1.0 INTRODUCTION

High cost of primary requirements for constructing the houses in places where people are below poverty line, is forming one of the most significant problems of people. On the other hand, urbanization growth will increase accumulation of waste especially non-degradable ones. A suitable approach for this situation is using some part of urban rubbish as required materials for building construction and also providing comfortable situation and suitable thermal comfort for building residents. Plastic bottle is considered as an urban junk with sustainability characteristic which can be used as a material instead of some conventional material such as brick in building construction.

M/s Samarpan Foundation, Chennai have requested CSIR – Structural Engineering Research Centre (SERC), to carry-out experimental seismic vibration tests and evaluate the seismic performance of their developed technology of building a structure using PET bottle bricks, reinforced with Nylon 6+ fishnets. The developed technology uses PET bottle filled with mud as bricks which helps to reuse plastic bottles and avoid plastic menace. It also gives a viable alternative for low-cost housing. A team of technicians and scientists from SERC carried out detailed vibration experimentation with excitation by a multi axial shake table. The response data collected during the experimentation are subsequently analyzed at the Advanced Seismic Testing and Research (ASTaR) Laboratory.

2.0 SCOPE OF THE PROJECT

1. To conduct shake table seismic tests on PET Bottle and Nylon+6 Fishnet based house for varying levels of base acceleration values
2. Analysis and inferences from the seismic performance of the house
3. Submission of report

3.0 STRUCTURAL GEOMETRY

The geometry and sizing of the structure is so chosen such that it can be accommodated in the 4m X 4m (30 t pay load with 1g of maximum acceleration) shake table of Advanced Seismic Testing and Research Laboratory (ASTaR) of CSIR-SERC. The test structure is a single room cubicle structure with four walls, square in plan with dimensions of 3m X 3m in plan, and height of 3m. One door opening and one window opening is provided on opposite walls of the structure.

3.1 PET bottle bricks and Nylon 6+ Fish net reinforcement

The structure is to be built with PET (Polyethelene Terephthalate) bottle bricks instead of conventional bricks. Standard half-a-litre and one litre used discarded PET bottles are compactly filled with dry mud and sealed. These mud filled bottle is used in the place of a brick and are cemented together to construct the columns and walls of the structure. Instead of steel reinforcement, commercially available Nylon 6+ fish nets are used. These fish nets are made of polyamides, often more commonly known as nylon and are believed to have high tensile strength. The mud-filled PET bottles and Nylon 6+ nets have been provided by M/s Samarpan foundations and no element level strength characterization of these materials have been carried out at CSIR-SERC.

3.2 RCC Base slab

A square base slab of reinforced concrete with 150 mm thick and plan dimensions of 4m x 4m is provided to take care of handling loads and for rigidly clamping the structure on to the shake table. The RC slab is provided with a grid of holes spaced at 250 mm centers with embedded mild-steel sleeves, welded to the reinforcement cage. The RCC slab is provided with an adequately reinforced stiffener beam of 3m x 3m, matching with the foot print and plan dimension of the super-structure. The beam is also provided with additional dowel bars of 16mm diameter, 5nos at each side, to take care of the handling stresses and for better anchoring of the structure to the rigid slab. Just immediately after the casting of this slab, the Nylon 6+ fish net measured and cut according to structure dimension is laid on the fresh concrete and one layer of pet bottle brick pedestal is kept on the slab such that there is a mechanical adhesion between this pedestal and concrete, over and above the frictional forces. Hence the chances of slipping of this pedestal from the concrete base slab is minimised. 8 Lifting hooks are provided in the slab for transporting and handling the structure. The RCC slab with one layer of PET bottle bricks is cured for 28 days before commencing the construction of the structure. Figure 1 to Figure 8 show the step by step construction sequence in progress and details of the RCC slab construction. The continuity between the super-structure walls and the foundation is established by the dowel bars, fish net and one layer of the pet bottle course.

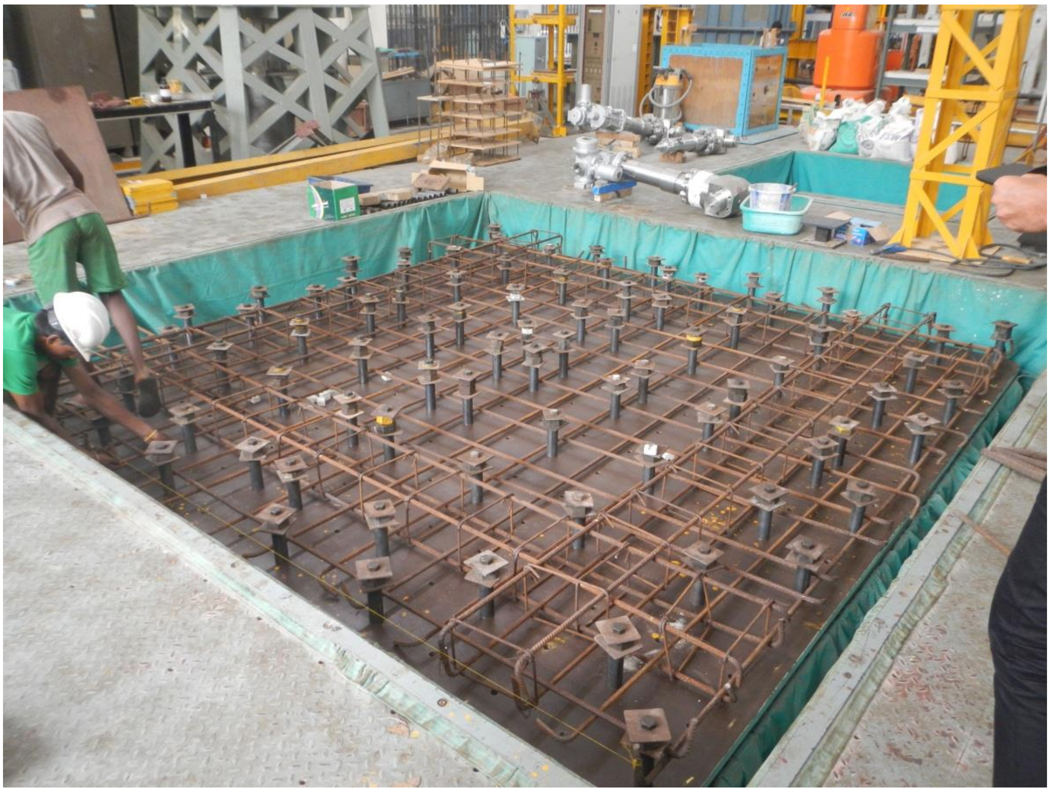

Fig. 1 Reinforcement for RCC rigid slab

Fig. 2 Reinforcement for RCC slab with handling hooks and dowel bars

Fig. 3 First layer of PET Bottle Column on fresh concrete slab

Fig. 4. PET bottle column built using horizontal and vertical bottles wrapped with fishnets

Fig. 5. Overall view of Fishnet arrangement running across to the opposite columns

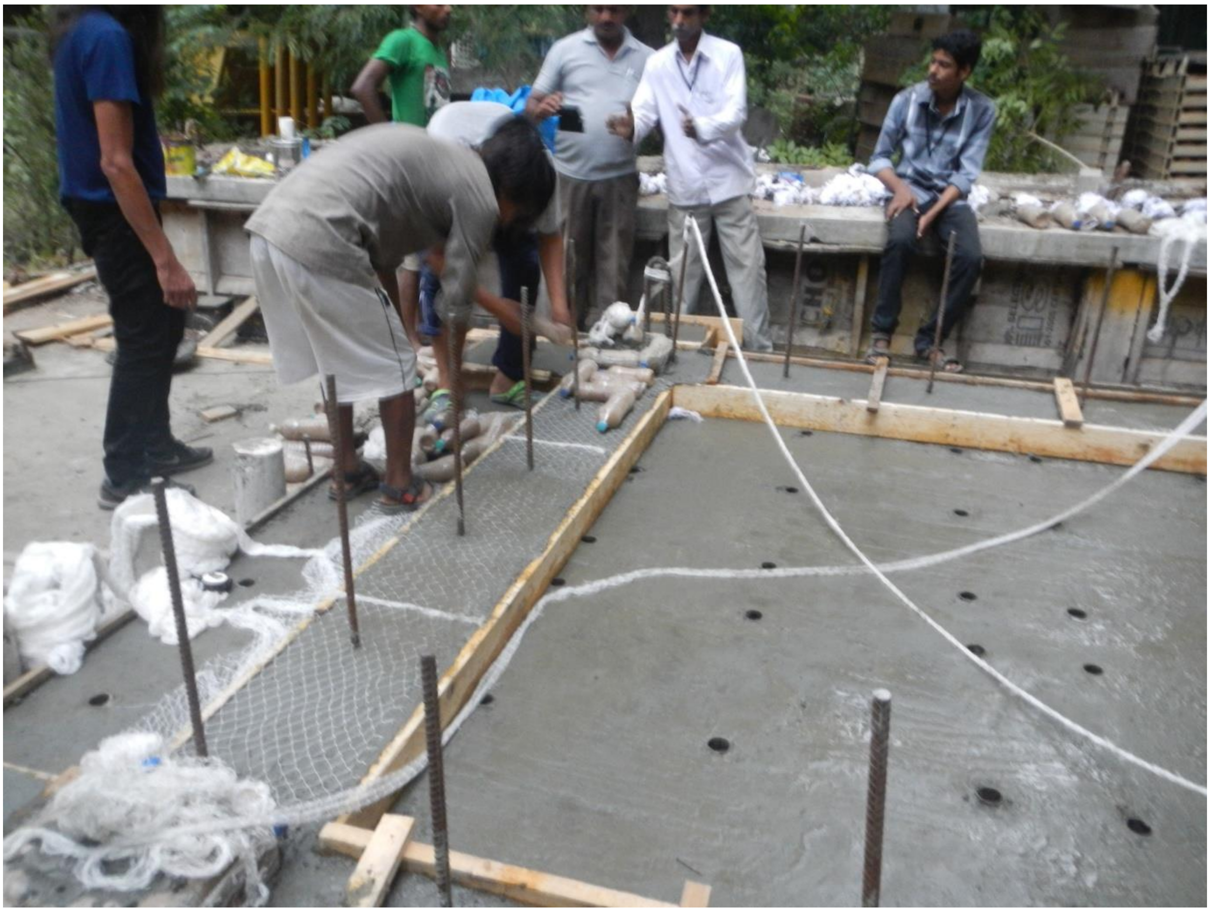

Fig. 6 First layer of PET bottle bricks laid using horizontal staggered bottles on fishnet

