COMPARING SEISMIC RESPONSE OF SOFT-STOREY STRUCTURE WITH AND WITHOUT BRACINGS

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Abstract

In general, multi-storey buildings in metropolitan cities require open taller ground storey for parking of vehicles owing to lack of horizontal space and high cost. Due to this functional requirement the first storey has lesser strength and stiffness as compared to upper stories, which are stiffened by masonry infill walls. This characteristic of building construction creates "weak" or "soft" storey problems in multi-storeyed buildings. Increased flexibility of first storey results in extreme deflections which in turn, lead to concentration of forces at the second storey connections accompanied by large plastic deformations. In addition most of the energy developed during the earthquake is dissipated by the columns of the soft stories. In this process the plastic hinges are formed at the ends of columns which transform the soft storey into a mechanism. In such cases the collapse is unavoidable. Therefore the soft stories deserve a special consideration in analysis and design.

A case study of a building located in Hyderabad which falls under the Seismic Zone II, is considered to show how the response of a soft storied building during an earthquake changes when it is provided with diagonal struts only at the corners bays of the soft storey. Since struts are being provided at the corners, they do not interfere significantly with the desired functionality of the soft storey. The aim of this paper is mainly to analyze the feasibility of this solution as the configuration of the building varies in different directions.

Keywords: *Softstorey, dynamic analysis, bracings, time history analysis*

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1. INTRODUCTION

Open Ground Storey (OGS) buildings are the popular building typology seen all over the developing and developed nations, especially for the multi storied buildings, they are built for two major reasons, first being for parking and second for commercial buildings either for gardens or architectural purposes . Former ones are seen all around the world and have suffered serious damages during the earthquakes and the later ones are more popular in countries like Turkey. These buildings with parking spaces in the ground floor are called stilt buildings, and ground floor is said to be stilt floor or soft storey. From the past few decades urban India has given rise to many soft storey structures since they provide the much-needed parking space to the users. According to Indian standard code IS-1893-2002 part I, an soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

Because these structures are vertically irregular, they are very much vulnerable to seismic activities. Much of the damage occurs in the first few stories of such buildings. Figure-1 shows the schematic diagram showing the possible collapse behavior of a soft storey structure during earthquakes from (a) – (e). Open ground storey buildings have consistently shown poor performance during past earthquakes across the world (1999 Turkey, 1999 Taiwan, 2001 Bhuj and 2003 Algeria earthquakes). Figure-2 shows the buildings which are soft storied and have failed during the past earthquakes in various countries. Ahmedabad alone has about 25,000 five-storey buildings and about 1,500 eleven-storey buildings; majority of them have open ground storey. More than a hundred open ground storey buildings collapsed in Ahmedabad (approximately 225km away from epicentre) during the 2001 Bhujearthquake. Large number of open ground storeys exist in the various towns and cities located in moderate to severe seismic zones.

2. LITERATURE

Literature states that the lateral resistance of the existing frame structures is inadequate for two major reasons. First, the perimeter frames, which feature weak short columns, are likely to fail in an undesirable mode. Secondly, code provisions may have been upgraded several times since construction, so that current seismic design loads are more than the original values [1].Priyanka et al. conducted a numerical study on softstorey strengthening and described the use of cross bracing, stiffer column, shear wall, light weight material infill which increase the stiffness of first storey and reduce the lateral drift demand [2], but not described particularly on kinds of bracing systems.Similarly Hiten et al. 2014 studied using numerical models of an G+5 reinforced concrete building with soft storey. Study mainly concentrated on calculation of inner storey drift by changing parameters of column and soft storey height at first floor, it concludes the displacement of codal lateral load patterns are smaller for the lower stories and larger for the upper stories and are independent of the total number of stories of the models [3].Shailendra and Sunil, 2013 did an experimental investigation on the ultimate strength of partially infilled and steel-braced reinforced concrete frames, experimental results showed central bracing is more effective than that of corner bracing. For the same load, braced and partially infilled frames deflected significantly less than that of bare frames [4], which is quite obvious.

3. METHODOLOGY

As a part of methodology to understand the location of bracing and its orientation four scenarios have been considered and in each scenario few cases have been shown according to the possible locations of bracings, can be seen in the figures (figure-3 to figure-9). In the first scenario a single bay two storey structure is considered figure-3(a-d) show cases without infill and figure-3(e-h)show with infill resembling the softstories. Numbers 1 to 6 indicate the joints at which the displacements are calculated and plots are plotted. Joint 3 and joint 6 indicate the second floor joints and joint-2 and joint-5 indicate the ground floor slab as shown in the figure-3. Boundary conditions are considered to be fixed at the bottom of the structure and same is applied for all the case studies and scenarios. A lateral load of 10 kN is applied at the top floor as seen in figure and for same plots are plotted which can be seen in the figure-4.

Figure-4 shows the results obtained for the cases figure-3(b)-3(d) and figure-3(f)-3(h), i.e with infill and without infill. Specifically, figure-4(a) shows the results of figure-3(b), 3(c) and 3(d) for joints 2 and 5, as seen in the figure. Similarly figure-4(b) and figure-4(d) show the results for figure-3(f), 3(g) and 3(h). Even though these models are very simple, they give fundamental understanding about the soft storey behavior. Observing figure 4(a), indicates that providing cross bracing will definitely decrease the lateral displacement. As for the results of figure-3(b) and figure-3(c), the main conclusion can be said is orientation of the bracing will effect the displacement. Top floor behavior is different from the ground floor slab, which is because of the provision of bracing. And provision of cross bracing has led to minimum displacement as expected but when compared between the cases figure-3(b) and figure-3(c), configuration of figure-3(b) has less displacements, that could be due to line of action of forces.

As seen, the results have varied by a large difference for soft storey and bracing structure. Similarly this effect is seen for all the scenarios analyzed. Provision of infill walls does effect the lateral displacements and change is very very large. That is displacements of ground floor are similar but top floor displacements with and without infill vary almost by 90%. In case of infill results are almost same for figure-3(g) and figure-3(h). So, instead of having ‘x’ bracing, a single bracing can be provided.

In the scenario-2, two bay doubled storied building is analyzed for all possible orientations of bracings as shown in the figure-5. Figure-5 (a-f) show without infill walls and figure-5(g-i) show with infill walls. Results of all these subcases are plotted in the figure-6. Case numbers in the plot indicate each subcase. For an example 1 in the plot indicate results obtained for the subcase shown in figure-5(b), 2 indicate for figure-5(c), 3 indicate for figure-5(d), 4 indicate for figure-5(e) and 5 indicate 2 indicate for figure-5(f). And it is similar for all other plots plotted. In the case, without infill provision of cross bracings would minimize the displacement to its maximum, when compared to other cases. Results are quite different between ground floor and first floor as expected. Results of figure-5(b) and figure-5(f) are almost same, so instead of ‘x’ bracing single bracing can be provided with 1350 angle orientation.Infill frame results are different, but yet these results for figure-5(k) as per given provision of bracings will minimize the displacements obtained on the top floor. Scenerio-3 which are shown in the figure-7 and figure-8, also show the similar results.

