PERFORMANCE OF R.C. BUILDINGS USING SITE SPECIFIC RESPONSE SPECTRA IN KOLKATA, INDIA

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Abstract. This paper presents the performance analysis of typical two storied (G+1), five storied (G+4), seven storied (G+7) and ten storied (G+10) Reinforced Concrete (R.C.) rigid frame buildings. Site specific response spectra of 144 borehole locations in Kolkata and response spectra as per IS-1893 (Part 1):2002 zone III for both Design Basis Earthquake (DBE) and Maximum Considerable Earthquake (MCE) have been used for this analysis. The performance criteria in terms of roof displacement and ground story drift have been compared for the buildings by nonlinear static analysis. The study has been conducted for both considering stiffness of infill wall (WI) and without considering (WOI) stiffness of masonry infill wall. However, for garage purpose no infill has been considered at ground floor for all the buildings. The study depicts that in most of the area the roof displacements obtained by site specific response spectra are more than that obtained by Indian codal response spectra for WI and WOI. Present study also reveals that, the ground storey drift remains below Immedeate Occupancy (IO) level during DBE and it remains Life Safety (LS) to Collapse Prevention (CP) level during MCE for almost all the buildings. However, the storey drifts of WI buildings are comparatively higher than WOI buildings due to soft storey effect. The inter storey drifts are also higher than the permissible limit stated in Indian code (0.4%) during both DBE and MCE. Therefore, the buildings designed according to the present codal provisions of India may not perform to their desired level during future seismic events in this region.

Keywords: Site specific response spectra, infill wall, performance-based analysis, nonlinear static analysis, storey drift.

1. INTRODUCTION

In India, earthquake resistant buildings are generally analyzed as per force based design concept according to (IS 1893 (Part 1):2002. However, the performance of a building during earthquake is not so reliable under this force based design, as the different important performance purposes corresponding to Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) for different buildings like hospital, school, office etc. are not properly addressed. Thus, in recent practice, the performance based seismic design has been used as a tool to predict seismic risk of buildings more reliably. Also it is important to introduce the nonlinear analysis of structures in this region to predict their performance during seismic events.

Nonlinear analysis of different buildings against earthquake has been made by several researchers ((Gautam, Forte, and Rodrigues 2016)(Sarkar, Prasad, and Menon 2016) (Isik and Kutanis 2015)(Massumi, Mahboubi, and Ameri 2015)(Bosco et al. 2015) (Yon and Calayir 2015)(Shiuly 2015)(Hwang and Lee 2015)(Diaz-Martinez, Ruiz-Garcia, and Teran-Gilmore 2014)(Dashti, Dhakal, and Pampanin 2014)(Meireles et al. 2014)(Shiuly, Mandal, and Sahu 2014) (Gautam et al. 2016, Sarkar et al. 2016, Isik & Kutanis 2015, Massumi et al. 2015, Bosco et al. 2015, Yon & Calayir 2015, Shiuly et al. 2015, Hwang & Lee 2015, Diaz-Martinez et al. 2014, Dashti et al. 2014, Meireles et al. 2014, Shiuly et al. 2014). Most of these studies are based on actual earthquake data of a particular site. However, nonlinear analysis based on site specific response spectra is now more important. However, several researchers found from their study that masonry infill walls plays an important role on stiffness, strength and ductility of the building during earthquake (Fenerci et al. 2016)(Ercolino et al. 2016)(Bergami and Nuti 2015)(Asteris et al. 2015)(Palermo et al. 2014)(Lima, De Stefano, and Martinelli 2014) (Fenerci et al. 2016, Ercolino et al. 2016, Bergami & Nuti 2015, Asteris et al. 2015, Palermo et al. 2014, Lima et al. 2014). Thus, during performance analysis of buildings with site specific ground motion parameter, effect of masonry infill should be taken into account.

