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# Seismic Analysis of Typical CSEB Masonry Building used in Reconstruction

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**Abstract**

After Gorkha earthquake 2015, CSEB masonry building are used extensively in reconstruction in major parts of earthquake affected area of Nepal like Sindhupalchowk, Gorkha, Nuwakot, Kathmandu and Dhading. The analysis of typical approved masonry building is performed using two different macro modelling approach of typical three-room building plan which is used extensively in reconstruction. SAP 2000 V22.0.0 and Abaqus/CAE 2020 is used as the analysis platform. Modeling is done considering masonry as a homogeneous material with material properties obtained from experimental, numerical and past research data. Linear Static and nonlinear static approaches are performed in respective platforms. Analysis of the result obtained shows that stresses in the building components are found to be within permissible range of masonry strength. Addition of seismic force resistive components in the structure enhances the ductility of the building thereby improving the performance in tension and compression. Symmetry in structure, addition of vertical reinforcement and increase in rigidity of roof improves the capacity of building.

**Keywords**

CSEB, masonry, modeshape, prism test

## 1. Introduction

Nepal is a small mountainous country in the South Asia, which lies at the center of the 2500 km long Himalayan range. The entire Himalayan terrain and its surroundings is a highly active seismic zone on earth. Nepal's proximity to earthquake hazard is mainly due to her young and fragile geology, haphazard and unplanned settlements and poor construction practices. Earthquake is the biggest threat to Nepal as it has encountered 19 major earthquakes since the twelfth century [1]. The devastating Gorkha Earthquake measuring to 7.8 Mw having the epicenter occurred near Barpak village of Gorkha district which is 81 km northwest of Kathmandu on 25 April 2015. It was the worst quake to hit the country after the 1934 mega earthquake (8.3 Mw). On 12 May 2015, a 6.8 Mw strong aftershock caused further damage and sufferings. These earthquakes took the lives of 8970 people where 198 people are missing, and 22,303 people were seriously injured. The earthquakes destroyed 604,930 houses completely and 288,856 houses were partially damaged [2].

Compressed stabilized earth bricks in masonry building are used as major reconstruction material after Gorkha earthquake. CSEB are ultimately greener, ecofriendly, comparable in strength, durability and thermal conductivity [3]. In Nepal CSEB has gained a lot of attention after the Gorkha Earthquake since it allows people to rebuild strong houses to a large extent using local soil. In Nepal it has many advantages compared to ordinary kiln fired bricks: higher strength, less emissions and lower cost. The earthquake assessment of those re-construction building is necessary and seismic assessment for future earthquake is much important and is studied here as research purpose [4]. The behavior of CSEB towards structural load differs in both tension and compression. Different modelling approaches of modelling are present. Micro modelling requires large number of material properties and each interaction surfaces are to be defined. It requires larger computational time and processor. Macro modelling is done assuming the masonry as a homogenous element and simplifies the computational process requiring lesser time of analysis [5]. Masonry properties are obtained from lab experiment as well as with the help of research papers [6].

Strength of CSEB varies from place to place, types of soil, compositions of material and with degree of compaction [7]. For this particular research following composition CSEB is used.

**Table 1:** Composition of CSEB

| Stone Dust | Cement |
|---|---|
| 90% | 10% |

**Table 2:** Properties of units

| | |
|---|---|
| Compressive strength of CSEB unit | 5.72$MPa$ |
| Strength of mortar | 15$MPa$ |
| Shear strength of mortar | 2.5$MPa$ |

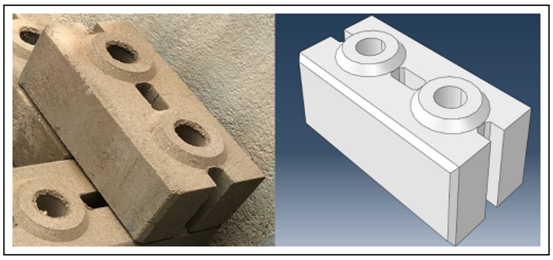

**Figure 1:** Typical CSEB interlock block used in analysis with its Solid Model

## 2. Objectives

The major objectives of research include:

1. To determine the stress in piers and natural time period of vibration of typical unreinforced CSEB masonry building without RCC bands and concrete grout using linear-static approach.
2. To determine the capacity of the same building with RCC bands and concrete grout in hollow section of CSEB interlock masonry and perform analysis adopting non-linear static approach.
3. To enumerate the outcomes with respect to stress variation in masonry elements after analysis and give if any modification in building to enhance its performance.

