ISSN No:-2456-2165

Condition Assessment and Strengthening Measured for Historical Building

Kirti Tiwari [1], Hima Shrestha[2] and Ramesh Guragain[3]
[1] Structural Engineer, National Society for Earthquake Technology-Nepal, Nepal
[2] Director, Earthquake Engineering Research and Training, National Society for Earthquake Technology-Nepal, Nepal
[3] Deputy Executive Director, National Society for Earthquake Technology-Nepal, Nepal

Abstract:- Charkhal is a historical building of Nepal, built of clay brick in mud mortar dated more than 105 years of age. This paper focuses on seismic vulnerability assessment and retrofit option of historic buildings charkha Adda carried by NSET just few years before the Gorkha Earthquake, which got damage during the recent Gorkha earthquake 2015. The building is a courtyard type; with a large number of openings in their facade. The building is three stories with a total height of 10.88m and largest dimension in the plan of 55.01m. The thickness of walls varies in the range of 0.8m to 0.35m with the greatest values attained at the ground floor. The building floors are thick with jack arch and steel I-sections. The foundation of the building is in strip footing. The plinth level is considerably high above the ground level with a provision for ventilation. A complete geometric and structural survey of the whole building was performed during the assessment of building. The need for safety of the building lying at high seismic zone in Nepal, the Seismic Vulnerability Assessment out was carried out to improve the building response in future earthquakes. The seismic vulnerability of the building was assessed after the following:(a) historical investigation about the building, (b) detailed geometrical investigation, (c) identification of materials by means of surveys and literature indications, (d) Detailed Intrusive Tests, (f) Detail linear static analysis of the building by means of a Finite Element (FE) model. After these steps, the FE model was used to assess the safety level of the building by means of linear static analyses, and identifying a proper retrofitting strategy for this building.

Keywords:- *Historical Building; Seismic Vulnerability; FE Modeling; Intrusive Test, Retrofit Option.*

I. STRUCTURAL SYSTEM OF CHARKHAL ADDA

The building is a courtyard type, having three stories with a large number of openings in their facade. The building contains long walls with rectangular shaped courtyards. The main structural system for lateral load resisting is thick un-reinforced masonry walls with about 800mm thickness in the ground and first floors, and a reduced thickness in the third floor of 0.56 to 0.35mm. The walls are made of burnt clay brick, and un-burnt brick (in some walls) in mud mortar. Floors are thick with jack arch and steel I-sections. The sizes of openings are the same in two floors and placed in symmetrical position. The foundation of the building is in strip footing. The plinth level is considerably high above the ground level with a provision for ventilation. The front view and footprint of Charkhal Adda are shown below in fig. 1 and fig 2.

Fig 1:- Front View of the Building

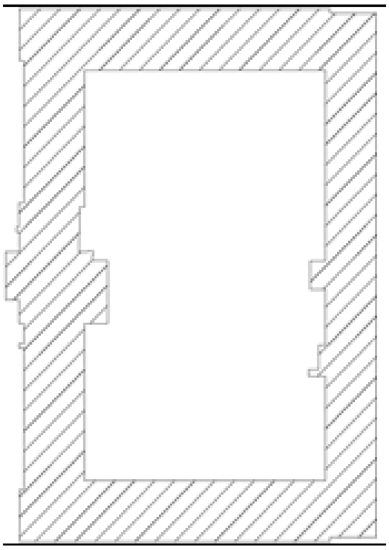


Fig 2: Building Foot Print

ISSN No:-2456-2165

II. FIELD INVESTIGATION BEFORE GORKHA EARTHQUAKE

A number of site visits were conducted for visual observation of the building. Detailed surveys of building geometry and materials made it possible to detect characteristic features such as type and configuration of floors, and disposition of resistant masonry walls.

The structural behavior of existing masonry buildings is often a complex issue due to the inevitable uncertainty regarding geometry, typologies and mechanical properties of materials. Observations of the building were conducted and listed below:

i. Inadequate number of the existing cross wall, which makes the large size of the rooms, long unsupported walls.
ii. The buildings were constructed with thick walls 800mm, in mud mortar.
iii. Most of floor/roof brick and steel I-beam in second floor was found damaged due to leakage of water.

A. Walls' decays/damages from the exterior and internal

Damage of the external wall is due to wetness, erosion, moss and wall cracks. The growth of plants and roots damage the brick masonry. The interior of the building generally is in a better state than the external walls: there are some minor damages due to wetness, and erosion on the interior walls. The mortar joints tend to be more exposed to wind and rain at the top and so tend to deteriorate more, weakening their seismic resistance. There are also some vertical cracks in the west wing and east wing walls. Photo documentation is included below:

