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RESEARCH ARTICLE

Finite Element and Experimental Analysis of 3D Masonry Compressed Stabilised Earth Block and Brick Building Models against Earthquake Forces

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Abstract

The main objective is to study the seismic behaviour of eight building models with scale 1:3 of 3D single room building constructed using country fired brick and three types of Compressed stabilised earth [CSE] blocks along with and without earthquake resistant features [EQRF]. Models were subjected to shake table tests. Four models were constructed using four different blocks along with EQRF. Other four models were without EQRF. To examine the seismic capacity, the models were subjected to long-period ground motion and the test specimen were shaken repeatedly until the failure. The test results from Hi-end Data Acquisition system show that model with EQRF behave better than without EQRF. And also CSEB building models behaved better than brick models. A comparison between the results of tests and the FEM analysis by ANSYS predictions is made. The data obtained from the experimental works were given as train set in Artificial Neural Network (ANN) and a tool was created in Matlab software for analysing various blocks.

Keywords

Earth Block · Artificial Neural Network Masonry · Ansys · Seismic loading · Brick

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1 Introduction

The traditional masonry buildings without any earthquake resistant features had proved to be the most vulnerable to earthquake forces and had suffered maximum damage in past earthquakes. The two most common modes of masonry failure may be called **out-of-plane failure *and* in-plane failure**. The structural walls perpendicular to seismic motion are subjected to out-of-plane bending results in out-of-plane failure featuring vertical cracks at the middle of the walls and in corners which may due to inadequate flexural strength of unreinforced masonry [1] or due to lack of integrity of a adjoining structural [2]. The structural walls parallel to seismic motion are subjected to in-plane forces i.e. bending and shear causes horizontal and diagonal cracks in the wall respectively which may be due to reduced shear capacity of poor quality mortar [3] or due to tension failure along the principal diagonal plane [4].

The past experimental studies under earthquake excitation have been conducted mostly on masonry models than on full-scale masonry structures due to lack of high capacity testing facilities to study prototypes of the large-sized actual structures. Under lateral load tests, both horizontal and vertical reinforcement [5] are effective in increasing the lateral strength and inhibit crack propagation in masonry buildings. Shake table tests [6] on masonry models, with and without openings, showed the permissible level of peak ground acceleration without any damage. Shock-table test on scaled single-storeyed masonry building [7] showed that RC lintel band, corner and jamb steel increased the strength and energy absorption capacity of the buildings. Appropriate design considerations can ensure desirable ductile response for masonry building with precast-prestressed hollow-core floor planks. Analytical models for in-plane response of brick masonry in the linear range and in the non-linear range [8] simulated the experimental behaviour of similar specimens.

The present study determines the seismic resistance capacity of 3D masonry building models constructed by four types of blocks such as country fired brick, Compressed Stabilised Earth blocks manufactured from locally available soil along with earthquake resistant features of horizontal and vertical bands under dynamic shake table loading. In this experimental investigation shake table tests were conducted on eight reduced models that represent normal single room building constructed by Compressed Stabilized Earth Block (CSEB). Four models were S2 of using solid compressed stabilized Earth Block(SCSEB), H2 of Hollow compressed stabilized Earth Block(HCSEB) M2 modified solid compressed stabilized earth block(MCSEB) and E2 using country fired brick were constructed with earthquake resistant features (EQRF) having sill band, lintel band and vertical bands to control the building vibration and other four models of same variety blocks S1,H1,M1,E1 were without Earthquake Resistant Features. To examine the seismic capacity of the models particularly when it is subjected to long-period ground motion by large amplitude by many cycles of repeated loading, the test specimen were shaken repeatedly until the failure. The test results from Hi-end Data Acquisition system show that the model constructed using MCSEB with and without EQRF behave better than other block models. This modified masonry model with new materials combined with new bands technology can be used to improve the behaviour of masonry building.

2 Manufacturing of Blocks

2.1 Bricks

For this project, special 1/3rd size bricks were specially moulded and used for construction of models. Average dimensions of burnt clay brick units used are 76 mm×36 mm×25 mm.

