Seismic Performance of CSEB Masonry Building

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ABSTRACT

The study aims to evaluate the seismic performance of Compressed stabilized earthen block (CSEB) masonry building with and without earthquake resistant features. FEM based structural analysis software ANSYS was used to model and analyse the structures. The building is modelled with macro-modelling approach and SOLID65 element was selected to represent the nature of the masonry. Linear and non-linear static analyses were conducted for both models. The nonlinear concrete model based on William-Warnke failure criteria was used. The pushover curves were developed for the normal masonry building (M1) and the timber reinforced masonry building (M2) to compare the seismic performance. The performance level of buildings was assessed using procedures stated in FEMA 356. The seismic analyses showed that the building model M2 having earthquake resisting features performed well during the earthquake. The first mode time period is decreased by 41.7%, the capacity is increased by 64.62% in x direction and 66.5% in y direction after addition of the reinforcement in M1 model. The performance level was at collapse stage (CO) in the unreinforced model in transverse direction, while, it was in range between immediate occupancy (IO) and life safety (LS) level after addition of timber reinforcement.

Keywords: FEM Based, Timber Reinforcement, Seismic Analysis

1. INTRODUCTION

Earthen walls are considered to be sustainable materials for their low embodied energy (Egenti & Khatib, 2016). Compressed stabilized earthen block (CSEB) masonry presents an environmentally and economically sustainable alternative to conventional residential construction materials such as clay brick masonry or concrete masonry (Maini 2005 and Hoff 2016). Compressed stabilized earthen blocks with specific composition and stabilization can show better performance against seismic failure (Riza, Rahman, & Zaidi, 2011). A number of researchers (Rigassi, 1985; ASTM International, 1989; Egenti, Khatib, & Oloke, 2014; Maini, 2005; Egenti & Khatib, 2016, Guinea 2015, Arumala & Gondal 2007) who have done extensive work in the field of earth construction have identified unique advantages from their studies. Reinforcing and introducing seismic character in the building can be a way to reduce vulnerability of the building (Maini, 2005).This study focuses on assessing the structural resistance of CSEBs with and without reinforcement with the help of Finite Element Modelling (FEM). The objective of the study is to evaluate the seismic performance of CSEB masonry buildings with and without timber reinforcement.

2. MATERIALS AND METHODS

The research was carried out aiming at finding the result based on cause and effect. Literature review was followed by the selection of suitable CSEB masonry building configuration (Betti et al 2016). The assessment of effect of introducing timber reinforcement in the building was carried out with the help of FEM. During the modeling, the element type and material properties, failure criteria, loading criteria and boundary conditions were selected (Chavez & Meli, 2012, Endo et al 2015). A non-linear finite element analysis was carried out using the ANSYS software. The masonry was modeled using homogeneous macro-modeling approach with solid65 element. The building was analyzed for both gravity and seismic loadings. The natural period and vibration mode were computed to recognize the dynamic properties of structure. Then non-linear static pushover analysis was carried out to determine the performance of the building in terms of storey drift as per FEMA 356.

3. NUMERICAL MODEL

Large number of numerical modellings of masonry has been done by using in the researches using FEM (Lourenço 1996, Rots 1997, Zucchini et al. 2007, Parajuli et. 2008 & 2011, Parajuli 2012 & 12016, Parajuli & Ghimire 2020, Mark et al 2004). A typical CSEB (Keshav et al.2012, Patowary 2015) masonry building of one storey with area 40.54 m2 (7.05m x 5.75m) and 2.475 m high was selected (Fig. 1). Model M1 (Fig. 2) was CSEB without any reinforcement and Model M2 (Fig. 3) is CSEB with timber reinforcement in plinth, sill, lintel and roof.

