

## **Static and dynamic analysis of unreinforced masonry wall using finite element modeling in senate hall building**

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### **ABSTRACT**

The paper is focused on the static and dynamic analysis of unreinforced masonry wall. The masonry wall of senate hall building is constructed with the combination of brick and mortar. The wall thickness varies from 1.5m to 0.6m through ground floor to the second floor. The geometrical plan and elevation of masonry wall is prepared from in-situ survey and old geometrical drawing of the building using AutoCAD design software. The finite element modelling of masonry wall has been modelled from macro modelling approaches on ANSYS simulation software. During gravity analysis of masonry wall, the maximum stress 0.758MPa on first floor stone panel columns and maximum deformation 17.87mm on top of the masonry wall has observed. Dynamic analysis of masonry wall has evaluated the mode shapes and frequencies, first three modal frequency is evaluating 0.703, 0.844, 1.23Hz respectively. Finally, the maximum stress and deformation behavior of FE analysis of masonry wall have compared from the actual behavior of masonry wall of the senate hall building.

**KEYWORDS** Historical Structure; Unreinforced Masonry Wall; In-situ Survey; Finite Element Modelling; Static and Dynamic Analysis; Cracks

### **1) INTRODUCTION**

The unreinforced masonry walls are constructed in old buildings, churches, towers, forts etc., from numerous thickness and heights [1]. The masonry material is utilized for infill walls, retaining walls, monuments and bridges, since long. Although this material has been replaced by steel and concrete in the 20<sup>th</sup> century, masonry buildings are still mainly used now for residence, educational buildings, and industrial constructions [2-4]. A commonly typical structure of masonry wall is frames with masonry infill wall which is still used around the world even in the highly seismic regions [. As a result, it is needed to identify much further behavior of unreinforced masonry wall. Masonry is a composite material consists of clay brick or concrete block and mortar [1]. There are many advantages of using it as building materials. Masonry wall also has a good behavior under vertical compression loading. However, despite of those advantages, masonry construction is vulnerable at resisting in-plane lateral loading such as seismic loading which caused by earthquake and wind loading. It is due the weakest element in masonry, the mortar connection between the brick units. Consequently, further research requires investigating the stress and deformation response of masonry wall subjected to own weight and wind loading [5-8]. It is essential to conduct a study of masonry wall itself to investigate the maximum capability of the wall to resist lateral horizontal loading before its failure. Furthermore, this study can lead to the development of proper retrofitting measures for masonry buildings and can be applied to new construction to expand design guidelines. It became an urgent need as existing masonry structures especially ancient building which collect the cultural heritage located on the seismic region around the world. There has been 40 years ago that many researchers have conducted on study of masonry panels subjected to lateral loading, but it is still limited research on unreinforced masonry (URM) wall with more than one opening [9]. As masonry building typically constructed with door and window openings, it is also need to identified behavior of the wall between two openings. Large number of study has performed to evaluate the behavior of masonry wall and panels concluded from crack propagation observation on the masonry wall that the collapse mechanism of the wall caused by diagonal shear failures located at piers and the compressed of the toe at the bottom right pier. During the finite model can well capture the behavior of unreinforced masonry wall with openings [9]. Therefore, it is necessary to conduct simulation research of identifying behavior of URM wall with openings under static and dynamic loading [10-14]. The aim of this study is to comprehensively investigate the behavior of URM wall with openings by identification of crack propagation on the wall during the analysis and investigation. The simulation is performed using finite element model of URM masonry wall with openings using a FE software ANSYS Workbench (ANSYS 14.0). In-situ survey of senate hall building investigating the failure crack pattern of the masonry wall. The FE simulation results has compared from actual behavior of masonry wall.

## **2) SENATE HALL BUILDING**

The Senate hall building has been built in 1915 at Allahabad University, India. The building has been constructed load bearing masonry wall. The building has been designed from mix of Mughal and British architecture components, designed by Indo Saracenic architecture style [15,16]. The Senate Hall building, were designed by Sir Swinton Jacob

and their construction was approved in 1910. The foundation of the Senate hall was laid on 17th January 1910 by Sir John Havett, the Chancellor. The construction of the Senate Hall building was commenced in 1910 and they were completed in 1915. The major structural components such as towers, arches, masonry walls, facades, domes, panels etc., has constructed in the building. In building, constructed for large halls, thick wall, arches and thick foundation. The entire senate hall building is built on 1.07m thick foundation base. The building has been designed with thick unreinforced masonry wall and stone arches, these elements is provided from numerous geometrical cross section dimensions such as width and height. The thickness of unreinforced masonry wall is variable from 1.5m to 0.6m due to ground floor to second floor level in senate hall building. The masonry wall of senate hall building is shown in (Fig. 3).