2.2 Compressed Stabilised Earth Block

Every soil is not suitable for earth construction. But with some knowledge and experience most of soils can be used. Top soil and organic soils should not be used [9]. The good soil with good proportions, raw or stabilized, for the solid Compressed Earth Block (SCSEB) and hollow compressed earth Block (HCSEB) are slightly moistened, poured into a steel press and then highly compressed by press AURAM 3000. Press AURAM 4000 was used for production of MCSEB. CSEB can be compressed in many different shapes and sizes [10]. The input of soil stabilization allowed the people to build higher with thinner walls, which have a much better compressive strength and water resistance. The blocks stabilized with 5% cement must be cured for four weeks after manufacturing [11]. After this, It can be dried and used like common bricks.

A good soil for HCSEB and SCSEB is more sandy than clayey. It have gravel (15%), sand (50%), silt (15%) and clay (20%).To achieve this proportion gravel 15% and clay 10%, coarse sand 10% were added. So 65% of locally available soil for mix and 5% cement for stabilization were taken. A good soil for MCSEB is earth soil (40%), Crusher sand (35%), Red soil (10%), Lime (10%) and cement 5% were taken. To find the moisture content for mix as per Auroville Recommendation, a ball using soil mix is prepared. The ball from 1 m height is dropped & the result is observed. If the ball does not burst into pieces, the mix is too wet. If the ball burst into more & small number of pieces, the mix is too dry. If the ball burst into 4 or 5 numbers of pieces, the mix is good for making CSEB blocks. Most of the soil particles retained between 425 μ to 75 μ (more than 64%) in the sieve analysis as per IS- 1498-1970 procedure show this soil is sandy soil (with fine sand).

Exact quantity water was mixed with soil and mix was subjected to press to get blocks (Fig. 1).

Average dimensions of Solid Compressed Stabilized Earth Blocks are 140 mm×70 mm×50 mm. HCSE block have 10% hollow and the size is equal to solid block. Average dimensions of MCSE Blocks are 80 mm×80 mm×35 mm (Fig. 2). The compressive strength obtained for individual block units as per the standard test procedure IS 3495, 1976 is higher than country fired bricks. The water absorption is around 10%. It is available in various sizes and shapes. It have some limitations like proper soil identification is required, lack of soil, wide spans, high & long building are difficult to do, low technical performances compared to concrete, under stabilization resulting in low quality products, bad quality or un-adapted production equipment, low social acceptance. Cement mortar 1:6 was used to construct all models. Locally available sand and 43 Grade Ordinary Portland cement are mixed as per volume to emulate the traditional constructional practices. M20 concrete was used for all concrete elements. 6 mm size coarse aggregate was used due to small thickness of elements. HYSD bars of 6 mm diameter were used as reinforcement for all RCC elements (Fig. 3). Construction materials were same for the building with EQRF and without EQRF. Earthquake performance of a masonry building strongly depends on the quality of building materials [12].

The test results show that compared to country fired brick model, hollow block model performed well and when comparing with hollow compressed block (HCSEB), solid block (SCSEB) performed good. And modified solid compressed block performed multi times better than other blocks. Thus these blocks satisfied basic requirements of block for building construction. The next stage of construction of building models (1:3 scale) with these reduced scale blocks to find seismic performance is to be carried out.

Compressed earth bricks demonstrated many advantages when compared to conventional fired bricks. Compressed stabilized earth bricks are ultimately greener, eco friendly, comparable in strength, durability and thermal conductivity [14]. The use of compressive earth bricks also promotes healthier living for the building dwellers. Still it has many possibilities to explore more in enhancing its properties. Data from related works showed that an average saturated compressive strength of CSEB is less than its average dry compressive strength. The average density of CSEB is almost equivalent with the common brick [15]. Also it has shown that compressed earth brick demonstrates comparable durability with that of normal fired clay bricks. Thermal value experiment indicated that thermal conductivity of CSEB showed compliance with the design thermal requirements for clay masonry and building regulations.

Fig. 1. Manufacturing of Solid , Hollow block in Auram 3000 and Modified solid block in Auram 4000

Fig. 2. Solid, Modified Solid and Hollow compresses stabilised Earth blocks

3 Construction of Building Models

In this experimental investigation the following eight models were constructed and tested. The scale adopted for the model was 1:3 (Prototype: Mode l). M1, M2- Modified Compressed Stabilized Earth Block masonry models without EQRF and with EQRF. S1,S2- Solid Compressed Stabilized Earth Block masonry model without EQRF and with EQRF, H1,H2- Hollow Compressed Stabilized Earth Block masonry model without EQRF and with EQRF. E1,E2- Brick masonry model without EQRF and with EQRF. Earthquake Resisting Features(EQRF) are the reinforced concrete seismic bands provided horizontally at plinth, sill, lintel roof levels and vertical ties provided at the corners and sides of door and windows openings of the model.

