ISSN (online): 2250-141X
Vol. 1 Issue 2, December 2011

SHAKING TABLE EXPERIMENT ON REINFORCED CONCRETE BARE FRAME, INFILED FRAMES AND BRACED FRAMES

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ABSTRACT

Reinforced concrete (RC) frames with unreinforced masonry infill walls are common in developing countries with regions of high seismicity. It is useful to estimate dynamic characteristics of structures with unreinforced masonry infill for ensuring the safety of rigid non structural components in structural system. Earlier experimental studies have shown that presence of unreinforced infill in the RC framed structure, increases the structures stiffness, reduces its fundamental period and increases the damping. In the present study, the behavior of different reinforced concrete frames models namely, bare, braced, in filled, in filled with opening and frame with engineered infill wall under harmonic base excitation on shaking table is studied. The response of each frame is recorded under different frequency ratio and different excitation level. Experimental result shows that as the stiffness of frame increases peak acceleration response of frames increases while, the peak displacement response decreases. Further it is shown that the peak displacement response of in filled frames reduces significantly due added damping and the performance of frame with engineered infill wall is found to be the best among the frames with infill walls, due to bonding between the frame and in fill.

KEYWORDS: Rigid Nonstructural Component, infill wall, engineered infill wall, peak response.

1. INTRODUCTION

Reinforced concrete frames with unreinforced masonry infill walls are common in developing countries with regions of high seismicity. Often, engineers do not consider masonry infill walls in the design process because the final distribution of these elements may be unknown to them, or because masonry walls are regarded as non-structural elements. Separation between masonry walls and frames is often not provided and, as a consequence, walls and frames interact during strong ground motion. This leads to structural response deviating radically from what is expected in the design. Moreover in multistory buildings,

the ordinarily occurring vertical loads, dead or live, do not pose much of a problem, but the lateral loads due to wind or earthquake tremors are a matter of great concern and need special consideration in the design of buildings. These lateral forces can produce the critical stress in a structure, set up undesirable vibrations, and, in addition, cause lateral sway of the structure which can reach a stage of discomfort to the occupants.

ISSN (online): 2250-141X
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In many countries situated in seismic regions, reinforced concrete frames are infilled fully or partially by brick masonry panels with or without openings. Although the infill panels significantly enhance both the stiffness and strength of the frame, their contribution is often not taken into account because of the lack of knowledge of the composite behavior of the frame and the infill.

In some cases non-structural element played an important role during earthquake like in Bhuj(26 January 2001), Gujarat. Many buildings were prevented from collapse by the presence of 'non-structural' infill wall panels which acted as shear walls despite not being designed for this purpose. Buildings survived collapse because these infill walls took the brunt of the lateral shaking. Building experienced severe shaking causing moderate to heavy damage to the infill panels, but this prevented column failure. It was noted that this wall was effective despite being compromised by the presence of a door opening. When masonry infill walls were ineffective because of large openings, column heads were subjected to large vertical and lateral seismic forces. The heavy eccentric compressive stresses crushed column heads and large shear deformations caused concrete to spall away from the main bars because of links being to far apart. The extent of damage to the column heads often depended on how well the infill wall panels were bonded to the columns.

Alidad Hashemi and Khalid M. Mosalam[1], carried out a shaking table experiment on prototype of three bay stilt plus four storied structure. The shaking table experiment was conducted on a substructure of this prototype consisting of the middle bays of its first storey. From the study it is found that the unreinforced infill wall has a significant role in the strength and ductility of the test structure and should be considered in both analysis and design. Globally, it makes the test structure stiffer by a factor of 3.8, shortens the natural period of the test structure by 50%, increases the damping coefficient depending on the level of shaking from about 4 to 5% and increases the dissipated energy in the system. Such changes significantly affect the level of demand forces on the structure and generally reduce the displacement demands. Locally, the unreinforced infill wall changes the load path and the distribution of forces between different elements of the test structure by increasing the demand forces on its adjacent elements, e.g. the top and bottom of the reinforced concrete columns and the reinforced concrete slab. Quantitatively, the unreinforced infill wall causes about 30% increase in the demand forces on the diaphragm and collector elements in the test structure.