Fig 3:- Weathering of west wing outer wall

Fig 4:- Damages due to weathering of west wing outer wall

Fig 5:- Growth of plant in external wall of west wing

Fig 6:- Erosion of brick/mortar in external wall of west wing

Fig 7:- Deterioration of brick of west wing outer wall

Fig 8:- Erosion of brick/mortar in external wall of North wing

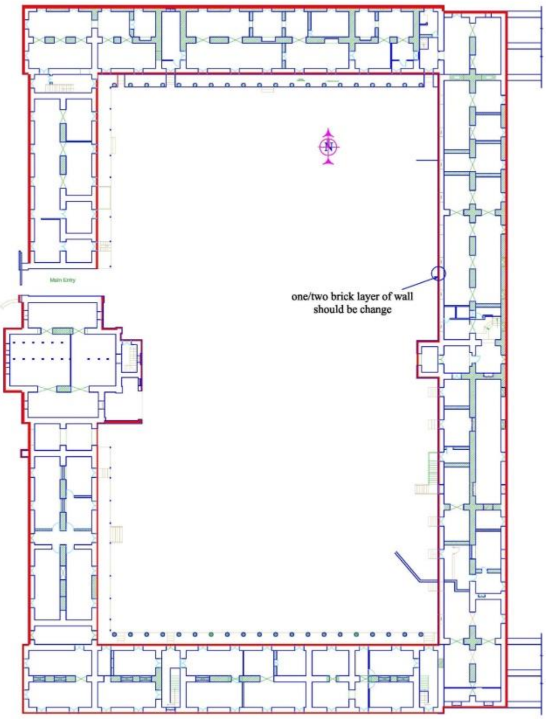


Fig 9:- Damage of outer wall in plan

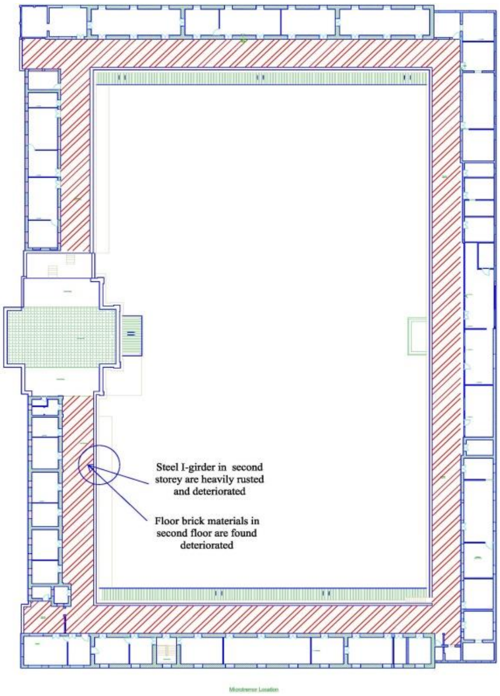


Fig 10:- Damage portion of roof in second floor

B. Non-destructive and Intrusive Tests

Nondestructive and intrusive tests carried out to determine the material properties of the building. In situ in-plane shear test, micro tremor test, flat jack test and wood drill tests conducted at the site.

➢ *In Situ In-plane Shear Test*

The test done at 16 locations at ground floor, 11 locations at first floor and 7 locations at second floor. The average shear strength of brick masonry of the Charkhal Building is 0.056 N/mm2 (ASTM Standard), 0.032 N/mm2 (IS Guidelines). Considering the uncertainty in the coefficient of friction and workmanship during construction, the value of 0.032 N/mm2 considered for analysis and design.

Fig 11:- Shear Test in second floor wall of north wing

ISSN No:-2456-2165

Fig 12: Shear Test in ground floor wall of south wing

➢ *Micro Tremor Measurements*

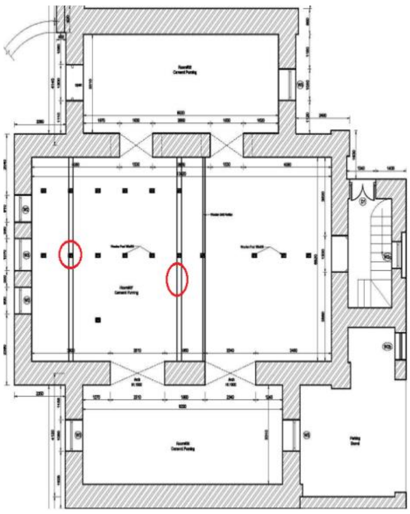
Micro Tremor measurements taken to calibrate the numerical analysis model. The Micro Tremor measurements obtained at 15 locations in the second floor and 1 location in the first floor. As far as possible, measurements taken at four corners and near CG of second floor of all four wings of the courtyard building. The average fundamental frequency in East-West (X) direction found to be 4.565 Hz, while in North-South (Y) direction was 3.71 Hz respectively shown in Table 2. The fundamental time period at X and Y-directions was found to be 0.219 sec and 0.269 sec.

➢ *Wood drill Test:*

Besides inspecting the surface visually, the condition of wooden members (beams, girders, rafters, posts, windows, doors, etc.) tested with the help of decay detection instrument, IML Resistograph PD Series. The IML Resistograph System based on the principle of measuring the drilling resistance.

Fig 13:- Conducting Wood Decay Test using IML Resistograph PD Series in Charkhal Adda

In this method of testing, a drilling needle with a diameter of 1.5 mm with a 3 mm cutting tip inserted into wood under constant drive. While drilling, the resistance measured as a function of drilling depth of the needle. The data plotted on a scale of 1:1 simultaneously. The high amplitude graphs represent the higher intact of wood. The test carried out only on the exposed wood surface at about 35 different locations. Very few beams found damaged. The location of damaged wooden beams and the test results shown in Figure 5.