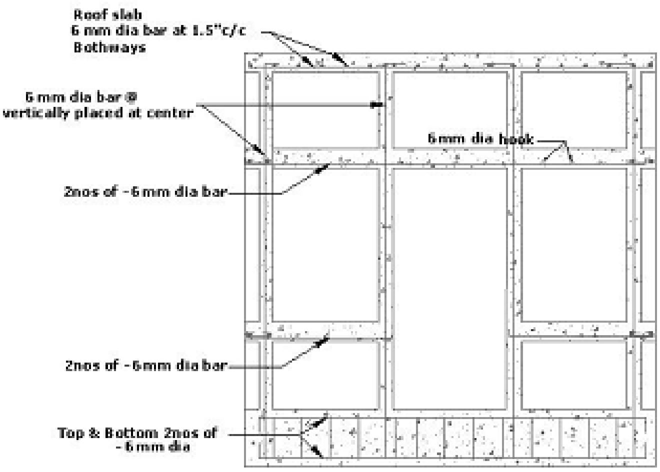

Fig. 3. Reinforcement details of Horizontal and vertical bands

Total weight of the shake table is 4 tonnes and its capacity is about 1000 Kgs. The shake table's movement can be controlled in any of the desired directions i.e., X, Y, XY. It's a Bi-axial shake table, therefore movement in vertical direction is not possible. The structure was tested under dynamic load condition. Dynamic load was created by varying the speed of the motor. The frequency achieved was in the range 0 Hz to 3 Hz. The Accelerations were measured in X-direction at plinth, lintel & roof level. For the shake table Accelerations were measured in both X & Y directions. Masonry models were tested under free vibration to find out the natural frequency and the damping characteristics of the models [16]. The bands were placed continuously along the wall length. Models were placed in bi-axial shake table and Accelerometers were fixed at table, plinth level, lintel level and roof level to measure the acceleration [17]. DEWE-5000 Data Acquisition System, DJB Accelerometers – 3 Numbers, DEWE Soft Software, Cables and Connector, Accelerometer Mounting Set-up were used to carry out the tests.

Cracking and disintegration gets initiated at the lintel level and collapse occurs due to failure of the corner of Model E1 at frequency 2 Hz as shown in Fig. 5. It can be seen that the cracking in model E2 is much less compared to E1. Though the model has lateral and diagonal cracks there is no collapse as in the case of model E1 upto frequency in direction $X = 2.6$ and $Y = 2.0$ Hz.

Fig. 4. E1 Model – Initial Stage

The maximum acceleration imposed at roof level for E1 is 0.812 g whereas for E2 Model with earthquake resistant features

Fig. 5. E1 Model – Final Stage

the acceleration levels imposed are much higher 1.248 g. Even under such large acceleration levels, the models with earthquake resistant features have performed very well. (Fig. 6, Fig. 7).

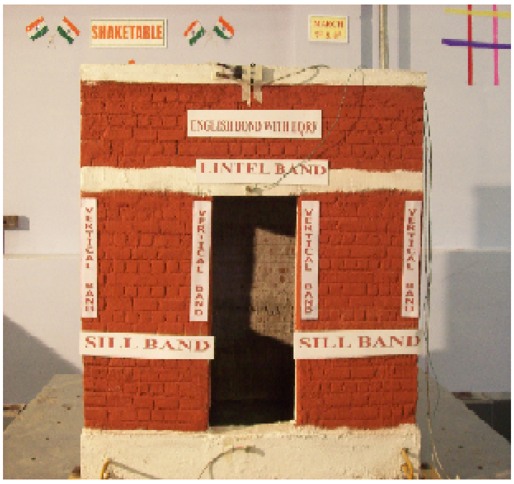

Fig. 6. E2 Model – Initial Stage

Fig. 7. E2 Model – Final Stage

The excitation given to the model H1 was in only one direction (X) because at X = 1.77Hz the model was collapsed (Fig. 8, Fig. 9). The model H2 was subjected to vibration in both X and Y direction (more severe) because at maximum frequency X = 2.503 Hz, the model didn't crack, so the frequency in Y-direction also given to the model H2 (Fig. 10, Fig. 11).

