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Seismic Vulnerability Study of Historical Monuments : An Analytical Study of Gol Gumbaz

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ABSTRACT: Natural disasters like earthquakes which cause heavy losses to man and material have attracted much attention in the recent times. The emphasis on regional identity, appreciation of cultural diversity, the growing tourism industry and general thrust on disaster preparedness have increased the attention being paid to the conservation of valuable historical architectural monuments all over the world. Seismic vulnerability studies and proactive measures to contain impending damage becomes highly relevant in this context. This paper presents the results of a three dimensional analytical study on seismic performance of the world famous Islamic mausoleum "Gol Gumbaz" using IS 1893-2002 Response Spectrum. Results of the ana-

1 INTRODUCTION

Heritage reveals the age-old cultural, social and architectural practices of a country. India has a rich heritage which stretches back to an unbroken sweep over 5000 years. These ancient Indian heritage artifacts in the form of Rock cut caves, Palaces, Tombs, Buddhist Stupas, Mosques, Victory pillars & minarets, Temples and Forts stand testimony to her political, architectural, social and cultural history. The recent times have witnessed large number of natural disasters viz, earthquakes, cyclones, tsunami's etc which have caused heavy damage to people and heritage monuments alike. In this scenario, it is imperative that attempts have to be made to take steps to conserve these monuments for posterity. It is therefore desirable to identify important heritage monuments particularly in the seismically active regions in the country and analyze their vulnerability to natural disasters, so as to initiate proactive measures for conserving the same.

2 SEISMIC ACTIVITY IN THE INDIAN SUBCONTINENT

More than 50 per cent of the Indian sub-continent is prone to damaging earthquakes. While the North-eastern region of the country including the Himalayan belt and Kuchh in Gujarat fall under Zone V and are susceptible to great earthquakes of magnitude 8.0, other regions such as the Indo-Gangetic plains and peninsular India are also prone to damaging earthquakes as proved by Koyna (1967), Latur (1993) and Jabalpur (1997) earthquakes. In Zone IV the damage was restricted to 50 per cent monuments while in the Zones III and II, 11 per cent of the monuments have been harmed by the earthquakes.

Further, the warning of experts regarding a great earthquake being 'overdue' in the Himalayas, combined with the unpredictability of earthquakes itself as revealed by the Latur stable continental region(SCR) earthquake of magnitude of 6.3(1993), with its epicenter in the aseismic Zone I, points out that seismic vulnerability studies of all important heritage monuments are essential even when not located in known seismically active areas so as to enable necessary proactive measures.

3 RELEVANCE OF THE STUDY

Gol Gumbaz, the chosen monument of study is an Islamic mausoleum located at Bijapur in the Northern Karnataka state in India. Karnataka situated on the Deccan plateau at an altitude of 305–915 m falls in Zone I, II and III which include zones with no earthquake risk, low risk and moderate risk respectively. Yet Bijapur in Northern Karnataka situated close to Maharastra border has experienced the tremors from both the devastating Latur earthquake1993 and the Koyna earthquake 1967 with magnitudes of 6.3 and several others with magnitudes of 5. The more recent ones in Koyna on March 14, 2005 with a magnitude of 5.4 and the Koyna-Warna region earthquake on April 17 2006 with a magnitude of 4.4 have raised concern among experts and public regarding the seismic safety of the region. Recent studies have identified several active faults in this region, particularly the coastal plain leading to seismologists demarcating quake-prone zones afresh, categorising most of the Konkan belt and north Karnataka under the moderate risk zone number three. A mapping for seismic activity prepared by the Union Government along with the United Nations Development Programme also put Karnataka in the high seismic zone classification along with Tamil Nadu and Andhra Pradesh. In response, the Government of Karnataka has already initiated steps to set up centres to monitor seismic activities and minimise risk in this regard. It is in this context that a study on Gol Gumbaz an important historical structure, roofed with the dome covering the largest uninterrupted floor space in the world (approx. 1833sq m) is being undertaken.