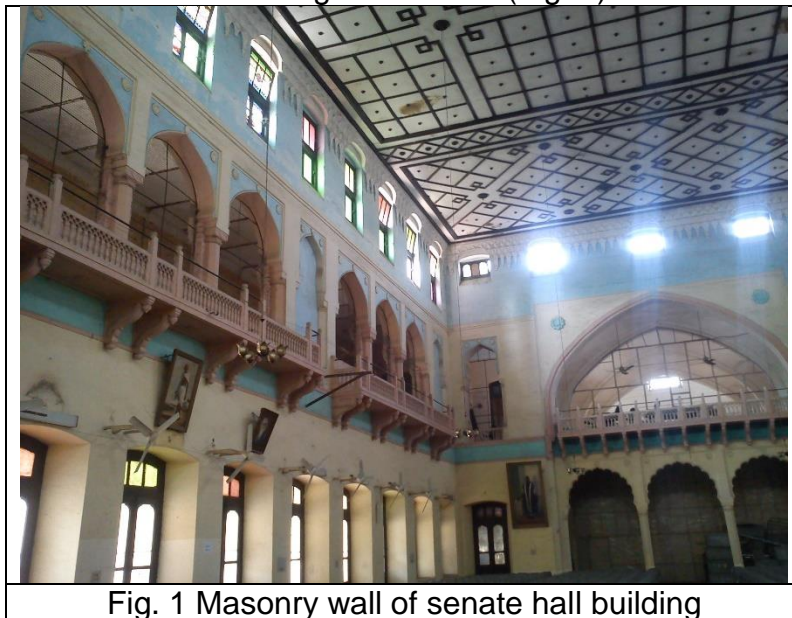
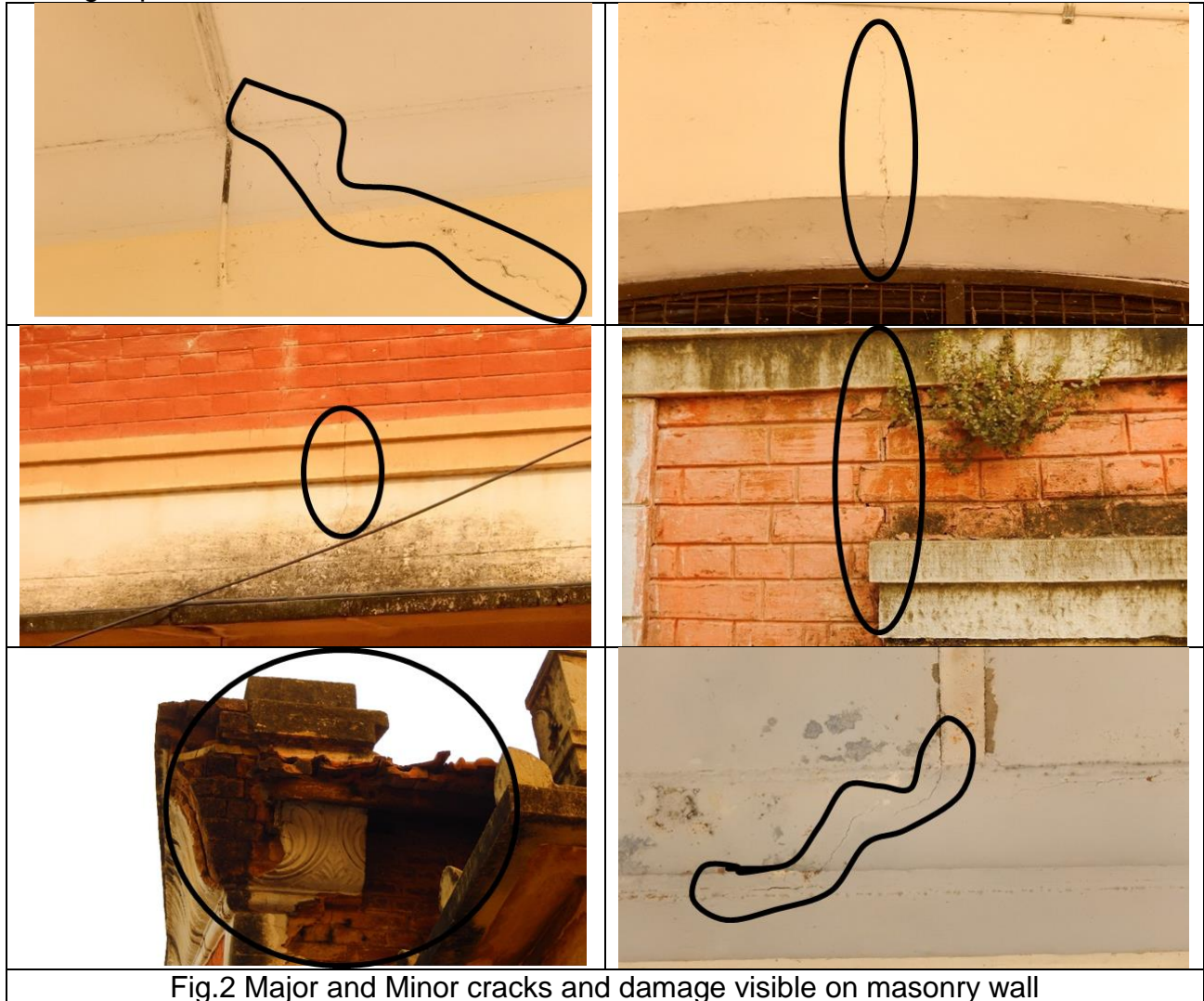


