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Finite Element modelling of 'Rang Ghar' monument, Assam

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Abstract: This paper presents the results of static and dynamic analyses of the masonry monumental structure 'Rang Ghar' constructed during the Ahom dynasty (1744-1751 AD) in Sibsagar district of Assam, India, using the commercial finite element (FE) software, Abaqus (2010). Rang Ghar is a two storied masonry monumental structure of 12 meter height, with a dome type roof, thick masonry walls and a series of arch openings at both floors. The static analysis shows that, in general, the structural configuration of the masonry complex is adequate to withstand gravity loads (self weight and live load). Most stressed region is the entrance arch walls at the ground level with a maximum value of compressive stress of about 0.45 MPa. Also, displacement resultant distribution suggests that a maximum displacement of around 0.94 mm at top arch roof. Based on the dynamic analysis, first three mode shapes of the Rang Ghar have been presented.

Keywords: Ran Ghar, FE Modelling, Static and Dynamic analysis, Modal Analysis.

I. INTRODUCTION

North-East India is seismically one of the most active regions of the world. The Indian Standard code of practice [8] identified north-east India, including Assam as a highly seismic zone by placing it in the highest zonal level i.e. zone V. The northeastern part of India has an exceptionally complex tectonic and geologic setup. It has the Himalayan mountain belt in the north, Mishmi hills in the west, Naga Patkoi mountain range in the south, and the Brahmaputra plain at the middle, along with the Shillong Plateau, the Burmese arc, the Tripura folded belt, and the Surma Valley, that makes this region among most seismically active regions of the world [15,19]. In the literature [2, 5] it is reported that the first known historic event for Northeastern region occurred near Guwahati around 825-835 A.D. (Mw ~8.0). [11] provided a list historical earthquakes, prior to 18 century A.D. Damages due to two major earthquakes i.e., the 1869 Cachar and the 1897 Great Assam earthquakes were well documented in [16,18]. As much as 18 large earthquakes (Mw > 7) have occurred in the recent centuries including the great earthquakes of Shillong (12.06.1897, Mw 8.7) and Assam-Tibet border (15.08.1950, Mw 8.6) [12, 15, 17]. Hence, it has become pertinent to assess the structural behaviour of landmark historical masonry monuments such as Ranghar, Kachari palace, Ahom Raja palace, Ghanashyam's house, Karengghar, etc., both due to static and anticipated earthquake loads. Many of these monuments have shown signs of damages due to material ageing, soil settlement etc., in addition to the possible earthquake effects. High seismic vulnerability historical structures can arise, both to the particular configuration (often characterized by open space, slender walls, lack of effective connections among the structural elements) and to the mechanical properties of masonry material (highly nonlinear behaviour and very small tensile strength) [3]. Structural analyses using state of art FE approach would enable to identify repairs and retrofitting techniques. Hence, in the present study, an attempt has been made to conduct static and dynamic structural analyses of an old masonry structure 'Ranghar' by employing finite element analysis using Abaqus [1]

II. DESCRIPTION OF RANGHAR

Rang Ghar is a two storied royal pavilion of Ahom kings with unique architectural features. The amphitheatre of

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Ahom Kings, situated by the side of NH-37 (opposite to the Kareng ghar), is a brick masonry, two storeyed, oval shaped structure, constructed in the year 1745 A.D. for the purpose of witnessing games, sports, animal fights etc. by the members of the Royal family. This monumental building is a 12 meter high masonry structure with a parabolic type roof which is supported by rows of massive columns and semi-circular arches. Figure 1 shows front elevation of the monument [20].