Roko Zarnic et al [2] carried out shaking table test on reduced scale of 1:4 on two models of in filled frames. Two models type 'B' of single bay and single storey and model type 'H' of two bay and two storeys were considered in this study. The models were shaken with the series of horizontal sine dwell motions with gradually increasing amplitude. Masonry in fills of tested models was constructed of relatively strong bricks laid in weak mortar. Therefore, typical cracks developed and propagated along mortar beds without cracking of bricks or

ISSN (online): 2250-141X
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crushing of infill corners. The similarity of local behavior of structural elements, e.g. reinforced concrete joints is less reliable due to limitation in modeling of steel reinforcement properties. The model responses showed that building designed according to Euro codes is able to sustain relatively high dynamic excitation due to significant level of structural over strength.

M.N.Fardis et.al [3] carried out shaking table test on a two-storey, square in plan frame structure, with two adjacent sides infilled and the two other open. From this study it is observed that the pre-cracking stiffness of the infills is large enough to impose twisting of the infilled structure about the common corner of the two infilled sides, with predominant period close to that of translation of the symmetric bare structure in the two horizontal directions X and Y. Parametric analyses and test results shows that the peak displacement components of the corner column of the two open sides are about the same as those of the bare structure under the same bidirectional excitation. It was concluded from the study that for the design of reinforced concrete frame structure with such plan-eccentric infilling, the columns near the common corner of the open sides should be proportioned for simultaneous occurrence of the full peak force or deformation demands due to both horizontal components of the seismic action. In all other aspects the reinforced concrete frame structure can be designed as if it were bare.

Khalid et.al.[4] have carried out Quasi-static experiment on quarter-scale semi rigidly connected steel frames infilled with non integral (i.e. without shear connectors between the frame members and the infill walls). In this experiment they concluded that equivalent strut acting in compression only can be used to represent the effect of the infill wall on the bonding frame members. The width of this strut tends to be larger towards the center of the infill wall. With this variable effective cross-sectional strut area, the concentration of strains and stresses at the corners may be captured.

Klinger and Bertero [5] studied the behavior of infilled frames experimentally and also confirmed his results with small analytical problems. He forwarded a term ‘engineered Infill walls’. In the research work Prof.Bertero selected an 11 storey apartment building having plan dimension of 18.3m by 61.0m with total height 30.14m (floor ht.2.74m each). The model of the building under 1/3rd scale was constructed. The desired ductility as that of the prototype was achieved by following the seismic design provisions in UBC (1970) and ACI code (1971). The reinforced infills were provided. The bare frame was tested along with the infilled frame under lateral loading, unloading and reloading cycles. The improvement in ‘high resistance to cycles of shear reversal’, ‘elongation in the time of final collapse’ was noticed. To cross check the results analytical, the infills were idealized as cross bracings and analysed using ‘ANSR-I’ program under a cyclic load. This concept was named as ‘equivalent strut concept’. From this study it was concluded that Lateral Stiffness of the infilled frame was found to be six times more than that of the bare frame. Post cracking behavior of the ‘engineered infills’

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gave striking results, which helped in the 'energy dissipation'. Even when subjected to sever ground motions the infills significantly reduced the 'P-Δ effect'. Energy Dissipation in bare frame occurred primarily through inelastic rotations at hinge regions near beam-column joints, whereas the energy dissipation takes place in the infilled frames through hysteretic behavior (i.e. friction across panel cracks, accompanied by gradual degradation of the whole body) and not concentrated only at joints, as in case of a concrete bare frame. The danger of sudden collapse was reduced and the infilled frame performed very well at all response stages.

All these studies were observation based and hardly any analytical work was done. The possible reason could be that, the analytical work is very intricate and involved. Also the old research work is found to be limited. For analytical solution, diagonal braces simulated the presence of infill walls [5]. This logic of diagonal braces has many constraints in itself viz. the openings crossing the diagonal braces make the problem more complicated, the sizes of equivalent braces are uncertain and the material properties to be assigned to these braces are unknown. In normal aseismic design, the effect of in filled wall is not considered.

In the present study shaking table experiments on two dimensional RC frames with and without infill wall under harmonic base motion is carried out. Also frame with in filled wall having central opening, frame with single and double steel bracing, and frame with in filled wall having wire mesh at the interface of infill and frame (Frame with Engineered infill wall) are considered in this study. In the present study the dynamic characteristics such as stiffness, natural frequency etc of bare, braced, in filled, in filled with opening and engineered in filled frame were evaluated. Effectiveness of infill wall and bracings are investigated. Behavior of ordinary in filled frame and infill frame with engineered infill wall is compared. The effect of opening in the infill wall is also studied.

