

Comparative Analysis of Soft Storey Mechanism using Different Codal Standards

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Abstract— The present study is to evaluate the behavior of G+9 reinforced concrete frame structure subjected to earthquake forces in severe condition. The reinforced concrete structures are analyzed by nonlinear static analysis using ETABS 2013 V 13.1.1 software. To analyse and compare results of soft storey mechanism of modeled 2D frame structure with different conditions as follows and also to compare results of maximum storey displacement and maximum storey drift of Indian and American Standards. To analyse and compare results of soft storey mechanism of modeled 3D frame structure with different conditions as follows and also to compare results of maximum storey displacement of Indian, American, New Zealand and European Standards.

Key words: Soft storey, Infill frames, Seismic drift, Storey displacement, Stiffness

I. INTRODUCTION

Reinforced concrete (RC) frame buildings constructed in recent times have the ground storey left open for the purpose of parking, i.e. columns in the ground storey do not have any partition walls (of either masonry or RC) between them and are often called open ground storey buildings or buildings on stilts. The relatively flexible in the ground storey or the relative horizontal displacement it undergoes in the ground storey is much larger than the above storeys, this flexible ground storey is called soft storey. 'Soft storey' and 'weak storey' are irregular building configurations that are a significant source of serious earthquake damage. In multi-storey buildings formation of a soft storey plastic mechanism shall be prevented, as such a mechanism might entail excessive local ductility demands in the columns of the soft storey. Large open areas with no or less infill and exterior walls and higher floor levels at the ground level result in soft stories and hence damage. In such buildings, the stiffness of the lateral load resisting systems at those stories is quite less than the stories above or below. During an earthquake, if abnormal inter-storey drifts between adjacent stories occur, the lateral forces cannot be well distributed along the height of the structure. This situation causes the lateral forces to concentrate on the storey (or stories) having large displacement (s). In addition, if the local ductility demands are not met in the design of such a building structure for that storey and the inter-storey drifts are not limited, a local failure mechanism or, even worse, a storey failure mechanism, which may lead to the collapse of the system, may be formed due to the high level of load deformation (P storey mechanism affect greater effect in storey displacement and storey drift criteria. The presence of walls in upper storeys makes them much stiffer than open ground storey. Hence the upper storey move almost together as a single block and most of the horizontal displacement of the building occurs in the soft ground storey itself. Such building swing back and forth like inverted pendulums during earthquake shaking and columns in the open ground storey are severely stressed.

A large number of buildings with open ground storey have been built in India in recent years. Open ground storey buildings have consistently shown poor performance during past earthquakes. Huge number of similarly designed and constructed buildings exists in the various towns and cities situated in moderate to severe seismic zones of the country. The presence of walls in upper storeys makes them much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself as shown in Fig. 1. The drift and the strength demands in the first storey columns are very large for buildings with soft ground storeys. It gives result of collapse of the building. Masonry infill is normally considered as non-structural elements and their stiffness contributions are generally ignored in practice. Masonry infill has several advantages like good sound and heat insulation properties, high lateral strength and stiffness. These help to increase the strength and stiffness of RC frame and hence to decrease lateral drift, energy dissipation capacity due to cracking of infill and friction between infill and frame. This in turn increases redundancy in building and reduces bending moment in beams and columns. Masonry infill has disadvantages like very high initial stiffness and compressive strength. This also induces torsional effect in the structure if not symmetrically placed. While analyzing multi storey buildings, designers usually neglect the contribution of masonry infill in resisting loads. They consider only dead weight of masonry and analysis is done by bare frame method.

Dande et al. (2013) has studied about soft storey mechanisms in RC frame building and concluded that the displacement and force (i.e. BM & SF) in the first storey columns are very large for building with soft ground storey. Arturo Tena- Colunga (2010) have studied irregularity Condition of Buildings with Soft First Story for Seismic Design and concluded that depending on the method of analysis used. Guney et al. has studied the nonlinear effect of infill walls stiffness to prevent soft story collapse of RC structures and concluded that to prevent soft story collapse, the inter-story drifts should be controlled and limited changing by stiffness of columns. Amit V. Khandve (2012) have studied seismic response of RC Frame buildings with soft storey and concluded that drift and strength demands in the first storey columns are very large for buildings with soft ground storey. Amit Gawande (2012) have done seismic analysis of RC frame with soft ground storey and concluded the action to reduce bending moments in beams supporting the masonry infill. Kasnale et al. has studied Seismic performance for soft basement of RC framed buildings and concluded that provision of infill wall enhances the performance in terms of displacement control, storey drift and lateral stiffness. Wakchaure et al. (2012) has done earthquake analysis of high rise building with and without in filled walls and concluded that the results show that infill walls reduce displacements, time period and increases base shear and is essential to consider the effect of masonry infill

for the seismic evaluation of moment resisting reinforced concrete frame.