Fig. 1 Masonry wall of senate hall building

### **3) IN-SITU SURVEY OF SENATE HALL BUILDING**

During the survey of senate hall building, visible cracks and damages through ground floor to second floor are observed. The masonry wall is constructed numerous thickness from ground floor to second floor for 1.5m and 0.6m respectively. The masonry wall thickness is similar at first floor and second floor levels. The masonry wall on ground floor and first floor has performed better due to second floor. The minor cracks are visible on doors, windows corner at ground floor level showing in (Fig.2). The plaster material is deformed on ground floor and second floor internal side portion in the masonry wall. The major cracks and damages has observed on first floor stone columns. The stone panel supporting octagonal columns has observed the major cracks and material deteriorated on both end joints. First floor complete panels of both masonry walls have retrofitted from brick masonry construction. The brick wall is constructed with parallel at each octagonal column. The decorating structural components such as balcony portion has closed due to material failure. Second floor portion of masonry wall has visible the major cracks and damaged at

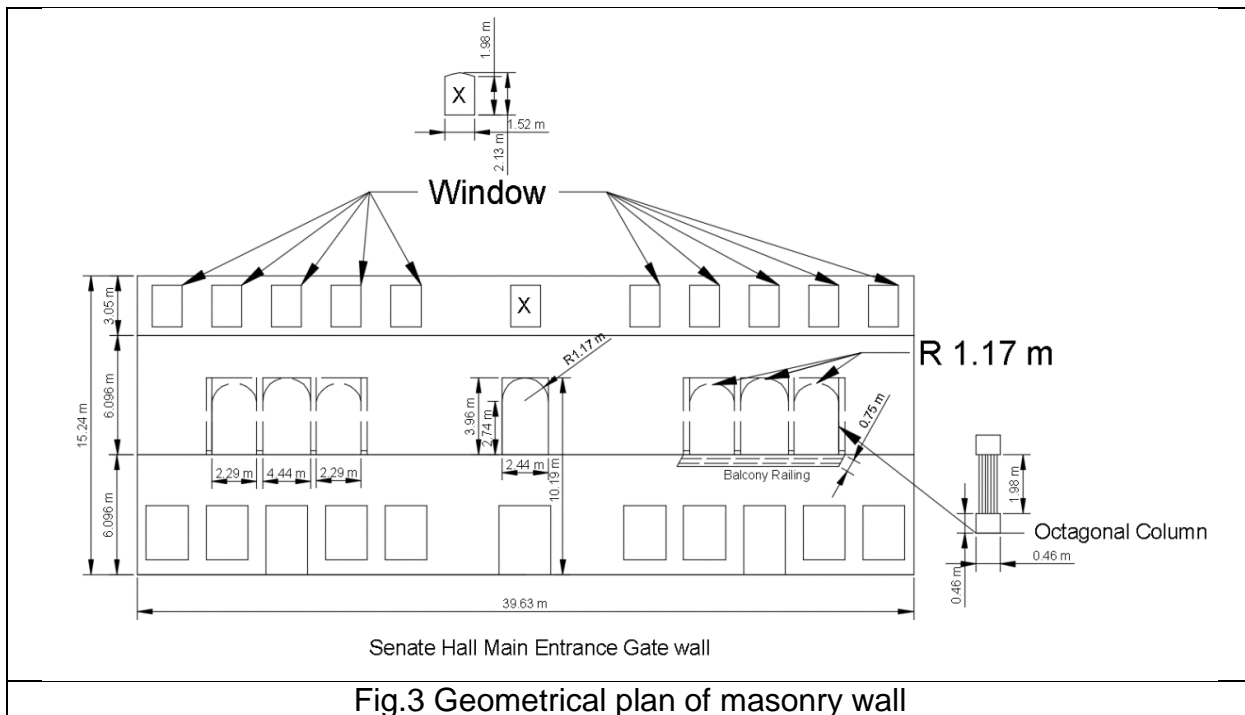
both side. The masonry wall has protected in thick plaster material from internal side but outer side wall has constructed without plaster material. the brick material has deteriorating on complete second floor level. The transverse and longitudinal major cracks have visible on without plaster masonry wall on second floor level. The survey of senate hall building, second floor portion of masonry wall has damages and material deteriorated for continuous time for various factors due to atmospheric effects, rain water and moisture conditions. This portion of senate hall building is argent need to strengthen and retrofitting damages portions.



