Abstract: This paper aim to present the static and dynamic analysis of stone arch of historical monument building of senate hall Allahabad University. The senate hall is old stone and masonry structure constructed in 1915 (102 year). The modelling of arch is performed using finite element software Ansys workbench 14.0. Static and dynamic analysis results shows that under standard gravity load of the arch, the maximum Von Mises stress are generated 2.24 MPa at middle of column main arch. The structure is safe under gravity loading. The maximum deformation of 9.69 mm is estimated at top of the main arch. The dynamic modal analysis of arch is performed for three mode frequencies (Hz) 0.21384, 0.70478 and 1.394.

Keywords: Historical structure, stone arch, standard gravity analysis, modal analysis, geometric survey

I. INTRODUCTION

The historical monumental structures which are located in seismic areas, required to be analysed for their safety and preservation. In analysis of monumental structures it is necessary to modelled the various component such as, its material, types of analyses, required experimental works on structures, monitoring and method required for seismic retrofitting etc. It is possible to do static as well as dynamic analysis of masonry structures along with mode shape [2] of the buildings, to get insight of the distribution of stresses and deformation pattern. Different type of approaches are available for the analysis of monumental structures viz. classical limit analysis for arch structure [3], advanced finite element analysis tools for blocky structures [4-6] and for spatial systems of vaults [7-8]. The nonlinear finite elements approaches can also proposed for the analysis of the complete structure [9] or representative substructures [10-12]. Analysis of these Old structures helps in Seismic retrofitting according to the ‘minimum intervention criteria’ to safeguard the loss of cultural value [13].

In most of the cases it is typically observed that the masonry historical buildings is prone to large deformation. To overcome this problem, the detailed limit analysis of a simple out-of-plane failure mechanism is developed based on static force-based and displacement-based approaches [14]. The behavior of a wall during collapse was studies by means of a rigid-plastic homogenization procedure, to account the actual disposition of the blocks [15]. Study of historical buildings provide precious information for a better understanding of the construction process.

The study of ancient buildings are important to account the significant damaging events which are increased recently and effecting the stability of structures [16-20]. Historical buildings research essential to provide information relevant to the natural phenomena or anthropogenic alterations which contribute the damage and deformation of the building and also useful to understanding the performance of structure during past events such as earthquakes. The large deformation of monumental buildings influenced by many factors, such as soil settlements, physical or chemical attack and long term deformation of materials etc., another cause of deformation, damage and eventually collapsed can be found in long-term processes developing gradually across the history of the building [21-25]. Present work is limited to gravity load and model analysis of Stone arch of Old Senate Hall of Allahabad University.

II. SENATE HALL

The senate hall building is constructed with masonry wall constituted by random assemblages of stones arches and bricks. This is a load bearing structure which is constructed in 1915. The building constructed on thick (1.07m) brick wall and stones are also used in arches, canopies, domes and balconies with various thickness. Front and back verandah are constructed by using stone arches. This building is constructed before release of first Indian seismic design code (IS1893: 1962). This hall basically used for the social, cultural program, meetings, examinations and convocation, the capacity of senate hall more than five hundred members. We perform the static and dynamic analysis of stone arch of meeting hall shown [Fig.1].
III. DESCRIPTION OF ARCH

The construction of the Senate Hall building of Allahabad University, Allahabad in India, started in the year 1910 and completed in 1915. This [Fig.1] shows one main arch and three internal arches which are supported by two external columns and two internal columns. The main arch having total height 12.20m from ground level, width 10.67 m and thickness 0.61m at first floor level. Other three internal arches are having equal height, width and thickness at 6.10m, 9.76m and 0.31m respectively. The supporting columns are having octagonal shape with diameter 0.31m and height 2.13m as shown in [Fig.2]. The thickness varies in main arch and internal vault arch are shown [Table-1].

IV. FINITE ELEMENT MODELLING

Finite element analysis and modelling of monumental building arches and columns are carried out by using programming software ANSYS Workbench 14 [26]. Analysis of arches are performed by choosing 20-Noded 3D solid element (SOLID 186). The main region to choose 3D 20-Noded solid Element is, it exhibits quadratic displacement behavior, the element supports plasticity, hyper-elasticity, creep, stress stiffening, large deflection and large strain capabilities.

Table: Thickness of different components in the two dimensional FE model shown [Fig.1]

<table>
<thead>
<tr>
<th>Location</th>
<th>Arch</th>
<th>Thickness (m)</th>
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<tbody>
<tr>
<td>A</td>
<td>Overall arch</td>
<td>0.61</td>
</tr>
<tr>
<td>B</td>
<td>Small arch</td>
<td>0.31</td>
</tr>
</tbody>
</table>

It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper-elastic materials. We analyse the structure by dividing very fine meshing size 50mm which having 168690 nodes and 38258 elements as shown in [Fig.3].