Fig. 7 First layer of PET bottle walls laid using horizontal staggered bottles on fresh concrete

Fig.8 Finished RCC slab with one layer of PET bottle walls and columns under curing

3.3 Structure

Formworks are made using plywood according to the structure dimension for the walls and columns. At each corner of the structure, PET bottle columns are constructed up to a height of 1m. To make the columns, 4 bottle bricks are kept horizontally and vertical bottles are kept in the centre for one bottle height tied using two separate fishnets. The space in between the bottles are filled with PCC. The fish nets are twisted and wrapped in opposite directions (CW and ACW) around the horizontally placed bottles and tied. In between the columns, the pet bottles are staggered horizontally next to each other for the walls and PCC is used to fill the gaps between the bottles and to bind them together. Then, the diamond shaped holes in the net are stretched and inserted in the bottle head and capped. In addition, the fishnets are twisted together to form fishnet ropes and two such ropes are placed in each wall to give additional reinforcement. All the fishnets start from one end, goes over the structure height across the wall, over the roof slab and anchored at the opposite end. The same is followed for opposing columns. This to ensure the continuity in the structure. The structure has one door and one window opening on the pair of opposite walls. Separate formworks are placed for the openings and built using PCC. The roof slab of the structure is constructed from plain concrete. The roof slab is built with a slight camber for arch action (in one direction only). The formwork for roof slab is laid, the fish nets are placed and PCC is poured. Suitable measures have been adopted to tighten the fish net ropes which run across the roof slab by suitably inserting wedging bottles. The fish net reinforcement for the roof slab include, (1) fish net ropes coming from walls and running parallel to the walls, (2) running diagonally across the corners. (3) In addition to this ropes, fish net grids also run across the slab simulating an orthogonal mesh. The outer surfaces of the structure are finished and plastered with PCC. The structure built is water cured for 28 days. After 28 days the structure is placed on the shake table and the slab is bolted using high-tensile bolts for seismic testing. Fig. 9 to 16 show the step by step construction and details of superstructure.

Fig. 9 Construction of PET bottle walls reinforced with Fishnets

Fig. 10. Step by step details of PET bottle column wrapped with CW and ACW fishnet

Fig. 11. Construction of PET bottle walls using horizontally staggered PET bottles

Fig. 12. Completed walls before plastering.

Fig. 13. Top view of the finished structure with fishnets across the roof slab.

Fig. 14. View of the fishnets across the roof slab.

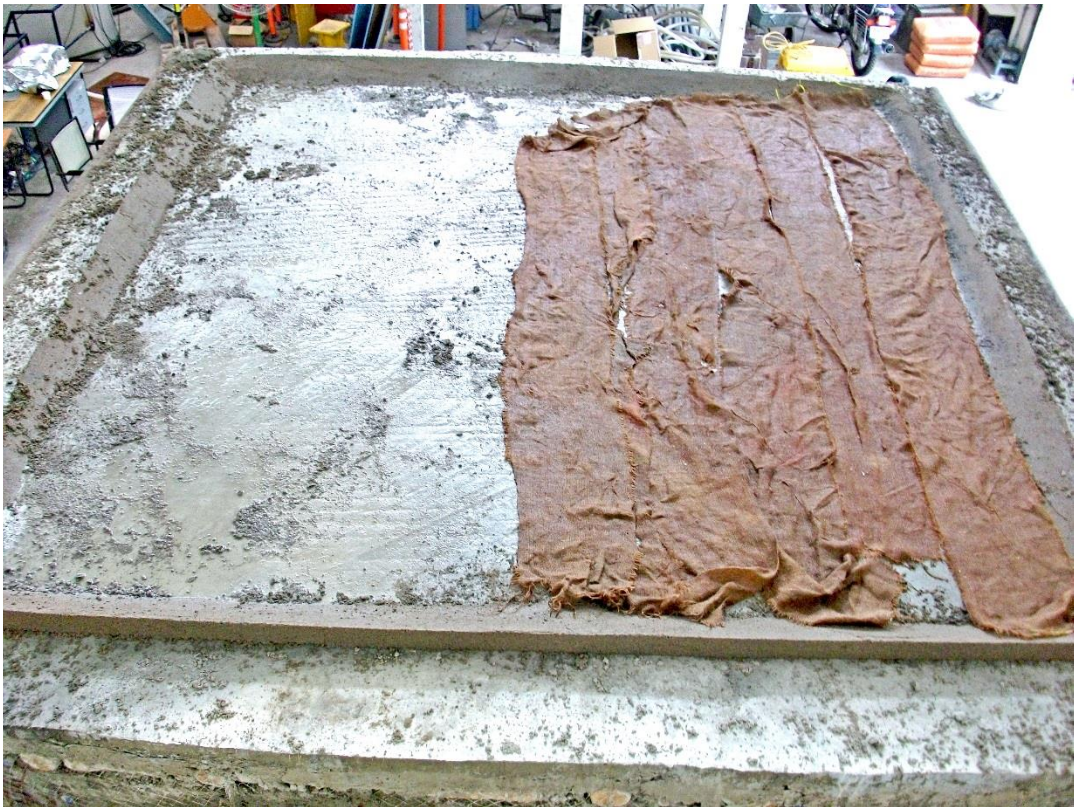

Fig. 15. Finished roof slab under curing.

Fig. 16. Finished structure with window and wall opening.

4.0 INSTRUMENTATION OF THE STRUCTURE

There are two sets of instrumentation used in the evaluation of seismic response of this building structure:

(a) Control accelerometers and LVDTs for the control of input excitation. **Table-1** gives the summary of these instrumentation details.

(b) Global acceleration and displacement responses measured on the structure. It is noted that both acceleration and displacement values are absolute values and are measured using a reference frame kept outside the shake table. **Table-2** gives the summary of the measurements.

Figs 17 & 18 show the overall view of the tested structure along with instrumentation scheme. **Fig.17** also shows the orientation of the structure with reference to North and East directions. North and southern walls are solid walls, western and eastern walls have openings with western side wall having a window opening and the eastern side wall having a door opening.

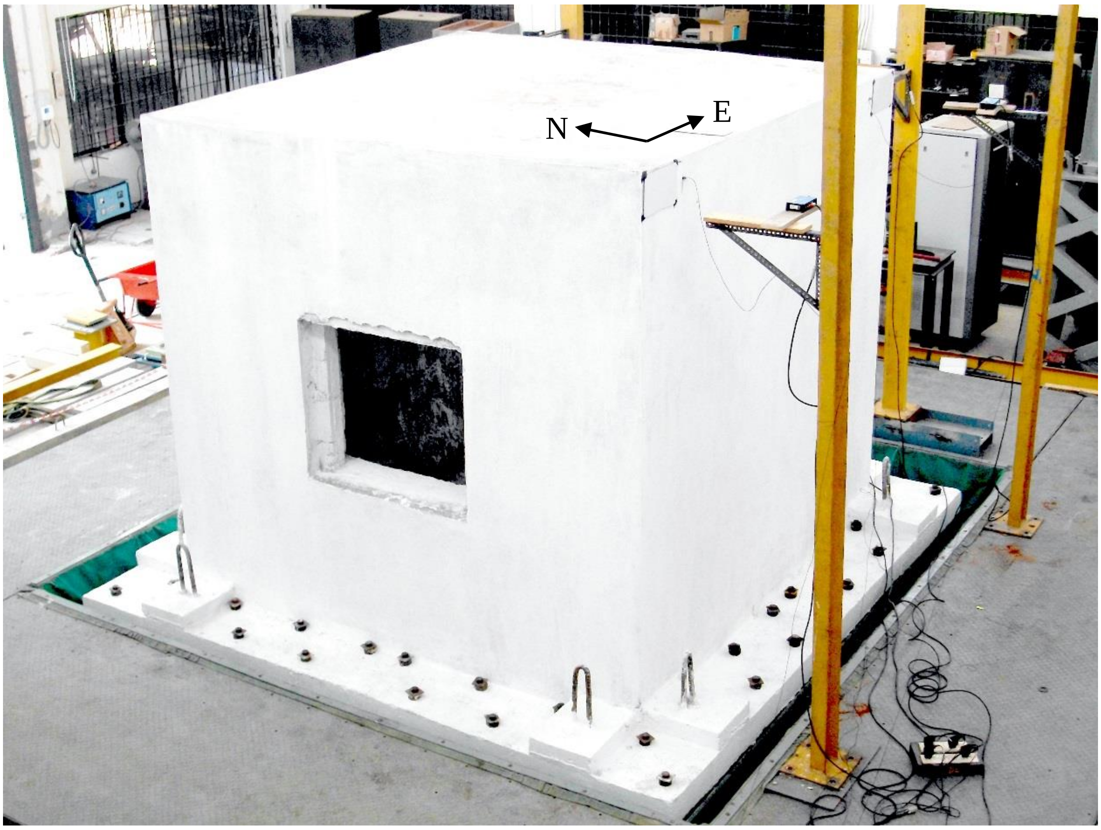

Fig. 17. Instrumentation details for the structure.

