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Seismic Performance of Compressed Stabilized Earth Block Masonry Building

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Abstract
As from past earthquake in 1934 and recent Gorkha earthquake 2015, Nepal experienced shows that an unreinforced masonry structures are the most vulnerable and leads to collateral damage to human life and property in future earthquakes. In the aftermath of the Gorkha Earthquake, many people in rural remote affected areas cannot afford brick masonry because of its expensive nature and not feasible in those areas, so to provide them an earthquake resistant building method for houses to build a safer house. With the help of Government of Nepal and Rural Housing Reconstruction Program (RHRP), Compressed Stabilized Earth Block (CSEB) an alternate to brick materials was introduced. This paper aims to study the seismic performance of un reinforced masonry building constructed with compressed stabilized earth blocks. This study highlights the building capacity to carry seismic loads and an assessment of building in terms of the strength, expected performance of the building and safety of building during an earthquake. When subjected to seismic effects, masonry material exhibits little ductility because they are brittle material with low tensile strength, so unreinforced masonry is highly susceptible to earthquake damage and usually characterized by sudden and dramatic collapse. This paper investigates the application of linear seismic analysis of masonry building using ANSYS software. Thus, result obtained will be useful to evaluate the seismic performance of building.

Keywords
Compressed Stabilized Earth Blocks(CSEB), Masonry building, Finite element modelling, Linear static analysis, Seismic performance

1. Introduction

Masonry is defined as a composite, non-homogenous and anisotropic material and masonry building is defined as the construction of building units such as bricks, stones or earth blocks bonded together with mortar such as cement mortar, soil-cement-sand mortar or lime mortar. The possibility of combining these elements with different qualities and geometry give masonry a wide range of alternatives of mechanical behavior and structural performance. Masonry building are the most common type of construction used for housing in Nepal and are constructed as massive structures which attracts large horizontal forces during earthquakes. Past earthquakes show that Un-reinforced masonry structures are the most vulnerable during an earthquake. Normally these are designed for vertical loads and since masonry has adequate masonry compressive strength, the structure behaves well as long as the loads are vertical. When these structures are subjected to lateral inertial loads during an earthquake, the wall develops shear and flexure stresses. The strength of masonry under these conditions often depends on the bond between units and mortar, which is quite poor. Shear failure in the form of diagonal crack is observed due to this. However, catastrophic collapse takes place when the wall experiences the out of plane failure. And this catastrophic collapse has been seen in remote earthquake affected areas during Gorkha Earthquake 2015.

The decision was made to use compressed stabilized earth blocks (CSEB), CSEB provides an earthquake resistant building technique approved and recommended by the government of Nepal and commonly used in other earthquake-prone countries such as Iran and India [1]. The method consists of mixing local soil with cement and water. The mixture is then compressed in a machine that forms the interlocking bricks under compression. The bricks are set to cure for 28 days before they can be used in construction. The benefits from using CSEB are that it is a material that can be produced locally by mostly local components, it is an earthquake resistant building technique and it has lower investment cost than for example fire bricks [2]. Nepal is a developing country and many people of remote and poor areas can't afford the modern construction materials and techniques. Therefore, people construct their home by using locally available materials as CSEB. Such buildings built without supervision of engineer or skilled manpower and also due to lack of national building code for CSEB are more vulnerable to earthquakes. Therefore, the purpose of this study was to help to improve the quality and the performance of CSEB buildings built by people with a non-engineering background. With the development of computational methods, Finite Element Analyses has become the most important tool for the analyses of historical structures. Generation of a finite element model of the building requires a good engineering experience to turn a complex geometry into a realistic geometrical simplification and better understanding of both gravity load transfer mechanism and lateral resisting system of such buildings is the vital issue for a comprehensive structural analysis, understanding of the analysis results.

In this paper, masonry referred as unreinforced masonry and the present study evaluates the seismic performance of masonry building constructed by non-engineered background people by locally available materials as compressed stabilized earth block. The aim of this study was to make an overview of the structural resistance of one of the approved designs, design number C.S.E.B 4.1 in the Design Catalogue for Reconstruction of Earthquake Resistant Houses- volume II by Department of Urban Development and Building Construction, Ministry of Urban Development, Government of Nepal.