Based on this background, the performance of some usual two storied (G+1), five storied (G+4), seven storied (G+7) and ten storied (G+10) buildings (3-D RC frame) have been analyzed under site specific response spectra of 144 locations in the Kolkata city, generated from Deterministic Seismic Hazard Analysis (DSHA) for both Design Basis Earthquake (DBE) and Maximum Considerable Earthquake (MCE). Fig. 1 shows the 144 Bore Hole (BH) locations in Kolkata city. Both considering (WI) and without considering (WOI) stiffness of masonry infill wall also has been incorporated in the study. SAP 2000 (2011) software has been used for carrying out nonlinear static analyses for the above buildings. In present study, the performance of those buildings have been analyzed in terms of roof displacement and inter storey drift with respect to FEMA 356 (2000) and the site specific response spectra for 144 borehole locations of Kolkata, obtained by DSHA (Shiuly, Sahu, and Mandal 2016) has been incorporated in the present study. In the response spectra analysis, the Peak Ground Acceleration (PGA) during Maximum Considerable Earthquake (MCE) has been evaluated as 0.184 g (g is the acceleration of gravity) at the level of bedrock considering the attenuation relationship established by Artificial Neural Network (ANN). Further, the time history compatible to Indiard standard has been generated at bedrock level. Ultimately, it has been transferred at the ground surface level using 1-D wave propagation software SHAKE 2000. Fig. 2 reveals site specific response spectra of some borehole locations and IS 1893 (Part 1):2002 zone III response spectra.

3. PROBLEM FORMULATION

The modelling of structure has been conducted for G+1, G+4, G+7 along with G+10 storied symmetric buildings using SAP 2000 (2011). It is to be noted that, each of the symmetrical square buildings consists of 4 by 4 bay of each having length of 5m and height of each floor is 3m. Fig. 3 shows the plan and elevation of a G+4 storied (WI and WOI) buildings. No infill wall has been assumed at ground floor level, as it kept bared for garage purpose. Table 1 represents the other details of the buildings. The buildings are assumed as fixed at base and rigid diaphragm at each level of floor has been assigned which represents the in-plane rigidity of slab. This has been assigned by “rigid diaphragm” option in SAP 2000 (2011) model. The seismic mass, time period (T) and base shear (V_B) for WI and WOI based on linear dynamic analysis are presented in Table 2.

4. NONLINEAR STATIC ANALYSIS AND PERFORMANCE POINT

Nonlinear static analysis has been performed to achieve the performance points of the above mentioned four buildings for MCE and DBE as per ATC 40 (1996). It is to be mentioned that, the displacement control vertical moment hinges (M_3) have been assigned at both ends of each beam, whereas the displacement control axial force along with the biaxial moment hinges (P-M_2-M_3) have been assigned at both extremities of each column. The default ACI 318-95 interaction surface has been used for the column hinge which is a in-built property in SAP 2000 (2011)(2011) software. A typical moment rotation curve for different hinges of G+1 storied building is shown in Fig. 4 a to Fig. 4 c. Fig. 5 a and Fig. 5 b represent the deformed shape of G+7 building with developed hinges at BH 130 during MCE for WI and WOI respectively. Further, Fig. 6 a and Fig. 6 b show the demand-capacity curve of G+7 storied building in BH 130 during MCE for WI and WOI respectively.

Fig. 7 reveals that the percentage of roof drift obtained by site specific response spectra for MCE is more than that obtained by codal response spectra in most of the locations for both WI and WOI. It signifies higher values of spectral acceleration at lower range time period in case of site specific response spectra than that of codal spectra. This is due to the presence of soft thick alluvial soil deposit at larger depth of the locations. However, in some areas, the roof drift percentage in site specific response spectra have been obtained less than that in codal spectra indicating the presence of relatively hard layer of soil at some specific depth with big contrast of impedance at lower and upper surface.

It is also noted that for DBE almost in all the areas, under site specific response spectra the percentage of roof displacement are much larger than codal spectra for both WI and WOI buildings (refer Fig. 7). This may be due to larger values of spectral acceleration in site specific response spectra compare to codal values of spectra at performance point. This may be due to the existence of soft velocity soil layer at larger depth in these locations. Thus, the G+1 storied building may undergo some structural damages during DBE and thus may not perform to their desired level. In BH 132 (Bangur Hospital, Tollygunge) the percentage of roof drift in site specific response spectra are less than codal spectra during DBE. This happens due to existnce of a soil layer with considerable difference of impedance at lower and upper surface of that layer. Thus, earthquake wave will strike at that layer and most of the waves reflect from it. On the other hand in BH 127 (Tollygunge) the percentage of roof displacement analyzed with site specifc response spectra are much higher than codal spectra indicating presence of river channel deposit at surficial layer.