The duration of acceleration sustained by H2 was significantly more than that of H1.

Fig. 8. H1 Model – Initial Stage

Fig. 9. H1 Model – Final Stage

Fig. 10. H2 Model – Initial Stage

Fig. 11. H2 Model – Final Stage

The maximum acceleration imposed at roof level for Model H1 without

earthquake resistant features was 0.6205 g, whereas for Model H2 with earthquake resistant features the maximum acceleration at roof level was much higher 0.8512 g in X direction and 1.503 g in Y direction. Even under such large acceleration level, the model with earthquake resistant features had performed well.

Fig. 12. S1 Model – Initial Stage Figure

Fig. 13. Model: S1 – Final Stage

At this 1.8 Hz frequency, Structural Damage in CSEB-solid block model S1 without EQRF Model is significantly more and the model collapsed (Fig. 12, Fig. 13). However CSEB-solid block model with EQRF Model survived without collapse, had only minor cracks.

At higher frequency (X = 2.503 Hz & Y = 1.892 Hz) Model with EQRF – S2 had major cracks and finally collapsed (Fig. 14, Fig. 15).The excitation given to the model M1 was in X-direction at Frequency 2.259 Hz (Fig. 16, Fig. 17)the model collapsed. The model M2 was subjected to vibration in both X and Y direction (more severe) because at maximum frequency 2.625 Hz in X-Direction, there was no cracks are formed. So the Y-direction frequency was also given to the model M2. The duration of acceleration sustained by M2 was significantly more than that of M1.

The maximum acceleration imposed at roof level for Model M1 without earthquake resistant features was 0.5920 g, whereas

Fig. 14. S2 Model – Initial Stage

Fig. 15. S2 Model – Final Stage

Fig. 16. M1 Model – Initial Stage

Fig. 17. M1 Model – Final Stage

for Model M2 with earthquake resistant features the maximum acceleration at roof level was much higher 0.6556 g. At higher frequency (X = 2.600 Hz, Y = 1.984 Hz) Model with EQRF Model only minor cracks had developed (Fig. 18, Fig. 19).

Fig. 18. M2 Model – Initial Stage

Fig. 19. M2 Model – Final Stage

4 Results-Acceleration Amplification

It is defined here as a ratio between response acceleration at a certain level of the structure usually the uppermost level and PGA. For each loading level, the Acceleration Dynamic Magnifications Factors (ADMF) at roof, lintel levels of the six models were computed. The ADMF was defined as the ratio of the maximum acceleration response recorded at the each level to the one at the base acceleration in the corresponding direction. The magnification of acceleration of M1 is less than other two models as shown in Table 1

Experimentally obtained values of the horizontal acceleration amplification ratio at roof level were in the range from 0.29 to 3.60 in Table 2. Comparison was made between the amplification ratios of models H1,S1 and M1 at roof level in Table 3 & lintel level and also for the models H2,S2 and M2 subjected to similar excitation level in Table 4 and also a comparative study on the system responses during test runs with increasing excitation levels was carried out.

It was shown that efficiency of the model M2 in terms of reduction in acceleration responses was more pronounced at the higher excitations. The displacement of roof level of model S1 was less than model H1.The displacement of model M2 was comparatively less than other two models and performed well than other all models.

5 Artificial Neural Network for Prediction of Displacement

Artificial Neural Network ANN is a branch of artificial intelligence which attempt to mimic the behavior of the human brain and nerves system. A neural network can be considered as a black box that is able to predict an output pattern when it recognizes a given input pattern [18]. An artificial network (ANN) is possessed of interconnected artificial neurons that mimic some properties of biological neurons. Even though there are many different models for artificial neurons, a common implementation has multiple inputs, weights associated with each input, a threshold that determines if the neuron should fire, an activation function that determines the output, and two modes of operation (training mode and learning mode). Here the input layer is designed by the following features:

Dimension – the dimension of the building like length, breadth and height (x, y, z).

Hollow – Percentage of hollow level present in a architecture (h (%))

Compressive strength – Compression strength of the blocks which one was used in building (c).