## 3. Methodology

The methodology adopted is to model the CSEB building recently constructed in earthquake affected area in Nepal in Finite element software, SAP 2000 and Abaqus CAE 2020 adopting macro modelling method. Lab test for determining masonry properties of interlocking CSEB blocks is performed. Macro modeling is adopted for unreinforced condition of masonry building to check any ductile demand. The stress level of each pier is observed. Linear static approach and nonlinear static analysis are performed in respective models. The additional material properties of masonry and concrete beyond test results are obtained from various research papers and with the help of Built-up Nepal.

## 4. Estimation of Masonry properties from Prism test in Laboratory

The masonry properties of the CSEB interlock brick for analysis in Abaqus/CAE are limited, lab test is performed to get those unknown properties. Thirty-nine CSEB interlocking bricks are taken and weighted.

### 4.1 Prism Test

Test of total nine prism (Three prism of five blocks and six prism of four blocks) under compressive load are performed as per IS 1905-1987 in CMTL, Pulchowk Campus.

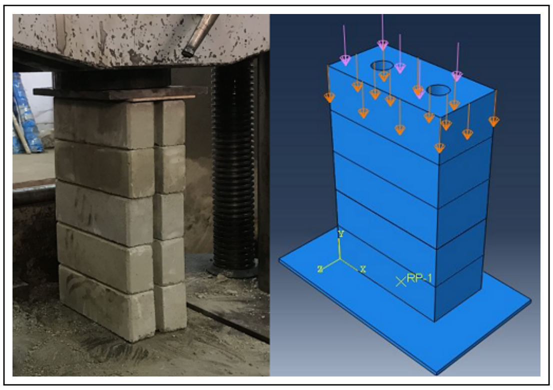

**Figure 2:** Physical Laboratory Setup and Numerical Model in Abaqus/CAE 2020

### 4.2 Numerical Validation of test with FE software

The test is numerically modelled in Abaqus/CAE platform and the failure pattern are observed. The failure pattern are observed as similar to the physical test in laboratory.

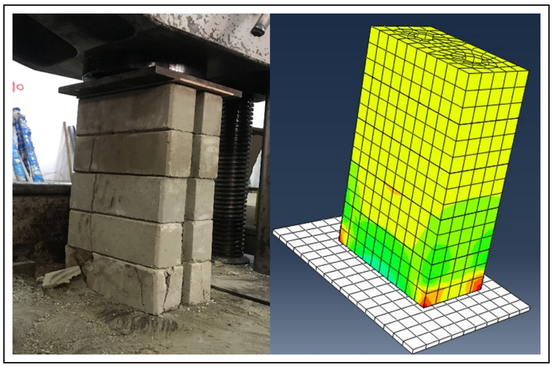

**Figure 3:** Failure of Masonry Prism (Experimental and Numerical Visualization)

### 4.3 Comparison with Numerical Modeling Data

The five-block masonry prism test is modelled in Abaqus/CAE 2020 and the boundary conditions are defined as per experimental setup.