3.1 The Gol Gumbaz

Built by Muhammed Adil Shah, the seventh ruler of Adil Shah dynasty in 1656 AD, the Gol Gumbaz has a simple square plan of 41.5 m inside and 62.5 m outside with four confining lofty walls 3m thick rising to a height of 33.5 m. Externally the tomb is a massive cube, with octagonal seven storied buttress towers of diameter 7.6 m topped by small rounded domes projecting at the four corners, the whole rising to a height of 45.7 m. The tomb has an approximate total height of 67m. The hemispherical dome over the square chamber with an inner diameter of 38.1 m and external diameter of 44 m was supported using the method of intersecting arches. The hemispherical brick dome with an average thickness of 3m was constructed of concentric over-sailing layers of brick masonry cast in concrete of a mix of ballast and rich lime mortar.

4 MATHEMATICAL MODELLING OF BASE AND DOME

An analytical study of Gol Gumbaz has been carried out to assess its seismic performance. A three dimensional analytical model of the same has been developed and its behavior has been assessed by subjecting it to a Response spectrum analysis. The Response spectrum used for analysis was IS 1893-2002.

4.1 Assumptions in Modelling:

1. All joints are assumed to be rigid.
2. Each node has six degrees of freedom.

4.2 Analytical Model Description:

The model is created in two stages:
1. Modelling of the square base
2. Modelling of the dome.

4.3 Modelling of the square base:

Each side of the square base is divided into three equal portions using the frame elements. In between these divisions, walls are modeled as plates of thickness 3 m, both in bending and in membrane action. The frames are modeled as square sections of 3m x 3m in cross section. The alternate frame elements are connected as shown in Fig. 1 below.

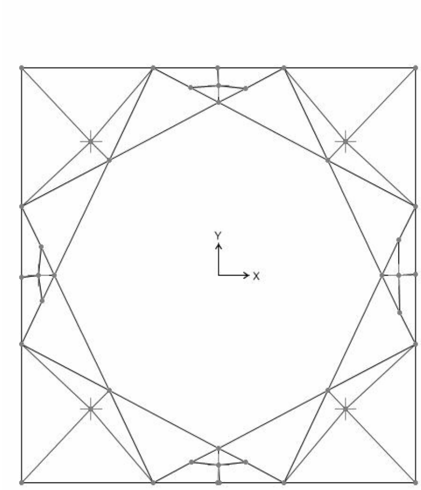


Figure 1 : Plan of the Analytical Model

The arch system in the real structure is modelled as a plane frame to predict the highest vulnerability of this structure to seismic action. The minarets are modeled as hollow tube sections and are rigidly connected to the wall sections to give an abutting effect. Assuming a medium soil condition, the foundation is modeled as a hinged base.

4.4 Modelling of the Dome.

The dome is modeled using the dome template from the SAP 2000 Modelling menu .The dome sections are modeled as shell elements of thickness 3 m. The dome is assumed to be hinge connected to the square base. The three dimensional analytical model is as shown in Fig. 2 below.