To understand the effect of third dimension, a three dimensional frame is considered with 3 bay by 3 bay three storied building for this analysis. As in previous cases, a lateral load of 10 kN is applied at the top most joints as shown in the figure-9. Analysis is done for both infill and without infill. In case of without infill figure-9(e) is very effective in minimizing the displacements but with infill figure-9(h) and figure-9(i) are very effective.

From this methodological analysis, two major observations can be written, first the behavior is completely different for the structures with and without infill. Second, the orientation of the bracing will effect the structural displacements due to lateral loads. Which means it is not always necessary to provide ‘x’ bracings. Even a single bracing will be sufficient of properly designed and can reduce the damage during the earthquakes.

4. CASE STUDY

As a case study a real existing structure in Hyderabad is considered which is constructed as a soft storey. Complete plan details of the structure are shown in the figure-11(a). The actual structure under construction is shown in the figure-11 (b) and computer generated model using SAP2000 is shown in the figure-11(c).The objective of this case study was to compare the displacements obtained between structure without bracings to structure with bracings. The dimensions of columns, beams and struts used for the modeling the considered building is given in the table-1, along with material properties.

5. MODAL ANALYSIS

As a characteristic behavior of any structure depends on its mode shapes, which actually depends on the geometry, material and boundary conditions, the same has been done for the structure considered. Table-2 shows the modal analysis values for the same structure with varying parameters. It shows the comparison of modal frequencies of structure with only bare frame, without strut having infill and with infill and strut. The first natural frequency of bare frame is less compared to other two cases, whichare due to absence of either infill walls or struts, which will decrease the stiffness of the whole building.

6. TIME HISTORY ANALYSIS

Basic linear time history analysis is carried out using bhuj earthquake ground motion for building and responses of results are compared between the provision of strut and without strut.The results obtained are shown in the figure-14. Two plots are plotted at two different points on the top floor of the building. Since the building is unsymmetrical the responses could have been different. The first plot shows the response without the strut is very high when compared to the structure with strut, but this comparison is done in x-direction. The second plot shows the response with and without strut are similar. This could be due to two reasons one is the location of the strut and other being the orientation of the strut.

7. CONCLUSION

This numerical study has been carried out for understanding the behavior of soft storey with and without struts for the given lateral loads. Apart from the understanding, a recommendation for providing single strut at the corner columns has been made, as it will decrease the response of the structure during the earthquakes and also in parallel it will help in normal parking. Yet, there is much research has to be carried out for more appropriate soft storey designs for earthquake resistant.

8. REFERENCES

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Table 1: Beam, column and strut dimensions used for the case study with material properties

Frame Sections				
beam 1	460 x 380 mm		column 1	380 x 380 mm
beam 2	460 x 230 mm		column 2	540 x 230 mm
beam 3	380 x 230 mm		column 3	460 x 230 mm
beam 4	300 x 230 mm		column 4	380 x 230 mm
Strut dimensions			**Material properties**	
strut 1	460 x 230 mm		Concrete	M20
strut 2	380 x 230 mm		Steel	Fe415
slab thickness	115 mm			
wall thickness	230 mm			

Table 2: Modal analysis comparison between bare frame, without strut and with infill and strut

Mode No.		Bare frame		Without strut		With infill and Strut	
		Time Period	Frequency	Time Period	Frequency	Time Period	Frequency
Mode	1	1.199517	0.83367	0.983759	1.0165	0.870259	1.1491
Mode	2	1.069425	0.93508	0.835384	1.1971	0.734973	1.3606
Mode	3	0.946387	1.0567	0.71115	1.4062	0.609112	1.6417
Mode	4	0.649487	1.5397	0.597226	1.6744	0.503715	1.9852
Mode	5	0.456295	2.1916	0.493649	2.0257	0.459615	2.1757
Mode	6	0.401467	2.4909	0.400392	2.4976	0.393051	2.5442
Mode	7	0.357543	2.7969	0.375535	2.6629	0.342567	2.9191
Mode	8	0.347605	2.8768	0.334961	2.9854	0.311349	3.2118
Mode	9	0.324948	3.0774	0.321525	3.1102	0.300356	3.3294
Mode	10	0.316893	3.1556	0.295087	3.3888	0.282827	3.5357
Mode	11	0.315858	3.166	0.288166	3.4702	0.275414	3.6309
Mode	12	0.273489	3.6565	0.280485	3.5653	0.266558	3.7515

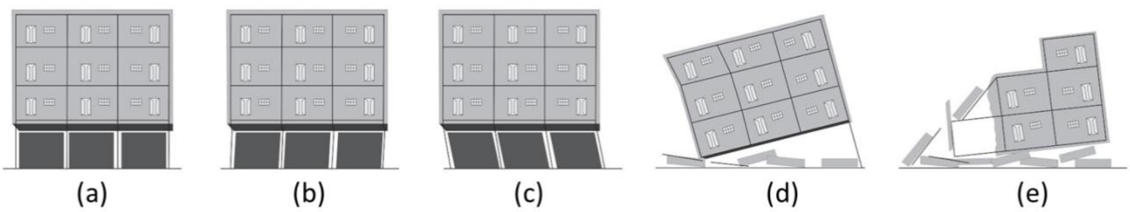

Fig-1 Schematic diagram showing possible collapse steps of a soft storey structure due to large lateral loads.

