust line approach on other hand does not require mechanical properties of masonry but its use for study of masonry structure remained limited to arches and vaults only. Furthermore it fails to study the effect of complex boundary conditions and settlement of support. This lack of knowledge and assessment due to limitation in analysis method lead to ad-hoc strengthening measure to such heritage structures [6]. Hence it becomes very important to find suitable method for masonry analysis and more specifically for masonry dome analysis. The method should be versatile to include the effect hoop forces and support settlement on stability of structure. In graphical thrust line method, the result is very easy to interpret for stability [7]. If the thrust line passes through middle third then structure is understood to be stable without any meridional tension. The method developed should also have similar ease in interpretation of stability; it is well documented fact that masonry domes are critical for stability and not for the stress. The method developed should not be sensitive to mechanical properties of the masonry [8, 9].

Recently, the center of the Global Vipassana Pagoda was built in Mumbai. It contains the world's biggest stone arch worked with no supporting columns [10]. The height of the arch is roughly 29 meters, while the height of the structure is 96.12 meters, the outside measurement of the biggest area of the dome is 97.46m and the shorter segments, is 94.82m. The internal diameter of the dome is 85.15m. Within the pagoda is empty and fills in as an exceptionally huge contemplation corridor with a territory covering more than 6000 sq. m (65,000 sq. ft). The massive inner dome seats over 8000 people.

**Design**

The design of the dome was done considering factors like end usage, climatic conditions and weigh bearing capacity [11]. The location was fixed to be near the entrance of the civil engineering department at MGM's Jawaharlal Nehru College of Engineering, Aurangabad. The size and shape were fixed, and the analysis was done using the Funicular Method. This method of graphical analysis for domes uses weight of every Voussoir is taken into consideration and vector lines are drawn and their behavior is studied. If the thrust line passes through the structure, the arch is safe to be built. If we rotate an arch about its central axis, we get a dome. Therefore, this method of analysis is justified to be used for domes. Four columns of 360×360mm were to be built over which a ring beam was to be rested. For this study, dome of span 1.92m, 0.15m thickness and 0.96m rise has been considered. Also an oculus of 0.57m from top is present. The diagrams for which have been provided in the paper.

**Test Program**

Test program involves the analysis and construction of masonry dome. For this first step is to determine the load coming on the structure as well as the load carrying capacity of brick masonry dome with lime mortar. The resources recycled for the structure are, Burnt clay bricks of size 150X 75X 15mm consuming compressive strength of 4.0N/mm$^2$ and 1:1:1:1.5 (Lime: Surkhi: Sand: Water) lime mortar having compressive strength 0.803N/mm$^2$ (dry) have been used for the construction of dome. The preparation time for lime to be used in the mortar is min 5hr. After that, preparation of lime mortar will take minimum 3-4hrs with Muller refer to Fig. 1.

***Figure 1:*** *Muller used for the preparation of lime mortar.*

Table 1 indicates the segment weight calculation for analysis of masonry dome by Funicular analysis refer Fig. 2. Which help us to construct the dome. Before starting the construction of dome, the ring beam of cross-section 230mm X 150mm has been constructed with RCC to support the dome. The ring beam rests on brick masonry square column of sides 360mm. The columns were constructed in 1:6 cement mortars with standard burnt clay bricks of class-I grade.

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***Table 1:*** *Segment weight calculations for funicular analysis.*

| Segment References | Segment Length (Median) (cm) | Depth (cm) | Thickness (cm) | Volume mass (kg/m³) | Weight (Kg) | Weight to draw (cm) |
|---|---|---|---|---|---|---|
| **W1** | 2.317 | 100 | 9.00 | 1900 | 3.96 | 0.7924 |
| **W2** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W3** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W4** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W5** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W6** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W7** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W8** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W9** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W10** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W11** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W12** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |
| **W13** | 10.9 | 100 | 9.00 | 1900 | 18.64 | 3.7278 |