2. Compressed Stabilized Earth Blocks

Soil is the main ingredient of the CSEB. Soil characteristics and climatic conditions of an area shall be evaluated before manufacturing soil building blocks. The soil shall be much more sandy than clayey. Top soil and organic soils shall not be used. Good soil for CSEB shall contain the following proportion of the four components: gravel, sand, silt and clay. It has gravel (15%), sand (50%), silt (15%) and clay (20%). The ingredients shall be mixed thoroughly. CSEB, is a type of manufactured construction material formed in a mechanical press (Aurum 3000) that forms a compressed block out of an appropriate mix of fairly dry inorganic soil, non-expansive clay, aggregate, and sometimes a small amount of cement or lime as stabilizer. Aurum 3000 machine is hand press machines. The machine consists of a frame, an interchangeable mould, a reverse toggle lever. Other accessories include scoops and bottom plates. The machine is mounted on the ground and secured in position using sand bags or stones. Measured quantity of this mixture is poured in the die of predefined shape and dimensions and is compressed by pulling the lever by hand. Then the compressed block is ejected from the die. The wet compressed blocks are stacked in rows. The blocks are set to cure for 28 days to gain strength before they can be used in construction[2, 3].

- Soil stablization: Soil stabilization is a process which improves the existing soil condition such as strength, decreases in porosity and improves in water proofing. There are three methods to make the soil stable, i.e. i) chemical ii) mechanical and iii) physical. In mechanical stabilization, soil property is improved by compaction, vibration and thereby soil density is enhanced and decrease in pores takes place. In chemical stabilization, reaction is achieved between ingredients in soil and cementing material to perk up the soil condition. Some of the chemical stabilizers to name: Ash from thermal station, lime and cement [4].
  The chemical admixtures such as lime, cement, and/or fly ash shall be used as a mean of chemically transforming unstable soils into structurally sound construction foundation. The selection of a stabilizer will depend upon the soil quality and the project requirements. Cement (4-10%) will be preferable for sandy soils and Lime (5-8%) will be rather used for very clayey soil [3].
- Strength: Strength of block depends upon the stabilization as, Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be rather used for very clayey soil, but will take a longer time to harden and to give strong blocks [3] .

- Water absorption and Moisture content: Strength and durability of stabilized block depends on water absorption and also the content of clay and cement. When the water absorption is high, there is swelling in the soil and strength reduction takes place. Due to increase in clay content, water absorption and porosity both increase [5].
  Moisture content effects strength and durability at time of construction. Dry brick absorbs water rapidly from mortar and prevents good adhesion. In case of very wet brick, mortar tends to float without proper adhesion [6].
- Durability: With lower clay content and partial increase in cement content durability improves. When the clay content exceeds 20%, durability deteriorates [7].
- Density: Density of the compressed stabilized earth block is consistently related to its compressive strength and compactive force applied during production. The density of compressed stabilized earth block is within the range of 1500 to 2000 kg/m^3 [7].
- Basic Data on CSEB: The properties of CSEB will vary with soil composition and production method why the values in Table 1 only give ranges. It is based on these values that design calculations of CSEB are made in Nepal today [3].

Table 1: Material properties of CSEB

Data on CSEB	Value
Apparent bulk density	1700-2200 kg/m^3
Young's Modulus	700-1000 MPa
Poisson's ratio	0.15-0.5
Compressive strength	3-6 MPa
Tensile strength	0.5-2 MPa
Bending strength	0.5-2 MPa
Shear strength	0.4-0.6 MPa
Water absorption	5-20%
Damping coefficient	5-30%
Coefficient of thermal expansion	0.010-0.015
Swell after saturation	0.5-2 mm/m
Shrinkage (due to natural air drying)	0.2-2 mm/m
Permeability	1.10-5 mm/s

3. Linear Static Analysis

Seismic analysis is to quantify the evaluation of the response of a structure to earthquakes. The general methods for seismic analysis of structures are namely the: (i) Linear static analysis - equivalent static method, (ii) Linear dynamic analysis - response spectrum analysis and (iii) Nonlinear static analysis - pushover analysis. In this paper, the equivalent static method has been used to evaluate the seismic performance of the masonry building.

Seismic codes are unique to a particular region or country. In this study, IS 1893[8] is the main code that provides outline for calculating seismic design force. This force depends on the mass and seismic coefficient of the structure and the latter in turn depends on properties like seismic zone in which structure lies, importance of the structure, its stiffness, the soil on which it rests, and its ductility. Part I of IS 1893:2002[8] deals with assessment of seismic loads on various structures and buildings. The seismic analysis of building is done using equivalent static method as described in the [8], in which seismic effect, that is, a horizontal force is considered as the percentage of the total weight of the building. In this method, dynamic forces, which act on the structure during the excitation, are converted into equivalent horizontal force.

