Masonry CSEB Building Models under Shaketable Testing-An Experimental Study

Lakshmi Keshav, and V. G. Srisanthi

***Abstract*—**In this experimental investigation shake table tests were conducted on two reduced models that represent normal single room building constructed by Compressed Stabilized Earth Block (CSEB) from locally available soil. One model was constructed with earthquake resisting features (EQRF) having sill band, lintel band and vertical bands to control the building vibration and another one was without Earthquake Resisting 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 was shaken repeatedly until the failure. The test results from Hi-end Data Acquisition system show that model with EQRF behave better than without EQRF. This modified masonry model with new material combined with new bands is used to improve the behavior of masonry building.

***Keywords*—**Earth Quake Resisting Features, Compressed Stabilized Earth Blocks, Masonry structures, Shake table testing, Horizontal and vertical bands.

I. Introduction

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 [2] are effective in increasing the lateral strength and inhibit crack propagation in masonry buildings. Shake table tests [1] 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 [5] for masonry building with precast-prestressed hollow-core floor planks. Analytical models for in-plane response of brick masonry in the linear range [3] and in the non-linear range simulated the experimental behaviour of similar specimens

The traditional masonry buildings without any earth quake resisting 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[6] or due to lack of integrity of a adjoining structural components [4]. 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 [9] or due to tension failure along the principal diagonal plane [10].

The present study determines the seismic resistance capacity of a single-room masonry building model constructed by Compressed Stabilised Earth block manufactured from locally available soil along with earthquake resisting features of horizontal and vertical bands under dynamic shake table loading. A new method with new material is proposed for the seismic strengthening masonry buildings, the effectiveness of this is experimentally investigated. The results are compared between building model constructed with EQRF and model without EQRF.

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II. Research Significance

Revolutionary changes in the construction method such as Base isolation, Dampers etc., may not be feasible to adopt in practical masonry construction due to lack of knowledge and increase in cost. It by doing some simple modifications in the traditional masonry construction methods it is possible to make them EQ resistant. It should be easily understood and adopted by the local artisans. The seismic performance of masonry structure models constructed by Compressed stabilized Earth block and equipped with and without horizontal and vertical bands are assessed using shake table test and results are compared. The final goal of this research was to determine the efficiency of the new bands system with new material that CSEB in reducing earthquake-induced vibrations.

III. Experimental Investigation

The good soil with good proportions, raw or stabilized, for a Compressed Earth Block (CEB) is slightly moistened, poured into a steel press (without or with stabilizer) and then compressed either with a manual or motorized press. 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 must not be used. They should be removed and kept for agriculture. CEB can be compressed in many different shapes and sizes. The input of soil stabilization allowed 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. After this, they can dry freely and be used like common bricks with a soil cement stabilized mortar. A good soil for CSEB is more sandy than clayey. It is gravel (15%), sand(50%),silt(15%) and clay(20%). To achieve this proportion gravel 15% and clay 10%, coarse sand 10% were added. So only 65% of locally available soil for mix and 5% cement for stabilization were taken.

To find the moisture content for mix as per Recommendation (Auroville), a ball using soil mix is prepared. The ball from 1m 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 425µ to 75µ (more than64%) in the sieve analysis as per the standard procedure IS- 1498-1970 show this soil is sandy soil (with fine sand).

A. Material Properties

Average dimensions of Compressed Stabilised Earth Blocks are 140mmx70mmx50mm. The compressive strength obtained for individual block units as per the standard test procedure IS 3495, 1976 is 1.7 times 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 or 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. 6mm size coarse aggregate was used due to small thickness of elements. HYSD bars of 6mm dia were used as reinforcement for all RCC elements. 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.

B. Construction Stages

In this experimental investigation the following four models were constructed and tested. The scale adopted for the model was 1:3 (Prototype : Mode l).

S1 - CSEB –Solid masonry model without EQRF
S2 - CSEB-Solid masonry model with EQRF
H1 - CSEB-Hollow masonry model without EQRF
H2 - CSEB-Hollow masonry model with EQRF

Earthquake Resisting Features 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. 1 shows the typical plan view of the models. The Model S1&H1 is not provided with bands and earthquake resisting features.