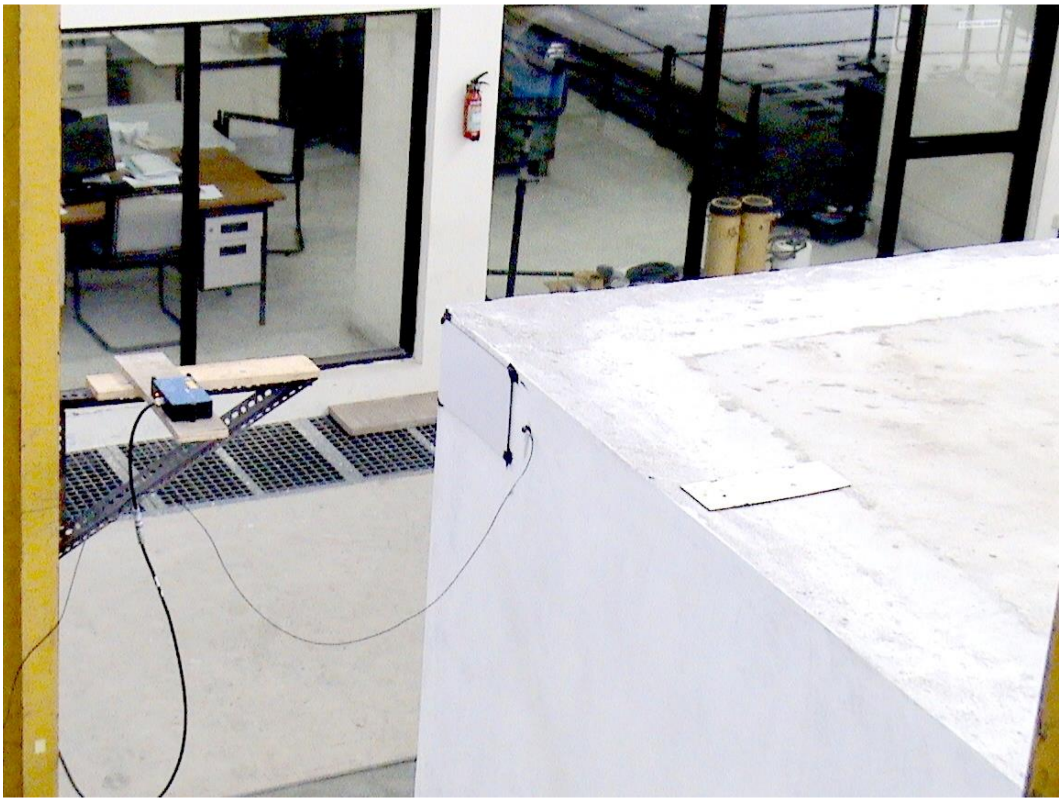

Fig. 18. Close-up view of LVDT and accelerometer sensors used

Table – 1 Instrumentation of the Structure – Control of Input Excitation and Operation of Shake Table

Serial No.	Measured Parameter and the location of measurement	Data Acquisition System
1	Displacement at the shake table level – X direction -1	Saginomiya Chnl-1
2	Acceleration at the Shake table level – X direction -1	Channel-2
3	ΔP pressure for force measurement X1	Channel-3
4	Displacement at the shake table level – X direction -2	Channel-4
5	Acceleration at the Shake table level – X direction -2	Channel-5
6	ΔP pressure for force measurement X2	Channel-6
7	Displacement at the shake table level – Y direction -1	Channel-7
8	Acceleration at the Shake table level – Y direction -1	Channel-8
9	ΔP pressure for force measurement Y1	Channel-9

10	Displacement at the shake table level – Y direction -2	Channel-10
11	Acceleration at the Shake table level – Y direction -2	Channel-11
12	ΔP pressure for force measurement Y2	Channel-12
13	Displacement at the shake table level – Z direction -1	Channel-13
14	Acceleration at the Shake table level – Z direction -1	Channel-14
15	ΔP pressure for force measurement Z1	Channel-15
16	Displacement at the shake table level – Z direction -2	Channel-16
17	Acceleration at the Shake table level – Z direction -2	Channel-17
18	ΔP pressure for force measurement Z2	Channel-18
19	Displacement at the shake table level – Z direction -3	Channel-19
20	Acceleration at the Shake table level – Z direction -3	Channel-20
21	ΔP pressure for force measurement Z3	Channel-21
22	Displacement at the shake table level – Z direction -4	Channel-22
23	Acceleration at the Shake table level – Z direction -4	Channel-23
24	ΔP pressure for force measurement Z4	Channel-24

As seen from Table-1, there are two accelerometers and LVDT's (for the measurement of displacements) in each orthogonal direction corresponding to each of the driving actuator. In the case of a rotational ground acceleration (rocking or yawing), these pair of accelerometers and LVDTs shall show different values.

However, for a rotation-free translational acceleration, these values are nearly same and are summed up and the mean values of acceleration and displacements are obtained. These average values of motion in each of the three orthogonal direction along with the response accelerometer locations are used for PGA recording.

Table – 2 Instrumentation for Global Response Measurement on the Structure (First Six of the Table Contain Input Excitation Details)

Serial No.	Measured Parameter and the location of measurement	Data Acquisition System	Reference in Figs 22 to 30
1	Shake Table Disp_X	Average of two DACS Displ. channels of Saginomiya in X direction	1ch
2	Shake Table ACC_X	Average of two DACS Accn channels of Saginomiya in X direction	2ch
3	Shake Table Disp_Y	Average of two DACS Displ. channels of Saginomiya in X direction	3ch
4	Shake Table ACC_Y	Average of two DACS Accn channels of Saginomiya in X direction	4ch
5	Shake Table Disp_Z	Average of four DACS Displ. channels of Saginomiya in Z direction	5ch
6	Shake Table ACC_Z	Average of four DACS Accn channels of Saginomiya in Z direction	6ch
7	Disp1 kept at top of the building South West side	Micro Epsilon laser Non-contact LVDT	7ch disp
8	Disp2 kept at top of the building in South east side	Micro Epsilon laser Non-contact LVDT	8ch disp
9	Disp3 kept at top of the building South west side	Micro Epsilon laser Non-contact LVDT	9ch disp
10	Disp4 kept at top of the building North west side	Micro Epsilon laser Non-contact LVDT	10ch disp
11	Acc1 kept at top of the building South West side in x direction	B&K Accelerometer Piezotron – ICP based	11ch Acc
12	Acc2 kept at mid-height of building South east side in x direction	B&K Accelerometer Piezotron – ICP based	12ch Acc
13	Acc3 kept at top of the building South west side in y direction	B&K Accelerometer Piezotron – ICP based	13ch Acc
14	Acc4 kept at mid-height of building Northwest side in y direction	B&K Accelerometer Piezotron – ICP based	14ch Acc

5.0 INPUT EXCITATION AND THE METHOD OF CREATING THE COMPATIBLE ACCELERATION TIME HISTORY

Seismic testing of PET bottle building is carried out by applying three non-correlated acceleration time histories at the base of the structural model (or the top surface of the shaking table) in the three orthogonal directions (X, Y being horizontal and Z being the vertical). Indian spectrum, IS-1893, based on Housner's average spectrum for soft type soil is adopted which has a peak plateau region between 0.1 sec to 0.67 sec (1.5 to 10 Hz). The zero-period acceleration for the initial time history iteration process is 0.1 g. 5% damped spectrum has a magnification of 2.5 from ZPA (PGA) and follows a rectangular hyperbola beyond 0.67 seconds with a constant spectral velocity and the tail portion cuts the horizontal ZPA (PGA) line at nearly 1.55 seconds. ZPA (PGA) in the vertical direction (Z) is two-thirds of the X and Y directions (Horizontal).

The following procedure is adopted for an iterative generation of target time history.

(a) The spectrum compatible time history for the soft soil type as defined in IS-1893, Part-I is generated so as to envelope the target for all time periods. This step is an analytical procedure and does not involve operation of the shake table. The three time histories generated become the target acceleration time histories which shall be used in the subsequent iterative process.

(b) A mass equal to the mass of the tested structure is rigidly clamped to the table.

(c) Initially a white noise signal containing all the frequencies of interest is applied to the shake table in the three orthogonal directions simultaneously and the transfer function relationship between the applied input displacement spectra and the table acceleration spectra is developed.

(d) The generated transfer function is used to build up the required displacement drive file so as to obtain the target acceleration mentioned in point (a).

(e) This drive file of displacement time history with various scaling levels is used to run the shake table replacing the rigid mass with the actual structure.