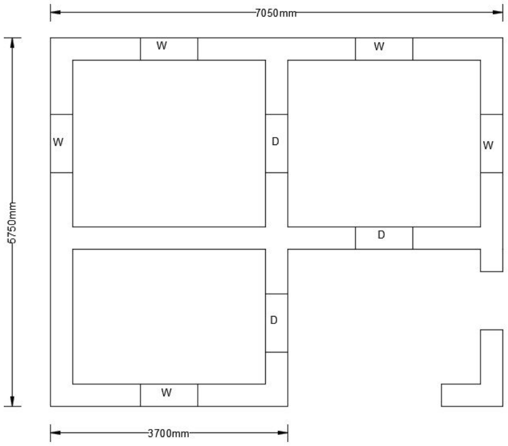

Fig.1: Plan of selected building

The size of the compresses stabilized earth block used is 300mm*200mm*100mm and block was stabilized by 8% cement as a stabilizer agent. The sizes of door and window are 900mm * 2100mm and 750mm * 1200mm respectively. The size of timber band is 75mm*100mm. The mechanical properties of the CSEB and CSEB masonry with 1:6 cement sand mortar was taken in reference to (Bhatta, 2015). The important factor was taken 1 as residential building, seismic zone V, response reduction factor (R) was taken 1.5 and medium type of soil was considered as seismic deign parameters as per IS 1893.The load are mentioned the Table 1.

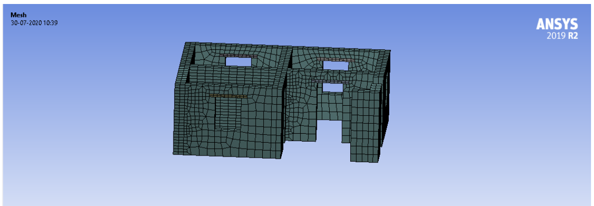

Fig.2: Model M1

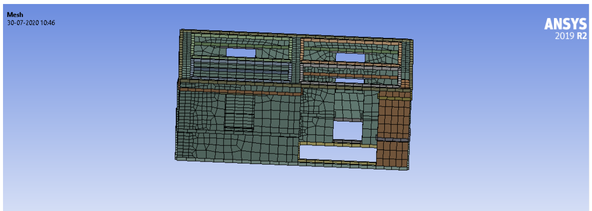

Fig.3: Model M2

Table 1: Load on the building

Roof live load	**1.5 kN/m2**
Live load	3.0 kN/m^2

The monotonic lateral loading was applied in the form of inertial load. The loads were applied through a horizontal acceleration. The static structural analysis included application of self-weight in a first step and a lateral load was applied in second step after the deformation. Material properties of CSEB (Murthy et al 2019), masonry and timber are explained in the Tables 2-4.

Table 2: Material property

Material	Description	Mean Value
CSEB	Specific weight of CSEB unit	1950 Kg/m^3
	Dry compressive strength of CSEB unit	8.1 MPa
	Wet compressive strength of CSEB unit	5.5 MPa
CSEB Masonry	Compressive strength of CSEB masonry	2.705 MPa
	Shear strength of CSEB masonry	0.146 MPa
	Modulus of Elasticity	338.125 MPa
	Shear Modulus	152.72 MPa
	Specific weight of masonry	1950 Kg/m^3
	Poisson's ratio	0.15
Timber	Density	650 Kg/m^3
	Modulus of Elasticity	11000 MPa
	Poisson's ratio	0.2

Table 3: Material properties for FEA simulation

Description	Value
Compressive strength of masonry	2.705Mpa
Tensile strength of masonry	0.27 Mpa
Open shear crack transfer coefficient	0.15
Closed shear crack transfer coefficient	0.75

Table 4: Stress-strain properties for accuracy

Stress (Mpa)	Strain(mm/mm)
0.0000	0.00000
0.8115	0.00240
1.7330	0.00580
2.3380	0.00920
2.6300	0.01260
2.7050	0.01600

4. SEISMIC ANALYSIS

Non-Linear Analysis

Analysis was evaluated through capacity curve, which represents the value of the applied action i.e. seismic load on the building in relation to the displacement of the control point. The most common control point is the top point of the structure. Pushover analysis can be performed in various direction (Rios & Dwyer 2018). The change in slope of a pushover curve can give an indication of damage of particular segments of the building. For, obtaining the pushover curve the procedure stated in FEMA-356 was followed and capacity curve was obtained. Procedures for performance assessment. The nonlinear concrete model based on William-Warnke 1975 failure criteria was used.

Capacity curves of both unreinforced and reinforced model (with different aspect ratios, compressive strength and loading conditions) are obtained by utilizing the previously mentioned analysis technique in ANSYS.

If a performance assessment is required, then the capacity curve is converted to Acceleration Displacement Response Spectrum (ADRS) format and compared with demand (in terms of acceleration spectrum).

The point where the capacity and the demand for that specific building intersects was regarded as the performance point and it was used in order to assess the seismic performance of the building.

The ranges for determining performance level for masonry in terms of storey drift is shown in Table 5.