West Wing

Fig 14:- Location of damage wooden beam and post in west wing of Charkhal

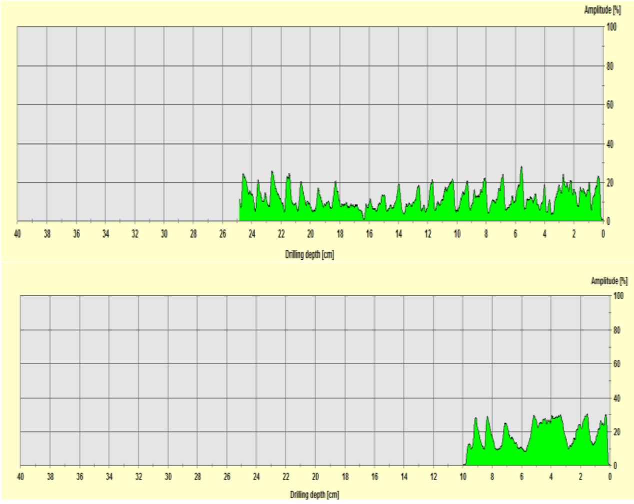


Fig 15:- Resistograph of beams with irregular surface

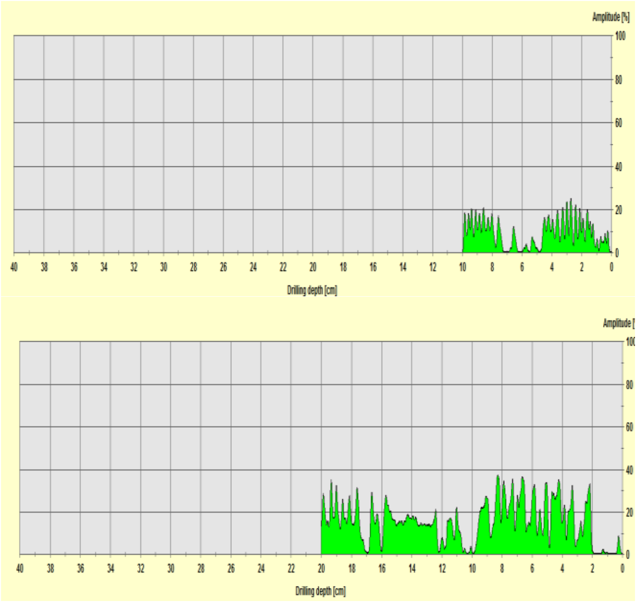


Fig 16:- Resistograph of decayed beams

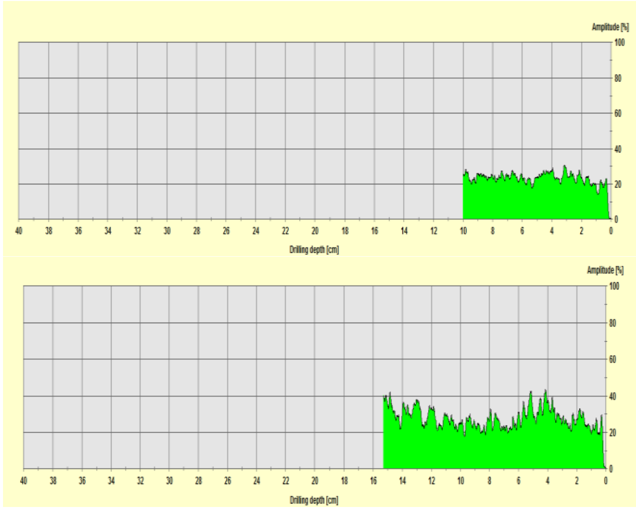


Fig 17:- Resistograph of intact beams

➢ *Flat jack Test:*

Double Flat Jack testing carried out at Charkhal building. In this test, a small volume of masonry in a structure is sandwiched between two jacks that react against the masonry above and below. It is thus possible to carry out a limited stress strain test on the masonry in-situ, provided a correction factor is applied which takes into account the characteristics of the jack and the ratio between the area of the jack and that of the cut.


Fig 18:- Flat Jack Test in Charkhal Adda

Testing is carried out as per ASTM Standards (ASTM C1196 and ASTM C1197) by using two flat jack palates of size R-6-16 (0.15" X 6" X 16"). Two slots of size 6.5" x 17" are prepared which are 18.5" apart (5 layers of brick) and gauge point pairs are selected to measure the deflection of the masonry units. Flat jacks then introduced into both slots, and the initial distance between gauge points are measured. By pressuring the flat jacks, loads applied to the wall specimen. With a pressure increase in the flat jacks, the distance between gauge point pairs decreases. By gradually increasing the pressure, the pressure and deformation

ISSN No:-2456-2165

recorded and stress-strain curve developed. The pressure increased until failure in the masonry specimen occurs.

Figure 9 shows the stress-strain curve of masonry obtained from the flat jack testing. From the flat jack test, the following results obtained.

Average Modulus of Elasticity of Masonry = 200 MPa
Average Compressive Strength of Masonry (Ultimate) = 0.6 N/mm^2

C. Investigation of members:

➢ *Brick Test Result*

Twelve brick samples taken from the building wall from different locations, with compressive strength and water absorption tests carried out at Central Material Testing Laboratory, Institute of Engineering. The average breaking strength of brick found between 16.97 kg/cm2 to 59.23 kg/cm2 and water absorption of 12 samples are 13.35% to 30.22%. The tests found that the brick compressive strength was very low.

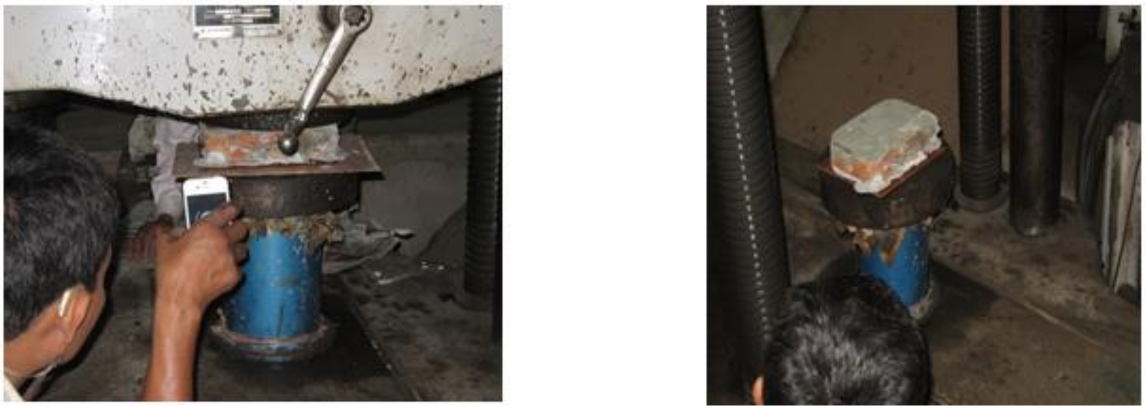


Fig 19:- Compressive Strength Test of Brick Unit

➢ *Foundation Inspection:*

To explore the foundation details of the building, excavation carried out on the south wing of the building. Foundation is made of brick masonry and there is no plinth band in walls. The depth of the foundation is 6’10”.

Fig 20:- Foundation Investigation in Charkhal Adda

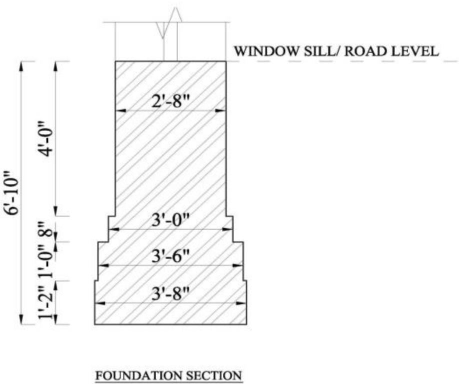


Fig 21:- Foundation Section of Charkhal Adda at inspected locations

➢ *Floor/Roof detail identification:*

The floor system is fitted with steel I-sections and considered flexible diaphragms. Despite the heavy dead load, the floor does not provide any kind of seismic-resistant function. Most of the roof/floor in the west and north wings were damaged due to the corrosion of the I-steel beam and leakage of water. In order to check the corrosion portion, the investigation conducted on different portions of the west, north and south wings. About 50% of the flange portion found to feature corrosion.