Figures 19 to 21 show the seismic Input in the form of response spectra with corresponding smooth, target and achieved spectra for directions X, Y and Z respectively.

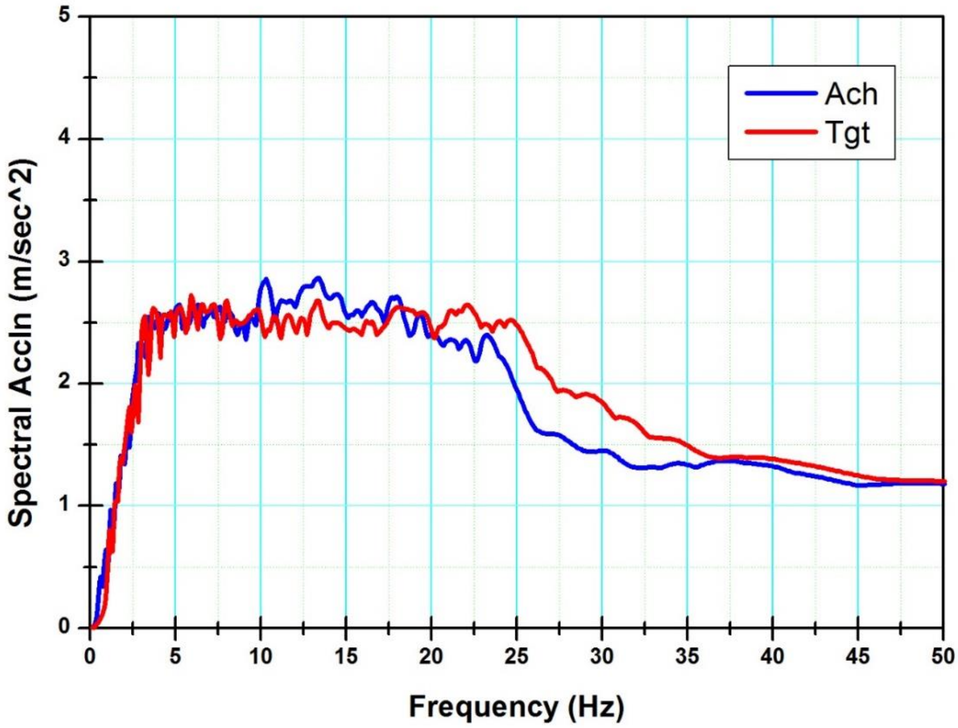

Fig.19 Input in X-Direction (North-South) with Corresponding Smooth, Target and Achieved spectra

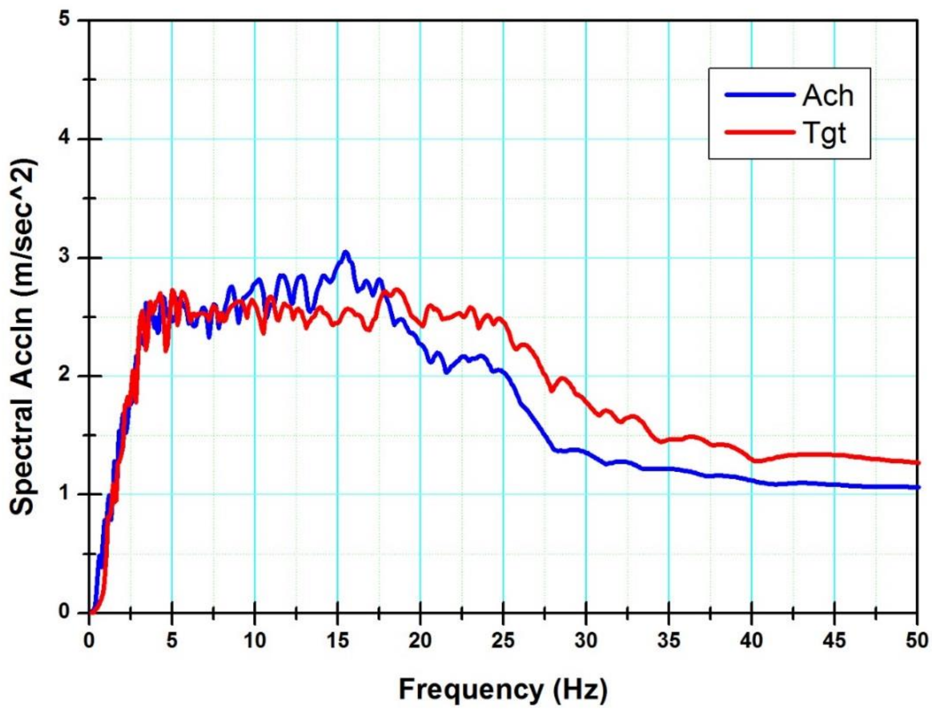

Fig.20 Seismic Input in Y-Direction (East-West) with Corresponding Smooth, Target and Achieved spectra

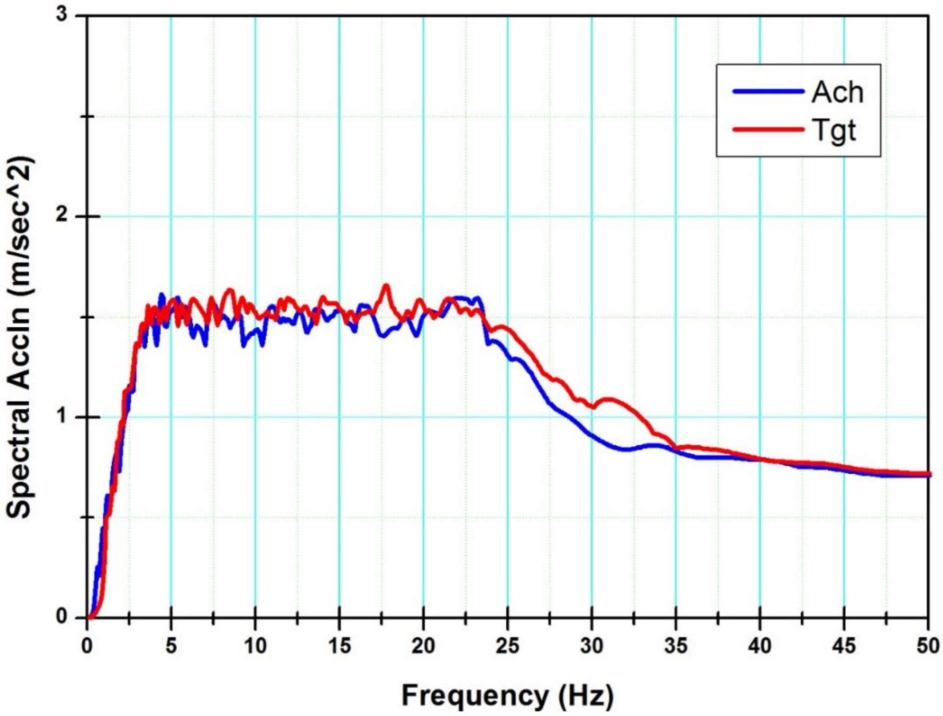

Fig.21 Input in Z-Direction (Vertical) with Corresponding Smooth, Target and Achieved spectra

6.0 EXPERIMENTAL EVALUATION OF SEISMIC PERFORMANCE

The constructed structure is rigidly clamped onto the shake table and after making suitable arrangements for instrumentation, the structure is subjected to a progressively increasing seismic excitation quantified by the ZPA of the seismic input until failure and excessive cracking of the structure is caused. The structure is tested for accelerations of 0.16g, 0.24g, 0.36g, 0.5g, 0.6g, 0.7g 0.8g and 0.9g, g being 9.81 m/sec^2. Each acceleration is repeated for two cycles of seismic loading.

6.1 Results and Discussion

Figures 22 to 30 show the recorded input and response displacement and acceleration values for the structure under different excitations. The first six channels of time signatures correspond to input displacement and acceleration values in global X, Y and Z directions respectively. The next four channels give the displacement time histories the first two along X axis and the next two along the Y axis. The two displacement channels along the X axis are on each of the two walls running parallel to X direction. The two displacement channels along the Y axis are on each of the two walls running parallel to Y direction. It should be noted that the recorded displacement time histories give the absolute displacement values and to obtain the drift, the base displacement time histories in the respective directions have to be subtracted from this absolute values to generate relative displacement motions.

The last four channels give the acceleration time histories, the first two along X axis and the next two along the Y axis. The two acceleration channels along the X axis are on each of the two walls running parallel to X direction. The two acceleration channels along the Y axis are on each of the two walls running parallel to Y direction. It should be noted that the recorded acceleration time histories give the absolute acceleration values.