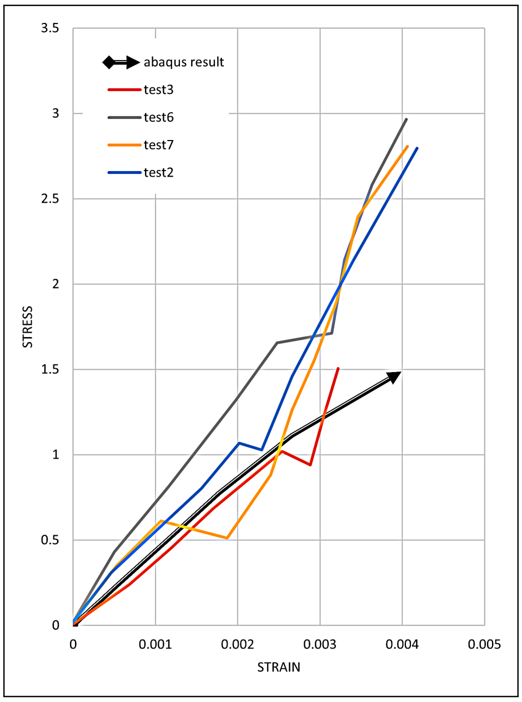


**Figure 4:** Comparison of Stress-Strain Diagram of Test results to Numerical model

### 4.4 Discussion of Test

The material properties are varied accordingly to get a match between the stress-strain diagrams obtained from the lab test to numerical model. After subsequent variation Damages parameters with experimental non-linear properties, the graph as seen in Figure 3-13 is obtained. The plot from Numerical model is likely to match with the experimental results.

### 4.5 Results of Test

Following damages parameters and nonlinear data are valid for analysis of whole building modelled in Abaqus/CAE 2020.

**Table 3:** Result of lab test

| | |
|---|---|
| Density of Block | $1754 kg/m^3$ |
| Modulus of Elasticity | $491 MPa$ |
| Average Compressive Strength of Masonry | $2.70 MPa$ |

Nonlinear analysis in Abaqus/CAE, the required input of nonlinear data for masonry (Yield stress vs. Absolute Plastic hardening) are obtained experimentally and tabulated as below:

**Table 4:** Druker Prager Hardening

| Yield Stress | Abs. Plastic Hardening |
|---|---|
| 1.156343 | 0 |
| 1.235690 | 0.0003825 |
| 1.597563 | 0.000625 |
| 2.030048 | 0.0010025 |
| 2.522950 | 0.0014525 |

## 5. Modelling of Building

### 5.1 Modelling in SAP 2000, V22.0.0

Macro modeling is performed in SAP 2000 V22.0.0 considering the CSEB masonry as shell element. RCC bands and vertical concrete grout in the hollow portion of the block is ignored Linear static method of analysis is performed.

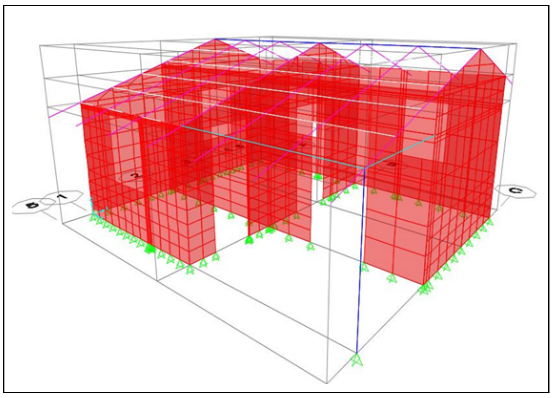

**Figure 5:** Macro-modelling of whole building in SAP 2000 V22.0.0

The force and stress in each masonry piers under linear static approach of analysis are studied. For particular walls, the walls are divided into pier and spandrel and stresses in piers are checked for shear sliding and rocking.

#### 5.1.1 Results of Test

The model was successfully run in SAP 2000 V22.0.0 and the output was obtained in terms of stresses in masonry wall. The calculations for capacity of masonry pier in rocking, shear sliding and diagonal cracking is done. The results from the analysis are then compared to the capacity of masonry in those possible failure and the following results are obtained:

- All compressive stresses in pier are in permissible limit of masonry.
- Fundamental time period of building is obtained as 0.1246 Seconds.
- Tensile stresses are seen in all pier for all load combinations hence showing a ductility demand.
- Seven piers of building are found to be critical in rocking and shear sliding. This is analyzed by using theory suggested by [8].

### 5.2 Modelling in Abaqus/CAE

About Abaqus/CAE 2020: A detailed modelling of building with all features i.e. plinth band, walls, lintel bands, sill bands, gable bands, gable walls, steel channel and tube is performed by defining their individual material properties and tied together. Gravity load and imposed load are applied in the building. The lower surface of tie band is constrained to ground.