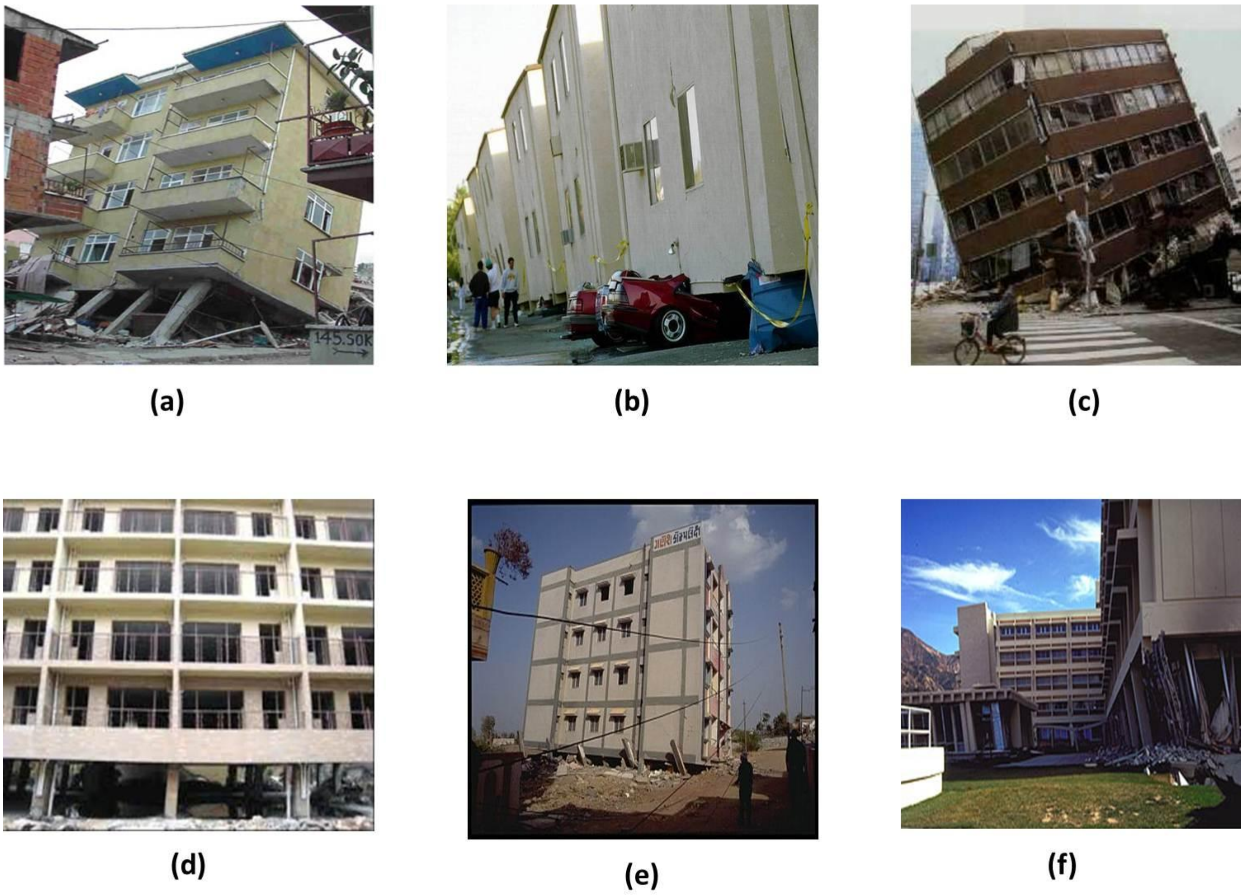

Fig-2 Past Soft Storey Failures (a)Turkey Earthquake(b) San Francisco Earthquake (c) Kobe Earthquake (d) China Earthquake (e) Bhuj Earthquake (f) California Earthquake

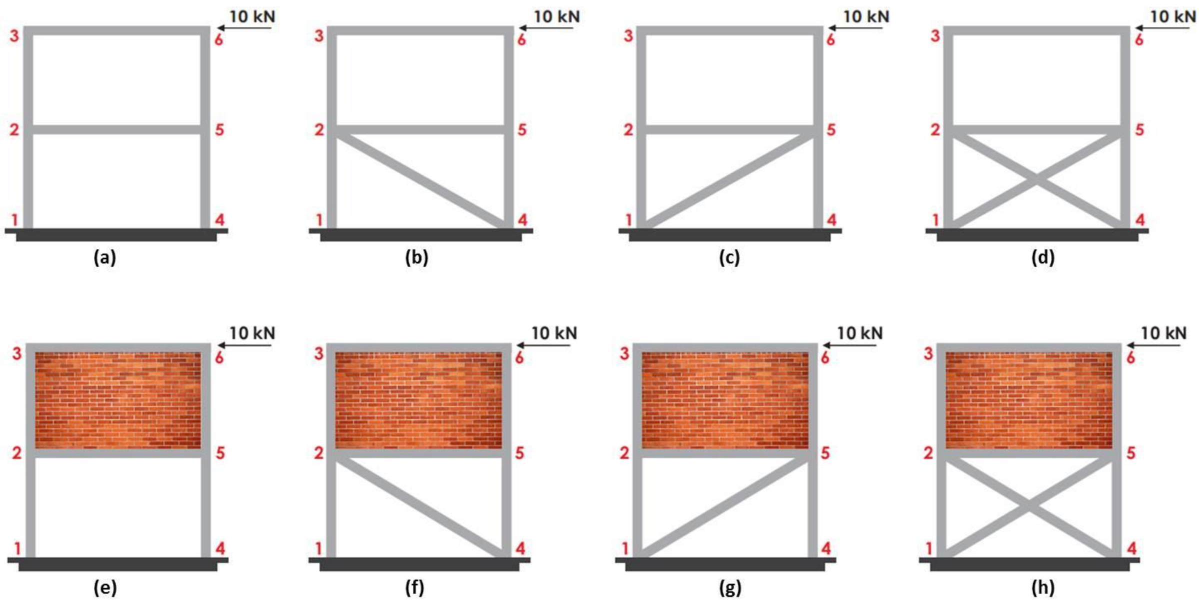

Fig. 3: One bay two storey frame considered for understanding importance of bracing orientation. (a) – (d) without infill walls (e)-(h) with infill walls.