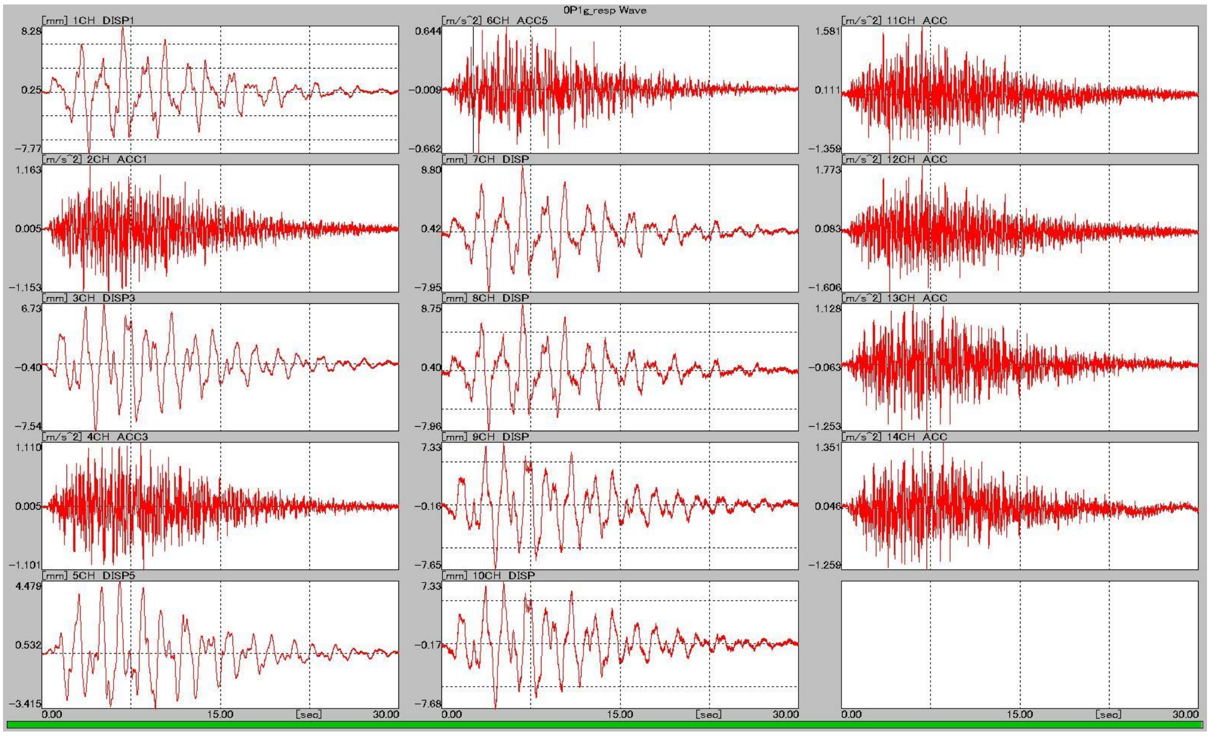

Fig 22. Input and response displacement and acceleration at 0.1g

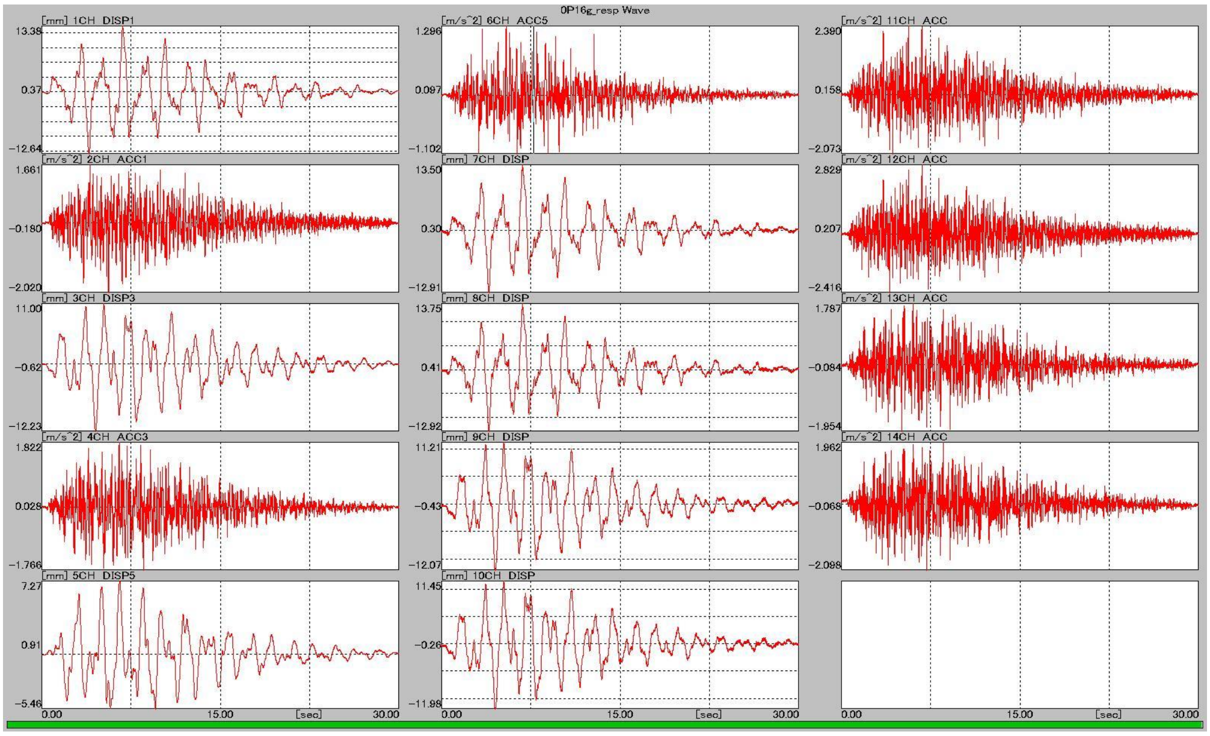

Fig. 23 Input and response displacement and acceleration at 0.16g

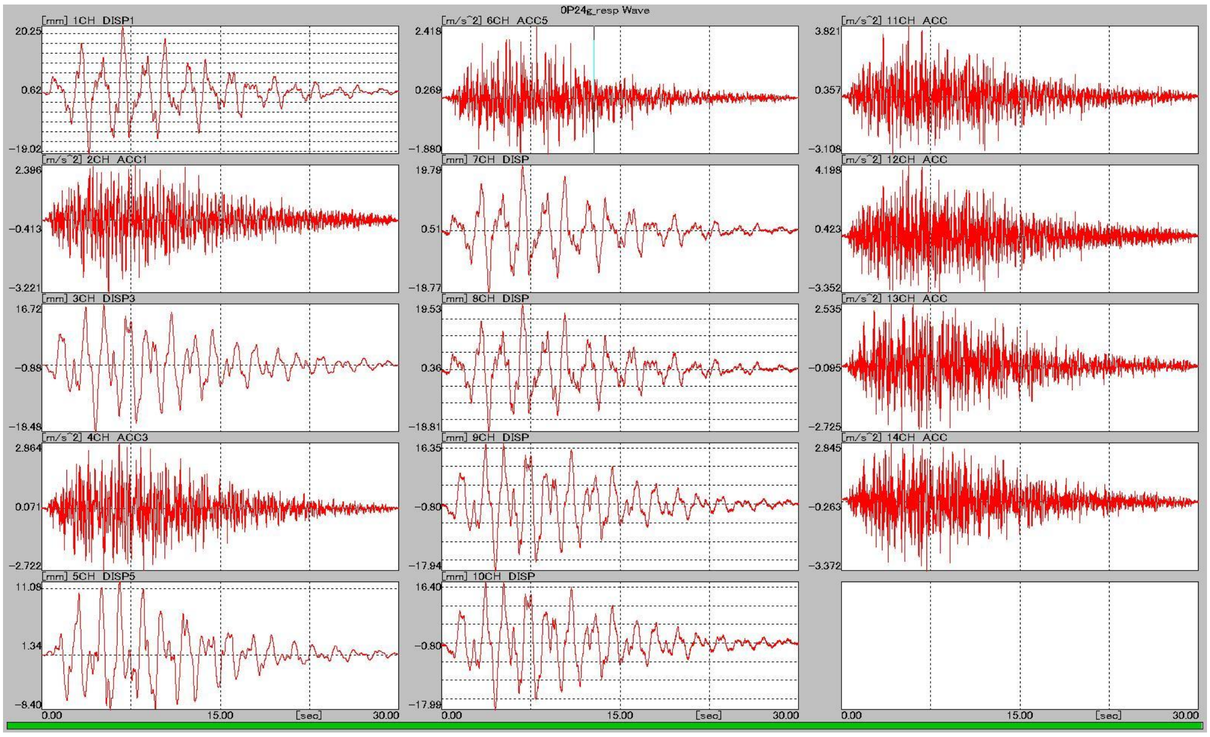

Fig 24. Input and response displacement and acceleration at 0.24g

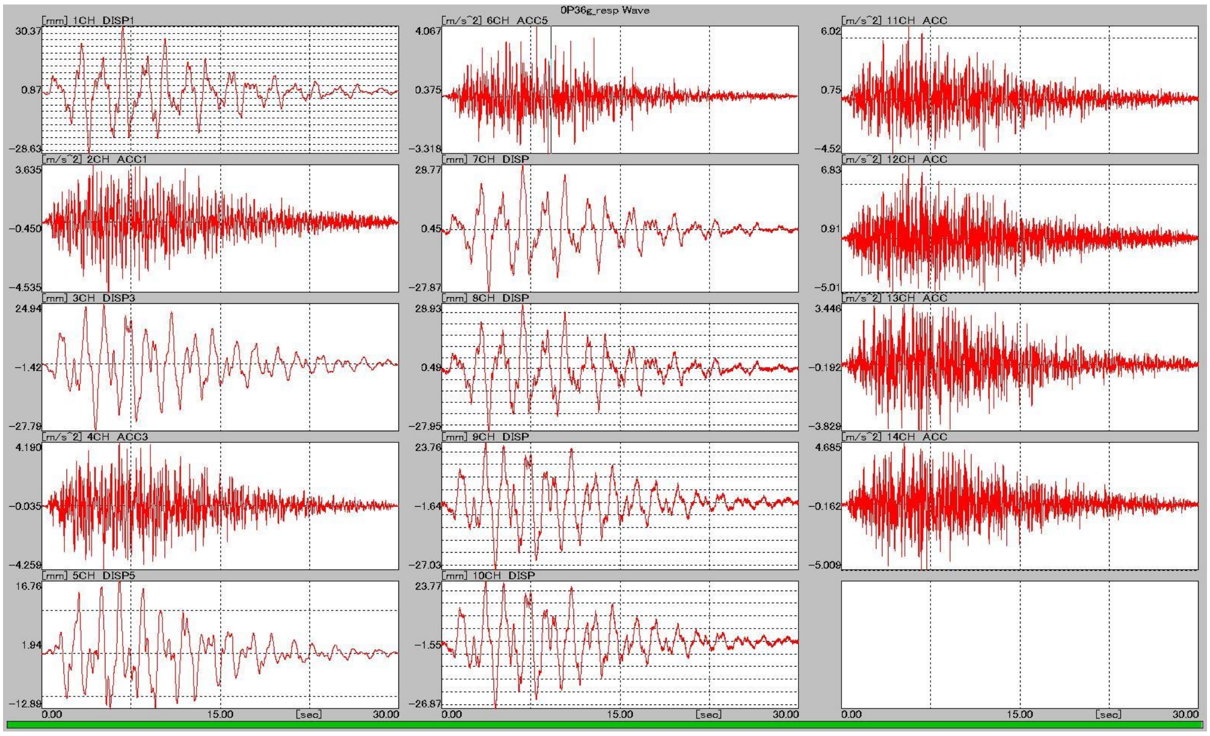

Fig 25. Input and response displacement and acceleration at 0.36g

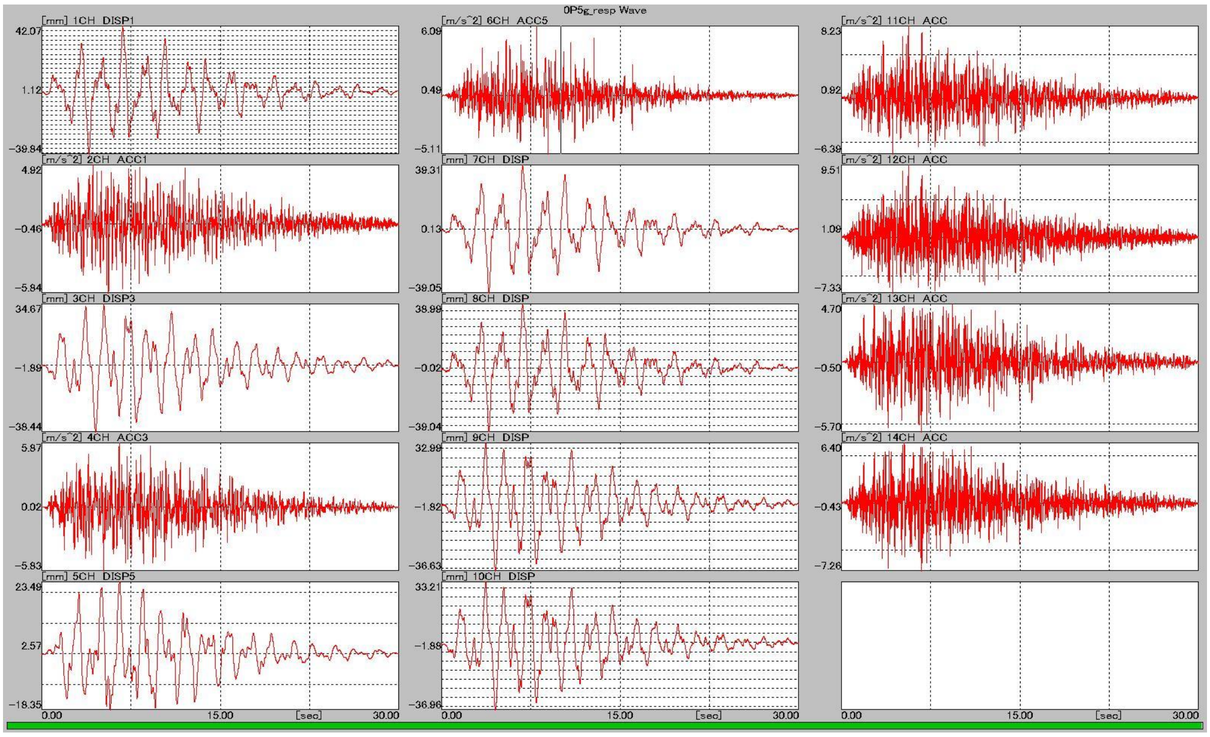

Fig.26 Input and response displacement and acceleration at 0.5g

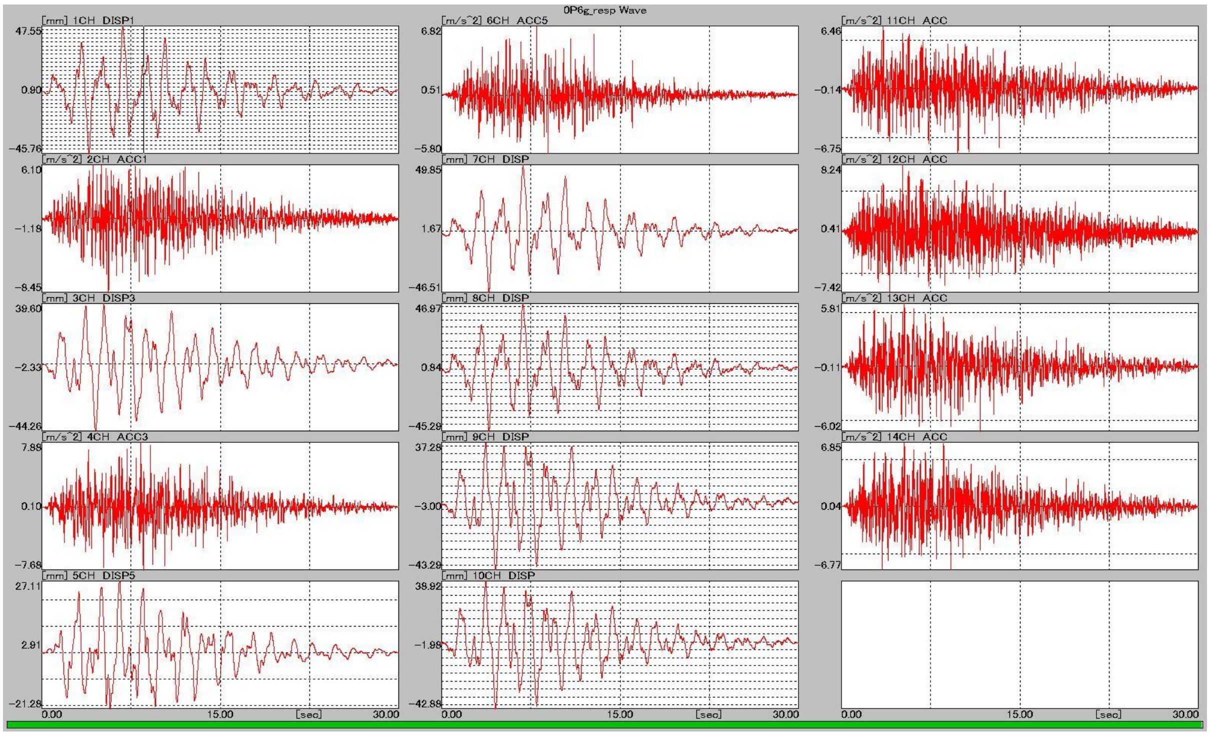

Fig.27 Input and response displacement and acceleration at 0.6g