Table 5: Performance drift limits (masonry buildings)

Building Type	Performance level for drift (%)		
	Collapse Prevention (CP)	Life Safety (LS)	Immediate Occupancy (IO)
Unreinforced Masonry	1	0.6	0.3
Reinforced Masonry	1.5	0.6	0.2

5. RESULT AND DISCUSSION

Modal analysis

From the free vibration analysis fundamental time periods were calculated and presented the Table 6.

Table 6: Fundamental Time-Period for M1 and M2

Model	Fundamental Time period (sec)		
	Empirical Formula		Modal Analysis
	X-direction	Y-direction	
M1	0.101	0.112	0.146
M2	0.101	0.112	0.085

The timber band reinforced as earthquake resistant features provided increases in stiffness of the building , maintaining structural integrity. Furthermore, the time period of building model reinforced with timber bands was seen to be less than that of unreinforced building model.

Development of capacity curves

Pushover analysis of the selected buildings was carried out in longitudinal (X) and transversal (Y) direction. Gravity was applied in a first loading step and then seismic forces proportional to mass of the structure were incremented until the analysis stops due to the collapse of the model. The capacity curves had been defined making reference to different control points. Finally, the performance point of buildings was determined as per FEMA 356.

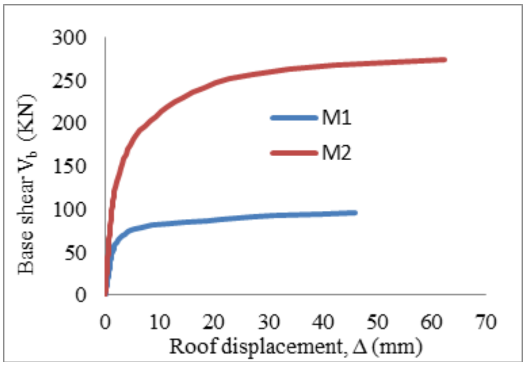

Fig.4: Capacity curve for M1 and m2 along x-direction

Along the longitudinal direction (+X), the first horizontal branch of the capacity curve was seen at base shear for 80 KN for M1 and 220 KN for M2. The ultimate state reached at base shear 97 KN and a roof displacement of 45.96 mm for model M1 while for model M2, the ultimate state is reached at base shear 274.175 KN and a roof displacement of 62.314 mm. Hence, it can be seen that after the addition of earthquake resistant features as wooden bands in building, the capacity of building increased by 64.62 % and roof displacement by 26%. This has been plotted in the Fig. 4

In the positive transverse direction (+Y), the first horizontal branch of the capacity curve is seen at base shear 72.346 KN for M1 and 235.79 KN for M2. The ultimate state is reached at base shear of 87 KN and a roof displacement 65.16 mm for model M1. Similarly, the ultimate state is reached at 260 KN and a roof displacement for model M2. Hence, it can be seen that after the addition of earthquake resistant features as timber bands in building, the capacity of building increase by 66.5 % and roof displacement is increase by 20%. The base share and displacement relations has been plotted in the Fig. 5.

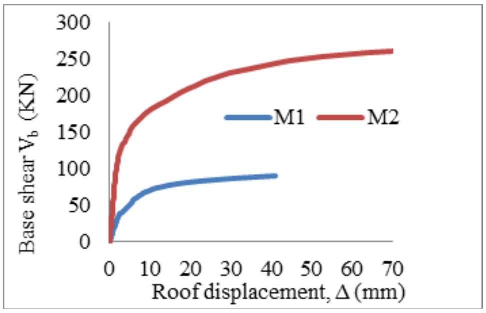

Fig.5: Pushover curve for M1 and M2 along y-direction

Building Performance

The performance point in terms of storey drift from analysis was found 0.81% for unreinforced masonry model M1 and 0.52% for reinforced masonry with timer bands model M2. The drift obtained from the analysis are shown in the Table 7. The comparison of building capacity and demand are show in the Figs 6-9.