Fig 22:- Floor/Roof detail exploration in west wing of Charkhal Adda

➢ *Investigation of the Brick Masonry Wall*

Status of bricks and mortar are important parameters to determine the status of the building. The wall is constructed using burnt clay brick with mud mortar. The average thickness of mortar is 10mm.

Fig 23:- Brick Lay Pattern in opening of wall

III. STRUCTURAL ANALYSIS OF CHARKHAL ADDA BUILDING

A 3D finite element model using the ANSYS code v.12.0 approached the structural analysis of the Charkhal Adda. The masonry walls were discretized with *Solid185 elements* is eight node iso-parametric brick element type with three degrees of freedom: translations in the nodal X,Y and Z direction, have plasticity, hyper elasticity, stress stiffening,creep,large deflection and large strain capabilities. It also has mixed formation capability for simulating the deformations of nearly incompressible elasto-plastic materials and fully incompressible hyper elastic materials. The brick floors and I steel beam were not considered in the model and their own weights were applied on the bearing walls by means of vertical concentrated loads.

Only symmetrical portion considered while modeling the building. While taking the advantage of symmetry, only a portion of the actual structure need to model, so that it reduce the analysis run time and memory required. Model consists of 10,406 nodes, 31490 *Solid185 elements*, corresponding to 597 DOFs.

Symmetry boundary conditions are applied to the north face of the bay to simulate the existence of adjacent bays. A fully rigid boundary condition, which prevents translation and rotation in all three directions, applied to the base of each foundation.

Finally, model result is also check with Etabs model.

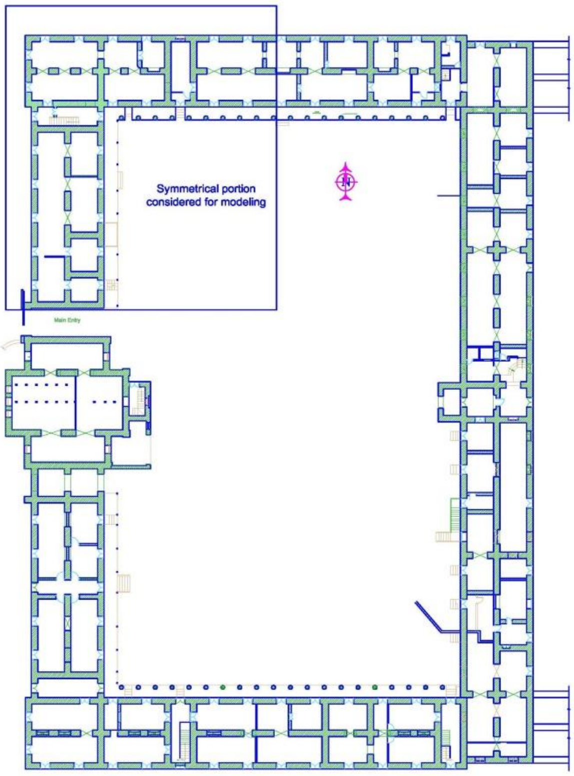


Fig 24:- Symmetrical portion considered while modeling (Ansys)

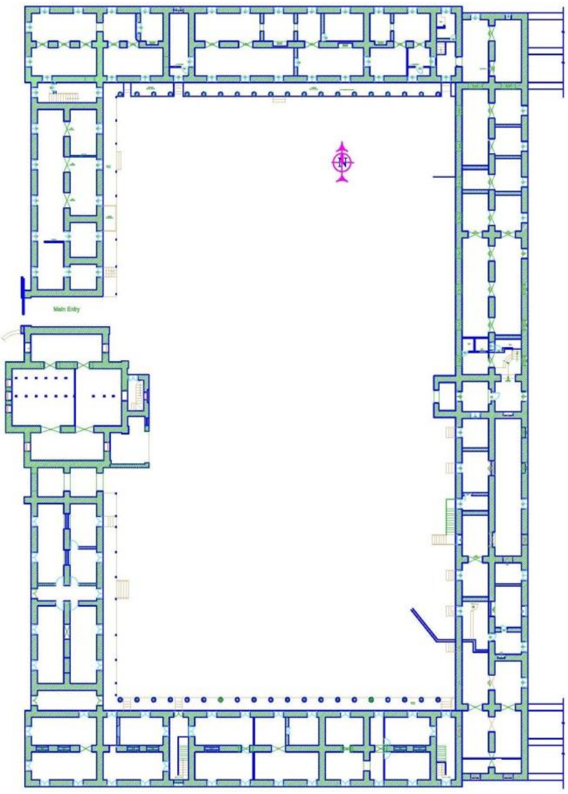


Fig 25:- Whole building in ETABS

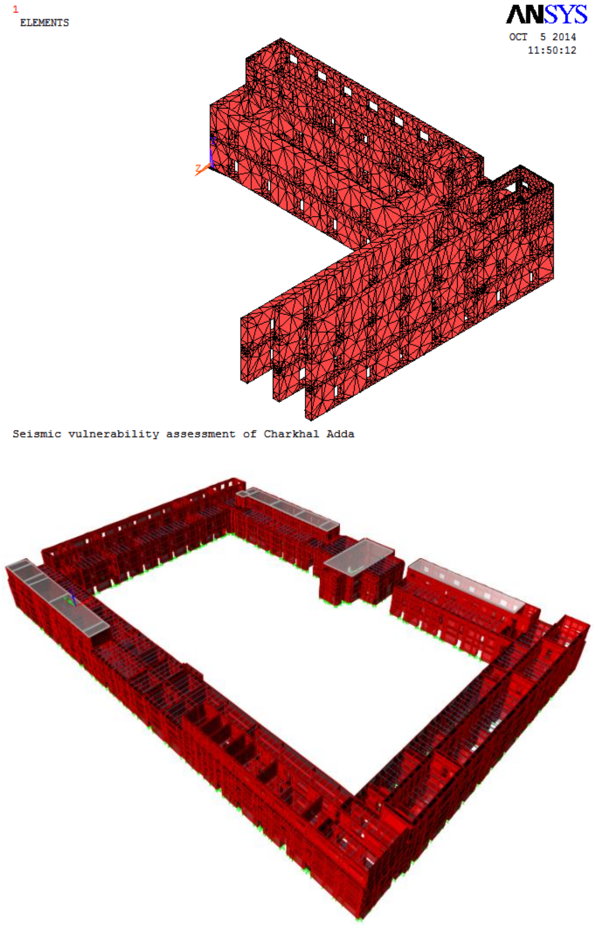


Fig 26:- Finite element model of the Charkhal Adda (Ansys and Etabs)

A. Seismic Analysis

The seismic analysis is a part of the detailed evaluation of an existing building. The steps involve in developing a computational model of the building include applying the external forces, calculating the internal forces in the members of the building, identifying deformations and capacity of the members and building, and finally interpreting the results. The structural analysis is carried out with the help of the available drawings and ETABS 2013/Ansys, a structural analysis and design software. IS 1893:2002; criteria for earthquake resistant design of structures is used to determine the base shear in the building.