#### **4) FINITE ELEMENT MODELLING**

The finite element modelling of masonry wall has difficult task for accurate model prepared. The geometrical drawing has prepared due to help of survey, old records and photographs of the building. the drawing is built in auto cad design software shown in (Fig.3). The

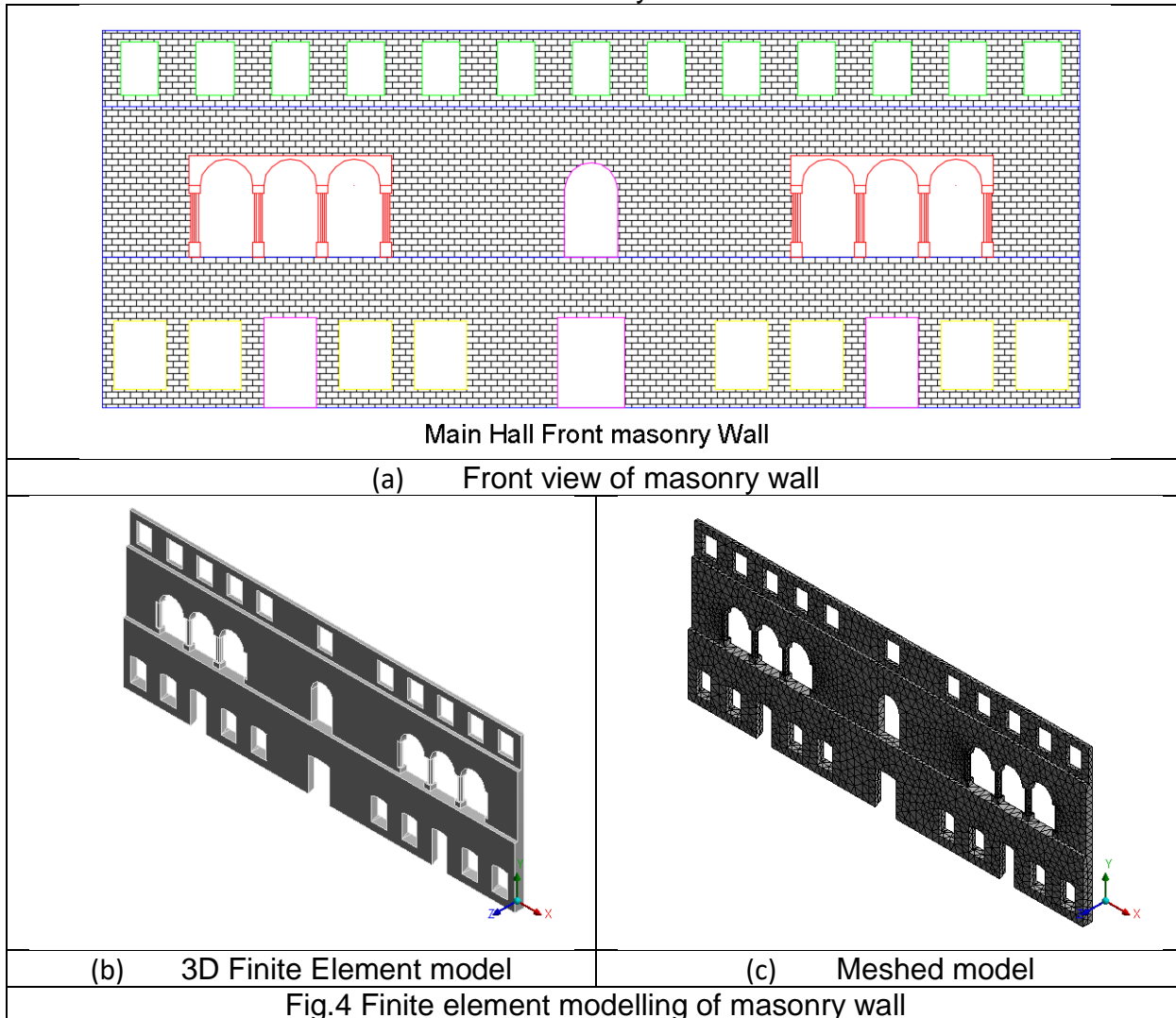
masonry wall has constructed for continuous brick (standard brick using 19<sup>th</sup> century ) and thick mortar joints (approx. 25mm side and bed joint). The wall has designed from rectangular shape length 39.63m and height 15.24m with variable thick due to height. the many openings such as doors, windows, arch panels are provided on each floor level. In ground floor has provided eight windows constructed from lofty style with similar dimensions width x height (2.14m x 2.75m at inner dimension and 1.524m x 2.134m at outer dimension) respectively. Three doors are constructed on ground floor level, two doors are similar dimensions (height 3.64m x width 2.1m) and one main door different dimensions (height 3.73m x width 2.7m). In second floor has constructed two arch panels and one door. Each panel are designed three stone arches with similar geometrical dimensions height and radius respectively. First floor door has constructed on middle portion in masonry wall, the geometrical dimension of door (2.44m width and 3.96m height) is directly connected in clock tower. In second floor portion of masonry wall has designed from eleven windows from similar geometrical dimension and construction techniques. Each window has been designed in parallel direction for masonry wall from ground floor to second floor. The geometrical dimension of complete window height 2.13m and width 1.52m respectively.