In the equivalent static method, the lateral force equivalent to the design basis earthquake is applied statically. The equivalent lateral forces at each storey level are applied at the floor level. The base shear (V = V_b) is calculated as per Clause 7.5.3 of IS 1893: 2002.

$$V_b = A_h * W \tag{1}$$

$$A_h = \frac{Z}{2} * \frac{I}{R} * \frac{S_a}{g} \tag{2}$$

where W=seismic weight of the building, Z=zone factor, I= importance factor, R= response reduction factor,S_a/g= spectral acceleration coefficient determined from Figure 1 , corresponding to an approximate time period (T_a) which is given by

$$T_a = \frac{0.098h}{\sqrt{d}} \tag{3}$$

The base dimension of the building at the plinth level along the direction of lateral forces is represented as d (in metres) and height of the building from the support is represented as h (in metres).

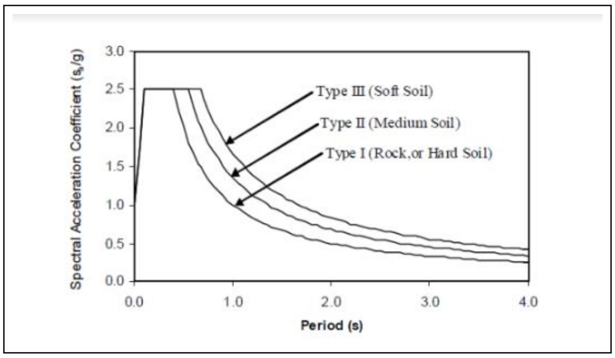


Figure 1: Response spectra for 5 percent damping (IS 1893: 2002)

As per IS Code 1893(Part I): 2002, the building is located in seismic zone V (Z=0.36). Being an unreinforced residential masonry building the importance factor, I =1.5, and Response Reduction factor, R= 2.25 is taken.The commonly adopted inverse triangular force distribution is not applicable to the flexible floor diaphragm. Because, the in –plane stiffness of the thick shear wall is relatively larger than the floor and the magnitude of lateral force at all level were nearly equal or same. Therefore, uniform pattern of 5KN/m^2 loading was used for the analysis of the loosely connected timber floor and roof including both dead and live load. The base shear in addition to other loads are generally applied to the structure modelled in a FE-program for analysis of the result.

3.1 Description of building

The seismic performance of building depends upon on the building plan configuration and opening on wall and eccentricity due to the asymmetric plan configuration of the building. To evaluate the global performance of a CSEB masonry building, first, a typical CSEB masonry building is selected from the Design Catalogue for Reconstruction of Earthquake Resistant Houses- volume -II [9]. Building used in this study is unreinforced masonry constructed with compressed stabilized earth block masonry. Blocks with mud mortar wall is considered as load bearing wall and masonry be of compressed stabilized earth block of size 300mm * 200mm* 100 mm size in mud mortar. The selected building is 2.2 meters high one storey building. The traditional buildings in Nepal usually have shorter story height than the modern buildings. The main load bearing element of the building is the masonry walls which are 200 mm in thickness. The wall generally has multiple layers blocks along its thickness. The general layout of the structure is presented in Figure 2. As can be seen from the figure, the building is rectangular in plan. The total length and breadth of the building are 5.4m and 4.5m respectively. The floor area of the building is 24.08 m^2.

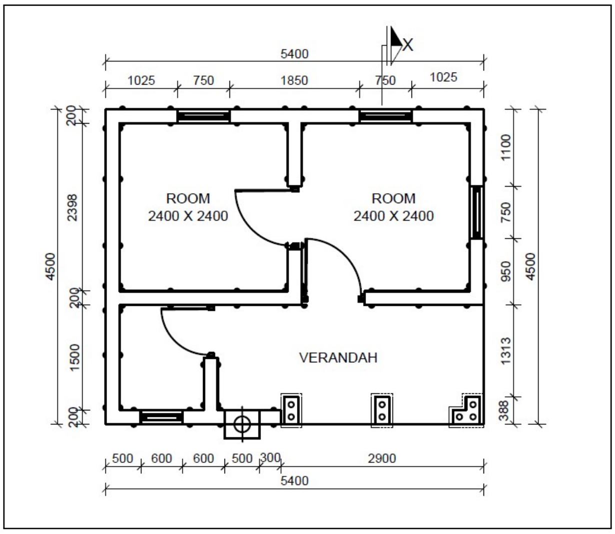


Figure 2: Typical Ground Floor Plan

3.2 Steps involved in Analysis

Collecting material parameters like Young's Modulus, Poisson's ratio, density etc.