Frequency – Frequency of the wave in Hz which one applied as input make damage in a building (f).

For this model the input layers have the six nodes which are passed to the hidden layers in a network. The input is denoted as I.

$$I_i = \{x_i, y_i, z_i, h_i, c_i, f_i\} \tag{1}$$

Here $i = 1, 2, \ldots n$. n is the no of training set used in a training.

The in-between input and output layer the layers are known as hidden layers which stores the knowledge of past experience / training (Fig. 20). The intermediate layer which one is use to find optimized weight matrix for the preferred training set. Intermediate layer consist of 20 hidden layers and each hidden layer have the neurons equals to the number of input nodes in input layer. The layer consists of 6 neurons and the one output node. Based on input layer and output layer the hidden layer values are modified in training process.

The connection between the layers are represented as,

$$Iw + B = Y \tag{2}$$

Here,

I Input
w Wieght matrix in hidden layers
B Costant in each hidden layer
Y output.

Tab. 1. Magnification of acceleration 'g' in models without EQRF at roof level

S.No	Frequency in Hz	Model H1 X Direction	Model S1 X Direction	Model M1 X Direction	Model E1 X Direction
1	0.427	7.77	7.11	3.747	19
2	0.794	5.21	5.24	2.645	13.54545
3	1.221	4.42	3.03	2.458	9.931034
4	1.587	1.66	1.64	1.903	10.91837
5	1.770	1.79	1.65	1.643	10.02469
6	2.259			1.869	

Tab. 2. Magnification of acceleration 'g' in models with EQRF at roof level

S. No	Frequency Hz in X,Y Directions	Model H2 X,Y Directions	Model S2 X,Y Directions	Model M2 X,Y Directions	Model E2 X,Y Directions
1	0.427,0	2.21,0	6.98,0	0.29,0	10.61 ,0
2	0.794,0	1.82,0	4.33,0	0.44,0	10.45, 0
3	1.221,0	1.53,0	2.74,0	0.45,0	10.60, 0
4	1.587,0	1.33,0	2.20,0	0.63,0	10.04, 0
5	1.770,0	1.36,0	1.20,0	0.63,0	9.65, 0
6	2.014,0	1.33,0	1.59,0	0.66,0	9.0, 0
7	2.320,0	1.53,0	1.32,0	0.72,0	8.20, 0
8	2.442,0	1.43,0	1.46,0	0.75,0	6.93, 0
9	2.503	1.72,0	1.57,0	0.68,0	6.67 ,0
10	2.503, 0.610	1.32,1.84	1.39,1.30	0.67,1.46	6.67,9.56
11	2.503, 1.038	1.07,2.11	1.75,1.43	0.69,1.27	6.71,9.1
12	2.503,1.221	1.33,2.08	1.61,1.43	0.71, 1.16	6.67,9.23
13	2.503,1.587	1.35,2.33	1.59,1.26	0.73,1.13	5.62, 8.25
14	2.503,1.892	1.24,3.60	1.55,1.38	0.71,0.94	4.56,7.24
15	2.503,2	-	-	0.69,0.62	4.38, 4.36

Tab. 3. Magnification of acceleration 'g' in models without EQRF at Lintel level

S. No	Frequency Hz in X Direction	Model H1 X Direction	Model S1 X Direction	Model M1 X Direction	Model E1 X Direction
1	0.427	0.56	0.47	0.89	3
2	0.794	1.16	1.03	1.41	1.36
3	1.221	2.32	1.23	1.84	1.52
4	1.587	1.34	1.04	2.03	2.53
5	1.770	1.04	1.23	2.15	3.79
6	2.259			2.23	

Tab. 4. Magnification of acceleration 'g' in models with EQRF at Lintel level

S. No	Frequency in Hz	Model H2 X Direction	Model S2 X Direction	Model M2 X Direction	Model E2 X Direction
1	X = 0.427	1.08	0.61	1.92	2.40
2	X = 0.88	1.36	1.19	2.29	1.97
3	X = 1.221	1.70	1.38	2.33	1.83
4	X = 1.587	1.62	1.32	1.90	2.21
5	X = 1.770	1.74	1.06	1.68	1.93
6	X = 2.014	1.66	1.37	1.72	1.82
7	X = 2.320	1.50	1.18	1.66	1.63
8	X = 2.442	1.54	1.30	1.48	1.54
9	X = 2.503	1.86	1.40		