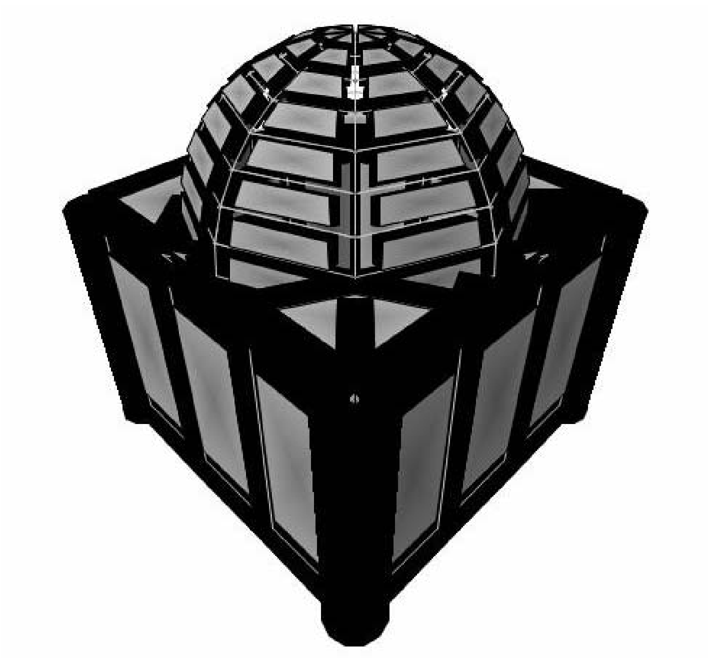


Figure 2 : 3D Model of Gol Gumbaz

5 ANALYTICAL STUDY

5.1 Design Seismic Action

Design Seismic actions are by definition the earthquake actions which in combination with the rest of the dead loads and live loads determine the limit state of the structure. Within the scope of IS 1893-2002 the earthquake motions for the calculation of design seismic action at a given point of the surface of the earth is presented by an elastic ground acceleration response spectrum shown in Fig. 3 below.

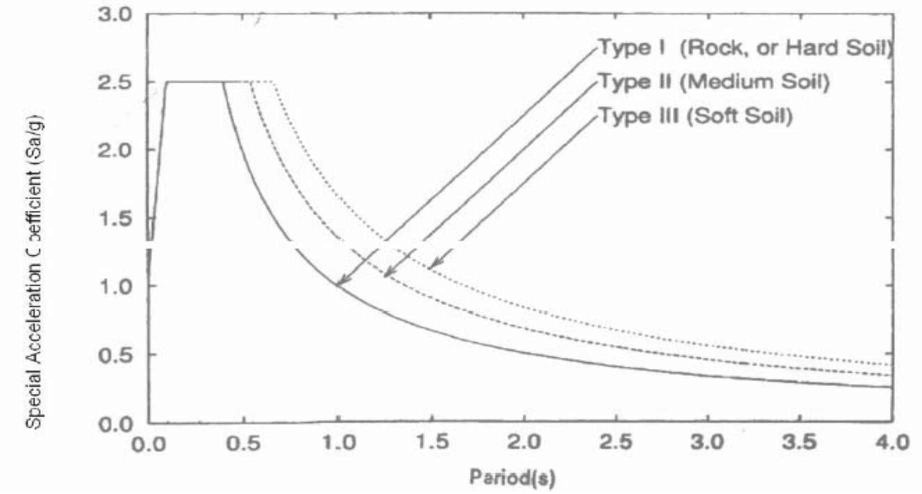


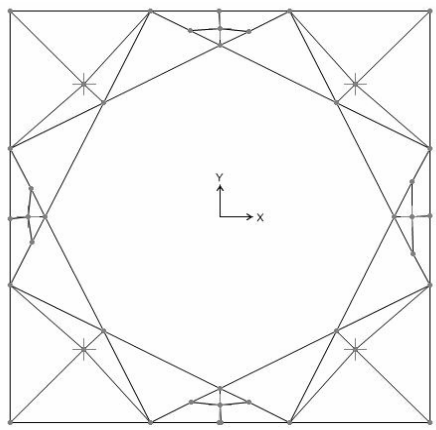
Figure 3 : IS 1893 2002 Response Spectrum

For Medium soil sites as per IS 1893 the equations for the curves are:

$$
Sa/g = \begin{cases} 1+15T, & 0.00<T<0.100 \\ 2.50 & 0.10<T<0.55 \\ 1.36/T & 0.55<T<4.00 \end{cases}
$$

5.2 Analysis

Gol Gumbaz being a symmetrical square structure, earthquake forces are only considered to be acting from one directon ie., +X direction. In the plan shown in Fig. 4 below, if the force is considered to act only in +X direction, then it is apparent that the two walls will be subjected to out of plane seismic action and the other two walls will be subjected to in plane seismic action.



Figue 4 : Plan of the model

6 MODELLING APPROACHES

As an attempt to predict the highest vulnerability two modeling approaches are experimented. In the first case the entire four wall segments are discretized into small four noded plate elements each having an approximate area of 4.634 m^2 and subjected to seismic action. In the second approach, the out of plane walls are dicretized into small four noded elements of area 4.634 m^2 but the in plane walls are modeled as single massive panels of thickness 3 m depicting a shear wall effect. These panels are rigidly connected to the discretized wall panels through the minarets. This modeling approach is justified by attributing infinite rigidity to the in plane wall elements.

7 RESULTS AND DISCUSSIONS

A three dimensional analysis of the structure is carried out using SAP 2000 and the results are presented.