- Modeling the masonry structure
- Meshing the model.
- Applying the boundary conditions
- Performing seismic coefficient method of analysis (Static method of analysis).
- Comparing the Analytical results.

3.3 Material Properties used in Analysis

The material properties are taken from the previous works based on the paper from Miccoli et al.(2014) [10] . The mechanical property of the CSEB masonry used in the calculations and simulation are in Table 2 as;

Table 2: Material properties of selected structure

SN	Properties of CSEB masonry	Value
1	Unit weight	1870 kg/m^3
2	Modulus of Elasticity	803Mpa
3	Poisson's ratio	0.37

3.4 Modelling of Masonry Building

The modelling of masonry compared to other materials such as concrete and steel is relatively complex due to the material complexity and structural composition. Masonry respond strongly non-linear to loading and is always build in combination with other materials such as steel, mortar or concrete making it a heterogeneous material. Therefore, masonry often require a model with 2D or 3D elements and a non-linear approach gives the most realistic results whereas a linear elastic approach gives approximate results. The largest difficulty when modelling masonry is the definition and use of appropriate material constitutive laws. Due to the complexity of the material composition of masonry several techniques have been adopted depending on the level of accuracy, simplicity desired and application field [11].

- Detailed micro modeling: Units and mortar joints are represented by continuum elements whereas the unit brick interface is represented by discontinues elements. “Figure 3” shows the detailed Micro modeling.
- Simplified Micro modeling: Expanded units are represented by continuum elements whereas the behaviour of the mortar joints and unit-mortar interface is lumped in discontinuous elements. These interface elements represent the preferential crack locations where tensile and shear cracking occur. “Figure 4” shows the simplified micro modeling.
- Macro-modeling: Units, mortar and unit-mortar interface are smeared out in the continuum. “Figure 5” shows the Macro-modeling. Macro-modeling is more practice oriented due to the reduced time and memory requirements as well as user friendly mesh generation. This type of modeling is most valuable when a compromise between accuracy and efficiency is needed.

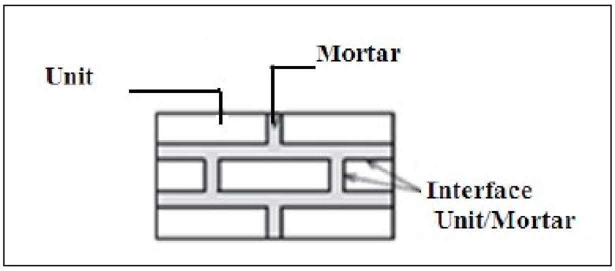


Figure 3: Detailed micro modeling

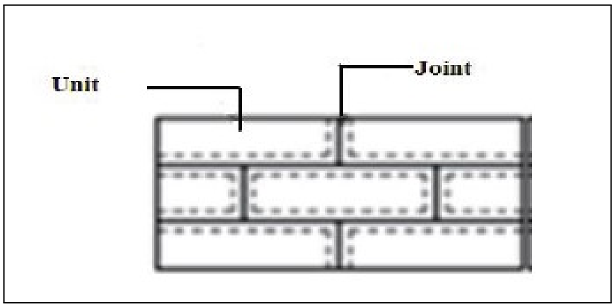


Figure 4: Simplified micro modeling

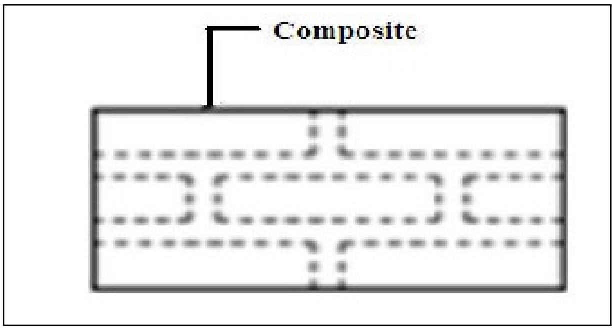


Figure 5: Macro modeling

Homogenous macro-modelling strategies is used for finite element modelling of masonry building in this study.

3.5 Element type : SOLID65

The element used for modeling the brick units, mortar and concrete is Solid 65. Solid 65 is used for the 3-D modeling of solids with or without reinforcing bars “Figure 6”. The solid is capable of cracking in compression. In concrete applications, for example the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. The element is defined by eight nodes with degrees of freedom at each node: translations in the nodal x, y and z directions. Up to three different rebar specifications may be defined. The most important aspect of this element is treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar can sustain tension and compression, but not shear. They are also capable of plastic deformation and creep [12].