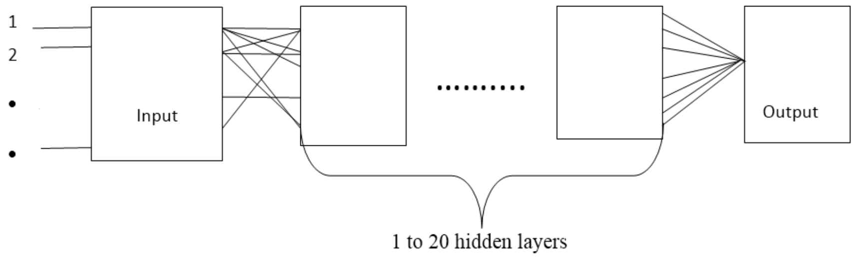

Fig. 20. Layers in ANN analysis

In training process the experiments results in a table are used as a training set.

The features are given to the input layer and damage level of the corresponding given in the output layer. By the continuous optimization process the net work which belongs to the training building modal is created. Experimental results are given as training set. After training the outputs for various frequencies for the Model 1 and 2 are given in Table 5 and Table 6.

MATLAB software is used to create neural network. For creation the network, totally 21 training data sets are used for Model1 and 31 sets for Model 2. These data sets were generated experimentally by testing models in shake table. The network was trained with six features and output after training of models without EQRF and Models with EQRF are given in graph (Fig. 21, Fig. 22)

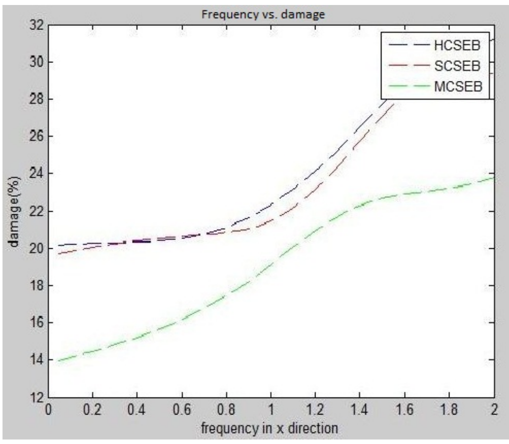

Fig. 21. Models without EQRF

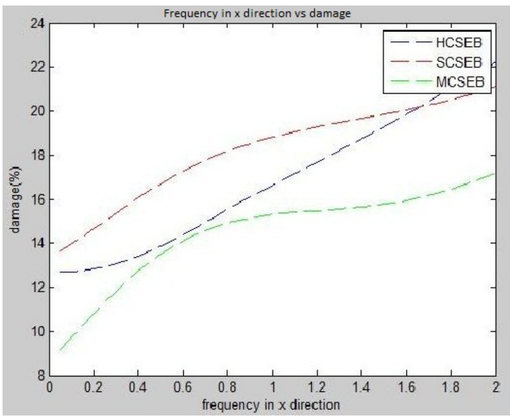

Fig. 22. Models with EQRF

The training of the system was performed by using the database corresponding to the real evaluations made from experimental tests. A system was developed by using computational intelligence such as Artificial Intelligence. The use of Artificial Intelligence tools in Civil Engineering has very little diffusion until present. It is recommended to promote their use to provide suitable and versatile solutions to different problems in this field of knowledge. A support tool based on innovative expert system is proposed in this research.

6 Analytical Validation Using Finite Element Method

Conventional methods used in the structural analysis are usually insufficient for the analysis of masonry structures because of the complex geometry and heterogeneous material properties of the structure. Today's computing facilities and methods make FEM the most suitable analysis method for complex structural geometry and heterogeneous material properties. Even the shrinkage, creep of the material can be considered in the analysis. Because of this reason Finite Element Method (FEM) is used to analyze such structures. FEM converts the structure into finite number of elements with specific degree of freedoms and analyses the structure by using matrix algebra. However, advanced FEM methods considering the inelastic and time dependent behaviour of material is a very complex and difficult task and consumes considerable time. Because of this reason, to analyze every historical structure is not feasible by applying advanced inelastic FEM, whereas elastic FEM analysis at low load levels is very helpful in understanding the behaviour of the structure. Comparison of results indicates good agreement between numerical analysis and experimental results.