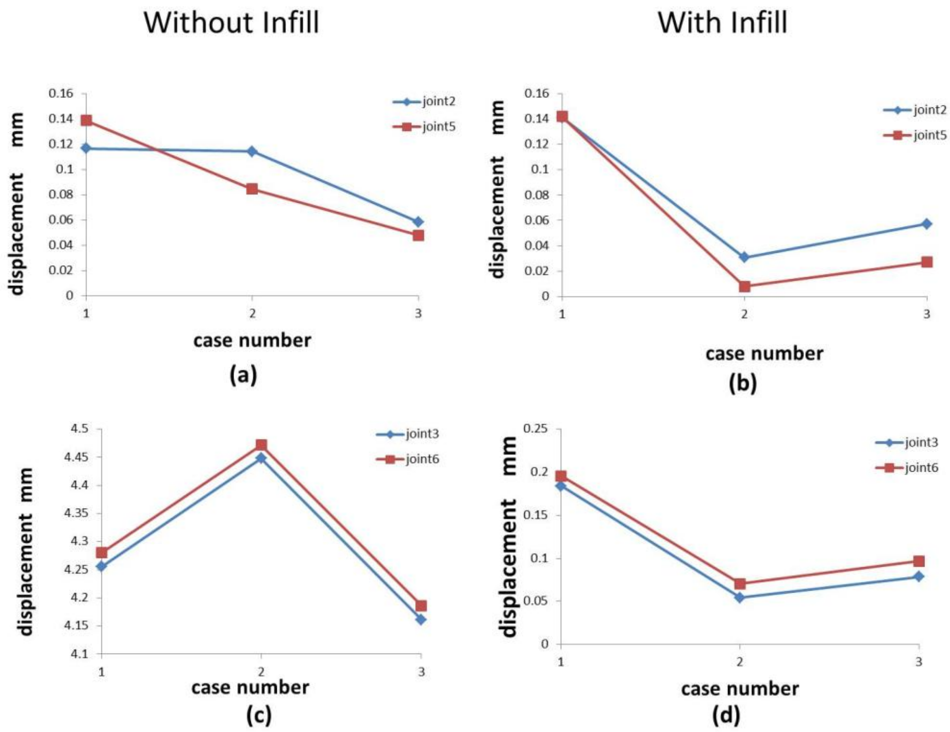

Fig.4: Results of one bay two storey frame (a) Displacements for joint 2 and 5 without infill (b) Displacements for joint 2 and 5 with infill (c) Displacements for joint 3 and 6 without infill (d) Displacements for joint 3 and 6 with infill

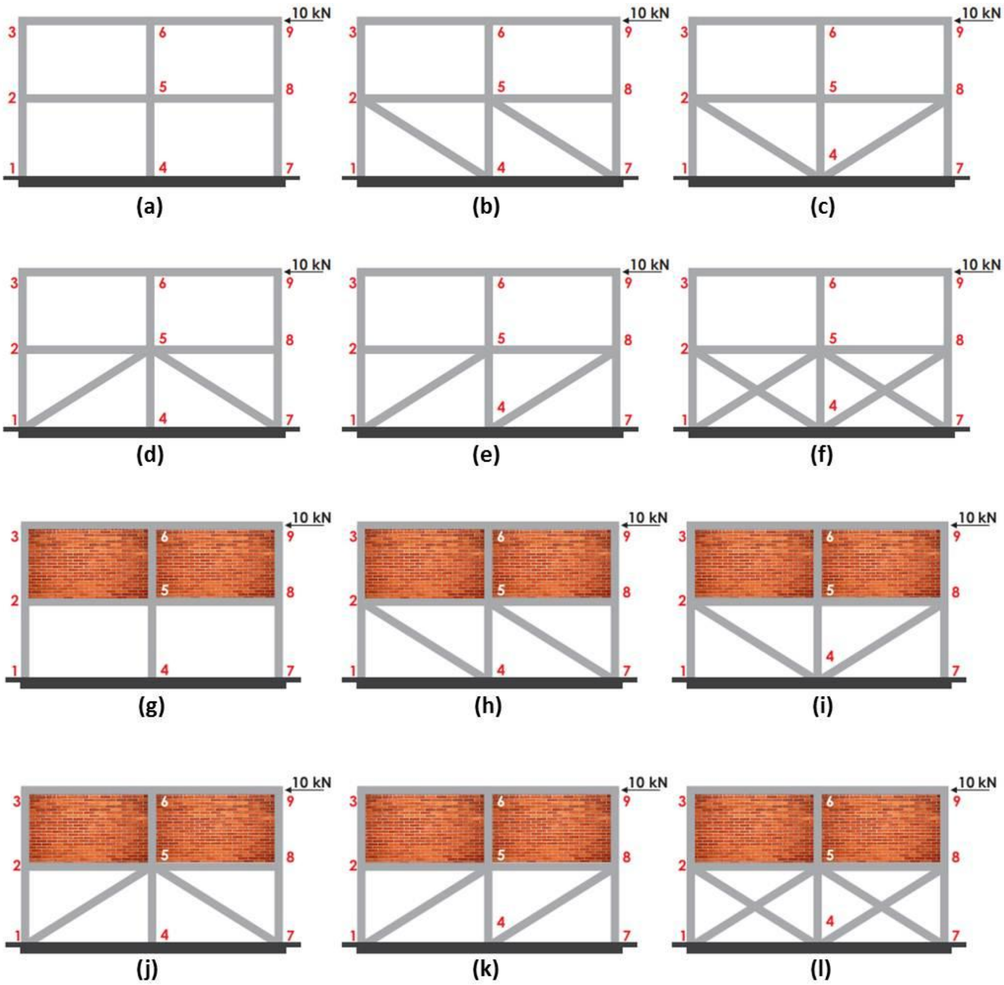

Fig.5: Two bay two storey (a) – (f) without infill wallswith possible orientations of bracings (g)-(i) with infill walls.