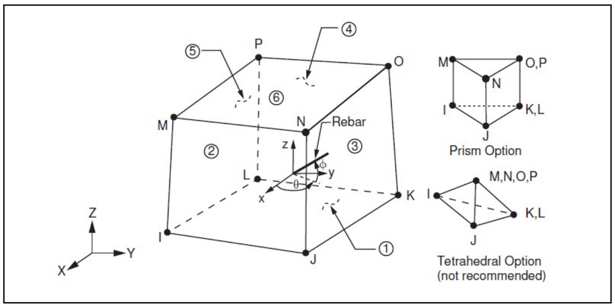


Figure 6: Element type: SOLID 65

Table 3: Natural Frequencies calculated from Modal Analysis

Mode	Frequency(cycles/sec)	Time Periods(sec)
1	12.982	0.077
2	14.876	0.067
3	15.802	0.063
4	17.075	0.058
5	17.787	0.056
6	20.114	0.050

4. Numerical Study

The present structure is analyzed using ANSYS 2019 R3 software, under the load combination gravity and seismic loading. After numerical simulation, the result thus obtained will be helpful for detecting weak failure zones of the building under seismic forces and expected performance of the building can be achieved. Calculation of permissible stresses for masonry to validate the analytical calculated stresses by using ANSYS 2019 R3. The following permissible stresses are calculated as per IS: 1905-1987, Indian Standard Code of Practice for Structural Use of Unreinforced Masonry [13] :

- Permissible Compressive stress (fc) : The value of permissible compressive stress of masonry is calculated as per IS 1905:1987 cl 5.4.1 was found to be 0.597 Mpa.
- Permissible shear stress (fs): The value of permissible shear stress of masonry is calculated as per IS 1905:1987 cl 5.4.1 was found to be 0.1 Mpa.
- Permissible tensile stress (ft): The value of permissible compressive stress of masonry is calculated as per IS 1905:1987 cl 5.4.2 was found to be 0.1 Mpa.

4.1 Analysis of Mode shapes and Frequencies

Natural frequencies and mode shape of the building have been obtained through modal analysis approach using ANSYS 2019 R3. The first six frequencies of the building obtained by Modal Analysis have been shown in Table 3. The first three modal shapes are shown in Figure 8. It is seen that the natural frequencies are closely spaced after second mode.

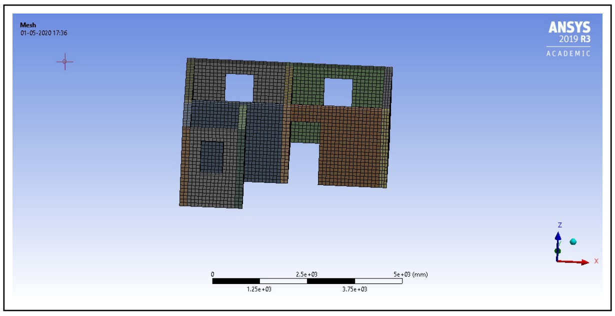


Figure 7: 3D meshed model of the building in ANSYS 2019 R3 using Solid 65 elements