2. EXPERIMENTAL SET-UP AND TEST PROCEDURE

2.1 Instrumentation used for the study:

Spectral Dynamic medium force shaker series shaking table model (SD-10-240/GT1075M) is used for the experiment. It is an electrodynamics unidirectional shaking table. It is fully automatic shaking table controlled by central computer. Besides controlling the shaking table it is also used for data acquisition and processing which is done by 'Puma software'. The size of table in plan is 1.0 m x 0.75 m. The range of maximum displacement is ±51 mm. The maximum operating velocity is 0.18 m/sec and the operating frequency is in between 5 to 3000 Hz. Four accelerometers can be used for data accusation. Out of which one accelerometer is attached to the base of slip table which controls the movement of slip table. In this shaking table many in-build sensors are attached which monitors the activity of shaking table. The laboratory set up is shown in figure 1. The data acquisition is also done with Oros system. It is an instrument in which data can be acquired, stored and analyzed. NVGATE

ISSN (online): 2250-141X
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is the software used by Oros to process the data. It is having 24 channels and it is more users friendly. In this project Oros instrument is used extensively and is shown in figure 1.

2.2 Structures considered in the study:

A single bay two dimensional reinforced concrete frame models were considered for this experimental study as there is limitation of shaking table dimensions and capacity. As shown in figure 2 the height of frame is 800mm and span is 600mm centre to centre. The size of the columns and beam is kept as 100mmX100mm. The design of frame was performed in accordance with I.S.456-2000[6]. The bare frame considered is made up of reinforced concrete with M20 concrete and Fe415 steel. The design is governed by minimum reinforcement, therefore in column section four numbers of 8 mm diameter bars are provided with 6mm ties at 100mm centre to centre spacing. In beam two numbers of 8 mm diameter bars are provided both at top and bottom with 6 mm stirrups at 60 mm centre to centre spacing. Siporex block (Ecolite) having density 16000Kg/cm^3 of size 600x240x150mm is cut into small bricks of size of 125x75x50mm and used as infill wall.

The following six different types of frames where consider for the experimental study.

(1) Bare frame which consists of only beam and column.
(2) Frame in which in filled wall is constructed using Siporex brick
(3) Frame with in fill wall with central opening
(4) Frame with engineered infill wall in which the interface of infill wall and frame is bonded together by using a wire mesh
(5) Frame with single diagonal steel bracing.
(6) Frame with double diagonal steel bracings.

For frame with single bracing, a diagonal bracing of mild steel plate of 3mm thick and width of 100 mm at centre which was tapered to 50mm at the end is used. Similarly for double braced frame, two diagonal bracings of mild steel of same dimension used for single braced frame were used and at intersection, the plate were welded to each other. The bracing plates were welded to base plate at bottom and to a bracket at top as shown in figure 2.

The bottom of frame is connected to two base plates the top and bottom base plates. The top base plate is of size 150mm x 150 mm with an angle section 50 x 50 x 5 welded to it at its centre and embedded into the concrete. The bottom base plate is of size 250 x 250 mm and welded to the top base plate. The frames were fixed on the top of the shaking table using threaded nuts to bottom base plates. For each type of frame considered two specimens were prepared. All above mentioned test specimens mounted on shaking table are shown in figure 3.

2.3 Test Procedure:

First oil pump is started at constant pressure, 10 minutes before the test so that slip table runs smoothly. Then the frame is mounted on shaking table. The base plate is fixed to

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the slip table with help of bolts. Spring fasteners were used so that bolts do not get loose due to vibration. After fixing frame to the shaking table one accelerometer is attached to the centre of beam column junction in the direction of excitation. Another accelerometer is connected to the base of the shaking table to monitor the movement of slip table. The desired motion is induced to shaking table with the help of controller then required data like sensitivity of accelerometer, frequency, acceleration etc inputs were given. The required dynamic parameters were measured.