**Fig.3 Geometrical plan of masonry wall**

The finite element modelling has prepared from finite element software ANSYS workbench (ANSYS 14.0). The masonry portion of the wall is showing in (Fig.4a). In modelling of masonry wall, the macro modelling approaches has been used. The accurate modelling has prepared for masonry wall, the entire openings such as doors, windows, and stone

panels has provided in exact location with similar geometrical dimensions. The 3D finite element model of masonry wall has showing in (Fig.4b). the meshed model of masonry wall has shown in (Fig.4c). The meshing of masonry wall has using 300mm fine meshing has observed 17737 Nodes and 8526 Solid elements. The solid elements are used solid 186 and solid 187 structural elements. The connections are used bounded between masonry wall and stone arches. Solid 186 is 10-noded three degree of freedom and Solid 187 is 20-noded three degree of freedom at each node. The contact 174 and target 170 has been used for connection of two solid body.



## 5) ANALYSIS

The historical masonry structures are analyzed from different methods with numerous finite element software [17-25]. The static and dynamic analysis has been performed on the single structural components of as masonry wall of senate hall building. The analysis

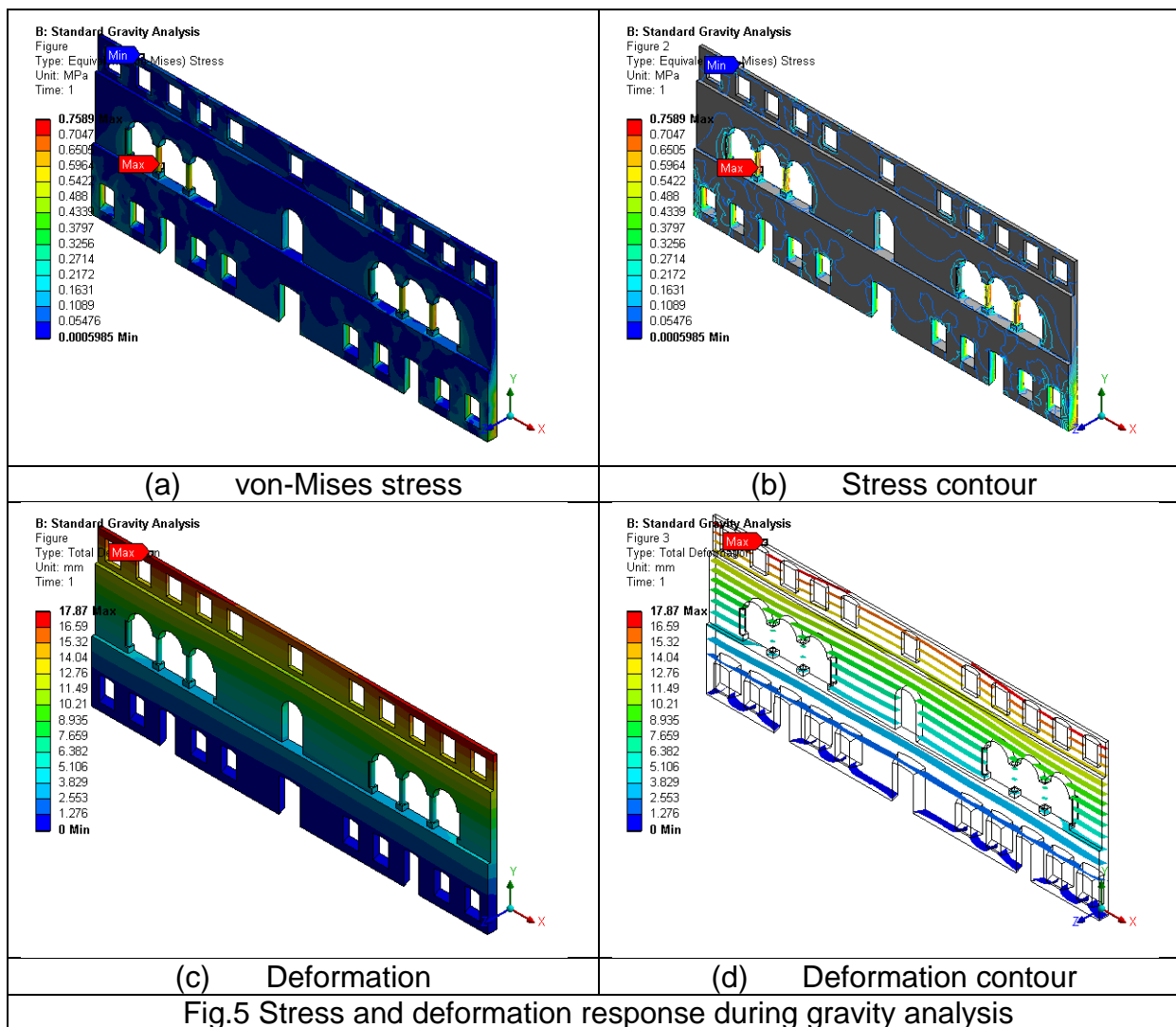
of masonry wall is considered from actual boundary conditions with fixed on base. The material properties are considered for experimental testing, the masonry and stone material such as Density, Young's modulus and Poisson's ratio are evaluated from non-destructive testing of the senate hall building. The mechanical properties such as brick masonry and stone has shown in (Table 1). The masonry wall has been analyzed from Indian standard guidelines and code provisions. The static standard gravity analysis has been performed from IS 875 Part 1 [26]. Dynamic wind and modal analysis has been performed from IS 875 Part 3 and IS 1893 Part 1 respectively [27,28]. The gravity load has considering in entire masonry wall, and wind pressure has applying in open portion of masonry wall from south direction. During static and dynamic analysis has evaluating stress and deformation response in masonry wall. The main reason to choose 3D 10-Noded and 20-Noded solid Element is to capture the quadratic displacement behavior. The element supports plasticity, hyper-elasticity, creep, stress stiffening, large deflection and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper-elastic materials.

Table 1 Mechanical properties of material

Material	Density (kg/m <sup>3</sup> )	Young's Modulus (MPa)	Poisson's ratio
Masonry	1900	2100	0.2
Stone	6470	2400	0.2

## 6) RESULTS AND DISCUSSION

The maximum von-Mises stress 0.75MPa observed on first floor stone panel. The maximum stress response has observed on the connection between octagonal columns and rectangular supporting base. The maximum stress contour has generated in the opening portion for doors, windows and arches on the masonry wall through ground floor to second floor. the maximum stress response and stress contour of masonry wall is showing in (Fig.5a) and (Fig.5b) respectively. The maximum deformation 17.87mm has observed on second floor portion on masonry wall shown in (Fig. 5c). The maximum deformation response is generated in the second floor portion each window shown in (Fig.5d).



During the wind analysis, the maximum stress is evaluated as 0.0022MPa on first window corner at second floor level shown in (Fig.6a). The maximum stress contour has generated in second, but ground floor and first floor masonry has observed the negligible response shown in (Fig.6b). The maximum deformation 0.0057mm has observed at similar location in masonry wall shown in (Fig.6c). The maximum response has visible on left top corner during the wind, the maximum damages and failure has observed for structural decorating materials and masonry wall cracks during the survey of senate hall building. During wind analysis, the stress and deformation response has observed very negligible from gravity analysis of masonry wall.

