Structural Analysis of Historical Constructions, New Delhi 2006
P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)

Stability of Masonry Dome: Special Emphasis on ‘Golagumbaz’

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ABSTRACT: The paper discusses some of the criteria’s for the safety of masonry domes. The case study of ‘Golagumbaz’ is presented where in number of cracks in the meridional and hoop directions are found. The validation of cracks and mode of failure is described with the use of finite element axisymmetric analysis.

The bi-axial and tri axial stress condition in masonry dome makes it difficult to conclude on the permissible limits; specifically the behavior of masonry dome in tension stress for centuries is difficult to answer.

In Golagumbaz, the ring for hoop tension is not provided; this induces the hoop tension in the masonry. The structure is still stable after three centuries, and seems failed against serviceability. Author has made attempt to decide on permissible stress limit for masonry dome from the analysis of Golagumbaz.

1 INTRODUCTION

Shell structures are abundantly found in nature and also in engineering designs. It seems that with shell structures, nature has maximized the ability to span over relatively large areas with a minimum amount of material – the shell of an egg is an impressive example. The penalty is that the shell structures are considered to be most difficult to analyses, design and construct.

Spherical domes are abundantly built in the history; most of them are designed and built by using empirical formulas and the individual’s experience. Today the advent of new methods of analysis and design, and mainly with the finite element analysis, it can become easier to analyze and predict the behavior of shell structures with maximum accuracy, number of attempts are made by the researchers to predict the behavior of masonry structure with the use of these modern analysis tools (Fanning and Boothby 2001, CHS 2002). Here the attempt is made to conclude on some of the stability parameters by studying the largest masonry dome in India – ‘Golagumbaz’.

1.1 Golagumbaz

‘Golagumbaz’ has been built by 7th king MOHD. ADILSHAH, in 1626 to 1656. This India’s largest dome(CHS 2002) was designed by Malik Sandal of Iran. The total height of structure is 177 feet, width 135 feet. The 350 years old structure is built with wonderful architectural features, whispering gallery is one of it for which tourist use to visit the structure. It was repaired in 1936–37 by adding a reinforced concrete to the outside to help tie the cracked segments of the dome together.

2 ANALYSIS OF MAIN DOME:

Structure is modeled using axisymmetric finite element. Material is assumed to behave linear elastic with properties given below. The stress level is maintained to 1/5th of masonry strength and hence this assumption of linear elasticity can be justified.

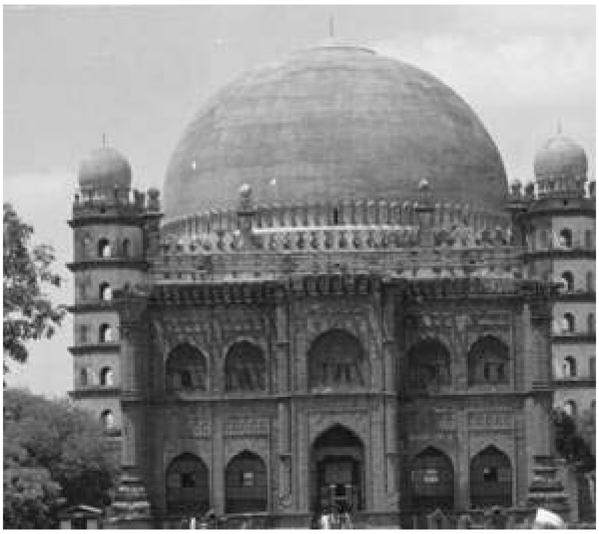


Figure 1 : Photograph of Golagumbaz.

2.1 Assumptions

Modulus of Elasticity (Hendry 1983)	E= $3X10^9$ N/m^2
Density of brick Masonry	D= 2000 N/m^2
Boundary condition	Hinged at base of dome