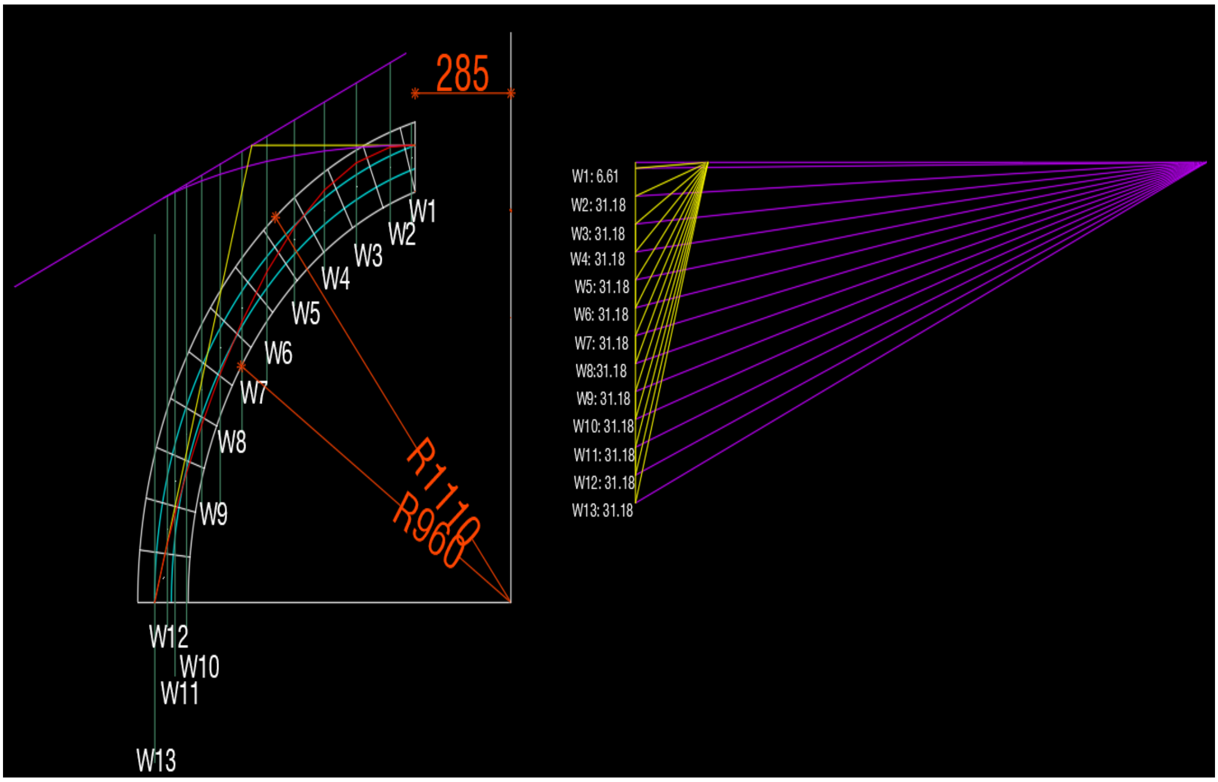


***Figure 2:*** *Funicular analysis of arch.*

The construction of dome completed layer by layer with lime mortar joint with thickness of joint 5mm to 15mm. Refer Fig. 3 for geometrical data. Not any type of formwork has been used for dome construction. The simple ancient technique was incorporated for it, a wooden flat log as seen in Fig. 4, with exact center of dome marking is used for constructing each course. Not more than 3 courses were constructed each day. This method of constructing reduces the cost of construction since no formwork needs to be used.