3. RESULTS AND DISCUSSION:

3.1 Natural Frequency of Frames

First the natural frequency of the frames is found. A harmonic base motion at frequency 20Hz to 260Hz is applied and frequency response graph are obtained for various frames using puma software. Frequency at which peak response occurs is the fundamental natural frequency of the frames. A typical frequency response graph for bare frame as recorded is shown in figure 5. Similar graphs are obtained for other types of frames also. The fundamental frequency of each frames thus obtained is tabulated in table 1. From the table it is observed that bare frame has lowest frequency and frame with double bracing has highest frequency. Compared to bare frame, frames with infill walls have higher frequencies indicating that their stiffnesses are higher that bare frame. Thus the infill walls increases the stiffness of the frame and hence resist more lateral loads than that of bare frame.

3.2 Dynamic Responses of Different Frames:

The peak acceleration and displacement responses of various frames are obtained for three different frequency ratios i.e. β = 1, 1.5, and 2 and for three different intensity levels of harmonic base motion. The three different intensities of base motion of shaking table considered are 0.1g, 0.2g and 0.3g. The dynamic responses of the bare frame, frame with infill wall, frame with infill wall but having central opening, frame with engineered filled wall, frame with single bracing, and frame with double bracings for three different frequency ratios and three excitation levels are obtained From these results it is observed that for all cases, the peak responses increases as the excitation level of base motion is increases and the peak responses are highest and resonant condition i.e., at frequency ratio β = 1.0. Therefore for discussion only the resonant responses are considered.

3.3 Peak Resonant Responses:

The peak resonant responses for different frames considered in the study for three excitation levels of base motion are presented in table 2 to 4. From the results presented in theses tables the following observations can be made the effectiveness of different types of frames is compared in terms of the following parameters:

Effect of infill wall:

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From the results presented in table 2 to 4, it is observed that the peak acceleration response of in filled frame at excitation level of 0.1g is slightly higher than of bare frame. This is may be due to higher frequency of excitation. However there is significant reduction in displacement response due to additional damping added by infill wall. However, at excitation level of 0.2g & 0.3g both the peak acceleration and peak displacement response are much lesser than that of bare frame. This may be due to more damping at higher level of excitation. Thus the frame with infill wall resists the lateral loads more effectively.

Effect of opening in infill wall:

Due to presence of opening, the stiffness of this frame is reduced which is reflected by reduction in its frequency. The peak acceleration responses of frames with opening and without opening are more or less same. However the peak displacement response higher in frame with infill wall with opening, because of reduced stiffness.

Effect of boding between frame and infill at their interface:

In case of frame with engineered infill, there is a strong bonding between the frame and wall at their interface as compared to frame with ordinary infill wall where the boding between the wall and frame interface is weak. Due to this reason, in case of frame with engineering infill, relatively the peak acceleration response goes on increasing as the level of excitation increases. However the peak displacement response of this frame is slightly less as compare to frame with non-engineered infill wall. This may be due to additional damping due to more friction at the interface of infill and frame.

Effectiveness of Bracings:

The peak acceleration responses as well as peak displacement response of frame with single bracing are higher as compared to the peak responses of frame with infill wall, since in frame with single bracing, the damping effect is less. As compared with the responses of bare frame the peak acceleration response of frame with single bracing is more than that of bare frame due to higher stiffness. But the peak displacement response is lesser than that of bare frame due to higher stiffness.

The frame with double bracing is stiffer than that of frame with single bracing. Therefore the peak acceleration response of double brace system is much higher than that of single braced system. This trend of result is due to fact that frequency (hence the stiffness) of double braced system is higher than that of single braced system. Therefore at β =1 the excitation frequency is much higher. However the displacement response is smaller than those corresponding to single braced system. This may be due to fact that double braced system has more damping than single braced system. Similar to single braced system, in double braced system the peak acceleration response is much higher than that of bare frame due to higher stiffness. But the peak displacement response is much smaller than that of bare frame due to more energy dissipation in double braced system.

4 CONCLUSIONS

A fairly comprehensive experimental investigation on effectiveness of six

ISSN (online): 2250-141X
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different models of single storey, single bay frames are carried out. Peak displacement response of bare frame is found to be highest among all frames, while peak acceleration response of frame with double bracing is found to be highest. Highest acceleration response of frame with double bracing is attributed from the fact that it has higher stiffness and is subjected to higher excitation frequency. Among the frames with infill walls, frame with engineered infill has lowest peak displacement response due to more energy dissipation. But the peak acceleration response of this frame is highest among the frames with infill wall due to higher stiffness and higher excitation frequency; however, its peak acceleration is lesser than that a bare frame because of damping effect. Presence of opening in the wall reduces its stiffness due to which its peak displacement response is highest among the frames with infill walls. In single braced frame peak acceleration response as well as peak displacement responses are higher as compared to the frame with infill wall. As in single braced frame damping effect is less compared to infill frame. The frame with double bracing is stiffer than that of single braced system. Therefore acceleration response of double brace system is much higher than that of single braced system. However the peak displacement response is smaller than that of a single braced system .This may be due to fact that higher energy dissipation in frame with double bracing than frame with single bracing.