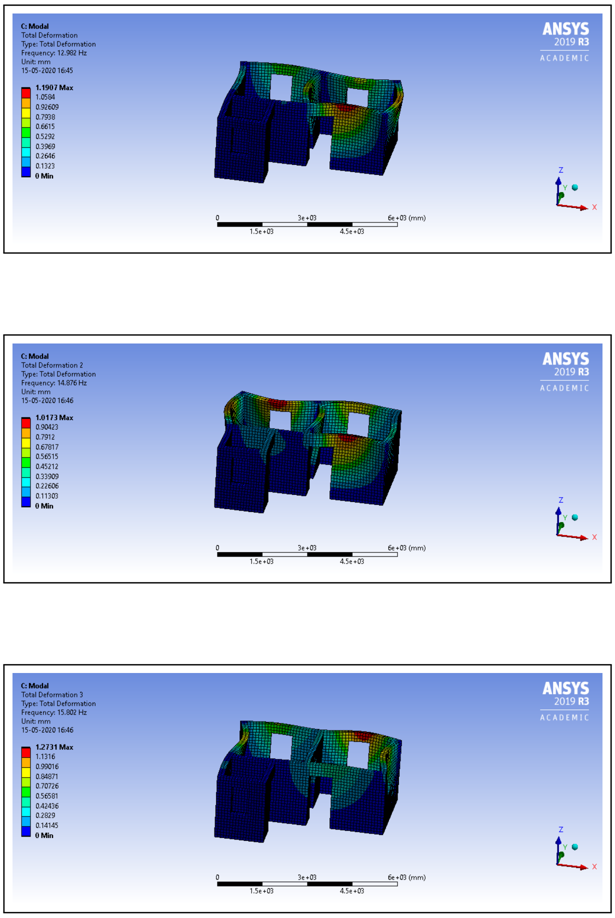


Figure 8: First three mode shapes

4.2 Analysis of stresses under Gravity loading

Most of the part of the building remains under compression within permissible limits as given in IS 1905: 1987 [13], while tensile stress is exceeded at very few locations i.e. around openings, wall junctions at roof level and at the bottom most corners of walls due to combined effect of dead load and imposed load as seen in Figure 9 . The maximum value of tensile stress is 0.0212 Mpa reached at a very few positions otherwise tensile stresses in the building are also within the acceptable range. Shear stresses in the building due to gravity loading are within acceptable limits and maximum value reached is 0.035 Mpa. The permissible shear stress value is 0.1 MPa, which is not exceeded anywhere.

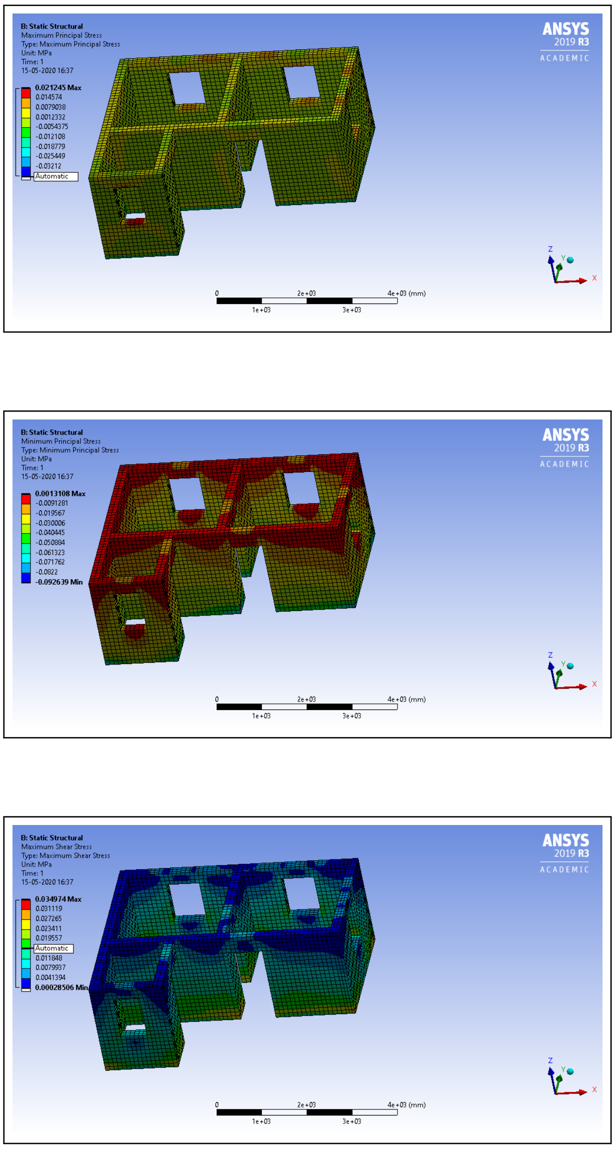


Figure 9: Tensile Stress, Compressive Stress and Shear Stress due to gravity loading

4.3 Analysis of stresses under Seismic loading

The building is analyzed for various load combinations of dead load, imposed load and seismic load for masonry buildings as given in IS 1905: 1987 [13]. The building is subjected to different PGA levels (0.2g, 0.3g, 0.4g, 0.5g) as input ground motion to determine its seismic performance. As seen from Figure 10 and Figure 11, due to seismic load in X and Y direction respectively, most part of the structure remains under compression within permissible limits. As for the gravity loading, here also tensile stress is exceeded at a few places as seen from figures.