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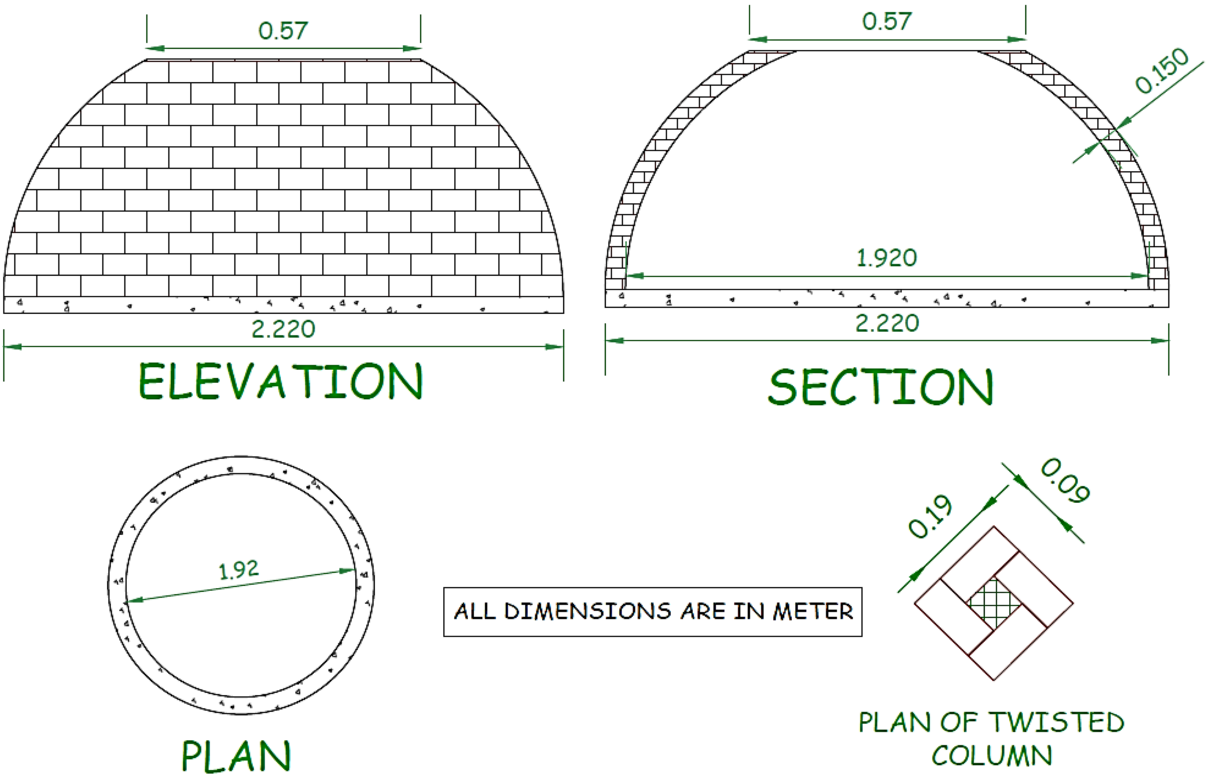


R.C.C. DETAILS OF BEAM

| SR. NO | Beam | Span M. | Cover MM. | Beam Size | Main Steel in Beam. Top St. | | Bottom St. | | ExtraTop. Contin Sup. | | Vertical Stirrups. At Supp. | | At mid | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Dia | Nos. | Dia | Nos. | Dia L/4 | Nos. | Dia L/4 | Spe. | Dia L/2 | Spe. | |
| 1. | B1 | - | 25 | 230 x 380 | 10 | 2 | 12 | 2 | - | - | 8 | 150 | 8 | 150 | - |


***Figure 3:*** *Elevation, section and plan for the steel reinforced concrete ring beam.*

***Figure 4:*** *Tool (wooden flat log) used for maintaining the levels and center of each layer.*

## RESULTS AND DISCUSSIONS

The study presented in this paper aims to address the load carrying capacity, analysis and construction technique of masonry dome without formwork refer Fig. 5 and 7.

 

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***Figure 5:*** *Masonry dome under construction without using formwork.*

- The method of construction is very versatile & can be implemented for up to 3m span.
- Funicular analysis method is used to identify the thrust line of dome which helps in stability analysis of the same.
- The efficiency in practice depends on the skills of the mason.
- The brick masonry dome in lime mortar is relatively easier to build since the workability increased exponentially due to the gummy mixture of the mortar used.
- The above construction technique is economical since it doesn't require any formwork.
- The major disadvantage of this type of construction is Time. It takes more days to complete as not more than 3 courses were constructed each day. Refer Fig. 6.

***Figure 6:*** *End of construction at day 2.*

***Figure 7:*** *Top view of the dome under construction.*

## CONCLUSIONS

- The design process was found to be quite convenient and can be implemented for larger spans.
- The method used or the construction was labor intensive.
- Skilled labor is necessary for a process like this.
- The method is considered economical since no formwork is required in the process to build the dome.

- No use of steel for the construction of roof ensures greater life span since no corrosion related issues occur (The steel used in the beam for this project can be replaced).
- Workability for Lime mortar is found to be quite difficult at times due to its unique components.
- A flaw for this construction methodology is that it takes a lot of time to be executed and a limited number of people can work at a time.

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