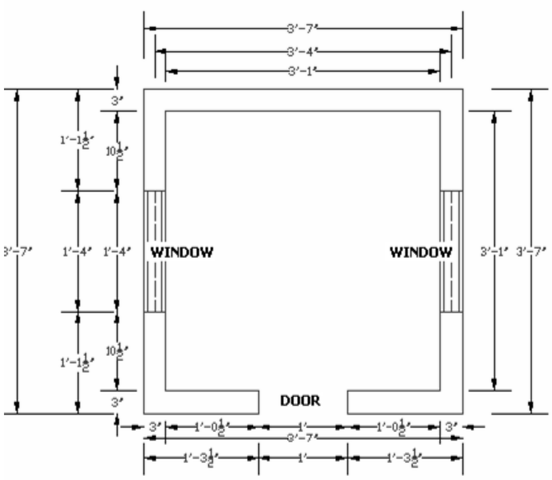

Fig. 1 Plan view of Model

Fig. 2 Upto roof level –Model S1 &H1

Fig. 3 Finished stage –Model S1 &H1

Fig. 4 shows the reinforcement details of horizontal and vertical ties of CSEB Model S2&H2. The horizontal reinforcements were placed continuously along the wall length. Horizontal rebars were anchored into the tie-columns; anchorage was provided with 90^{o} hooks at the far end of the tie column. The use of prefabricated ladder-shaped reinforcement is explicitly excluded because its mode of failure under cyclic loading is undesirably brittle. The lintel and sill bands were given with two numbers (2nos) of 6 mm *diameter (dia) bars as main reinforcement and hook.* Plinth beams provided was same for two models. The models were constructed in the same sequence as it was constructed during

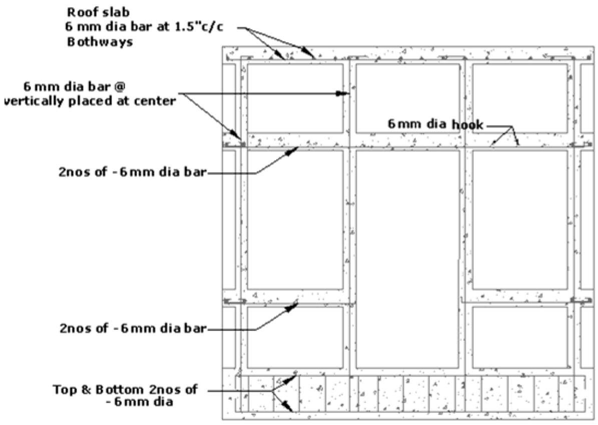

Fig. 4 Reinforcement Details of Horizontal and Vertical Ties

the construction of a typical single storey brick building. Fig. 5 and 6 show the reinforcement details at junction and corner for Model S2& H2 with EQRF. Tie-columns were provided at the intersection of walls and around openings since horizontal and vertical dimension of an opening are larger. Door and Window openings are placed in the same position up the building height. Proper detailing of the tie-beam-to-tie-column connections is a must for satisfactory earthquake performance of the entire building. Fig. 7 shows the provision at roof level. The finished Model S2 with the continuous bands and vertical ties is shown in Fig. 8.

Fig. 5 Reinforcement Details @ junction

Fig. 6 Reinforcement Details @ corners

Fig. 7 Upto roof level - Model S2& H2

Fig. 8 Finished stage –Model S2 &H2

C. Conducting the Experiment in Shake Table

It is possible to simulate the earthquake ground motion by the use of a shake table. Total weight of the shake table is 4000Kgs and its capacity is about 1000Kgs .The shake table's movement can be controlled in any of the desired directions i.e., X, Y, XY. The shake table is designed on the principle of minimum weight and maximum rigidity. The arrangement of stiffener plates is in both directions X and Y. These stiffener plates increases the flexural stiffness against bending. It's a Bi-axial shake table (not Tri-axial), therefore movement in vertical direction is not possible. But Earthquake has vertical acceleration also, which is approximately equal to 2/3 of horizontal acceleration. Base excitation – Frequency cannot be increase vary with time. For a particular period frequency and acceleration is constant. But acceleration will vary with time for Earthquake. The structures were 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. Two models were constructed in *Structural Engineering Laboratory*, *Coimbatore Institute of Technology*, *Coimbatore*, *Tamil Nadu* and the models were transferred to the shake table by crane & tested using shake table. Accelerometers were fixed at table, plinth level, lintel level and roof level to measure the acceleration as shown in Fig. 9. The instruments and software used to carry out the tests are DEWE-5000 Data Acquisition System, DJB Accelerometers – 3 Numbers, DEWE Soft Software, Cables and Connectors, Accelerometer Mounting Set-up.