According to FEMA 356 (2000), inter storey drift limit for concrete frame structure are 1%, 2% and 4% for IO, LS and CP respectively. On th other hand, according to Indian seismic code (IS-1893 Part 1:2002), the inter storey drift limit of is 0.004 (0.4%). In the present analysis, plastic hinges have developed at ground floor in all the buildings. Further, in WI building, the ground storey will be subjected more drift due to soft storey effect. So during earthquake, ground floor inter storey drifts will be more compared to other floors. For this reason, only storey drift at ground floor has been studied. The box plot of ground storey drift for 144 bore hole locations four buildings for MCE and DBE are shown in Fig. 8 and Fig. 9 respectively. The plot is a simple way to represent the ground storey drifts of all 144 locations. The rectangular portion of the plot represents the second and third quartiles. Further, the horizontal line inside the box indicates the median value. In addition to that the lower and upper quartiles are presented as the two horizontal lines of lower and upper side of the rectangle respectively. The minimum and maximum value are the lowermost and upper most point of the lower and upper vertical line of the plot respectively. The spacing between the different components of the box signifies the extent of scattering of the data. It is noted that storey drift for DBE are within the limit of 0.004 (IS 1893) but for MCE the drifts are above the limit.

In most of the locations, the storey drift at ground floor for WI, varies from 0.005 to 0.01 for DBE (refer Fig. 9) indicating the below IO performance DBE. However, in almost all the locations, during MCE, the drift of the ground storey for the buildings have been found 0.01 to 0.02 which signifies the building will perform LS to CP. Fig. 9 also depicts percentage of ground storey drift of G+1 storied building is much more than that of other storey buildings. This is due to high values of spectral acceleration having lower time period. The study also reveals that in almost all the locations the drift at the ground storey exceed Indian codal (IS-1893 (Part 1):2002) permissible limit (0.4%) for the four types of buildings.

For the WOI, the ground storey drifts, have been obtained below IO level during DBE. However in most of the locations, during MCE, it varies IO to LS level. During both DBE and MCE, the ground drifts of the ground floor are larger than Indian seismic codal (IS-1893 (Part 1):2002) allowable limit (0.4%). However, for BH 11, BH 85, BH 132 the ground storey drifts have been obtained comparatively low. This may be due to low spectral acceleration values are low at lower time period at performance point due to presence of soft clay layer at some depth. In BH 127 (Tollygunge), ground storey drifts of all buildings exceed LS limit. This may be due to presence of river channel deposit at this location. The result signifies that percentage of drift in ground storey WI are comparatively higher than WOI as expected.

5. CONCLUSIONS

In the present investigation the performance of some typical G+1, G+4, G+7 and G+10 storied buildings (3-D R.C. frame) under site specific response spectra generated from DSHA and IS-1893 (Part 1):2002 zone III response spectra have been determined by nonlinear static method. Both considering stiffness of masonry infill wall (WI) and without considering stiffness of masonry infill wall (WOI) has also been incorporated in the study. The performances during both MCE and DBE have been obtained in terms of roof drift and ground storey drift.

The study signifies that, in most of the area the percentage of roof displacements observed by sites specific response spectra are more than that obtained by codal response spectra for both considering WI and considering WOI. When the buildings are analysed as WOI, percentage of roof displacement and interstorey drift will be higher. The drift of ground storey will below IO level at the time DBE and it remains LS to CP level at the time MCE for almost all the cases. Further, the inter storey drift is greater than Indian seismic codal (IS-1893 (Part 1):2002) allowable limit (0.4%) during both MCE and DBE. The percentage of ground storey drift at ground floor level in low rise buildings analyzed using the site specific response spectra is high. It signifies damage at a great extend to low rise building during future seismic events. However, the storey drifts analysis WI are comparatively higher than WOI. This is probably due to effect of soft storey in the ground floor for with considering stiffness of masonory infill wall at other floor.