Figure 2 shows the octagonal plan layout of the building. The plan comprises of rectangular shape of 21m x 10.7 m sides annexed with trapezoidal ends of 10.7 m x 4.5 m x 5 m x 4.5 m sides. The length of the monument is around 27m and width is over 10.7 m. The base of the monument has a series of five arched entrances on either side of the plan. The arch length of these entrances varies from 1 m to 2.9 m with a maximum opening at middle entrance. The arched entrance extends to a length of 2.4 m inside the structure. The base of the structure is subdivided into 3 separate chambers from inside, interconnected with arched gateway of height 4.5 m and length 1 m. Also, these chambers have a roof of dome shape with a maximum height of 5.6 m in the middle chamber and 2.7 and 3.5 m height respectively of chambers located on either side of middle one. The first floor of the Rang Ghar is quite similar with the ground floor with an exception of an extra arched window at each of the four trapezoidal slant sides with a height of 0.9 m and length of 0.8 m extruded inside up to 0.5 m.

Figure 1. Rang Ghar [20].

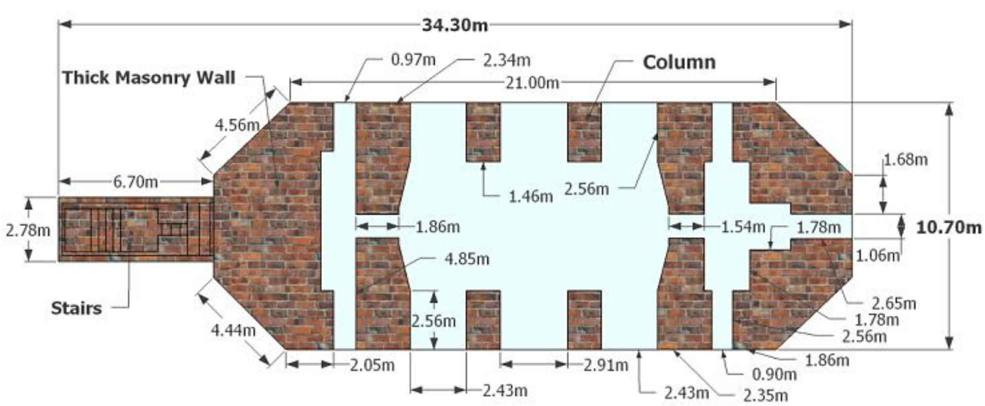

Figure 2. Plan layout of the building

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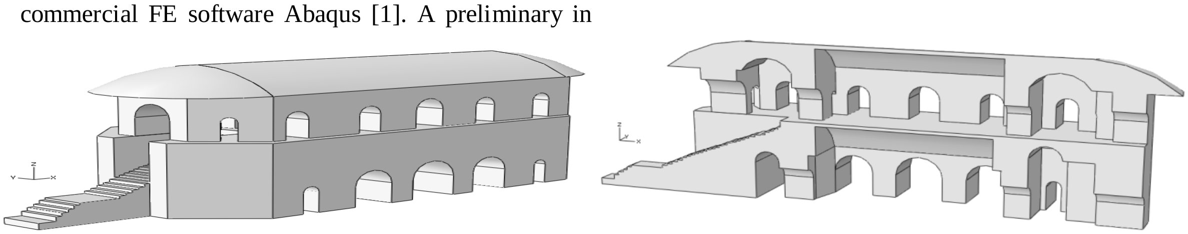
The front part of the structure has a series of around 25 stairs extending to 6.70m. The outer walls of this pavilion are beautifully curved with geometrical and floral design.

III. FINITE ELEMENT MODELLING

The analysis of the static and dynamic behaviour of any masonry buildings is a difficult task due to several aspects: the difficult numerical modelling of the nonlinear behaviour of masonry material, with almost no tensile strength; the incomplete experimental characterization of the mechanical properties of masonry structural elements; the complexity of the geometrical configuration [13]. Although, a complete three-dimensional (3D) non-linear behaviour of the masonry material can be conducted by the mechanical models proposed in the literature [7] it is however difficult and computationally expensive considering the complex structural systems with large number of degrees of freedom required for meshing the structure. Hence, in this study an initial step is attempted considering linear elastic analysis as adopted by various researchers [14]. A preliminary linear elastic static and dynamic analysis of the 3D structural complex provides valuable information on the global behaviour and on the interaction among the single elementary parts, which constitute the structure. The overall structure is analysed in the linear range to overcome the complexities, with the aim of characterising the static and dynamic behaviour, defining the internal force distribution and identifying the weak points of potential failure in the building.