Acknowledgements:

This research work has been carried out using shaking table facility (Electro Dynamic Vibration System), which was set up under the grant received from Department of Science and Technology, Government of India, under FIST program 2007. This financial support is gratefully acknowledged.

REFERENCES

1 Alidad Hashemi and Khalid M. Mosalam, ‘Shake-table experiment on reinforced concrete structure containing masonry infill wall’, Earthquake Engineering and Structural Dynamics, Vol. 35, 2006, p 1827–1852.

2 Roko Zarnic, Samo Gosti, Adam J. Crewe and Colin A. Taylor, ‘Shaking Table Tests Of 1:4 Reduced-Scale Models Of Masonry infilled Reinforced Concrete Frame Buildings’, ‘Earthquake Engineering and Structural Dynamics, Vol. 30, 2001, p 819-834.

3 Fardis.M.N, S.N.Bousias, G.Franchioni and T.B.Panagiotakos ‘Seismic Response and Design of RC Structures with Plan-Eccentric Masonry Infills’, Earthquake Engineering and Structural Dynamics Vol. 28, 1999, p 173-191.

4 Khalid M. Mosalam, Richard N. White., and Peter Gergely, ‘Static response of infilled frames using quasi-static experimentation’ Journal of Structural Engineering (ASCE) vol. 123, No. 11, 1997, p 1462-1469.

5 Richard E. Klinger and Vitelmo V. Bertero, ‘Earthquake resistance of infilled frames’, Journal of

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the structural engineering (ASCE), vol. 104 No. 6, 1978, p 973-989.

6 I.S.456-2000(4th Revision), 'Plain and Reinforced Concrete-Code of Practice', Bureau of Indian Standard, New Delhi.

Figure.1 Laboratory arrangement of shaking table experiments showing various components of instrumentation.

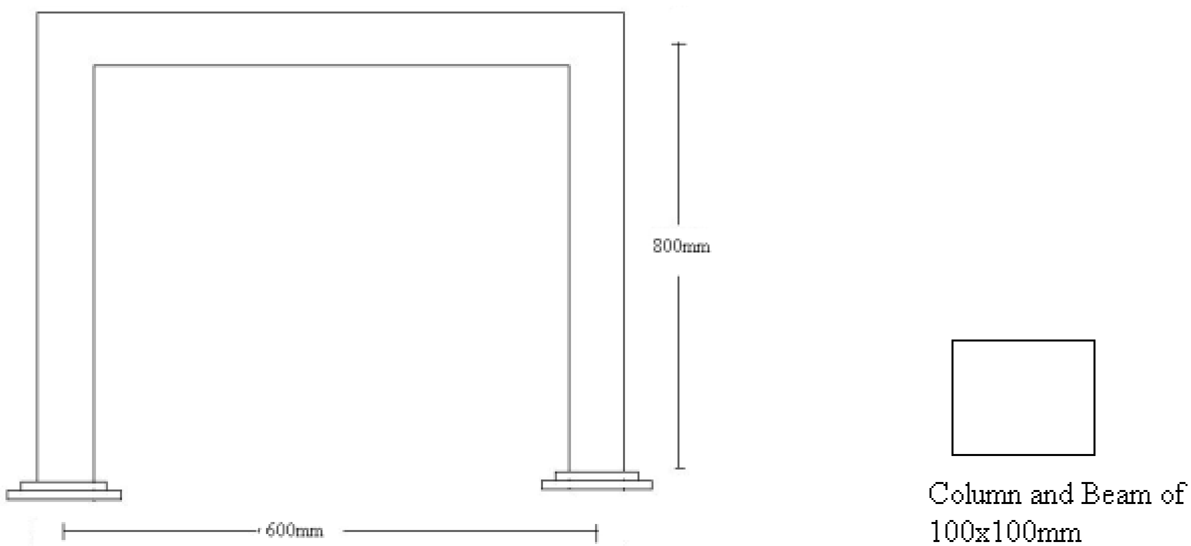

Figure.2 Reinforcement Concrete frame considered in the study

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Bare frame Infilled Frame Infilled frame with Opening

Frame engineered infill wall Single Braced Frame Double Braced Frame

Figure.3 Different types of frames considered for shaking table experiment.