Fig. 9 Instrumentation and location of Accelerometers

D. Testing of Model S1&H1 – CSEB Masonry Model without Earthquake Resistant Features

First crack was initiated at sill & lintel level then disintegration of wall from the plinth beam was occurred. Finally, at X=1.77Hz collapse of the model was observed. Cut lintels though have not fallen off, not helped prevent splitting of the building.

Fig. 10 @ frequency X=1.77Hz –Model S1

Fig. 11 @ frequency X=0.799 Hz –Model H1

Fig. 12 Final Stage of S1

Fig. 13 Final Stage of H1

E. Testing of Model S2&H2 - CSEB Masonry Model with Earthquake Resistant Features

Development of cracks happened with increasing acceleration of the shake table for the Model S2 with earthquake resistant features. The cracking and disintegration experienced by the Model S2& H2 is even less than experienced by Model S1&H1 respectively. The superior performance has resulted from the use of earthquake resistant features At X direction 2.503Hz, Y direction 1.892Hz, the wall above lintel at backside of model had fallen & below lintel level, wall separated by layers of bricks of Model S2 as shown in Fig. 14.

Fig. 14 Final Collapse – Model S2

Fig. 15 Final Collapses – Model H2

IV. Results and Discussions

Table II and III shows the type of base excitation that was given to the two models. The excitation given to the Model S1 was only in one direction (X) because at X=1.77Hz the model was collapsed. The Model S2 was subjected to vibration in both X and Y direction (more severe) because at maximum frequency X=2.503Hz, the model didn't crack. So the frequency in Y-direction was also given to the Model S2. The duration of acceleration sustained by S2 was significantly more than that of S1.

The maximum acceleration imposed at roof level for Model S1 without earthquake.

Resistant features was 0.4553g as shown in Table IV, whereas for Model S2 with earthquake resistant features the maximum acceleration at roof level was much higher 0.9057g as shown in Table V**.**

TABLE I
Test Duration In 180 Seconds

CSEB-SOLID BLOCK MODEL WITHOUT EQRF-S1,H1		
S. No.	Shake Table Frequency in Hz	Period 'T' in seconds
1	0.429	2.33
2	0.8	1.25
3	1.2	0.833
4	1.6	0.625
5	1.77	0.565

TABLE II
Test Duration in 180 Seconds

CSEB-SOLID BLOCK MODEL WITH EQRF-S2,H2		
S. No.	Shake Table Frequency in Hz	Period 'T' in seconds
1	X=0.427	2.34
2	X=0.88	1.136
3	X=1.221	0.820
4	X=1.587	0.63
5	X=1.770	0.565
6	X=2.014	0.497
7	X=2.320	0.431
8	X=2.442	0.410
9	X=2.503	0.40
10	X=2.503,Y=0.610	0.40, 1.64
11	X=2.503,Y=1.038	0.40, 0.963
12	X=2.503,Y=1.221	0.40, 0.82
13	X=2.503,Y=1.587	0.40, 0.63
14	X=2.503,Y=1.892	0.40, 0.53

TABLE III
Vibration Measurement - Acceleration in Terms Of 'G'

CSEB-SOLID BLOCK MODEL WITHOUT EQRF-S1& H1									
S. No	Frequency in Hz	Table – X direction		Plinth Level		Lintel Level		Roof Level	
		S1	H1	S1	H1	S1	H1	S1	H1
1	0.429	0.036	0.0305	0.0233	0.0199	0.017	0.0171	0.256	0.2369
2	0.811	0.0502	0.0456	0.0488	0.0485	0.0518	0.0527	0.268	0.2374
3	1.24	0.0986	0.1224	0.1208	0.3157	0.121	0.2837	0.299	0.5405
4	1.597	0.2253	0.2202	0.2193	0.2816	0.2333	0.2944	0.3704	0.3646
5	1.81	0.2758	0.3466	0.2803	0.4159	0.3388	0.3591	0.4553	0.6205