3.1. Finite element description

The 3D finite element model is built using the commercial FE software Abaqus [1]. A preliminary in situ survey of the masonry complex during September, 2012, was made to obtain basic information on the geometry, configuration, the structural details and any irregularities. This investigation also aimed at characterization of masonry texture. A near-real numerical model has been built to accurately reproduce the geometry of the structure complex, focusing on the variations in the arch dimensions at various openings, wall thickness and structural irregularities. Interior roof at ground floor and first floor are assumed to be semi-circular to simplify the model, while in real, they have trapezoidal roof geometry. This approximation is done to remove the complexity in the modelling and make the analysis easier. Figure 3 (a) shows the geometrical model of the masonry structure. Since, the masonry complex is symmetrical about the longitudinal x-axis; only half of the structure has been firstly constructed using Abaqus [1], next the mirror part has been replicated before joining two symmetrical parts to reproduce the geometry of the complex structure. Figure 3 (b) shows the cross section of the geometrical model which indicates all elements and arches within the structure is adequately represented in the mathematical model. Figure 4 shows the 3D mesh model consists of 24038 nodes and 112902 C3D4 elements. C3D4, a 4-noded tetrahedral element is adopted for this model, due to the complex geometry of the monument, and to avoid mesh distortion (see e.g. [4]). [6] concluded that the results obtained with quadratic tetrahedral elements, provide acceptable accuracy and convergence characteristics and are also comparable in terms of both accuracy and CPU time, compared to other elements. Fixed boundary condition is applied to the base of the finite element mesh.



(a) (b)

Figure 3. (a) Geometrical model of the masonry structure; (b) Longitudinal Cross section of the model

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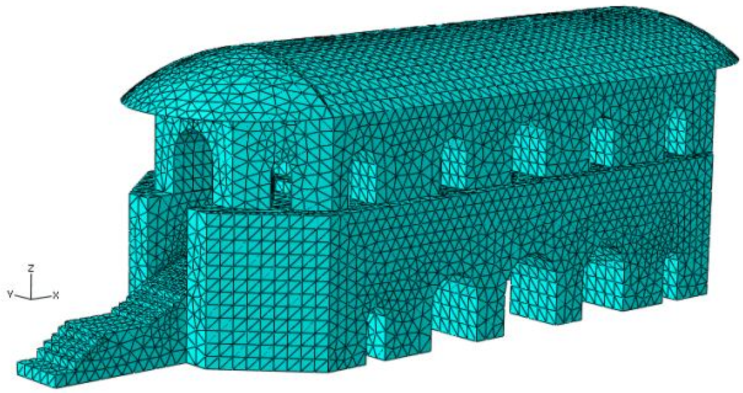

Figure 4. Finite Element Mesh (24038 nodes and 112902 C3D4 elements)

IV. LINEAR STATIC ANALYSIS

The static structural behaviour of the masonry monumental structure has been analysed under constant vertical loads deriving from the own weight and from the live load of 4 kN/m^2 according to the Indian standard IS: 875 (Part 2)-1987 [10] under occupancy classification of Assembly building that includes museums and art galleries. Linear elastic material behaviour is used in the analyses. The overall structure has been analysed in the linear elastic range with the aim to obtain valuable information on the global behaviour and on the interaction between different parts which constitute the structure and to identify (if present) the weak points of potential failure in the structure. A crucial task in masonry building modelling is the evaluation of the mechanical properties. In the absence of the actual experimental material properties, based on the material elastic properties used by researchers available in literature for masonry type structure and mass density values for Lime mortar from 1600 to 1840 kg/m^3 and 1920 kg/m^3 for masonry brick mentioned in Indian Standard IS: 875 (Part 1)-1987 [9], values assumed in this study are: Young's modulus, E equal to 2100 MPa, Poisson modulus, ν equal to 0.2 and mass density, ρ equal to 1800 kg/m^3. Results of the static analyses on the 3D masonry model in terms of von-Mises stress distribution are reported in Figure 5.