This model considers solid65 element to represent bricks and reinforced concrete. The solid65 element models the nonlinear response of reinforced concrete. Solid65 models the concrete material based on a constitutive model for the triaxial behaviour of concrete . It is capable of plastic deformation, cracking in three orthogonal directions at each integration point [19]. Solid65 element is capable of cracking in tension and crushing in compression.

7 Conclusions

The objective of this research work was to determine the behaviour of masonry buildings constructed using brick,compressed stabilized Earth Blocks with earthquake resisting features subjected to seismic loadings. Based on the ex-

Tab. 5. After training the output of Model 1

Dimensions mm			Hollow %	Compressive Strength N/mm^2	Frequency Hz	Displacement mm
X	Y	Z				
140	70	50	10	5.13	0.429	20.5
140	70	50	10	5.13	0.8	21.23
140	70	50	10	5.13	1.22	28.25
140	70	50	10	5.13	1.58	37.08
140	70	50	10	5.13	1.77	49.34
140	70	50	10	5.13	2.014	52.24
140	70	50	10	5.13	2.32	58.54
140	70	50	10	5.13	2.44	62.56
140	70	50	10	5.13	2.503	70.45
140	70	50	0	5.68	0.429	19.79
140	70	50	0	5.68	0.8	20.71
140	70	50	0	5.68	1.2	23.11
140	70	50	0	5.68	1.6	28.63
140	70	50	0	5.68	1.77	34.94
140	70	50	0	5.68	2.014	38.32
140	70	50	0	5.68	2.32	42.42
140	70	50	0	5.68	2.44	54.54
140	70	50	0	5.68	2.503	60.80
80	80	35	0	20.6	0.429	16.42
80	80	35	0	20.6	0.8	17.24
80	80	35	0	20.6	1.1	20.84
80	80	35	0	20.6	1.53	23.12
80	80	35	0	20.6	2.01	25.69
80	80	35	0	20.6	2.25	28.83
80	80	35	0	20.6	2.44	30.63
80	80	35	0	20.6	2.625	33.51
76	36	25	0	3.12	0.40	22.04
76	36	25	0	3.12	0.79	32.11
76	36	25	0	3.12	1.22	53.65
76	36	25	0	3.12	1.60	62.71
76	36	25	0	3.12	2.00	69.54