TABLE IV
VIBRATION MEASUREMENT - ACCELERATION IN TERMS OF 'G'

CSEB-SOLID BLOCK MODEL WITH EQRF-S2							
Sl. No	Frequency in Hz	Table - X direction	Table - Y direction	Plinth Level	Lintel Level	Roof Level-X	Roof Level-Y
1	X=0.427	0.0335	---	0.0209	0.0205	0.2341	---
2	X=0.88	0.0574	---	0.0711	0.0682	0.2491	---
3	X=1.221	0.1101	---	0.1496	0.1522	0.3019	---
4	X=1.587	0.1942	---	0.2549	0.2562	0.4285	---
5	X=1.770	0.3679	---	0.4153	0.3894	0.4449	---
6	X=2.014	0.3115	---	0.3980	0.4278	0.4954	---
7	X=2.320	0.5101	---	0.5481	0.6031	0.6742	---
8	X=2.442	0.5176	---	0.6045	0.6722	0.7578	---
9	X=2.503	0.4971	---	0.6031	0.6958	0.7838	---
10	X=2.503,Y=0.610	0.5960	0.2258	---	---	0.8318	0.2941
11	X=2.503,Y=1.038	0.5163	0.2166	---	---	0.9057	0.3099
12	X=2.503,Y=1.221	0.5289	0.2221	---	---	0.8544	0.3194
13	X=2.503,Y=1.587	0.5436	0.3342	---	---	0.8665	0.4237
14	X=2.503,Y=1.892	0.5763	0.4236	---	---	0.8983	0.5863

TABLE V
COMPARISON OF TWO MODELS W.R.TO ACCELERATION, VELOCITY, DISPLACEMENT MODELS H1 & H2

Sl.No.	Model Type & Frequency	Acceleration in terms of "g" – at various levels					Velocity in m/sec at Roof level	Displacement in mm at Roof Level
		Table - X	Table – Y	Plinth LVL	Lintel LVL	Roof LVL		
1	H1_without EQRF_1.77Hz	0.347	---	0.416	0.359	0.621	0.548	49.30
2	H2_with_X_2.503Hz	0.406	---	0.607	0.754	0.699	0.436	27.74
3	H2_with_X2.503_Y_1.582Hz	0.521	0.342	---	---	0.703	0.439	27.67

TABLE VI
COMPARISON OF TWO MODELS W.R.TO ACCELERATION, VELOCITY, DISPLACEMENT OF MODEL S1&S2

Sl.No.	Model Type & Frequency	Acceleration in terms of "g" – at various levels					Velocity in m/sec at Roof level	Displacement in mm at Roof Level
		Table -X	Table – Y	Plinth LVL	Lintel LVL	Roof LVL		
1	S1_without EQRF_1.8Hz	0.2758	---	0.2803	0.3388	0.4553	0.395	34.9
2	S2_with EQRF_X_2.503Hz	0.497	---	0.603	0.696	0.784	0.489	31.1
3	S2_with EQRF_X2.503_Y_1.9Hz	0.5763	0.424	---	---	0.854	0.533	33.9

TABLE VII
FOR THE SAME FREQUENCY - COMPARISON OF TWO MODELS W.R.TO ACCELERATION, VELOCITY, DISPLACEMENT

Sl.No.	Model Type & Frequency	Acceleration in terms of "g" – at various levels					Velocity in m/sec at Roof level	Displacement in mm at Roof Level
		Table -X	Table – Y	Plinth LVL	Lintel LVL	Roof LVL		
1	S1_without EQRF_1.8Hz	0.2758	---	0.2803	0.3388	0.4553	0.395	34.94
2	S2_with EQRF_1.8Hz	0.245	---	0.337	0.352	0.431	0.374	33.09

Even under such large acceleration level, the model with earthquake resistant features have performed well.

Table VI and VII compares the overall behavior of the two models. It is to be noted that roof level displacements of the Model S2 with earthquake resistant features are less than for Model S1 without earthquake resistant features. This is in spite of the fact that the applied g values at foundation levels were more for the Model S2 with earthquake resistant features.