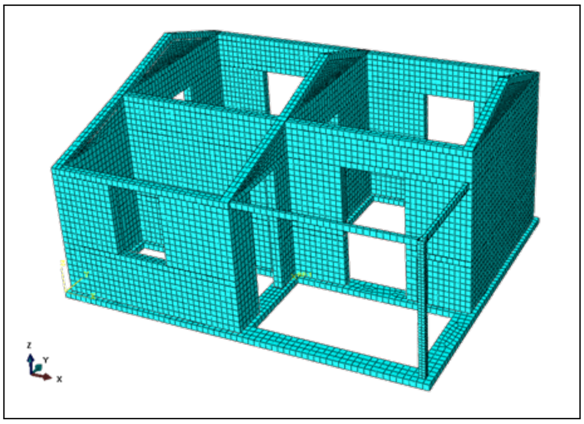

**Figure 6:** Modelling of whole building in Abaqus/ CAE 2020

### 5.3 Results

#### 5.3.1 Model Analysis of Abaqus/CAE Model

The model analysis resulted in a number of natural modes. Fundamental time period of vibration is found to be 0.09 Seconds which is obviously lower in the case of unreinforced masonry system thus providing more rigid structure. First three modes shapes are shown as below with their respective frequency of vibration:

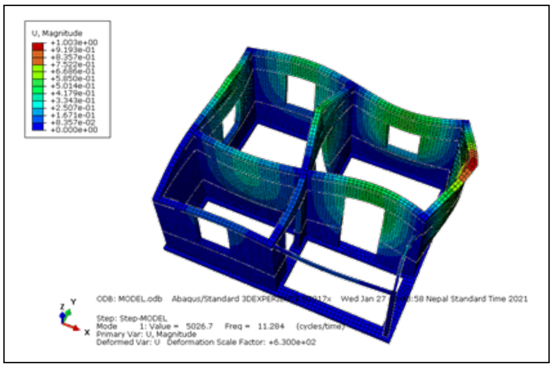

**Figure 7:** Fundamental mode shape of building: Frequency 11.294 Hz.

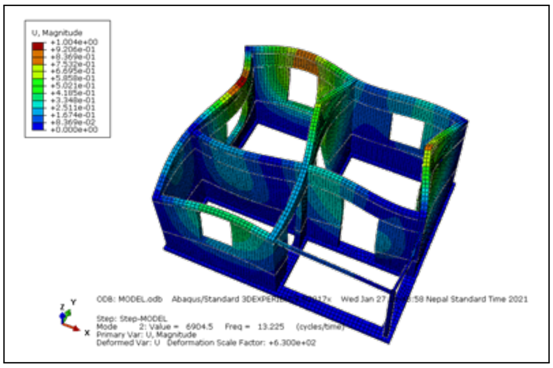

**Figure 8:** Second mode shape of building: Frequency 13.225 Hz.

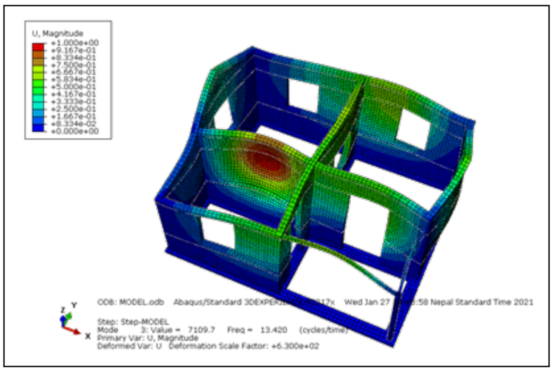

**Figure 9:** Third mode shape of building: Frequency 13.420 Hz.

### 5.3.2 Stress Observation

The stress for static loading conditions i.e., Dead load and imposed load on roof is shown in figure below. Maximum stress is developed in the corners of opening and change in direction of walls. Steel column and pipe section in the balcony is found take maximum stress throughout the building as shown.

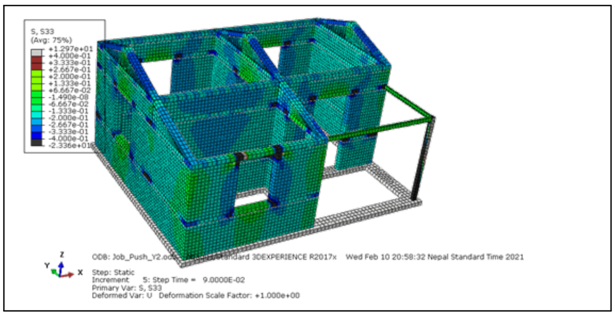

**Figure 10:** Stress in various components of building with Dead load + Imposed load

### 5.3.3 Rebar Configuration and stress variation around corner of walls

The maximum stresses in solid walls are observed around the corner of the walls at a maximum distance of 600 mm.