Figures

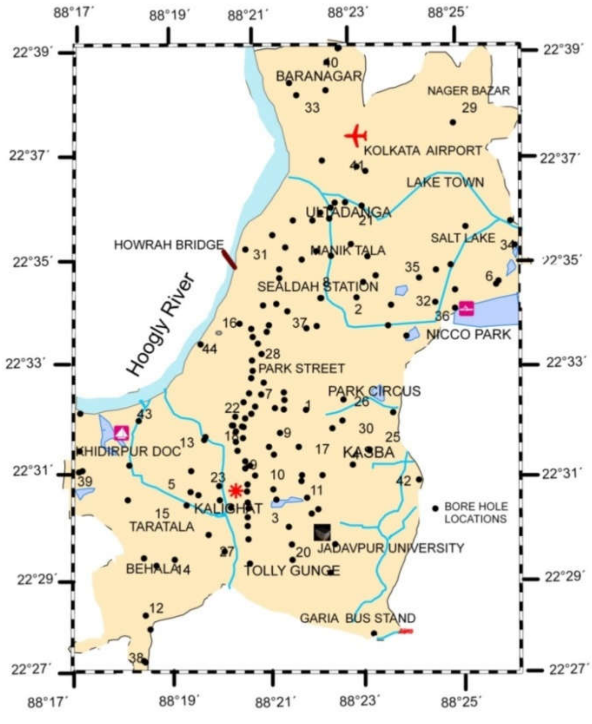


Fig. 1 144 BH locations in Kolkata city.

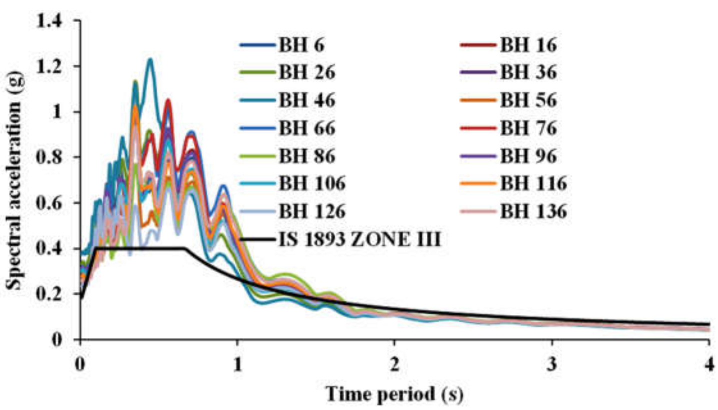
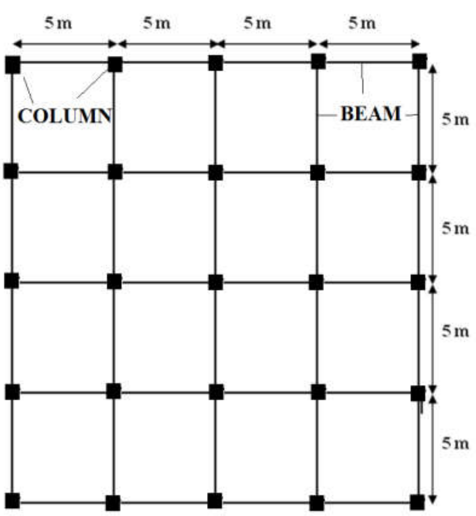
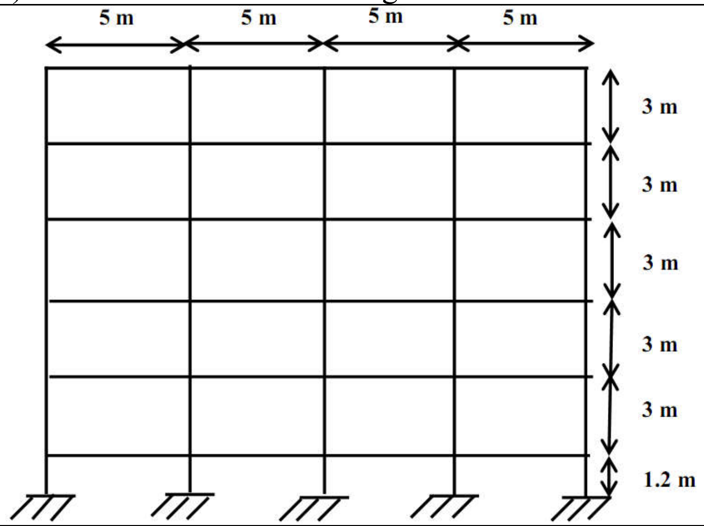