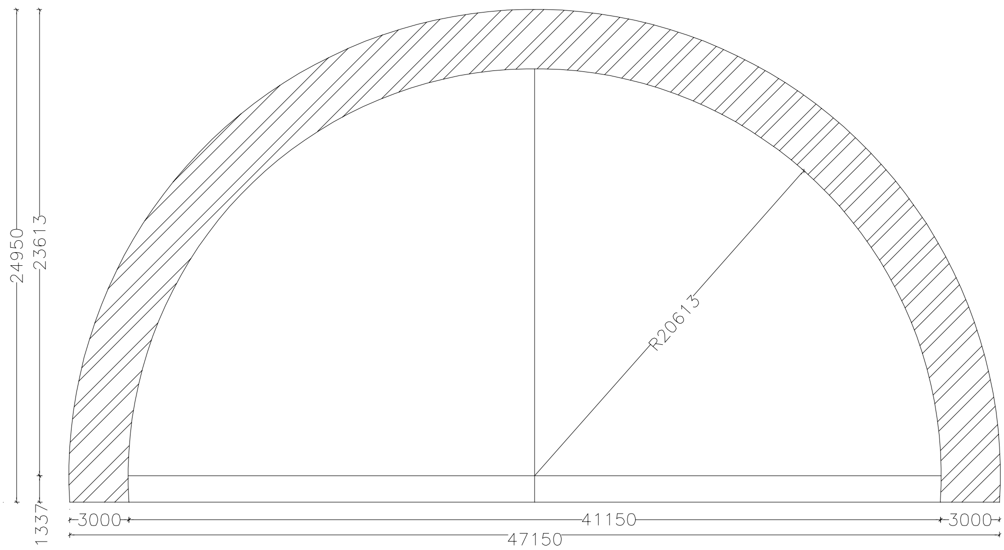
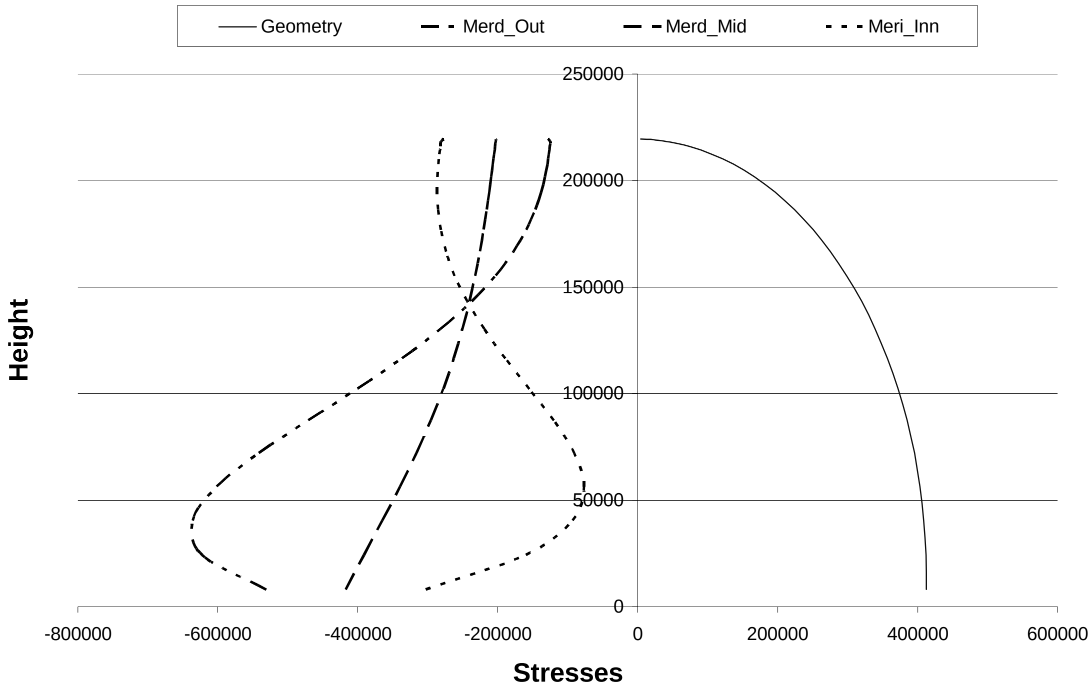


Figure 2 : Idealized section of Golagumbaz.

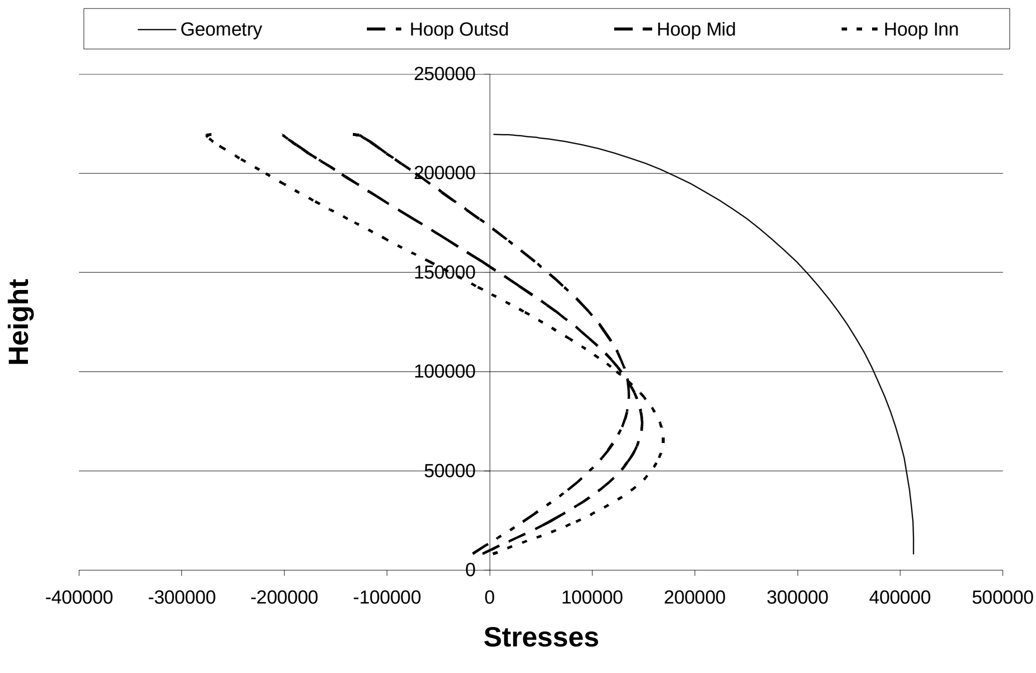
2.2 Results

Meridional Stress: Graph 1 shows the meridional stress at outer face, middle, and inner face in KN/m^2. The values are also tabulated and compared in Table 1 with the permissible values suggested in National Building Code of India.