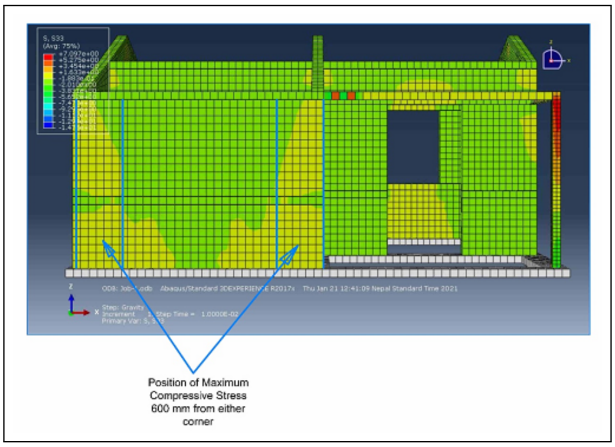


**Figure 11:** Stress around solid wall corners

### 5.3.4 Stress Observation for nonlinear static loading condition

By applying continuous push displacement in the building the corner stresses are developed in the building as shown in figure below showing that the provided reinforcement in the corner of the wall and around the opening are well placed to take theses stresses.

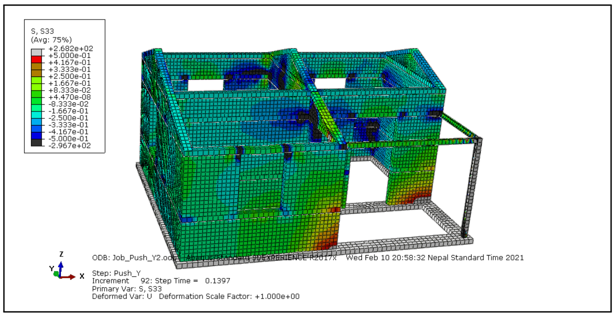

**Figure 12:** Stress in various components of building during push over analysis

## 6. Conclusion

The time period of building is found to be increased thus giving more rigid structure. Since, the design of this building was based on structural safety but also on an architectural vision of a family home. Oftentimes the architectural vision does not coincide with the structurally optimal design. A conflict of what is most important then takes place. The building was designed as a three-room building but with the possibility to build a fourth room. This offers prospects for the future to the family living in the house but also results in an asymmetrical building. The following chapter will address the improvements of the design of the building only with regard to structural safety.

### 6.1 Symmetry of Structure

The importance of symmetry is of great importance when designing an earthquake resistant building. As can be seen in Figure 13 the plan symmetry is not ideal (in neither x- or y-direction) when only three rooms are built. Also, the three existing rooms are of different sizes since the two orthogonal inner walls are not centered. This in turn results in openings, for both windows and doors, that are not symmetric around the center-point of the building.

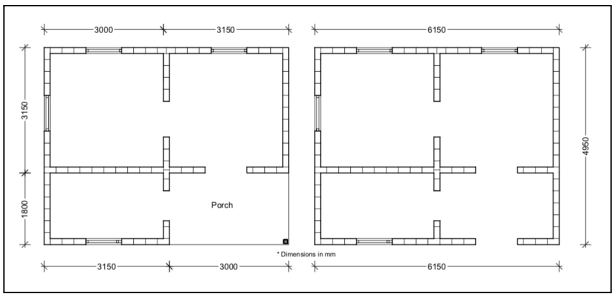


**Figure 13:** The actual layout and improved layout of building plan

### 6.2 Vertical rebar positioning

As per stress distribution pattern in figure 11, maximum compressive stress in the wall presents at maximum distance of 600 mm on either side of wall corner. It is to increase the vertical rebar and concrete grout to extend upto 600 mm at each corner on either side as well as continuous at 1.2 meters interval in solid wall.

### 6.3 Isolated Column in replacement of vertical and horizontal steel tube and channel

The isolated column in balcony can be replaced by isolated column and horizontal tube by a beam such that the better stress distribution can achieved.

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