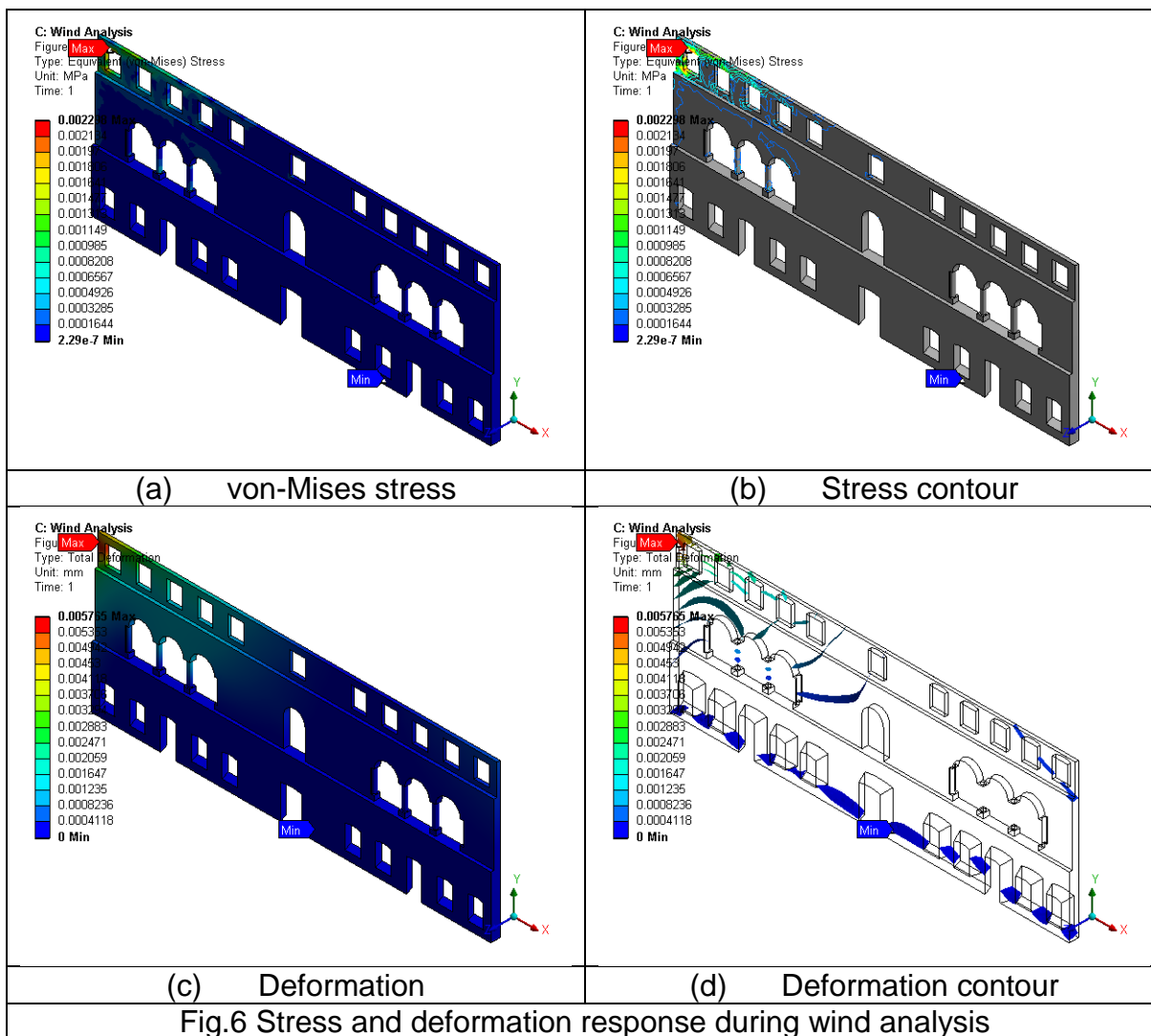