➢ *Modeling Output for Existing Building:*

Initially, the existing building is modeled and in-plane stresses along with out-of-plane moments are studied. From the analysis, large amounts of out-of-plane moments are produced on the walls due to the large wall span. The in-plane stress and moment diagrams obtained from analysis are shown in Figures below.

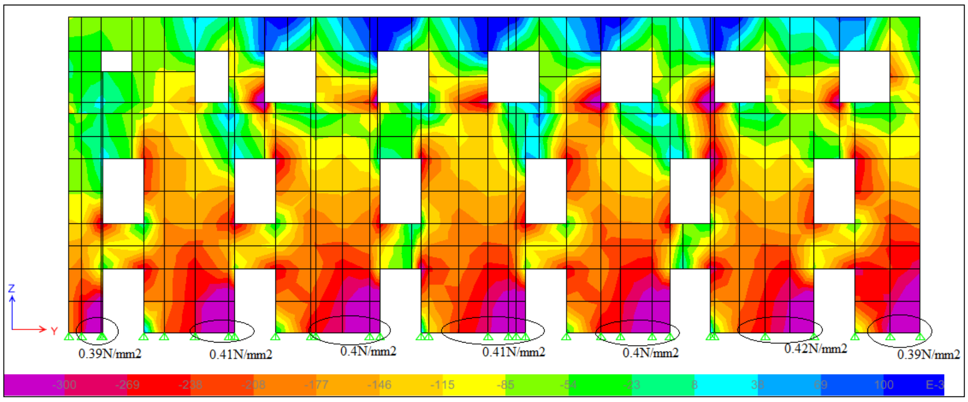


Fig 27:- Compressive stress in wall (In plane stress (S22)) (Y-direction)

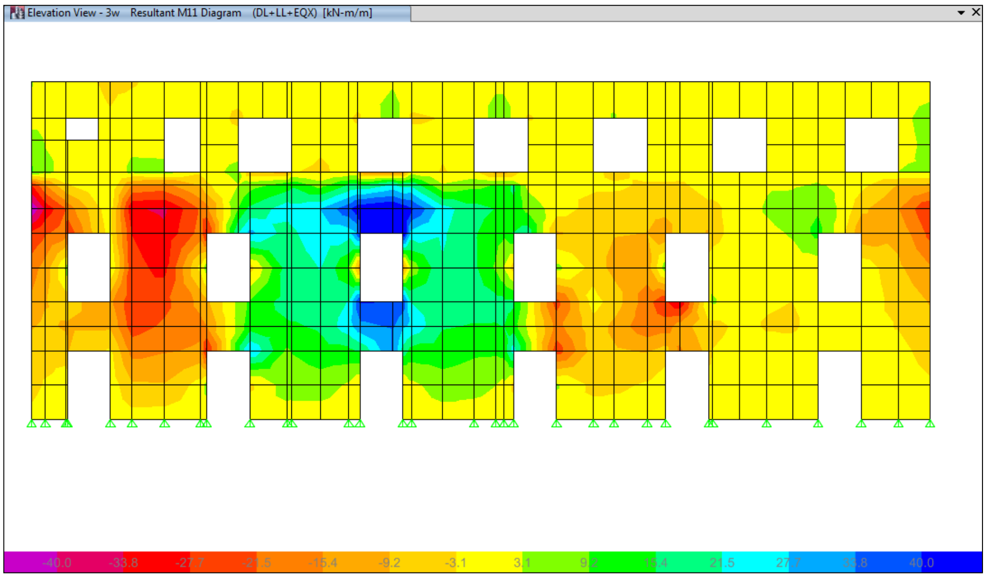


Fig 28:- Out-of-plane horizontal bending moment diagram obtained from analysis

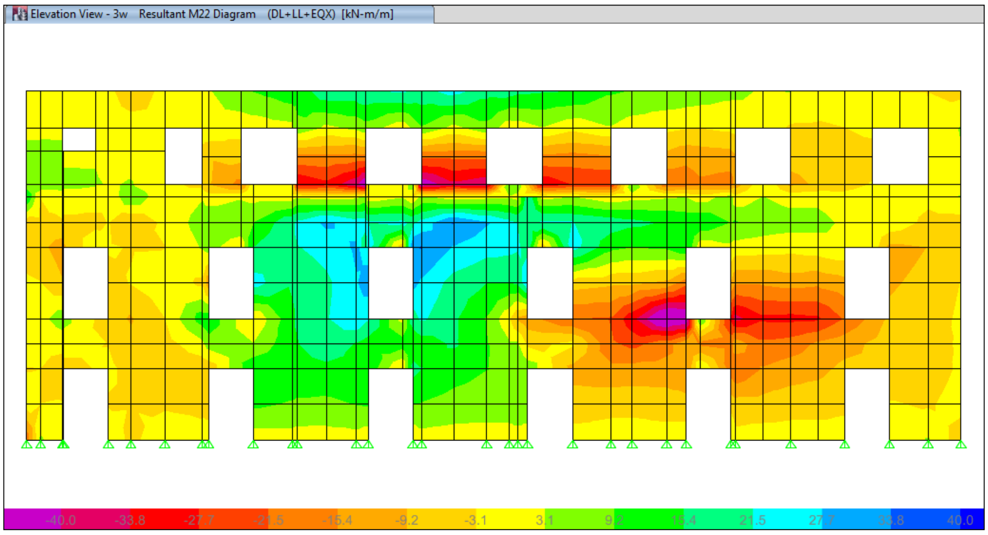


Fig 29:- Out-of-plane vertical bending moment diagram obtained from analysis

To reduce the out-of-plane moments, some cross walls are added on the building. To tie the walls and make floors rigid, bracings are introduced