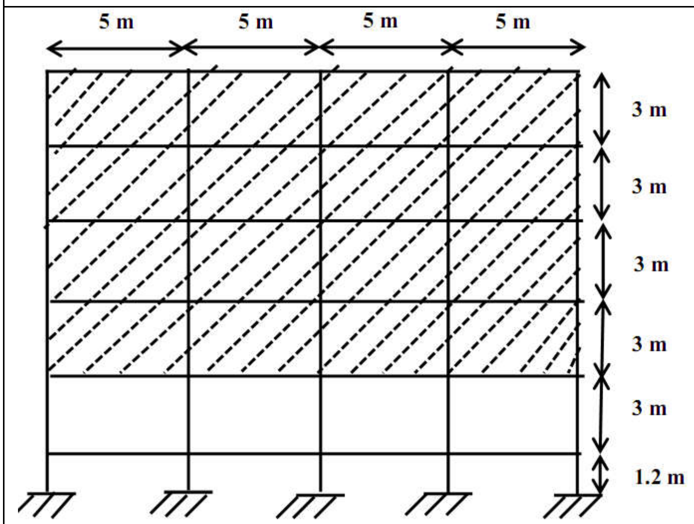
Fig. 2 Some of the generated site specific response spectra in Kolkata city



a) Plan of G+4 storied building.

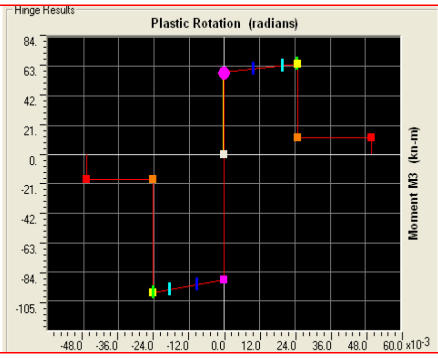


b) Elevation of G+4storied building WOI.

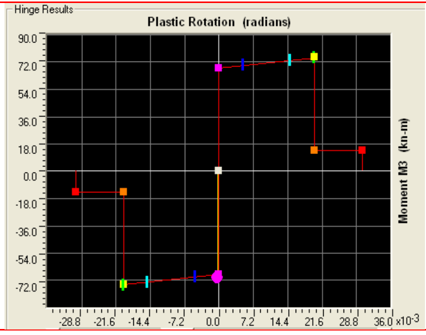


c) Elevation of G+4storied building WI.

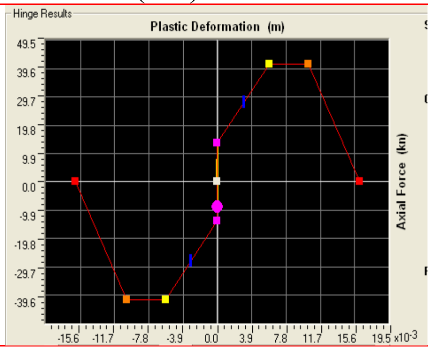
Fig. 3 a, b and c the plan and elevation of G+4 storied building.



a) Moment rotation curve of beam.