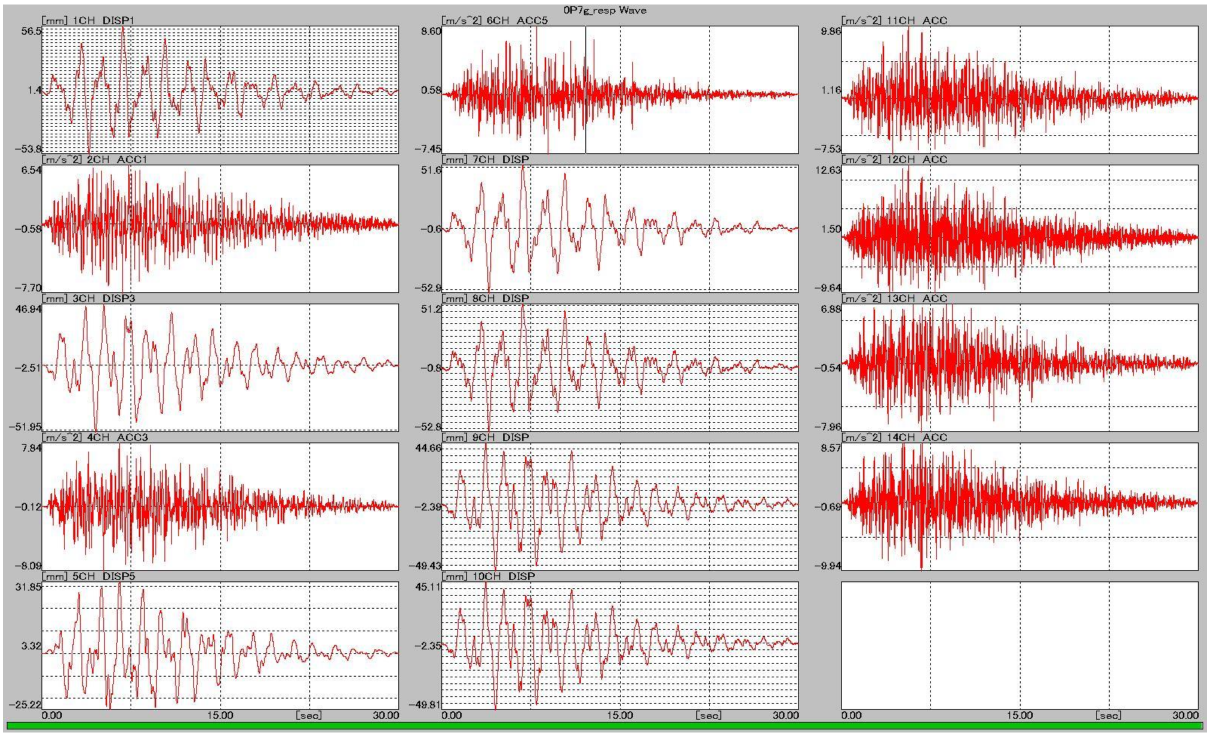

Fig. 28 Input and response displacement and acceleration at 0.7g

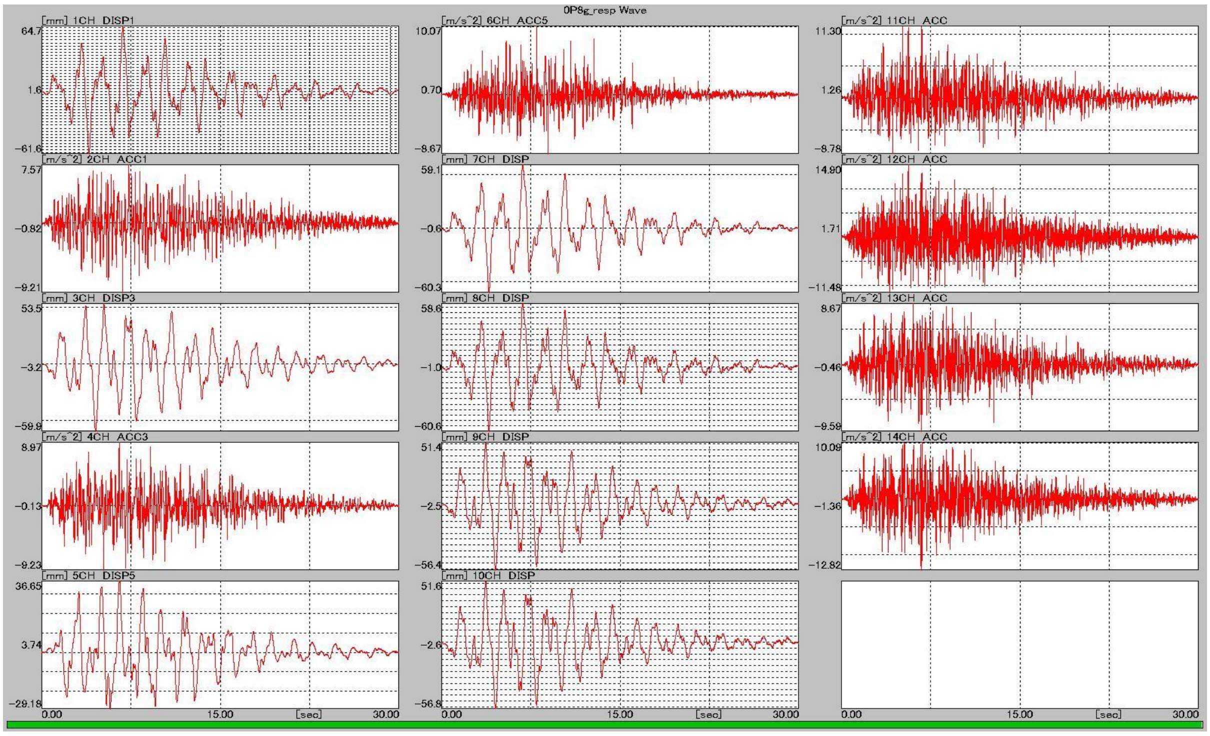

Fig. 29 Input and response displacement and acceleration at 0.8g

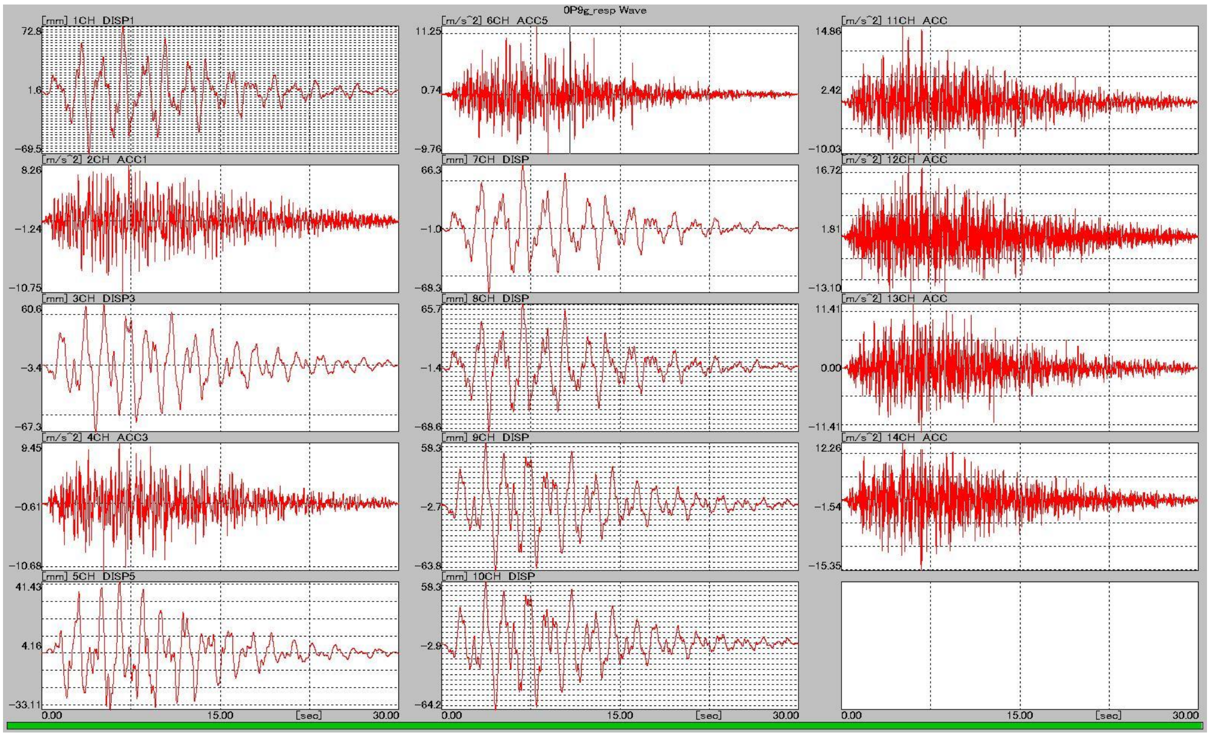

Fig 30 Input and response displacement and acceleration at 0.9g

6.2 Failure Mechanism of the Structure

Initial horizontal cracks (parallel to the course of the wall) on the structure started opening up on the solid wall located on the north side of the structure at base acceleration of 0.24 g. This crack spread to eastern wall (wall with a door opening) till the door opening and to a little extent on the western solid wall. This remained stable until 0.6g when cracks on the solid wall on the southern side also started elongating. This was little stable until 0.8g and at 0.9g the horizontal crack totally enveloped all the four walls on the weakest horizontal plane below the sill level of the window.

The structure has been very un-stable at 1.0 g and repeated loading at 1.0 g has been futile and the test runs had been aborted in the middle of this for both the cycles. The structure is deemed to have survived until 0.9g of base acceleration levels without total collapse. Figs 31 to 38 show the crack patterns observed in each walls after the testing.