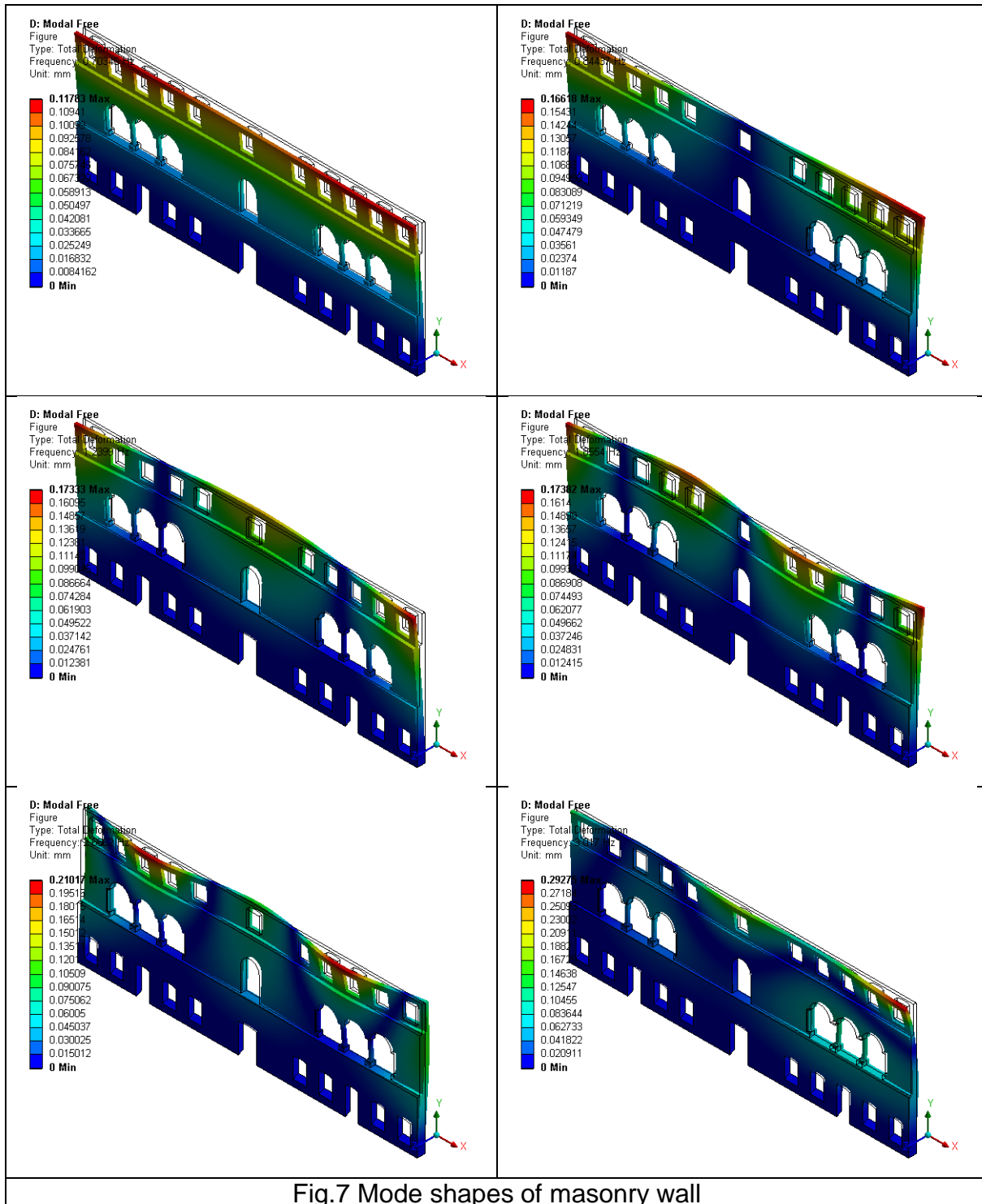