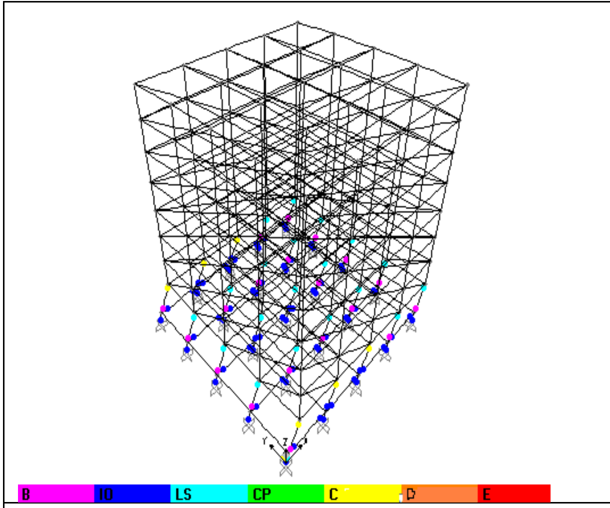


b) Moment rotation (M3) curve of column.

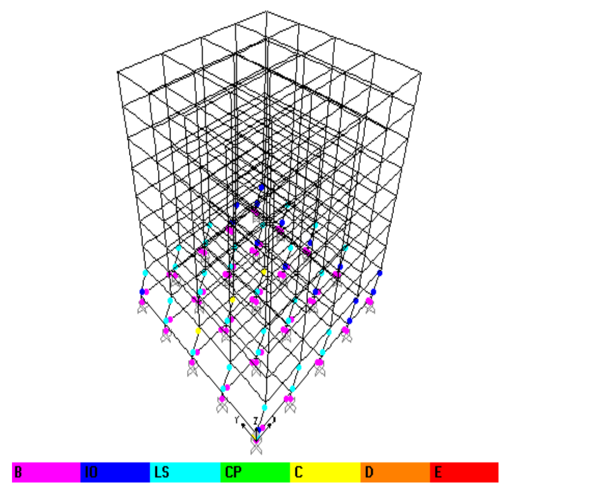


c) Force deformation curve of equivalent strut for infill.

Fig. 4: The different hinge details used in the analysis of buildings.



(a) Deformed shape with developed hinges during MCE WI (G+7) building at



(b) Deformed shape with developed hinges during MCE WOI (G+7) building at

performance point.	performance point.

Fig. 5 a and b The deformed shape with developed hinges during MCE of G+7 building WI and WOI respectively.

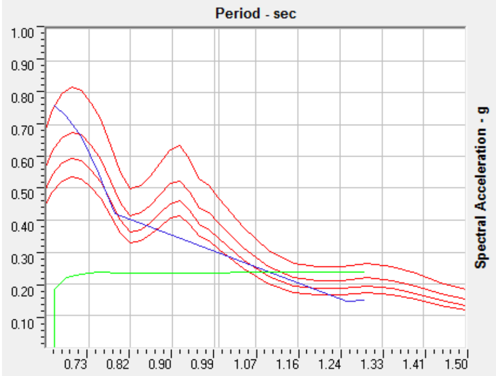
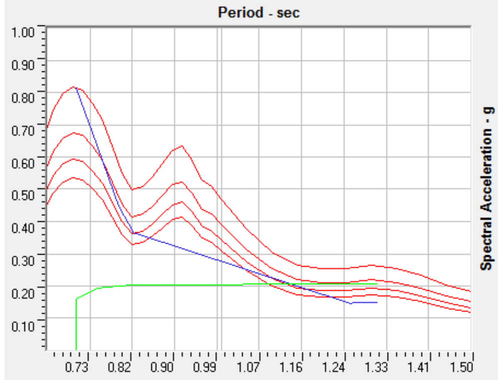
	
(a) Demand-Capacity curve during MCE of BH 130 G+7 storied building WI.	(b) Demand-Capacity curve during MCE of BH 130 G+7 storied building WOI.

Fig. 6 a and b The demand-capacity curve during MCE of BH 130 G+7 storied building WI and WOI respectively.