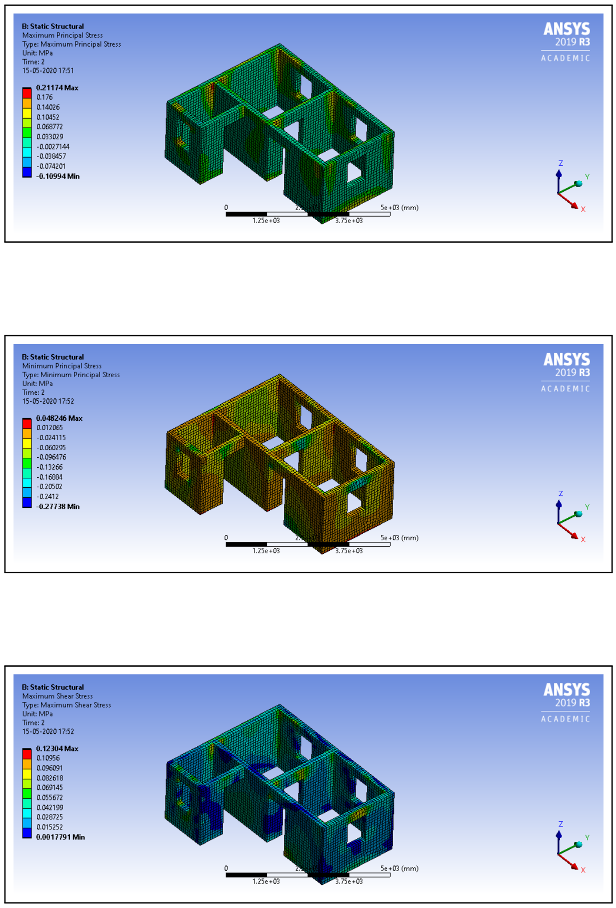
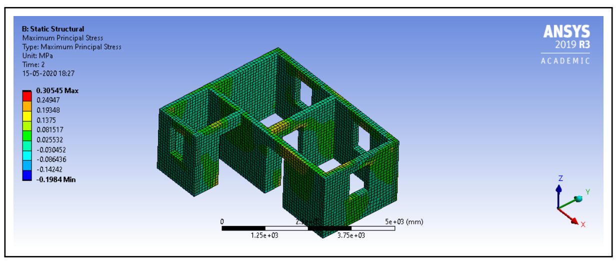
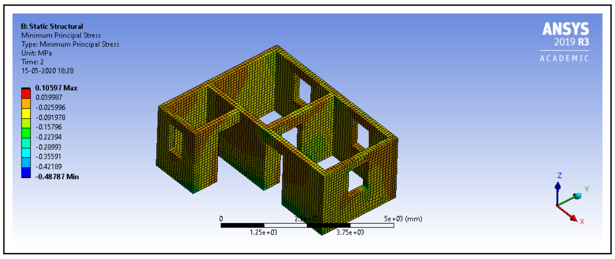


Figure 10: Tensile Stress, Compressive Stress and Shear Stress due to seismic loading in X-direction





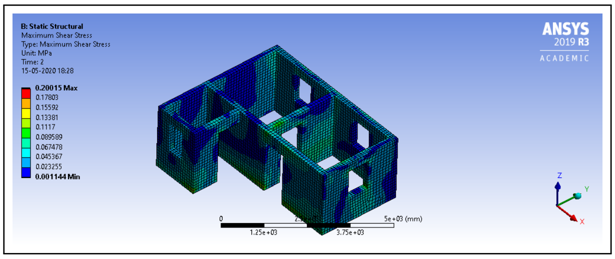


Figure 11: Tensile Stress, Compressive Stress and Shear Stress due to seismic loading in Y-direction

Table 4 and Table 5 shows maximum values of stresses reached for different Peak Ground Acceleration (PGA) levels of 0.2g, 0.3g, 0.4g and 0.5g under seismic loading in X and Y direction. It can observe that maximum compressive stresses for all PGA levels are within permissible limits but tendency of structure to fail in tension increases with increase in PGA level.

Table 4: Maximum Value of stresses reached for different PGA due to seismic loading in X-direction

PGA	Compressive stress (Mpa)	Tensile stress (Mpa)	Shear stress(Mpa)
0.2g	0.160	0.088	0.065
0.3g	0.195	0.129	0.084
0.4g	0.236	0.171	0.103
0.5g	0.277	0.211	0.123

Table 5: Maximum Value of stresses reached for different PGA due to seismic loading in Y-direction

PGA	Compressive stress(Mpa)	Tensile stress(Mpa)	Shear stress(Mpa)
0.2g	0.241	0.0915	0.099
0.3g	0.323	0.162	0.132
0.4g	0.405	0.233	0.166
0.5g	0.487	0.305	0.200

5. Conclusions

Masonry buildings in mud mortar are prone to severe damage during an earthquake due to poor bond strength. The major failure of masonry walls is due to out of palne failure.This study shows that without earthquake resistant features, seismic performance of building was highly vulnerable because of the lack of effective connection between walls at corner and the insufficient in-plane and out of–plane strength. If no proper earthquake resistant features is applied, this kind of building will undergo severe damage with increase in seismic loading and responsible for casualties during a strong earthquake. The objective of this study was to evaluate the seismic performance of unreinforced masonry building constructed using compressed stabilized earth block subjected to seismic loading. Based on analytical works, the following conclusions and recommendations are made.