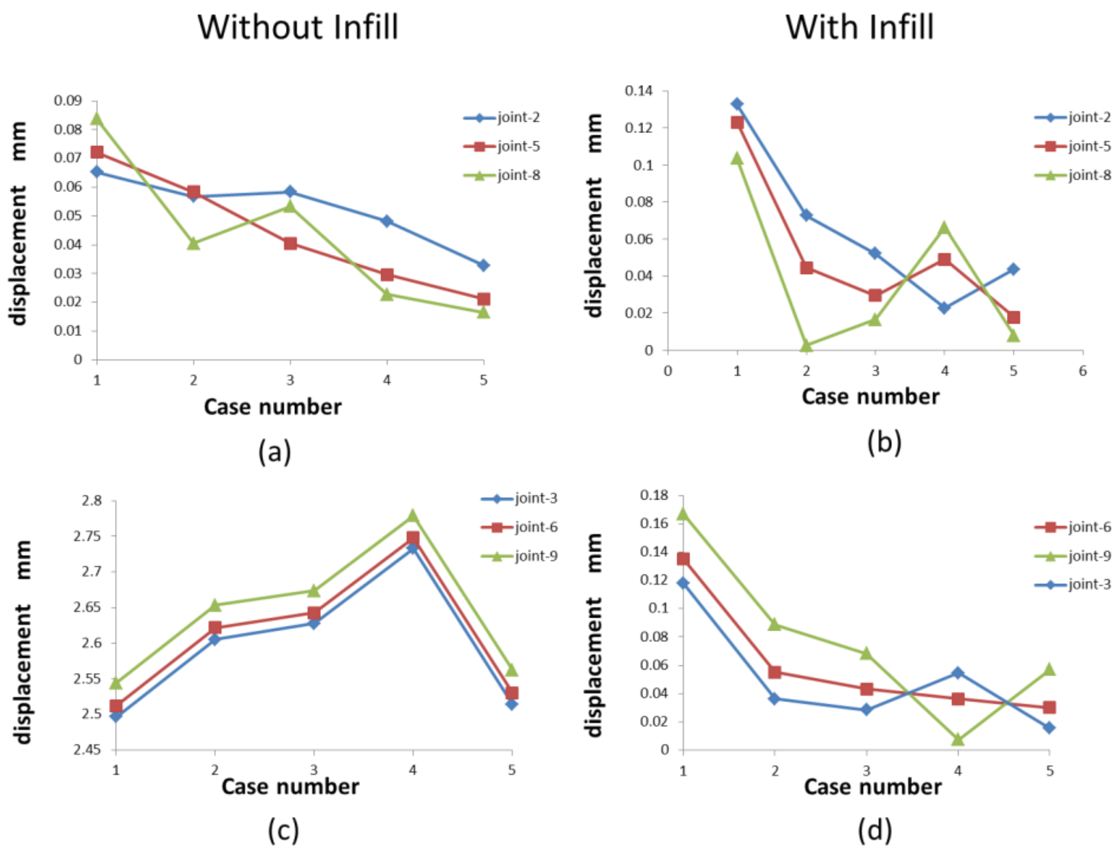

Fig. 6: Results of two bay two storey frame (a) Displacements for joint 2,5 and 8 without infill (b) Displacements for joint 2,5 and 8 with infill (c) Displacements for joint 3,6 and 9 without infill (d) Displacements for joint 3,6 and 9 with infill

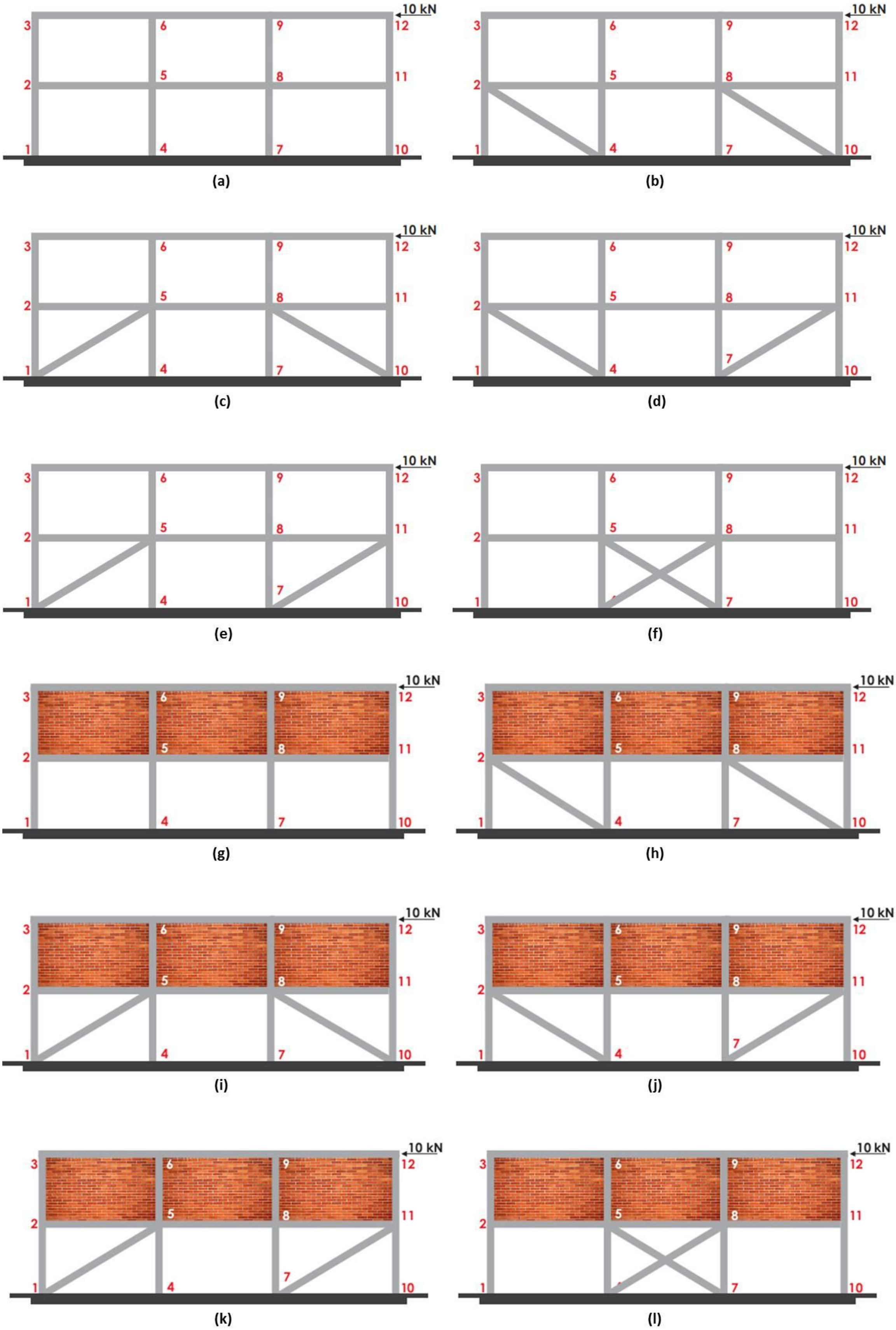

Fig. 7: Three bay two storey (a) – (f) without infill walls with possible orientations of bracings (g)-(i) with infill walls.