A. Comparison of CSEB -Solid Block Model with EQRF and without EQRF

1 Acceleration, Velocity, and displacement at roof level for CSEB-solid block model without EQRF are 1.056 times more than that of CSEB-solid block model with EQRF (Both are at 1.8 Hz).

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

3 At higher frequency (X_2.503 Hz & Y_1.892Hz) Model with EQRF – S2 had major cracks and finally collapsed.

4 Many of the damages observed in Model S1 during testing were similar to the actual earthquake damage. Separation of

5 Brick layer (failure) occurred at CSEB solid block model without EQRF.

B. Comparison of Hollow-CSEB Model with EQRF and without EQRF

1. Acceleration, Velocity, displacement at roof level for HCSEB-solid block model without EQRF are 1.76 times that of HCSE block model with EQRF(Both are at 1.77 Hz
2. At this 1.77 Hz frequency, Structural Damage in HCSE block model without EQRF Model is significantly more and the model collapsed
   However HCSE block model with EQRF Model survived without collapse, had only minor cracks.
3. At higher frequency (X_2.503 Hz & Y_1.892Hz) Model with EQRF – H2 had major cracks & finally collapsed Fig. 20
4. Many of the damages observed in Model H1 during testing were similar to the actual earthquake damage as shown Separation of Brick layer (failure)occurred at HCSE block model without EQRF

V. Conclusion

It is concluded that the CSEB-solid and Hollow block model with EQRF (Model S2&H2) performed well compared to that of CSE -solid and hollow block model without EQRF (Model S1&H1) due to the joint action of masonry wall and their confining elements. The cost of EQ resistant bands in masonry building increases by 4 to 6% of overall construction cost.

This investigation 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, higher strength & sustainable development.

If CSEB-block can be used as a construction material, there will be saving of materials per m^3 finished wall around 19 times compared to that of country fired bricks. But guidelines and trainings are required for artisans to properly manufacture CSEB blocks. It is recommended that CSEB block masonry model with earthquake resistant features be adopted extensively as it is able to sustain seismic load and also cost effective.

References

[1] Clough RW, GulkanP and Mayes RL (1979), "Shaking Table Study of Single Storey Masonry Houses-Vol 3: Summary, Conclusions and Recommendations," *Report No. UCB/EERC-79/25*, EERC, University of California, Berkeley, CA, USA

[2] Krishna J and Chandra B (1965), "Strengthening of Brick Buildings Against Earthquake Forces," *Third World Conference on Earthquake Engineering*, New Zealand.

[3] Mengi Y, Sucuolu H and McNiven HD (1984), "A Linear Mathematical Mode for the Seismic In-plane Behaviour of Brick Masonry Walls, Part 1: Theoretical Considerations," *Earthquake Engineering and Structural Dynamics*, 12(3): 313-326..

[4] Murty CVR, Dayal U, Arlekar JN, Chaubey SK and Jain SK (2001), "Preliminary Field Report on Gujarat Earthquake," *The Indian Concrete Journal*, The ACC Limited, Thane, 75(3): 181-190. IS 3495-1976 Part-I 1976, Code of Practice for Preparation and Use of masonry Mortars, First Revision, Bureau of Indian Standards, New Delhi.

[5] Seible F, Priestley JN and Kurkchubasche AG (1994), "Seismic Response of Full-Scale Five-Storey Reinforced Masonry Building," *Journal of Structural Engineering*, ASCE, 120: 925-946.

[6] Sommers P (1996), "Northridge Earthquake of January 17, 1994: Reconnaissance Report, Volume 2 – Unreinforced Masonry Buildings," *Earthquake Spectra*, EERI, 11: 195-217.

[7] Qamaruddin M, Arya AS and Chandra B (1978), "Experimental Evaluation of Seismic Strengthening Methods of Brick Building," *Sixth Symposium on Earthquake Engineering, Roorkee*

[8] IS: 13828-1993 (1993), *Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines*, Bureau of Indian Standards, New Delhi.

[9] Shea GH (1993), "Erzincan, Turkey Earthquake of March 13, 1992: Reconnaissance Report Earthquake Spectra EERI

[10] Tomazevic M (1999), *Earthquake Resistant Design of Masonry Buildings,Imperial College Press*