- The masonry building is modeled using homogeneous macro-modeling with solid elements in the software ANSYS 2019 R3. The finite element model is analyzed for both gravity and seismic loading.
- The first six natural frequencies of the building are obtained by Modal Analysis. It is seen that after second fundamental frequencies are closely spaced.
- The building does not show any cracks under gravity loads. Considering all the Load cases, the structure remains in compression within permissible compressive stresses (0.597 MPa) for all values of PGA levels.
- Permissible shear stresses (0.1 MPa) are exceeded for PGA of 0.3g for seismic loading in Y direction and also for PGA of 0.4g for seismic loading in X direction. The maximum value reached is 0.200 MPa.
- But tendency of structure to fail in tension increases with increase in PGA level. Only at a few places tensile stress is exceeded ($>$ 0.1 MPa), mostly at the corners of walls at bottom and roof level and at beam-wall junctions.
- The portions around the openings were found to be highly vulnerable in all cases because presence of opening in the bearing wall reduce their strength under the action of horizontal forces and lead to local failure. Similarly, L and T corner are vulnerable due to insufficient connection between wall at corner.
- The structure is safe under static loading, only

few weak zones are seen which can be strengthen accordingly using proper strengthening techniques.
- Heterogeneous modelling is recommended because it gives more accurate results than homogeneous modelling.
- Recommendations for non-linear and/or a micro approach analysis needs to be carried out to get more extensive and accurate result.

Finally, it is also evident from the different scenarios discussed above that damage zones in the walls of the present masonry building will vary depending upon the seismic excitation to which the structure is subjected, geometry of walls and material properties of the masonry work. Therefore, recommendations regarding to increase the seismic performance of various part of the building can be only made after the numerical model of the structure under the given conditions are thoroughly investigated. And after investigation of numerical model of building, recommendations for repairing, retrofitting and strengthening of masonry as per the building code can appear to improve the performance and prevent complete collapse of building can be made.

References

[1] Satprem Maini. *Auroville-earth Disaster resistance*. http://www.earth-auroville.com/disaster_resistance_introduction_en.php.

[2] Satprem Maini. *Auroville Compressed stabilized earth block*. http://www.earth-auroville.com/compressed_stabilised_earth_block_en.php.

[3] Hari Darshan Shrestha. *Standard Norms and Specifications for CSEB Blocks On CSEB Green School Buildings in Nepal*. Government of Nepal - Ministry of Education, 1st edition, 2012.

[4] Bachir Taallah and Abdelhamid Guettala. The mechanical and physical properties of compressed earth block stabilized with lime and filled with untreated and alkali-treated date palm fibers. *Construction and Building Materials*, 104:52–62, 2016.

[5] Peter Walker and Trevor Stace. Properties of some cement stabilised compressed earth blocks and mortars. *Materials and structures*, 30(9):545–551, 1997.

[6] JE Oti, JM Kinuthia, and J Bai. Engineering properties of unfired clay masonry bricks. *Engineering Geology*, 107(3-4):130–139, 2009.

[7] Fetra Venny Riza, Ismail Abdul Rahman, and Ahmad Mujahid Ahmad Zaidi. A brief review of compressed stabilized earth brick (cseb). In *2010 International Conference on Science and Social Research (CSSR 2010)*, pages 999–1004. IEEE, 2010.

[8] D IS. Is 1893–2002 (part-1), criteria for earthquake resistance design of structure. *Bureau of Indian standard*, 2002.

[9] NR NRA. Design catalogue for reconstruction of earthquake resistant houses. *Nepal Government, Department of Urban Development & Building Construction. Kathamandu: Ministry of Urban Development*, 2015.

[10] Lorenzo Miccoli, Urs Müller, and Patrick Fontana. Mechanical behaviour of earthen materials: A comparison between earth block masonry, rammed earth and cob. *Construction and building materials*, 61:327–339, 2014.

[11] Paulo B Lourenço. Computations on historic masonry structures. *Progress in Structural Engineering and Materials*, 4(3):301–319, 2002.

[12] Ansys Inc. Ansys user's manual for revision 8.0, 2003.

[13] Indian Standard. Code of practice for structural use of unreinforced masonry, 1905.