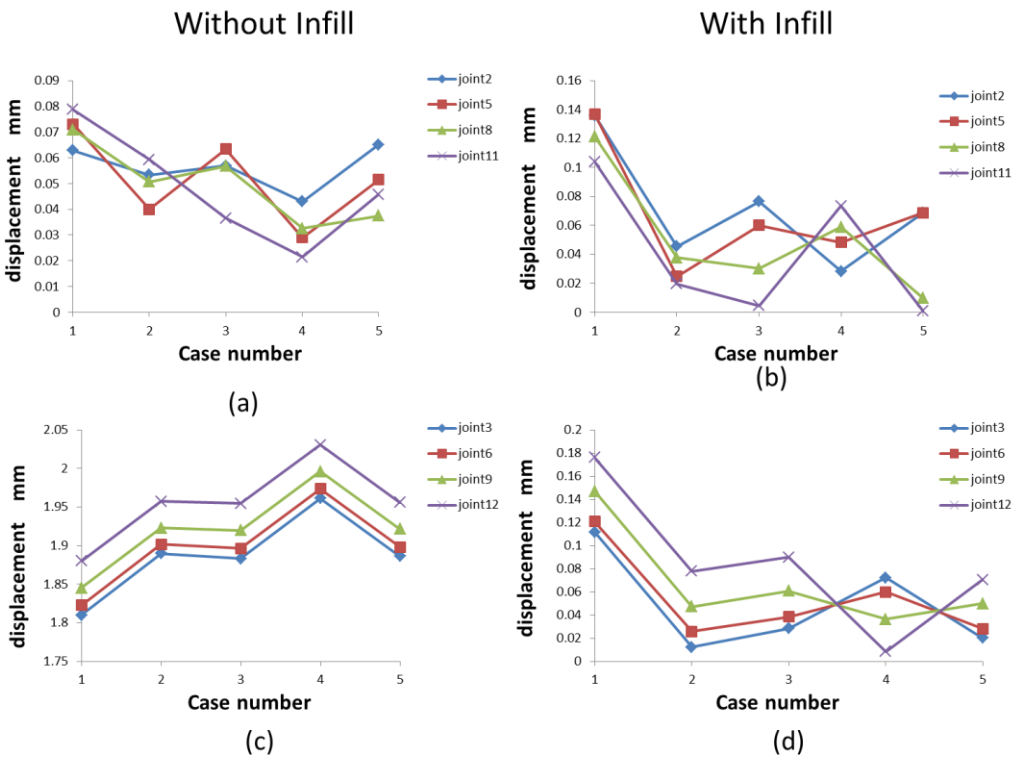

Fig. 8: Results of three bay two storey frame (a) Displacements for joint 2,5,8 and 11 without infill (b) Displacements for joint 2,5,8 and 11 with infill (c) Displacements for joint 3,6,9 and 12 without infill (d) Displacements for joint 3,6,9 and 12 with infill

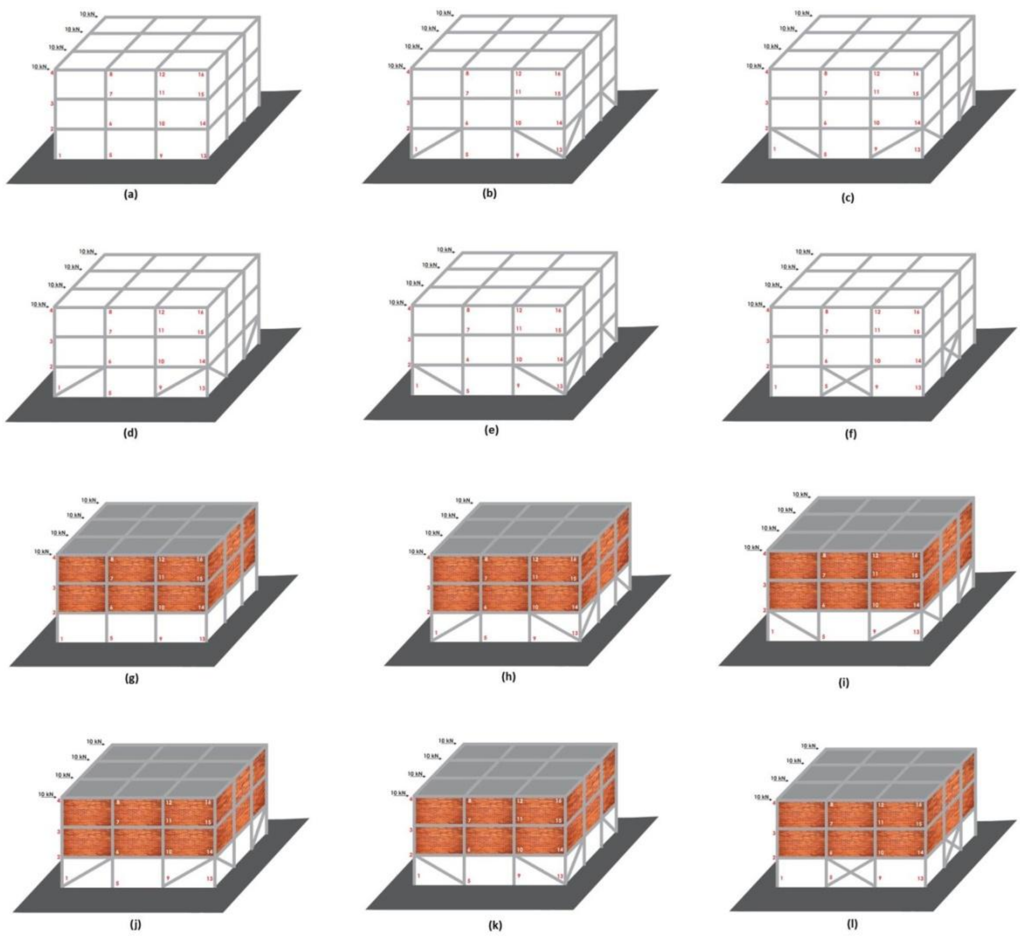

Fig. 9: Three bay by three bay two storeied building (a) – (f) without infill walls with possible orientations of bracings (g)-(i) with infill walls.