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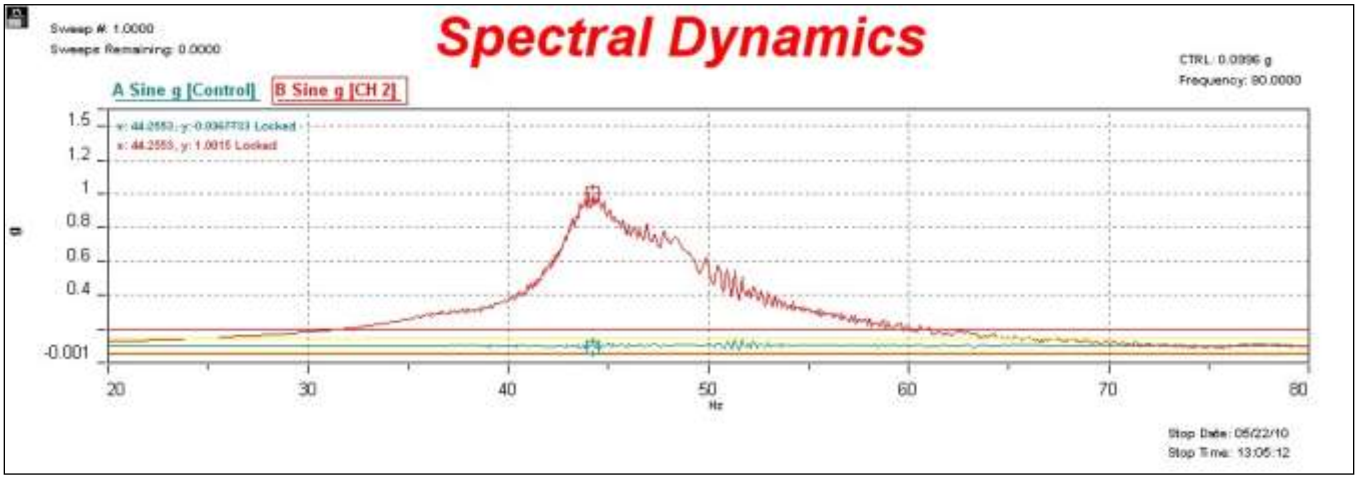

Figure 4. Frequency response graph for Bare frame

Table 1 Fundamental Frequency of different frames.

Fundamental Frequency of different frames.		
Sr. No.	Type of Frame	Frequency in Hz.
1	Bare	44.2553
2	Infilled	80.8761
3	Infilled with opening	73.3667
4	Frame with engineered infill wall	127.66
5	Single braced	88.1727
6	Double braced	116.809

ISSN (online): 2250-141X
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Table.2 Peak responses of different frames at resonant condition and base acceleration of 0.1g

Type of Frame	Bare Frame	Infill Frame	Frame with in fill wall with central opening	Frame with engineered infill wall	Frame with Single Bracing	Frame with Double Bracing
Acceleration (g)	1.052	1.19	0.84	0.747	1.45	1.74
Displacement(mm)	0.18	0.075	0.12	0.066	0.116	0.064

Table.3 Peak responses of different frames at resonant condition and base acceleration of 0.2g

Type of Frame	Bare Frame	Infill Frame	Frame with in fill wall with central opening	Frame with engineered infill wall	Frame with Double Bracing	Frame with Single Bracing
Acceleration (g)	1.85	0.814	0.88	1.43	3.23	1.75
Displacement (mm)	0.27	0.081	0.121	0.079	0.095	0.124

Table.4 Peak responses of different frames at resonant condition and base acceleration of 0.3g

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Type of Frame	Bare Frame	Infill Frame	Frame with in fill wall with central opening	Frame with engineered infill wall	Frame with Single Bracing	Frame with Double Bracing
Acceleration (g)	2.32	1.0	1.2	1.93	1.42	4.12
Displacement (mm)	0.33	0.079	0.10	0.077	0.124	0.109