Table 7: Roof drift of M1 and M2 in x and y direction

S. N	Loading	Model	Roof Displacement (mm)	Storey Height (mm)	Roof Drift (%)
1	Along X	M1	21.088	2475	0.852
2		M2	12.880	2475	0.520
3	Along Y	M1	25.967	2475	1.049
4		M2	15.525	2475	0.630

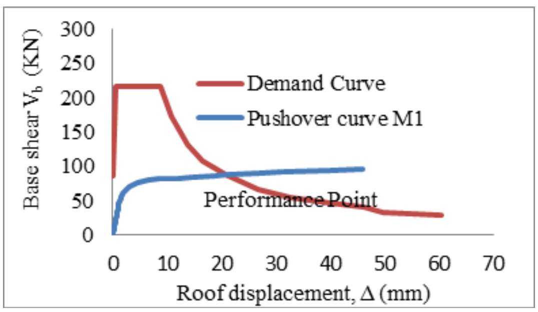

Fig.6: Performance level for M1along X-direction

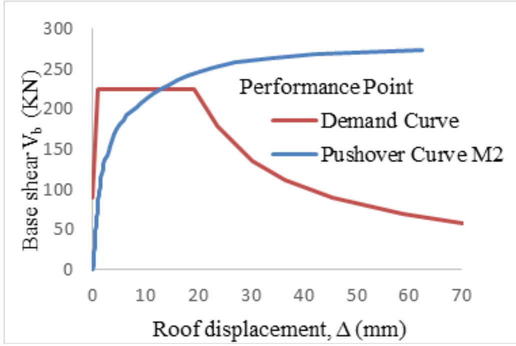

Fig.7: Performance level for M2 along X-direction

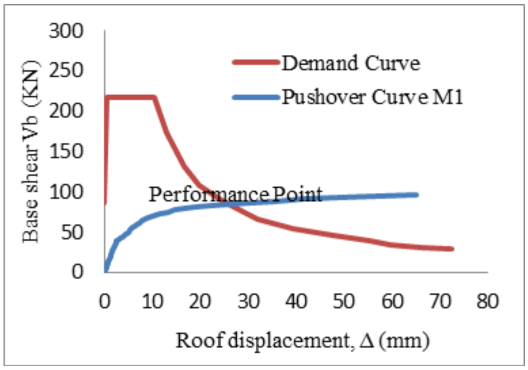

Fig.8: Performance level for M1 in Y direction

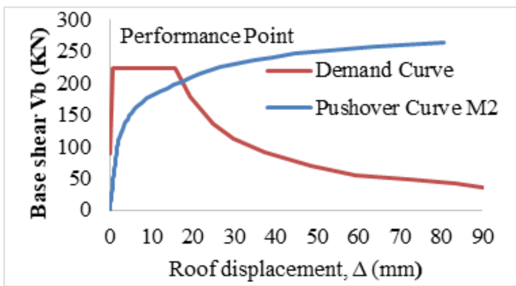

Fig.9: Performance level for M2 along Y-direction

The performance point in terms of storey drift from analysis was found to be found 1.05% for unreinforced masonry M1 and 0.63% for reinforced masonry with timer bands model M2. This due to the reason that timber bands give structural integrity to the building and during the earthquake, building shows box behavior and prevent from collapse and causalities.

6. CONCLUSION

From the investigation through numerical analysis, following conclusions are made.

1. Comparing the fundamental time period of both models obtained from empirical formula and seismic analysis, the time period decreased in Model M2, due to change in mass and structural stiffness which was increased by addition of timber bands as earthquake resistant features in model M1. The first mode time period of Model M2 decreased by 41.7% than that of model M1.

2. Wooden bands can contribute to the improvement of the seismic capacity of CSEB masonry building in both cases. The capacity of model M1 increased by 64.62% and 66.5% in case of x-direction and y-direction respectively. These Earthquake resisting features could prevent collapse of out-of-plane walls of buildings.

3. From the numerical study, after the addition of timber bands, the performance point of the building as per FEMA-356 is increased. Even though the capacity curve increased with the timber bands, the performance level was at collapse stage at unreinforced model at transverse direction. However, building's performance level reached in range between immediate occupancy (IO) and Life safety (LS) level after addition of timber bands.

4. This study aims at making extensive use of raw earth as a building material, there by using a local resource to help develop technologies that are energy saving, eco-friendly (Auroville, 1989 & 2005) higher strength and sustainable development. The result of this study shall be used for the understanding the seismic behavior of unreinforced and timber reinforced masonry building as built by using locally available materials. It shall also be helpful in deciding the use of CSEB as alternative building materials and use of timber bands as earthquake resistant features for sustainable and low-cost housing. Macro modelling approach for modelling of masonry was considered during seismic analysis. In present study non-linear static analysis was carried out and for further work dynamic nonlinear analysis may also be carried out.

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