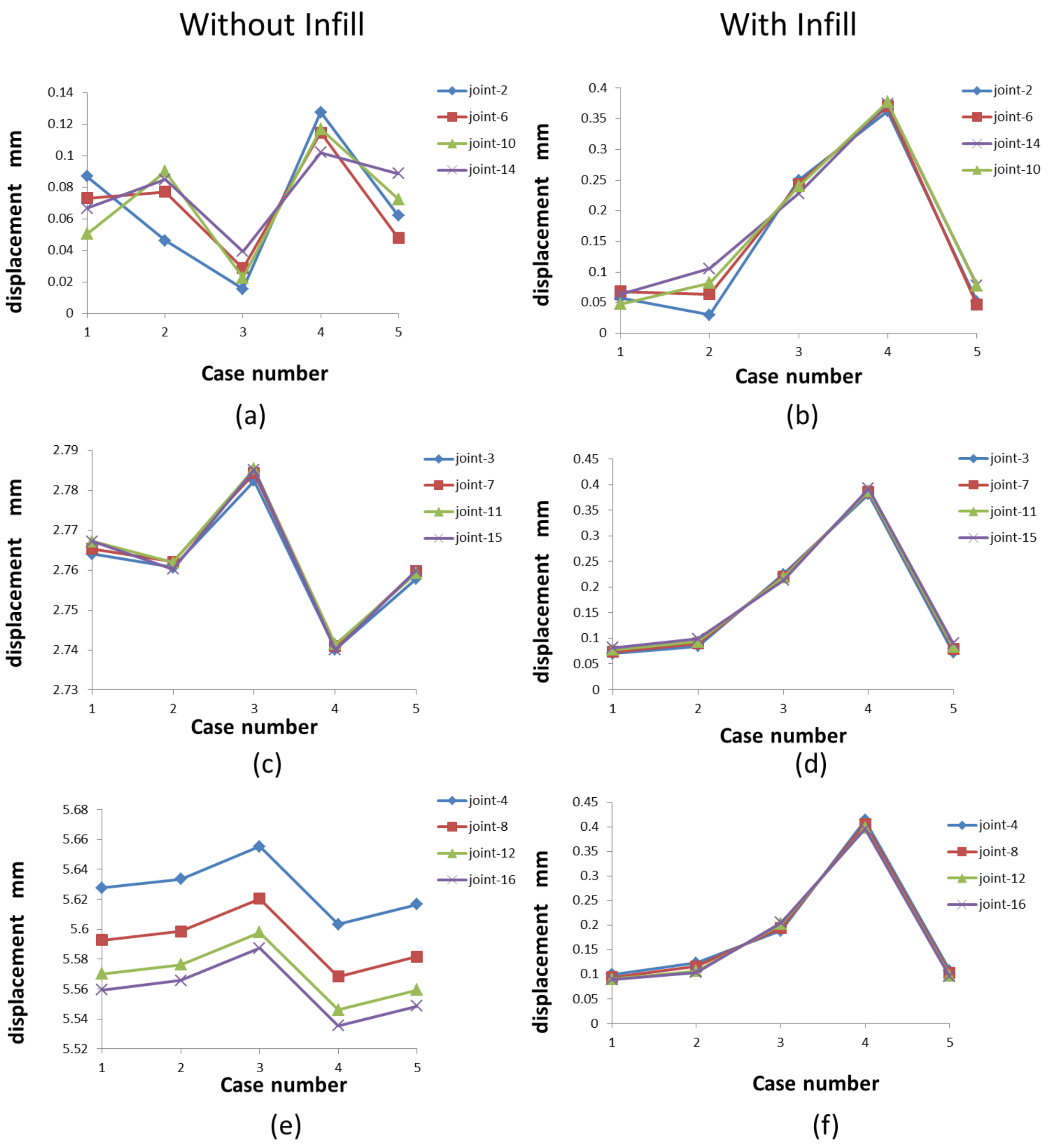

Fig. 10: Results of three dimensional three bay two storied building (a) Displacements for joint 2,6,10 and 14 without infill (b) Displacements for joint 2,6,10 and 14 with infill (c) Displacements for joint 3,7,11 and 15 without infill (d) Displacements for joint 3,7,11 and 15 with infill (e) Displacements for joint 4,8,12 and 16 without infill (f) Displacements for joint 4,8,12 and 16 with infill

Fig. 11: Case study structure (a) Plan of the structure (b) Actual structure (c) Model developed using SAP2000

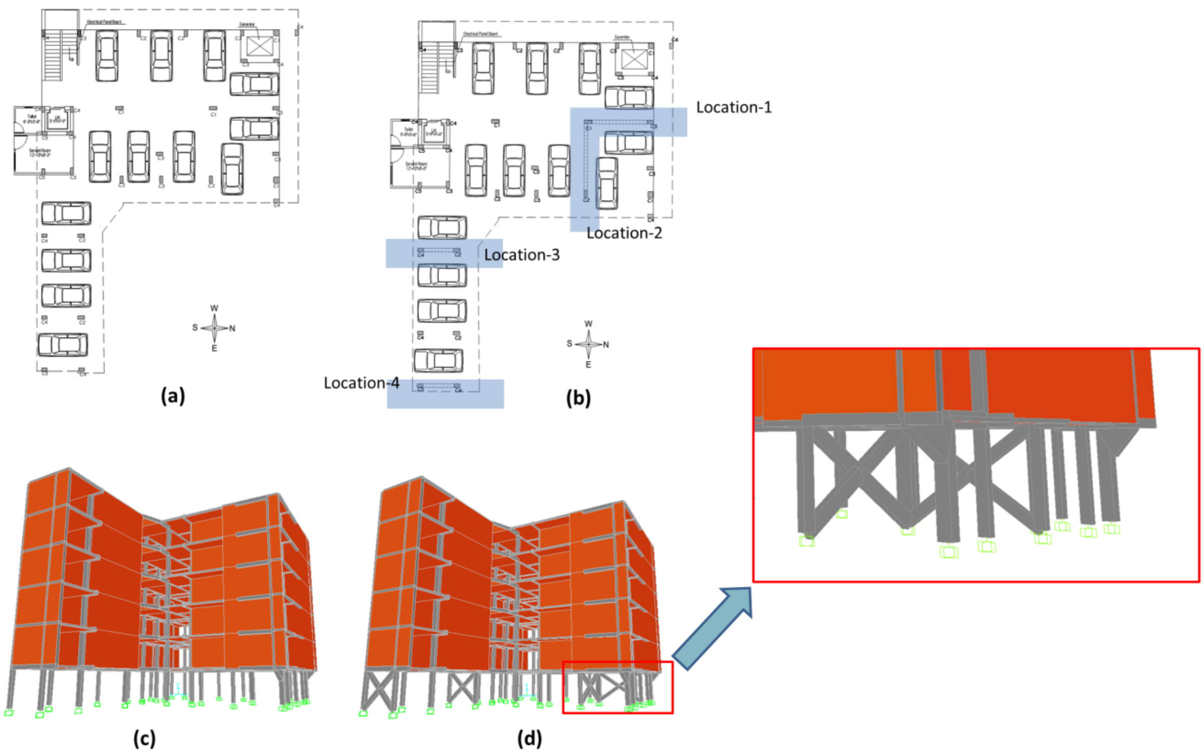

Fig. 12: (a) Location of columns and plan of parking (b) Four recommended locations of cross bracings (c) computer generated model without bracings (d) computer generated model with bracings