Moderate von-Mises stresses are induced on the structure by the static vertical loads. Maximum value of compressive stresses is obtained on the entrance arch wall at ground level is about 0.45 MPa. Low value of compressive stress appears on the thick interior masonry walls at first floor whereas significant compressive stresses of about 0.3 MPa are seen on the thick interior masonry walls at ground.

Displacement resultant distribution may be of more interesting than the local value of the stress resultant distribution. Results of the static analyses on the 3D masonry model in terms of displacement resultant are reported in vertical directions in Figure 6. The maximum value of the displacement is reached close to the arch roof at top is around 0.94 mm, although it is very less deformation.

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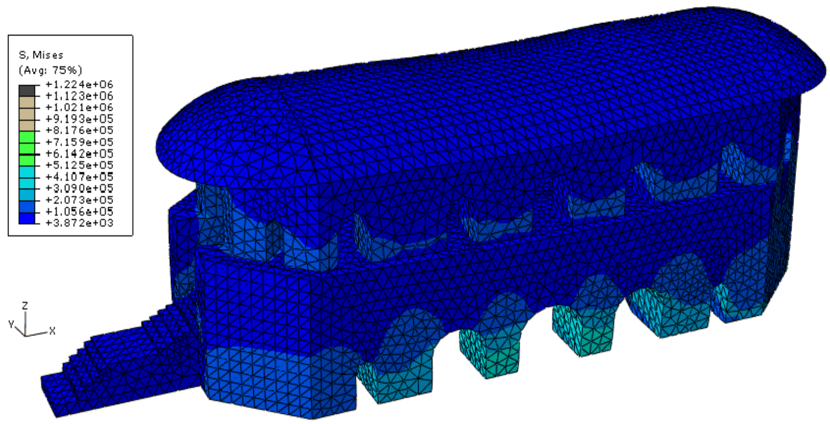
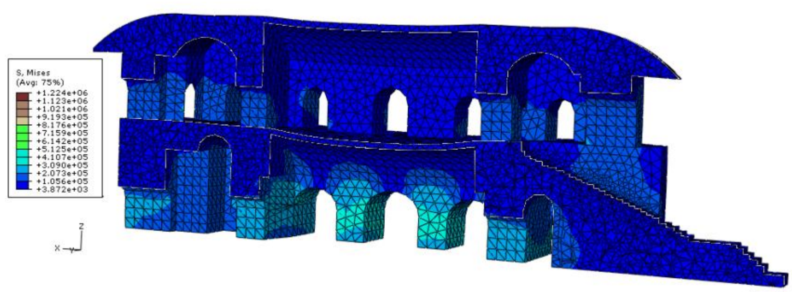
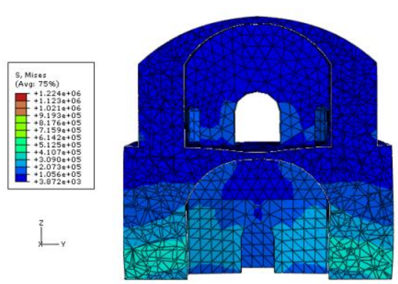


(a)





(b) (c)

Figure 5. (a) Von-mises stress distribution in N/m^2; (b), (c) cross section view of 3D model.

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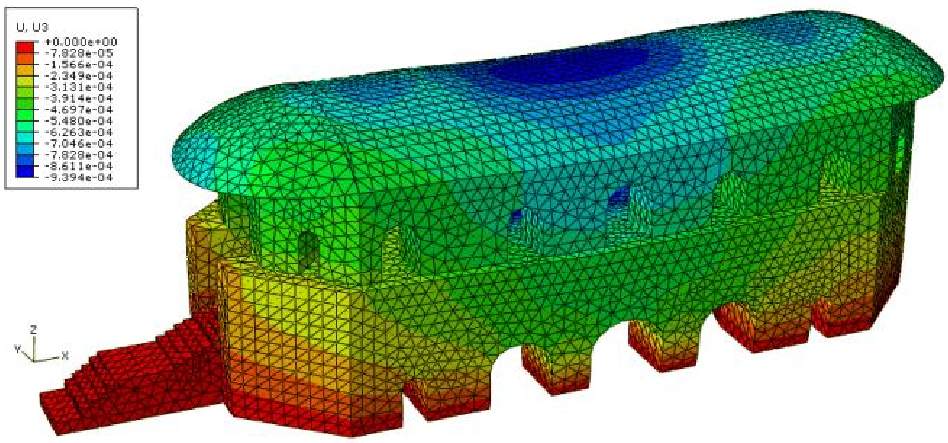