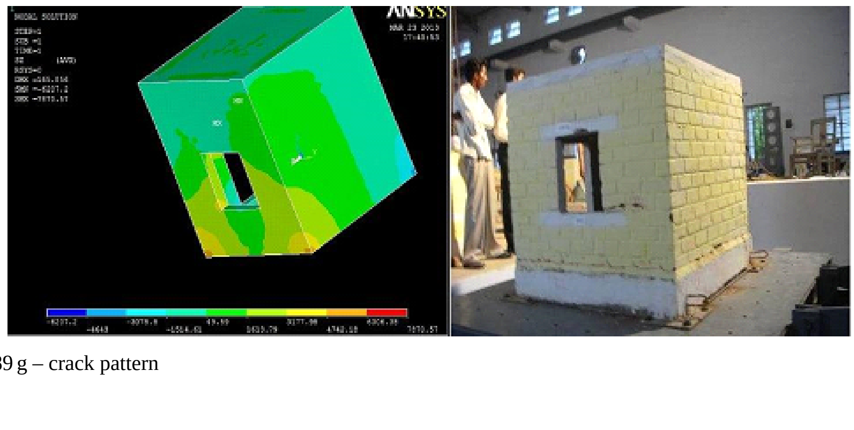

Fig. 23. S1 Model at 0.2689 g – crack pattern

Tab. 6. After training the output of Model 2

Dimensions mm			Hollow %	Compressive Strength N/mm^2	Frequency Hz	Displacement mm
X	Y	Z				
140	70	50	10	5.13	0.429	16.51
140	70	50	10	5.13	0.8	17.23
140	70	50	10	5.13	1.22	18.25
140	70	50	10	5.13	1.58	19.34
140	70	50	10	5.13	1.77	20.45
140	70	50	10	5.13	2.014	22.24
140	70	50	10	5.13	2.32	23.54
140	70	50	10	5.13	2.44	25.56
140	70	50	10	5.13	2.503	26.45
140	70	50	0	5.68	0.429	15.79
140	70	50	0	5.68	0.8	16.71
140	70	50	0	5.68	1.2	18.11
140	70	50	0	5.68	1.6	22.63
140	70	50	0	5.68	1.77	22.54
140	70	50	0	5.68	2.014	24.32
140	70	50	0	5.68	2.32	26.42
140	70	50	0	5.68	2.44	28.54
140	70	50	0	5.68	2.503	30.80
80	80	35	0	20.6	0.429	13.42
80	80	35	0	20.6	0.8	16.24
80	80	35	0	20.6	1.1	17.84
80	80	35	0	20.6	1.53	18.12
80	80	35	0	20.6	2.01	19.51
80	80	35	0	20.6	2.25	21.42
80	80	35	0	20.6	2.44	22.63
80	80	35	0	20.6	2.625	23.51
76	36	25	0	3.12	0.43	22.78
76	36	25	0	3.12	0.79	36.45
76	36	25	0	3.12	1.22	42.11
76	36	25	0	3.12	1.6	48.32
76	36	25	0	3.12	2	53.65
76	36	25	0	3.12	2.6	60.6

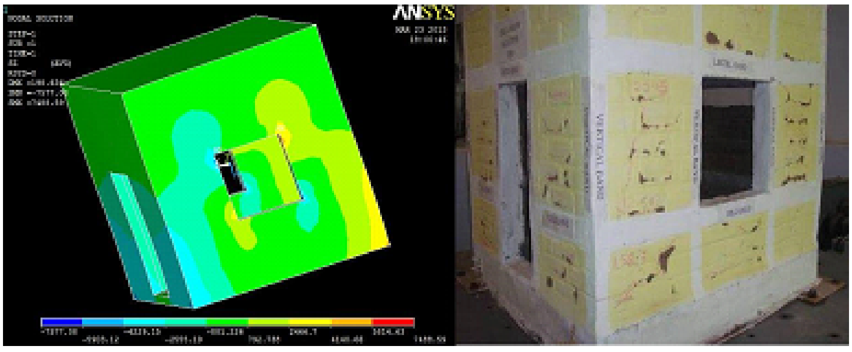

Fig. 24. S2 Model at 0.78 g – Crack pattern

perimental and analytical works, the following conclusions and recommendations are made.

1. From the Experimental study it is concluded that the models constructed using brick,hollow,solid and modified solid blocks (E2,H2,S2,M2) with EQRF performed better than that of models without EQRF(E1,H1,S1,M1). The models constructed using CSEB performed better than fired brick models.

2. The cost of EQ resistant bands in masonry building increases by 4 to 8% of overall construction cost. If CSEB-block used as a construction material, there will be saving in material around 19.4 times compared to that of country fired bricks.

3. These Earthquake resisting features could prevent collapse of out-of-plane walls of both single and double story buildings at strong earthquake, if proper monolithic behavior of tie columns and masonry walls is achieved.

4. The code requirements for the design of confined masonry buildings seem stringent for single story building.

5. Single story confined masonry buildings properly designed and constructed could be used in high seismic zones (zone III and IV).

6. The results obtained from Finite element analysis by ANSYS-13 for Models are compared with experimental results and the variation is marginal.

7. This research aims at using of raw earth as a building construction material extensively. And also by using a local resource that are energy saving, eco-friendly, higher strength & sustainable development to help develop technologies**.**

8. Finally CSEB masonry model with Earthquake Resistant Features (EQRF) had performed well compared to the other models. But guidelines and trainings are required for artisans to properly manufacturing CSEB blocks. It can promote a sustainable future. Obviously, labours have to master the material the techniques of producing so as to obtain the optimum possibilities for a harmonious, durable, agreeable and efficient architecture.

9. This research project was based on making compressed earth blocks with local soils to determine their suitability for use in affordable residential building with earth quake resistant features. In order to postpone the collapse of masonry buildings, it is recommended to provide horizontal joint reinforcement to connect the masonry walls and tie-columns.

10. The training of the system was performed by using the database corresponding to the real evaluations made from experimental tests. It is recommended to promote the use of ANN to provide suitable and versatile solutions to different Problems in this field of Knowledge.

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