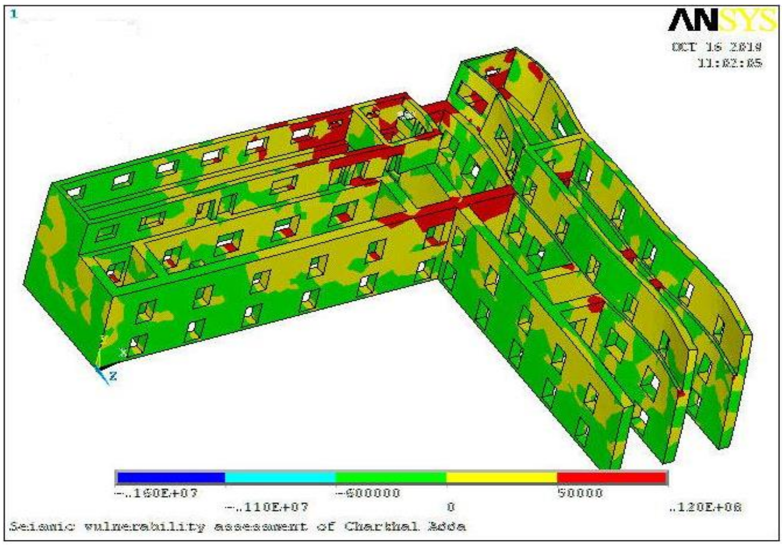


Fig 30:- Diagram showing normal stress (Sx) in building during earthquake in X direction before addition of cross wall.

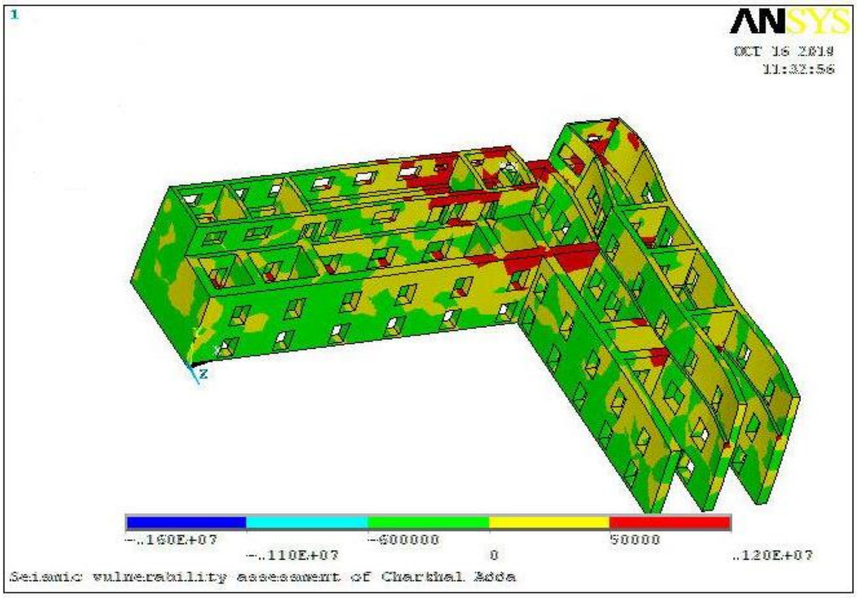


Fig 31:- Diagram showing normal stress (Sx) in building during earthquake in X direction after addition of cross wall.

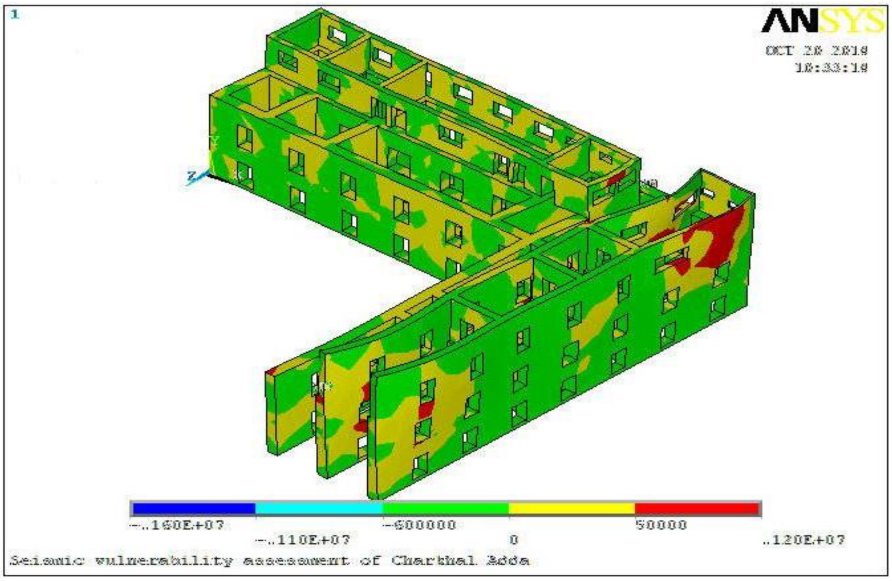


Fig 32:- Diagram showing normal stress (Sz) in building during earthquake in X direction

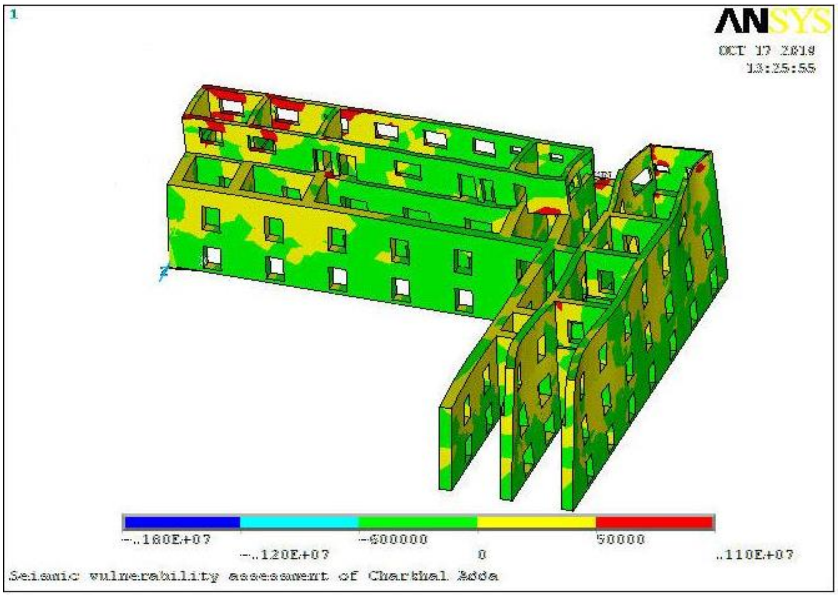


Fig 33:- Diagram showing normal stress (Sx) in building during earthquake in Neg-X direction