Figure 6.Vertical Displacement (m)

V. MODAL ANALYSIS

The 3D numerical model has been used to assess the modal behaviour of the masonry structure, through dynamic analysis. The period and modal shapes of the 3D FE models are provided in Figure 7. Frequencies of the first three natural modes are shown in Table 1. Modal analysis of the building is performed using block Lanczos method with fixed boundary condition at the base of the building. The first and second modes are translation in transversal and longitudinal directions with fundamental period of 8.42 Hz and 10.63 Hz respectively. The third mode is a torsional mode with a period 10.91 Hz. Figure 7c shows the torsional mode shape of the building which is a combination of the transversal and the longitudinal structural elements. The higher modal shapes of the masonry structure are combination of transversal vibration mode and torsional mode. The distribution of the modal shapes demonstrates that the masonry complex has significant deformations of the elements due to low transversal and torsional stiffness.

Mode	Frequency (Hz)
1	8.42
2	10.63
3	10.91

Table 1. Frequency of the first three natural modes.

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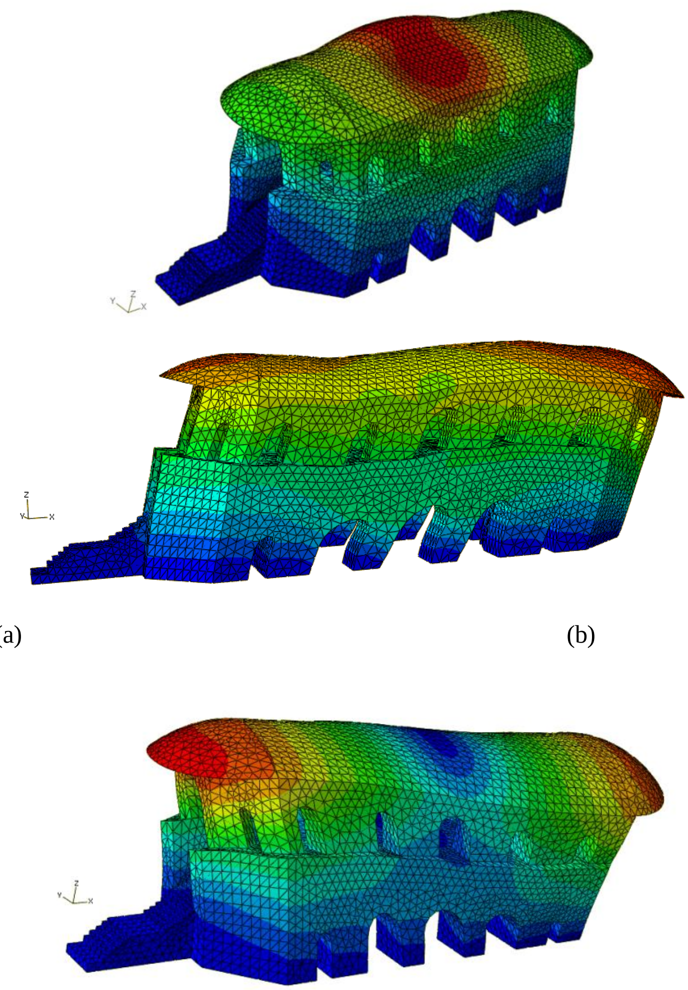

(a) (b)

(c)