Maximum compressive meridional stress of 600 KN/m^2 is observed on inner face of dome at approximately 6 meter height, and at same height on inner face the minimum compressive stress of 100 Kn/m^2 is observed.



Graph 1 : Meridonial stresses.



Graph 2 : Hoop stresses.

Hoop Stress: Graph 2 shows the hoop stress at outer face, middle, and inner face in KN/m^2. The values are also tabulated and compared in Table 1 with the permissible values suggested in National Building Code of India.

Maximum hoop tension of 170 KN/m^2 is observed at about 7 meter height.

Table 1 : Stress comparison between the permissible and actual stress.

Sr.	Description	Permissible stresses as per NBC (Hendry 1983)	Stresses in Golagumbaz
01	Max. Compression in KN/m^2	330^*	825
02	Max. Tension in KN/m^2	140**	100
04	Max. Shear stresses in KN/m^2	237	138
05	Max. Vertical deflection in mm	-	3.82
06	Max. Horizontal deflection in mm	-	0.75

3 VALIDATION OF CRACKS OBSERVED AT GOLAGUMBAZ

Following are some photographs showing the cracks in Golagumbaz.

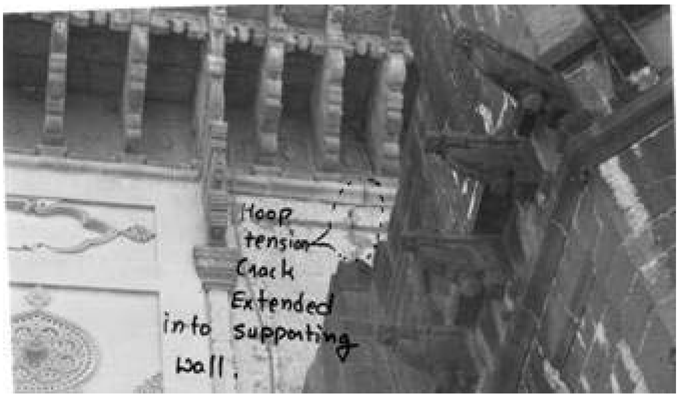


Figure 3 : Showing hoop cracks developed in vertical walls.

Figure 4 : Hoop cracks in radial direction all around terrace (Base of main dome).

Figure 5 : Showing hoop cracks developed in dome (inner side).

The analysis results shows the maximum hoop tension at the 6.5 meter level where the hoop tension crack is observed in dome from inner side as shown in picture 3. The same cracks are extended to the floor and then to the supporting wall as shown in picture 4. External side of the dome is covered with the Ferro cement /reinforced concrete [2] and hence the cracks are not much visible from out side of dome.

Other opinions are also published [2] about cracks in Golagumbaz. As per CHS News Letter and Construction History Society 'Masonry, like all materials will expand and contract with changes in its temperature. A structure composed of small elements of stone or brick in a lime mortar will move as a result of thermal changes, but generally the cracks that result will be spread evenly over the whole of the structure and consequently small in size. A large monolithic structure will tend to produce larger cracks that concentrate along lines of weakness. This seems to have been the cause of the radial cracks to the dome of the Golagumbaz. The Author does not agree with above reason; as the cracks are present only in specific region that is at 4 to 10 meter from terrace level. This region is as per analysis comes under hoop tension. Only possibility is aggravation of the cracks due to temperature effect; which should be considered. This effect of aggravation of cracks or hoop tension due to temperature effect is documented by Heyman (Maini 2003).

4 CONCLUSIONS

Bijapur dome is still stable and only fails in serviceability condition. This verifies the philosophy of dome getting converted into number of arches with crown portion as the keystone (Maini 2003).

This indicates that the hoop tension occur in Golagumbaz is just within limit to produce hair crack in the structure and not sufficient to produce the failure. The tensile strength of masonry limit can be set as tension observed in Golagumbaz i.e. 100 KN/m^2 as permissible tension for primary design in masonry dome. This value will change depends upon the masonry detailing and mortar used for final design calculations.

Authors are involved in designing of Masonry Pagoda where one small Pagoda is already constructed with dome diameter of 14.20 meter without tension ring with similar magnitude of hoop tension and it is found safe.

In Authors opinion the tension rings or buttresses should be provided in large span Masonry domes; specifically to hemispherical domes. The structure like Gol Gumbaz, Bijapur can now also be provided with the tension rings after cracking to increase the life of structure and to avoid any accidents. The notable example in this regard is that of St. Peter Church wherein the cracks started aggregating and the chains are added afterwards and that stood the taste of time.

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