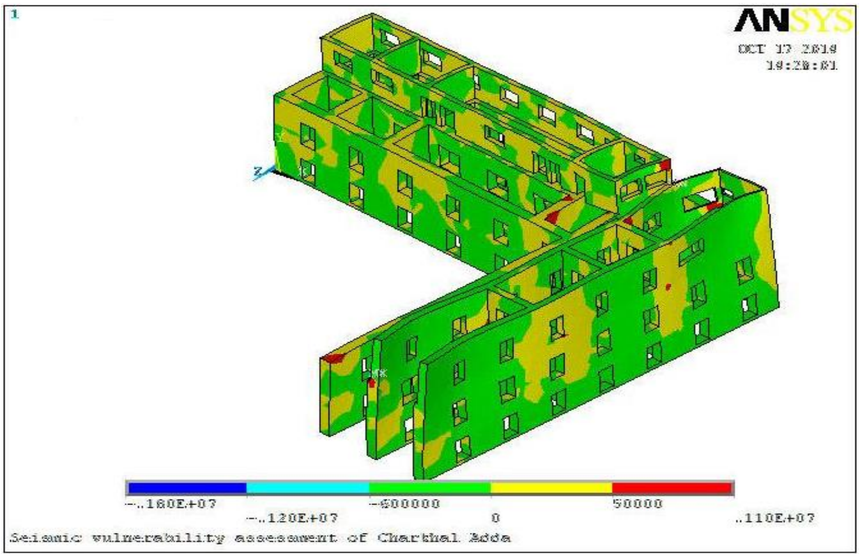


Fig 34:- Diagram showing normal stress (Sz) in building during earthquake in Neg-X direction

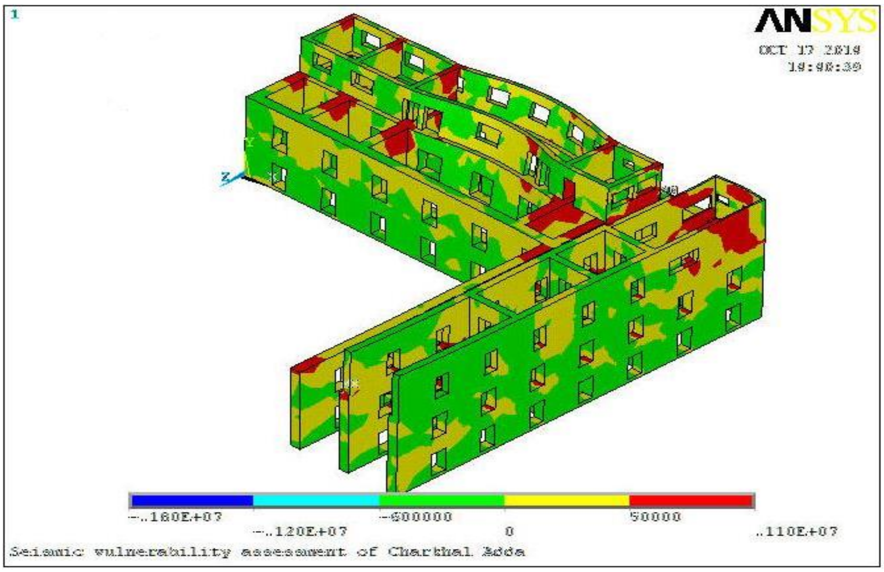


Fig 35:- Diagram showing normal stress (Sz) in building during earthquake in Z direction

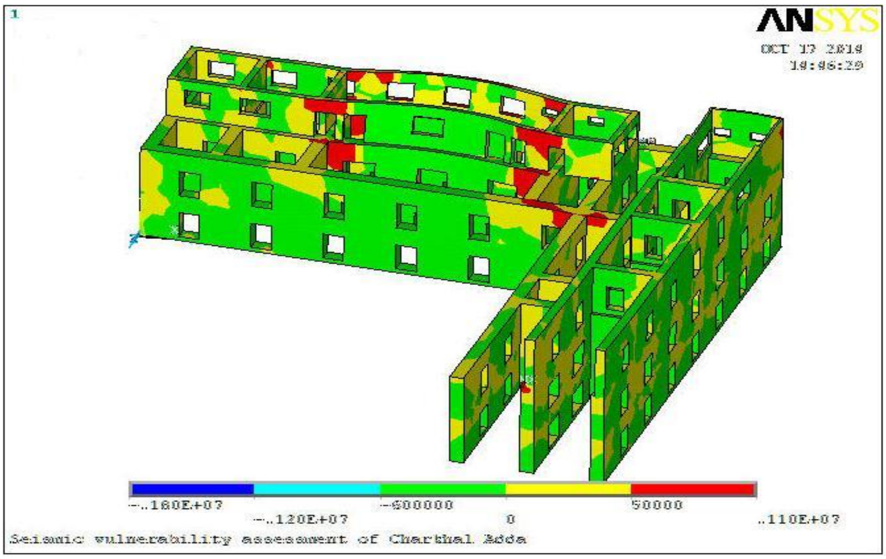


Fig 36:- Diagram showing normal stress (Sx) in building during earthquake in Z direction