Fig.6 Stress and deformation response during wind analysis

The modal analysis has evaluating mode shapes, natural frequencies, period and participation factors of masonry wall. The modal analysis of masonry wall has evaluated the mode shapes and natural frequencies of each mode as 0.703, 0.844, 1.239, 1.855, 2.666, 3.017Hz shown in (Fig.7). First and second mode has performed the transverse direction with minimums deformation response 0.117mm and 0.166mm respectively. Third mode has performed the torsional behavior on both top corners of the masonry wall with minimum deformation response 0.173mm. The next three modes of the wall are performed in torsional behavior on first and second floor.



## CONCLUSIONS

The stress and deformation response of unreinforced masonry wall, 102-year-old in senate hall building of Allahabad University, India are evaluated using FE analysis. The masonry wall is constructed from unreinforced materials with three floor level in east and west side on main hall in the senate hall building with various openings provided through ground floor to second floor. First floor octagonal panel supporting columns are strengthen and retrofitted with masonry materials for both side each panel. The static and dynamic analysis of masonry wall has evaluated the stress and deformation response very negligible at thickness of ground floor and second floor. The in-situ survey of senate hall structure shows major cracks and damages in masonry wall. the similar results were found during finite element analysis. This confirms the reliability of developed model. The stress response has observed on similar location for deteriorating structural materials and damage portion of masonry wall due to rain water and moisture.

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