Fig. 31 Cracks observed in the western wall (with window opening)

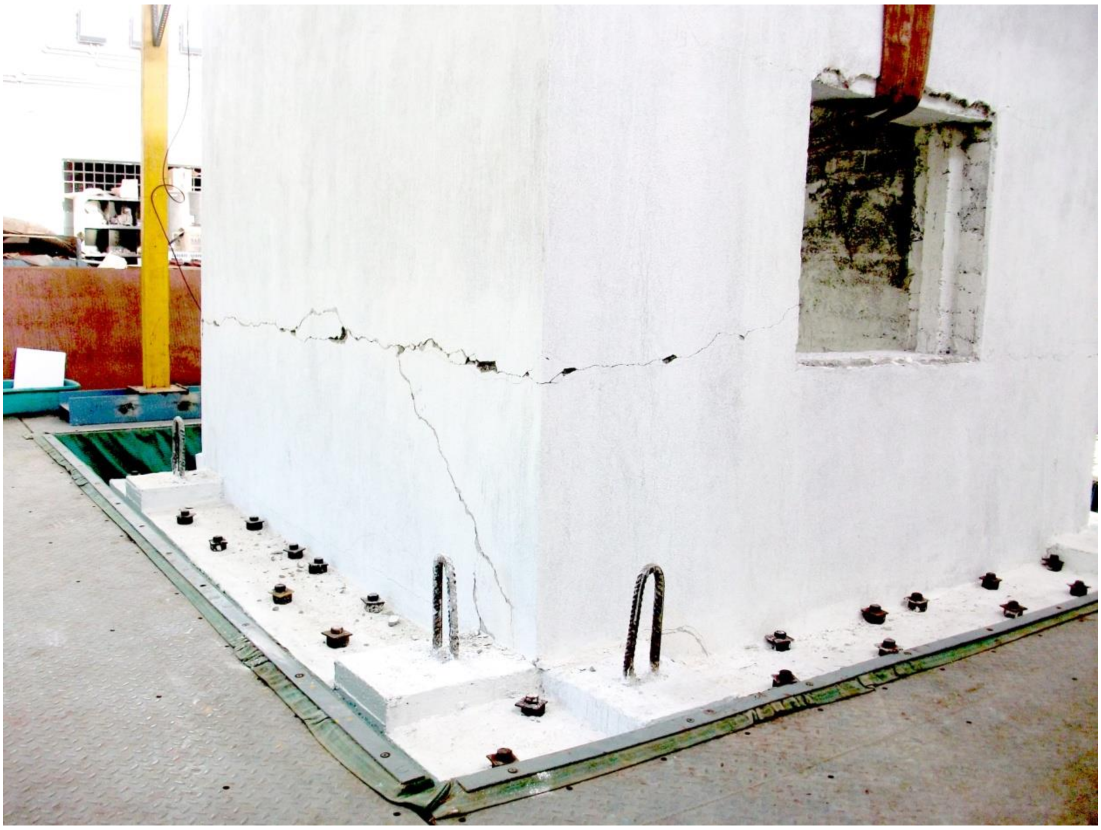

Fig. 32 Cracks observed in the North West corner

Fig. 33 View of the cracks in the northern solid wall

Fig. 34 Failure cracks in the north eastern corner

Fig. 35 Cracks in the eastern wall with door opening

Fig. 36 Cracks at the bottom level in the eastern wall with door opening

Fig. 37 Cracks in the eastern wall at the top level near door opening

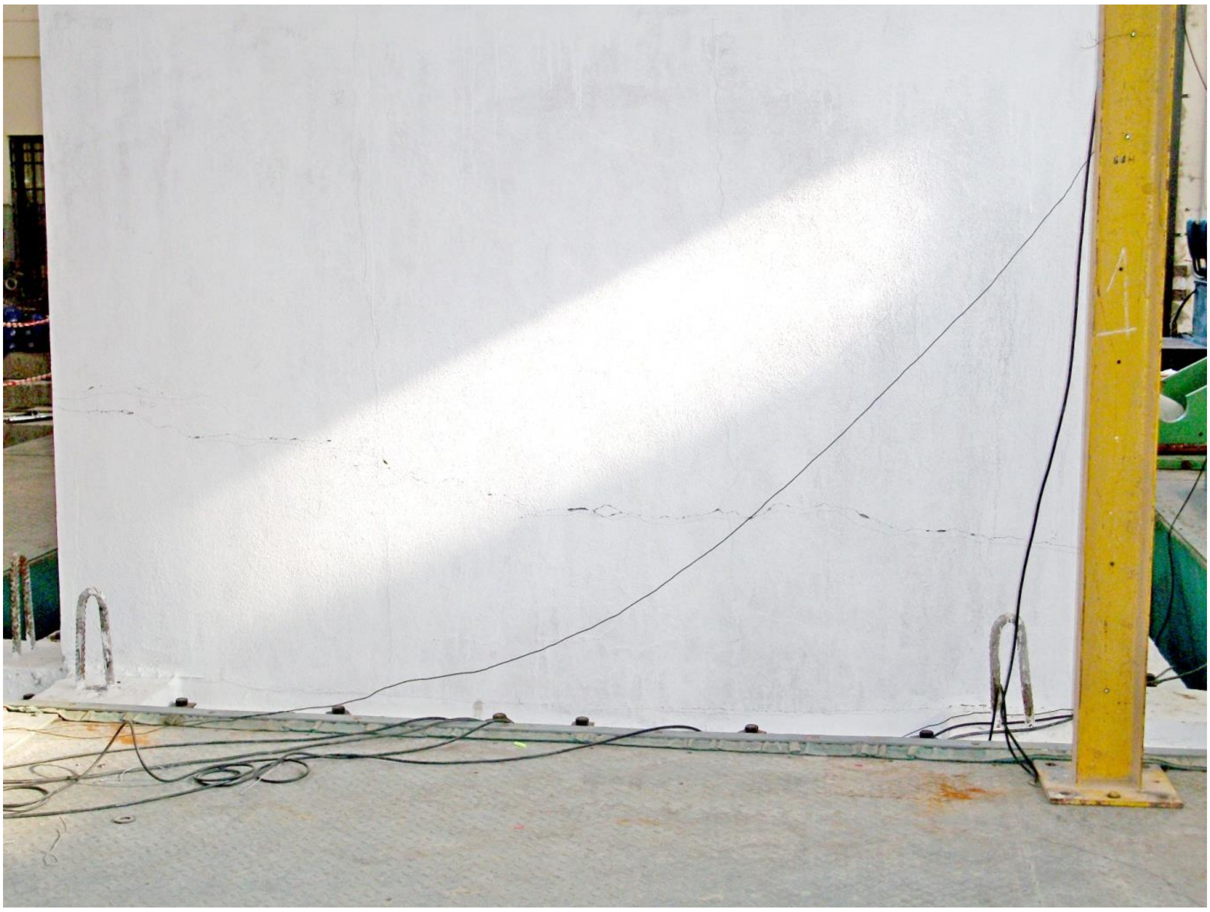

Fig. 38 Crack pattern in southern solid wall

7.0 INFERENCES AND CONCLUSIONS

- The mud-filled PET bottles and Nylon 6+ nets have been provided by M/s Samarpan foundations and no element level strength characterization of these materials have been carried out at CSIR-SERC.
- The structure is tested for a tri-axial input motion with simultaneous excitation of two horizontal and one vertical excitation. All the three motions in the form of acceleration time histories are not correlated with each other and peak acceleration inputs shall not match.
- These acceleration time histories are compatible with the spectra defined in the Indian code of practice IS-1893 spectra and vertical acceleration is 2/3 of the horizontal peak ground acceleration. The acceleration is given insteps of 'Z' values specified in the code for zones II, III, IV and V (0.10, 0.16, 0.24 and 0.36g). After this the test is conducted with PGA increments of 0.1 g until failure is observed.

- There is no scaling carried out for the spectra and response, as the structure is deemed to be a 1:1 scale model.
- The failure mode of the structure is through horizontal shear on the weakest plane below the sill level where the resisting area is the minimum.
- No additional mass over and above the existing self weight of the structure has been added on the top slab.
- The structure withstood a maximum acceleration of 0.9g beyond which there is an un-stable response of the structure.
- The maximum magnification of acceleration of the one storied structure between the base to the roof acceleration is 1.33 and the structure generally behaved as a rigid structure.
- The test conditions and results correspond to this particular thickness of the wall (350 mm) along with the characteristic orientation of nylon wire mesh.

7.1 Word of Caution

1. Generally the overall and global behaviour of the structure under simulated seismic loading is found to be satisfactory. However, the local behaviour may not be full captured through experimental study. This limitation in an experimental program due to model distortions, lack of fit, marginal out-of-plumb and dimensional tolerances has to be borne in mind.

2. The results of the experiments are valid under conditions of rotational and translational fixity of the foundation. The uncertainties and vagaries arising out of soil flexibility and settlement may adversely effects the performance of the structure. This has to be suitable taken care of in the actual design.

3. The experiments are based on the design spectrum suggested by Indian standard code of practice (IS 1893-2002, Part-1). The spectrum has been used to create the compatible time history. In case of real earthquake being different in terms of frequency content and PGA levels, this may alter the response of the structure different from, what is observed from the experiment.

4. The problems arising out of de-lamination, wind loading, soil settlement and other phenomena are not covered in this experimental study and have to be suitable taken care of in the actual design

5. The test does not include the vertical load carrying aspect of the un-reinforced roof slab and the horizontal and inertial actions of the self-weight of the roof slab alone shall be captured in the response.
6. The wall spacing is limited to 3.0 m X 3.0 m in the experiment along both the horizontal directions and additional mass due to live loads have not been accounted for. In case of increased live loads and increased centre to centre distances of the load carrying elements, the failure acceleration shall substantially be reduced.

ACKNOWLEDGEMENTs

The project members express their deep gratitude to Dr Nagesh R Iyer, Director, CSIR-SERC for his constant encouragement and guidance throughout the course of the project. The team also thank the scientists and laboratory staff of ASTaR laboratory at CSIR-SERC for their support.

REFERENCES

1. IS 1893-2002, 'Indian Standard – Criteria for Earthquake Resistant Design of Structures, Part-1, General Provisions and Buildings', Bureau of Indian Standards, New Delhi
2. IS 456:2000, 'Indian Standard Code of Practice for Plain and Reinforced Concrete', Bureau of Indian Standards, New Delhi