7.1 Modal Periods

The first modal response of the structural model is assessed and the modal periods are recorded below separately for both the modeling approaches.
a. Modal period and mode shape for the first approach is as shown in Fig. 5 below. The modal period was found to be 0.9991 seconds.

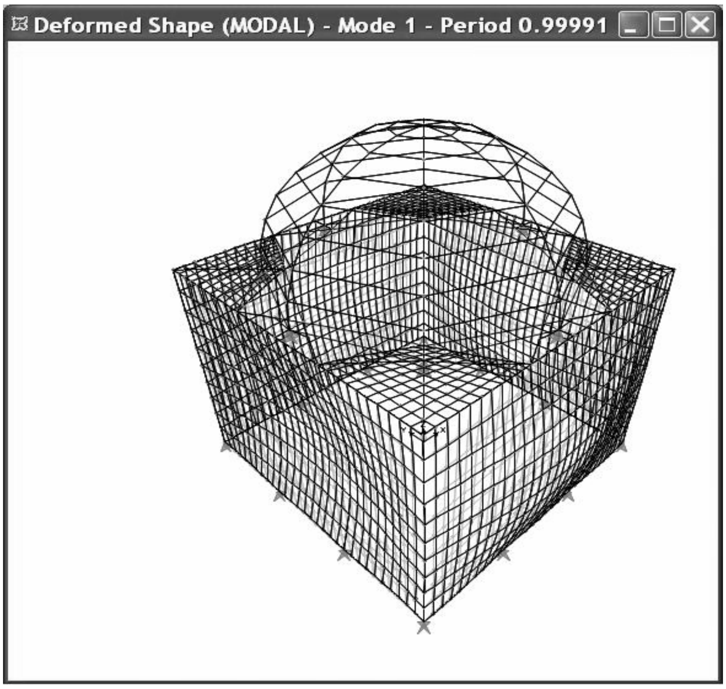


Figure 5 : Mode 1 Deformation of fully Discretized model

b. Modal period and Mode shape for the second approach is as shown in Fig. 6 below. The modal period was found to be 1.08 seconds.

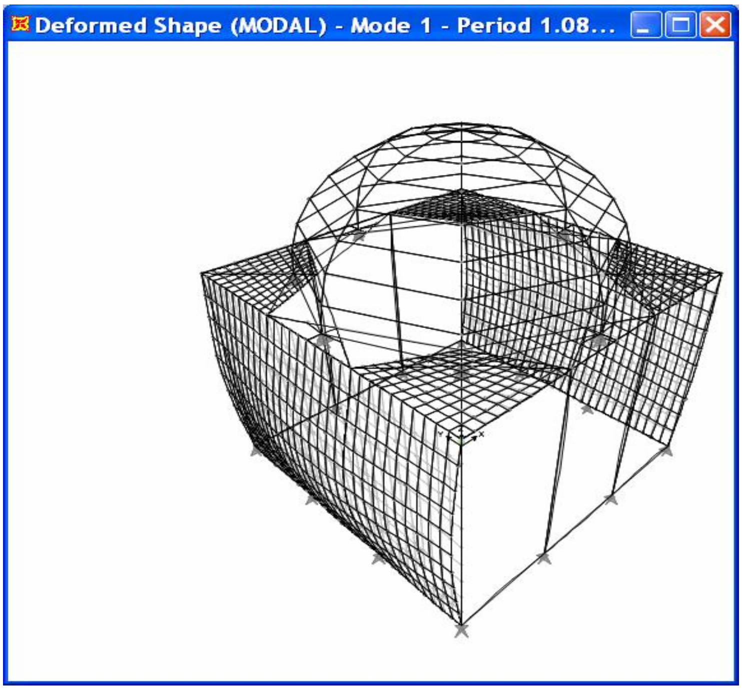


Figure : 6 Mode 1 Deformation of partly discretized model

8 CONCLUSIONS

The seismic vulnerability of the first modeling approach was found to be higher since the modal period for the first approach was lower than that of the modal period of the second approach. The results of the first approach which seems to appropriate real life conditions more closely may hence be used for devising appropriate proactive measures.

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