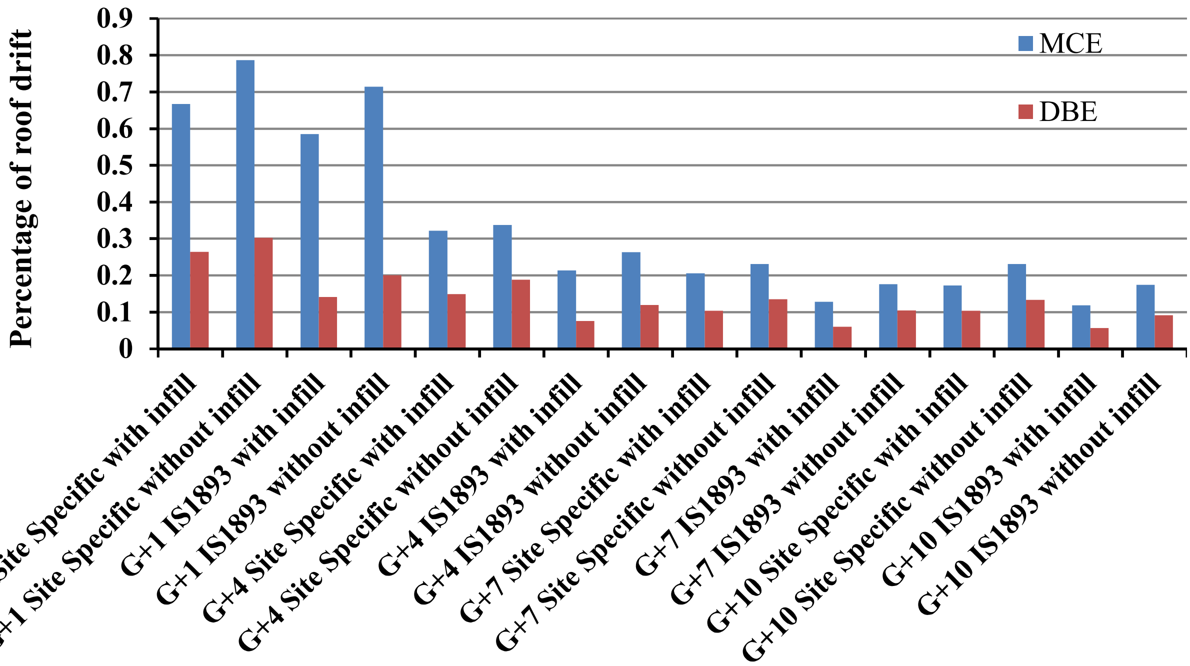


Fig. 7: Average values of percentage of roof drift for 144 borehole locations at performance point.

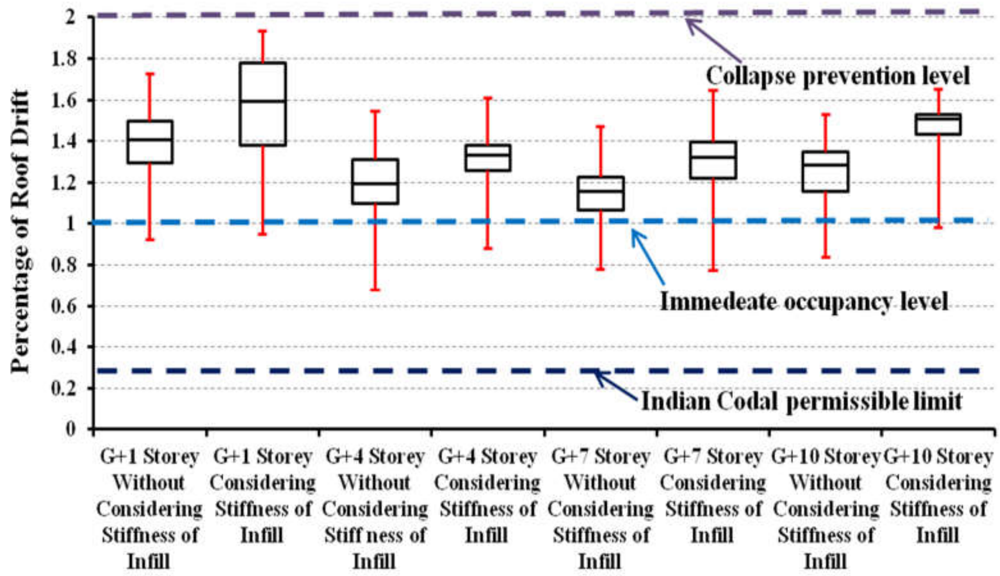


Fig. 8: Average percentage of ground storey drift due to MCE for 144 borehole locations.