Figure 7. (a) First mode deformed Shape (8.42 Hz); (b) Second mode deformed Shape (10.63 Hz); (c) Torsional mode deformed Shape (10.91 Hz)

VI. CONCLUSION

The paper approaches the assessment of the static and dynamic behaviour of a masonry monumental structure ‘Ranghar’ through a finite element methodology. A numerical model has been used to evaluate the static behaviour of the masonry complex under gravity and live loads. The static analysis shows that, in general, the structural configuration of the masonry complex is adequate to withstand vertical loads; the most stressed elements are the arch walls at the ground level with a maximum value of compressive stress of about 0.45 MPa. Also, displacement resultant distribution suggests that the maximum displacement of around 0.94 mm will occur at top arch roof. Based on the dynamic analysis, first three mode shapes of the Rang Ghar have been presented.

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REFERENCES

[1] Abaqus, Version 6.9-EF1, (2010), Simulia, Providence, RI, USA.

[2] Banerji, R. D., (1923), Annual report, Archaeological Society of India, 80-81, New Delhi.

[3] Betti M., Vignoli A., (2008), Modelling and analysis of a Romanesque church under earthquake loading: Assessment of seismic resistance, Engineering Structures 30 (2008) 352–367.

[4] Casolo S., Sanjust C.A., (2009), Seismic analysis and strengthening design of a masonry monument by a rigid body spring model: The ``Maniace Castle" of Syracuse, Engineering Structures 31 (2009) 1447-1459.

[5] Chaudhury, P. D., (1964), Archaeology in Assam, Department of Archaeology, Gauhati, India.

[6] Cifuentes, A.O., Kalbag, A., (1992), A performance study of tetrahedral and hexahedral elements in 3-D finite element structural analysis, Finite Elements in Analysis and Design, 12 (1992) 313-318.

[7] Grimaldi A, Luciano R, Sacco E., (1992), Nonlinear dynamic analysis of masonry structures via FEM. In: Computing methods in applied sciences and engineering, Nova Science Publishers; 1992. p. 373–82.

[8] IS: 1893-Part I, (2002), Indian standard criteria for earthquake resistant design of structures, fifth revision, part-1, Bureau of Indian Standards, New Delhi.

[9] IS: 875-Part 1, (1987), Code of practice for design loads (other than earthquake) for buildings and structures: Dead loads, Bureau of Indian Standards, New Delhi.

[10] IS: 875-Part 2, (1987), Code of practice for design loads (other than earthquake) for buildings and structures: Imposed loads, Bureau of Indian Standards, New Delhi.

[11] Iyengar, R. N., (1999), Earthquakes in ancient India, Current Science, 77, 827-829.

[12] Kayal, J. R., (2008), Microearthquake seismology and seismotectonics of South Asia, Capital Publishing Company, New Delhi.

[13] Lourenco PB., (2002), Computations of historical masonry constructions, ProgStructEng Mater 2002;4(3):301–19.

[14] Mele E, De Luca A., (1999), Behaviour and modelling of masonry church buildings in seismic regions, In: Proceedings second international symposium on earthquake resistant engineering structures.

[15] Nandy, D.R., (2001), Geodynamics of Northeastern India and the Adjoining Region, 1st edition, ACB Publications, Kolkata.

[16] Oldham, T., (1882), The Cachar earthquake of 10th January, 1869, Geological Survey of India Memoirs, 19, 1-88.

[17] Oldham, T., (1883), Catalogue of Indian earthquakes, Geological Survey of India Memoirs, 19,163-215.

[18] Oldham, R. D., (1899), Report on the great earthquake of the 12th June 1897, Geological Survey of India Memoirs, 29, Reprinted, 1981, Geological Survey of India, Calcutta, 379.

[19] Pallav K., (2010), Seismic microzonation of Imphal city and probabilistic seismic hazard assessment of Manipur state. PhD thesis, Indian Institute of Technology Guwahati.

[20] Wikipedia (2013), http://en.wikipedia.org/wiki/File:Rang_Ghar_Sibsagar.jpg (accessed on 10/10/2013)