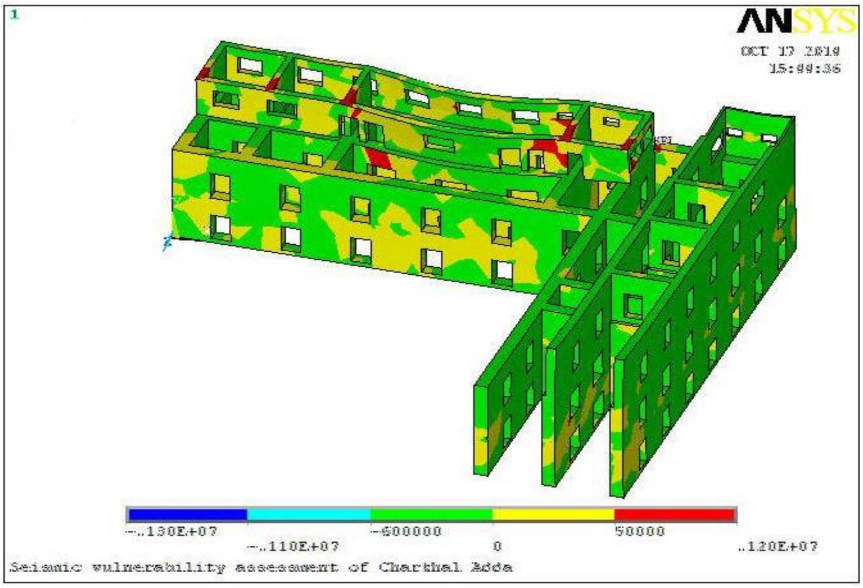


Fig 37:- Diagram showing normal stress (SZ) in building during earthquake in Neg-Z direction

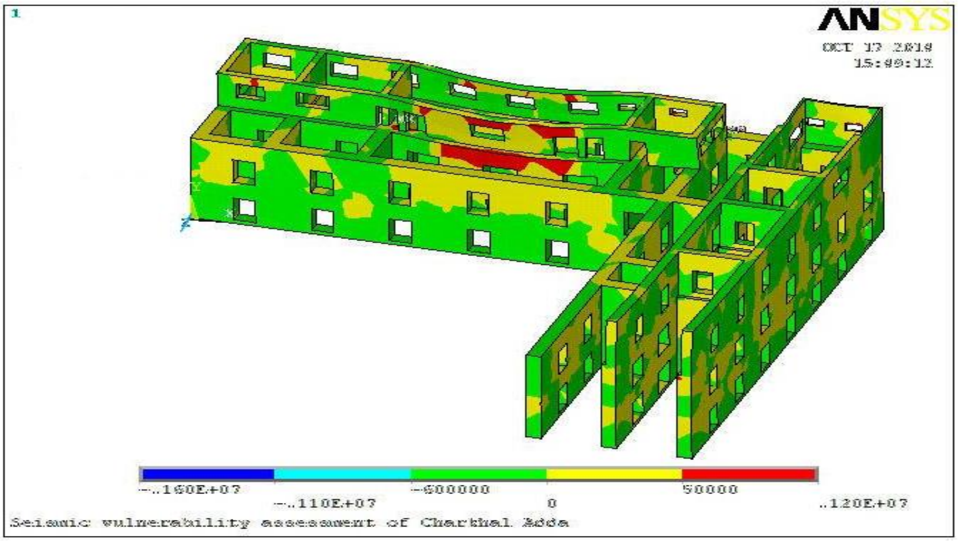


Fig 38:- Diagram showing normal stress (SX) in building during earthquake in Neg-Z direction

The maximum value of tensile stress is seen in figures (denoted by red colour).The portions around the openings and wall corner were found to be highly vulnerable in all cases. From analysis it found that tensile stress decrease to some extent after addition of cross wall.

IV. RESULT AND DISCUSSION OF ASSESSMENT

- The global behavior of building depends on the semi rigid or loosely connected floor and unreinforced masonry walls. The vulnerability of Charkhal Adda is mostly due to the absence of adequate connections between the walls and the floor/roof of the building, deterioration of load bearing walls due to weathering effects, lack of proper maintenance, water leakage from roof, growth of grass in load bearing walls and rusting of steel beams that support the brick floor.
- The large sizes of the rooms without cross walls, loosely connected floor, and unreinforced masonry wall are the main drawbacks of this building.
- Some structural modifications, floor stiffening and wall strengthening are required to enhance the building performance.
- The portions around the openings and wall corner found to be highly vulnerable.
- From the analysis results, large amounts of out-of-plane moments produced on the walls.
- From analysis, both in-plane and out-of-plane tensile failure are still observed on the walls.

REFERENCES

[1]. NSET [2015] A report on "Seismic Vulnerability Assessment and Retrofit Design of Kaiser Mahal Building"

[2]. Dr. Rai, D.C. [2005] "IITK-GSDMA Guidelines for Seismic Evaluation and Strengthening of Buildings: Provisions with Commentary and Explanatory Examples", IIT, Kanpur

[3]. Varum, H. et al. [2006] "Seismic Evaluation of Old Masonry Buildings: Performance and Strengthening", Paper 85, Proceeding of the Eighth International Conference on Computational Structures Technology, Civil-comp Press, Stirlingshire, Scotland.

[4]. Romeu Vicente et al. [2011], Evaluation of strengthening Techniques of Traditional masonry buildings: Case Study of a Four Building Aggregate", Journal of Performance of constructed Facilities ASCE/May/June/2011

[5]. Department of Archeology [1998] "An Assessment of the Structural Condition of 55 Windows Palace, Durbar Square, Bhaktapur" Investigation Team's Report Volume 1, Kathmandu.

[6]. Ceroni Francesca et al. [2012] "Assessment of Seismic vulnerability of a historic masonry building", Buildings 2012, 2,332-358; doi:10.3390/buildings2030332

[7]. Look W. David et al. [1997] "The seismic retrofit of historic buildings: Keeping preservation in the forefront", US Department of the Interior, National park service cultural resources, heritage preservation services.

[8]. ASTM C1197-04 [2013] "Standard Test Method for In Situ Deformability Properties Using Flat Jack Measurements", ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, US

[9]. ASTM C1196-09 (2013) "Standard Test Method for In Situ Compressive Stress Within Unit Masonry Estimated Using Flat Jack Measurements", ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, US

[10]. ASTM C1531-09 (2011) " Standard Test Methods for In Situ Measurement of Masonry Mortar Joint Shear Strength Index", ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, US

[11]. RILEM MDT.D.4 [2004] "In-situ Stress Tests based on the Flat Jck", RILEM TC 177-MDT: Masonry Durability and On-site Testing, Material and Structures, Vol. 37.

[12]. RILEM MDT.D.5 [2004] "In-situ Stress-strain Behavior Tests Based on the Flat Jack", RILEM TC 177-MDT: Masonry Durability and On-site Testing, Material and Structures, Vol. 37.