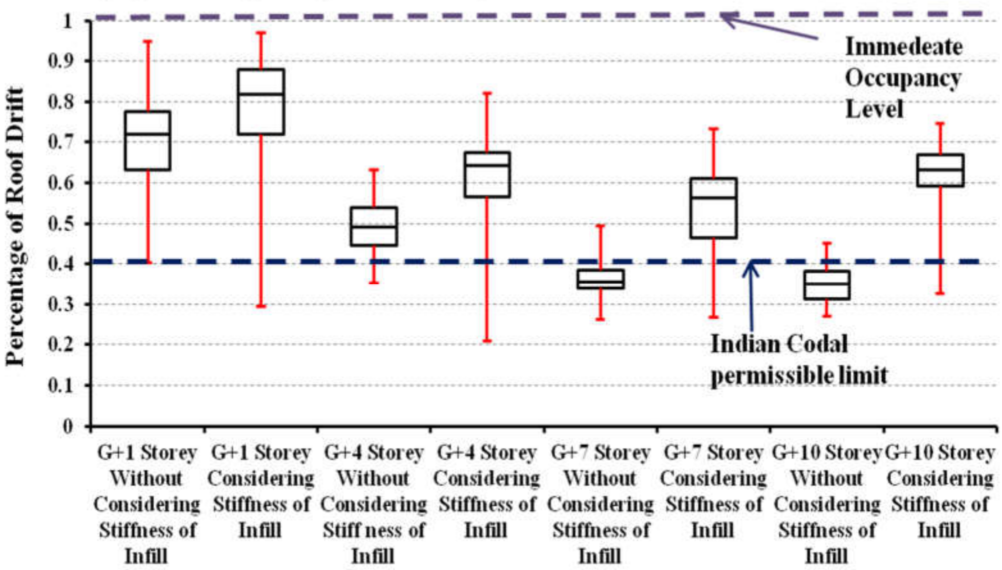


Fig. 9: Average percentage of ground storey drift due to DBE for 144 borehole locations.

Table 1: Details of the buildings.

1	Grade of concrete	M 25	13	Building is resting on	Soft soil
2	Grade of steel	Fe 500	14	Building frame type	OMRF
3	Floor to floor height	3.0 m	15	Density of concrete	25 KN/m^3
4	Depth of foundation	1.2 m	16	Density of masonry	20 KN/m^3
5	Slab thickness	150 mm	17	Size of Column G+1	300X300 mm
6	Parapet height	1 m	18	Size of Column G+4	400X400 mm
7	External wall thickness	230 mm	19	Size of Column G+7	500X500 mm
8	Internal wall thickness	150 mm	20	Size of Column G+10	550X550 mm
9	Live Load	4 KN/m^2	21	Size of Beam G+1	250X300 mm
10	Floor finish	1 KN/m^2	22	Size of Beam G+4	250X400 mm
11	Roof treatment	1.5 KN/m^2	23	Size of Beam G+7	300X500 mm

12	Site located in IS-1893	Zone- III	24	Size of Beam G+10	300X550 mm

Table 2: Seismic mass, time period and base shear obtained by linear static and dynamic analysis with without considering stiffness of infill.

Parameters	**INFILL**	**G+1**	**G+4**	**G+7**	**G+10**
Seismic Mass (kN)		9223	25592	47065	63882
T (s)	Without	0.56	0.71	0.81	0.91
	With	0.56	0.68	0.74	0.80
V_B(kN)	Without	468	903	1310	2081
	With	468	929	1518	2605
$\overline{V_B}$(kN)	Without	615	960	1546	1864
	With	615	1000	1704	2117
V_B = base shear in dynamic analysis, $\overline{V_B}$= base shear in linear static analysis					

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