The main issue in setting the numerical model was related to the definition of the boundary conditions, as the side wall intact to the column of the arch has not been consider on both side. To incorporate the same in the representative model of the actual behavior of single stone arch, in it’s the specific attention was devoted to the careful modelling of the arch, in terms of geometry shown fig.3 (a). The stone piers of main arch and vault were modelled as fixed at the base.

V. CRACK OF SENATE HALL STONE ARCHES

In visual survey of senate hall building, the damages and cracks in stone arches, masonry wall and roof are observed. The senate hall building looks mostly in stable. The major cracks are observed at opening of doors, in masonry walls with and without plaster, entrance elevation stone arches, middle portion of main gate arches, window corners and between the joint of masonry wall to stone arches.

We also observe major cracks in front verandah arches shown Fig.4(a), top of columns Fig.4(b) and main entrance arch vault shown Fig.4(c). Minor damages are observed at internal side masonry slab Fig.4(d).

Some of these cracks are repaired recently. These cracks, seemingly caused by the compression forces,
appear close to the corners (the less confined parts) of the octagonal column section. The main causes for crushing cracks in columns are due to heavy compressive force. In case of one column, these cracks were repaired in historical time and no reopening has occurred. Both distortion and deformation in piers appear to be random with no systematic pattern. In particular, both the amount and direction of lateral deformation in piers are variable in nature.

VI. ANALYSIS

The static and dynamic analysis of monumental building stone arch has been carried out by applying gravity loads as per IS:875 (Part 1)-1987. Dead loads were applied by taking into account the contribution of filler at the main arch and vaults. Presently no live load is applied to the stone arch. The linear elastic material behavior is used in the arch analysis are considered as homogeneous. The material properties are taken as, Young’s modulus, E equal to 1100 MPa, Poisson modulus, ν equal to 0.2 and mass density, ρ equal to 1700 kg/m³ [18]. The mechanical properties are used in present study is based on literature survey of historical monument structures which are experimental and damages in the past earthquakes. Results of the static analyses on the stone panel model in terms of Von-Mises stress distribution are shown in Fig.5.

VII. RESULTS AND DISCUSSION

The Von-Mises stresses induced in stone arch standard gravity analysis. Maximum compressive stresses 2.247 MPa is obtained in the middle portion of external column. Although the compressive force is less than the compressive stress of material. The maximum stress were also observed on the same area where crack is formed. It is near the main and internal vault joint of external column as shown in [Fig.5]. Displacement result distribution of the static analysis on 3D finite element stone arch is shown [Fig.6]. The maximum value of the displacement 9.69 mm at top at main arch. The deformation vector is generated from ground floor column to first floor arch is increased as shown [Fig.6].

VIII. MODAL ANALYSIS

The dynamic analysis of the model has been used to assess the modal behavior of arch structure of senate hall. The dynamic analysis of monumental building arch is carried out to find out the mode shapes and fundamental frequencies as shown in following table 2.

The modal analysis of building is performed using block Lanczos method by applying fixed boundary condition at base of arch. The distribution of frequencies in first and second modes in transverse and longitudinal directions with the fundamental frequencies of 0.21384 Hz and 0.70478 Hz respectively which are shown [Fig.7(a) & (b)], and the third is torsional mode shape of arch whit the frequency 1.394 Hz is shown [Fig.7(c)] of arch. The torsional mode shape of the structure which is the
combination of transverse and longitudinal structural elements.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency [Hz]</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.21384</td>
</tr>
<tr>
<td>2</td>
<td>0.70478</td>
</tr>
<tr>
<td>3</td>
<td>1.394</td>
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CONCLUSION
In this paper, study of the 102-year old senate hall historical monumental masonry building in Allahabad University. The detailed geometric survey, cracks propagation and deformities of senate hall building are shown. The gives the impression that the arch is safe under standard gravity loading. Further, dynamic analysis of the meeting hall stone arch (height 12.20 m and width 10.67 m) gives its fundamental frequency in the range of 0.21 Hz. The maximum stress is induced at mid portion of external column which is connected with internal vault. The minor crack is generated at the top end of ground floor vault which is connected with main arch. In the study based on conclusion, the proposed procedure provides indications that may be very valuable in the weakness of building components and also in the design of retrofit solutions.

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REFERENCES

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