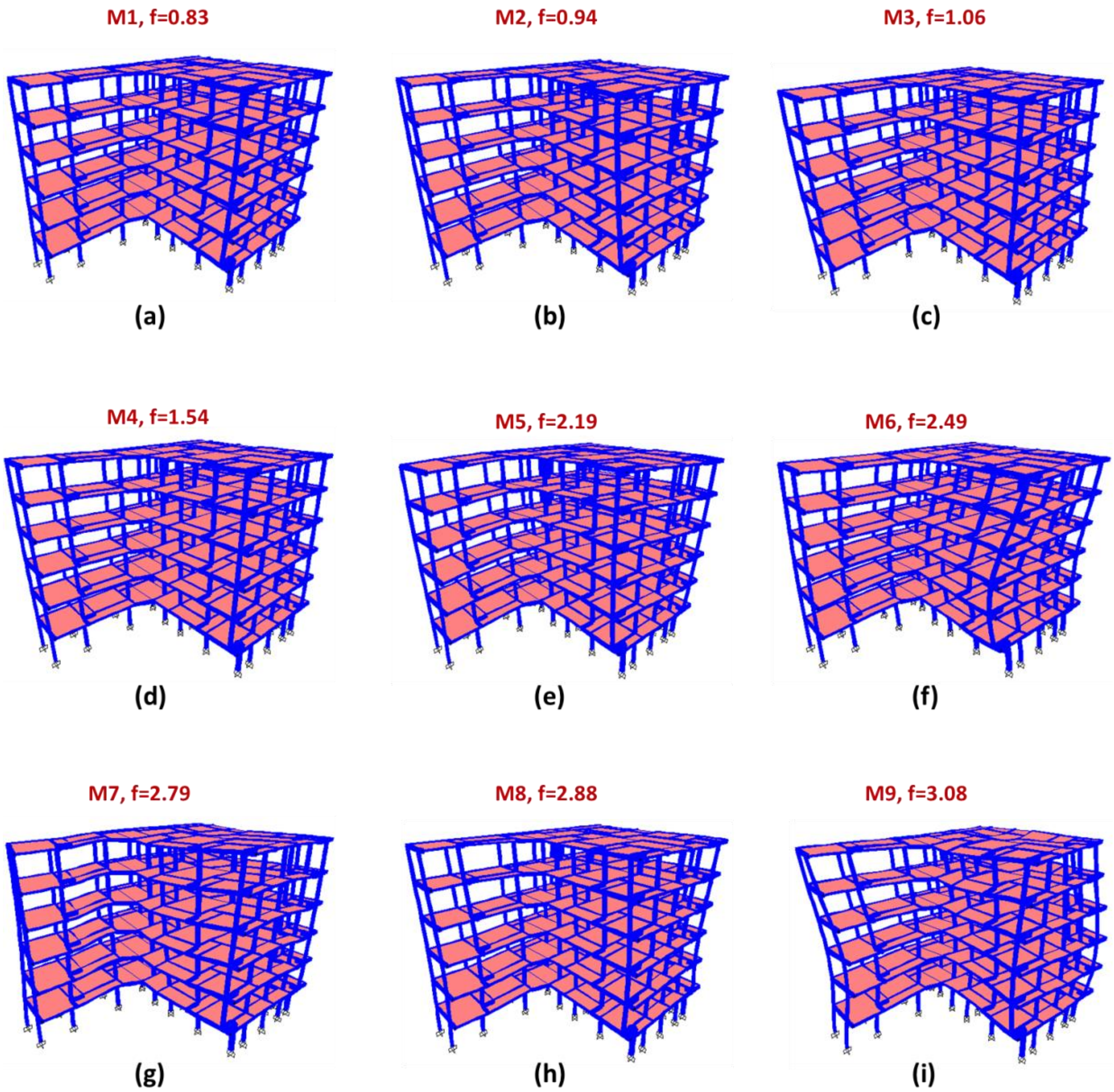

Fig.13: First nine mode shapes obtained for the building considered

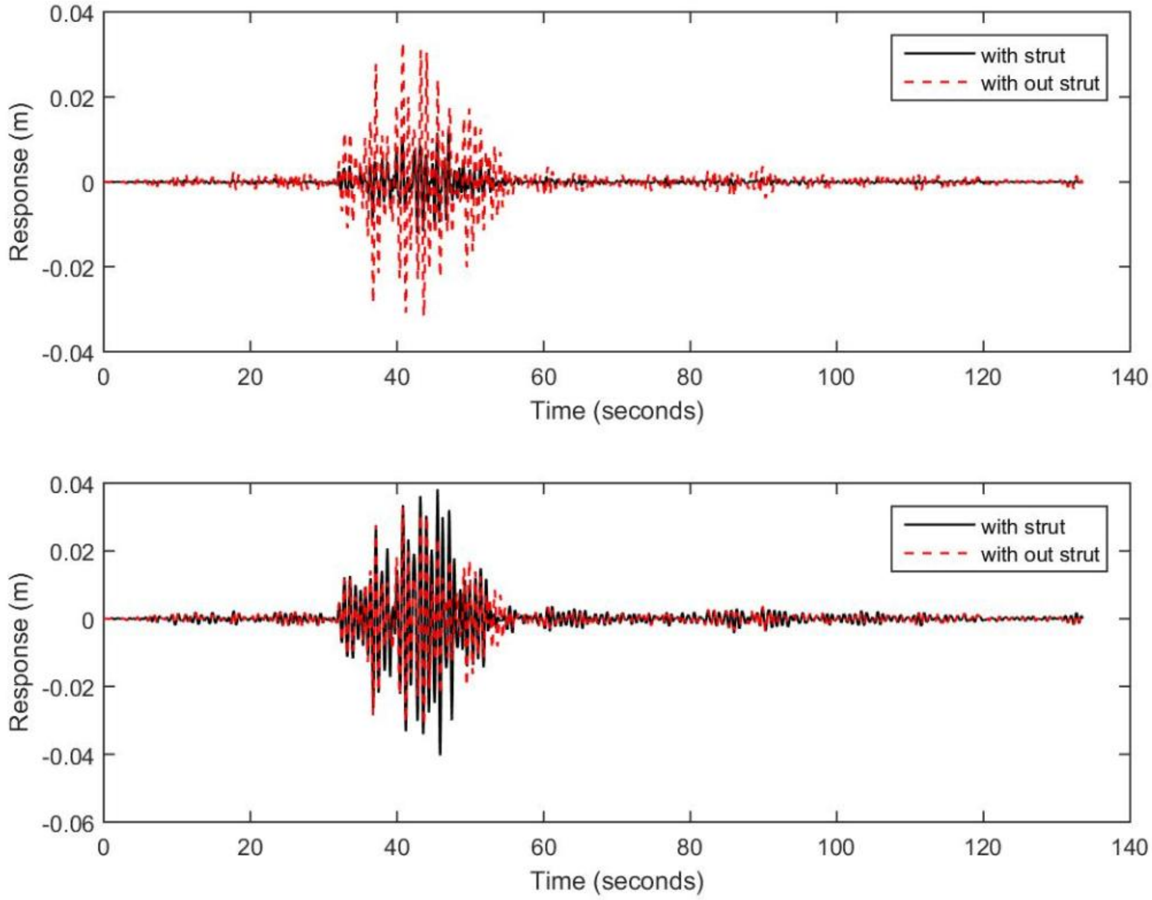

Fig. 14: Comparison of responses obtained at the top floor with and without struts provided