Desai Pallavi et al. (2013) has studied seismic performance of soft storey composite column and concluded that soft storey effect will increase the total seismic horizontal load, which will induce huge moments in the columns and also increase the axial force in some columns thereby creating very serious problems for columns. SaraswatiSetia et al. (2012) has studied seismic response of R.C.C building with soft storey and concluded that building having masonry infill in upper floors and with increased column stiffness of bottom story and building with shear wall in core has a small first storey displacement of about 18% and 16% respectively of that of building having masonry infill in upper floors only. Past research work has shown that there is a considerable improvement in the lateral load resisting system by adding the walls. Rahiman et al. (2013) concluded that, as we shift the soft storey to higher level the intensity of hinge formation becomes lower and lower and at the same time displacement increases and base shear also. Maximum yielding occurs at the base storey, because of soft stories maximum plastic hinges are forming though the base force is increasing. As we shifted soft storey to higher level, yielding is less than lower level soft storey and lower intensity hinges are forming after maximum number of push-over steps. The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behavior of structures. It is advisable to provide soft storey at higher levels in addition to ground soft storey.

II. MATERIALS AND METHODS

In this research paper, methods like providing stiff column, Infill wall in ground storey are adopted to improve the performance of building to lateral loads. Building models with frame with open ground floor, frame with stiffened column at ground storey and frame with infill at corner columns in ground storey was considered and analytical study was carried out with the help of ETABS 2012 V 13.1.1. Frames were analyzed two dimensionally and three dimensionally to study the effect of dimensionality. The parameters such as base shear, time period, natural frequency, storey drift and bending moments are studied. Maximum storey displacement and maximum storey drift was calculated using the provisions given in IS: 1893(2002), ASCE 7-10, NZS 1170 2004 and EUROCODE 8 2004. During Modeling in ETABS 2013 v 13.1.1 for soft storey analysis precautions were taken in defining the loading properties and their locations. The stiffness of the column is increased by providing higher dimensional values.

A. Model Geometry

The structure is analyzed as a 2D frame and 3D structure with five bays along X-direction and five bays along Y-direction with ten storeys (G+9) along Z-direction. Storey height is 3.5 m and bay width along X&Y-direction is 5 m. The concrete floors are modeled as rigid and frames as moment-resisting frame of reinforced concrete (RC). The plan of the building is shown as Fig.2. Size of columns is 450 x 450 mm at all typical floors (Area, $A = 0.20m^2$, Moment of Inertia, $I = 0.003417m^4$ and Stiffened column at ground storey is 550 x 550 mm ($0.30m^2$, $I = 0.007625m^4$). Size of beams is 300 x 450 mm at all floors ($A = 0.135m^2$, I

$= 0.0023m^4$) and thickness of w panels is 250 mm at all floors (including infill at soft storey).

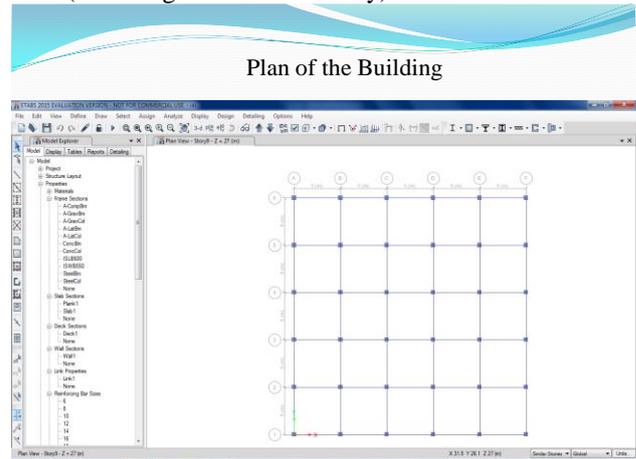


Fig. 1: Plan of the Building

Fig.2. ETABS Modeled 2D Frames

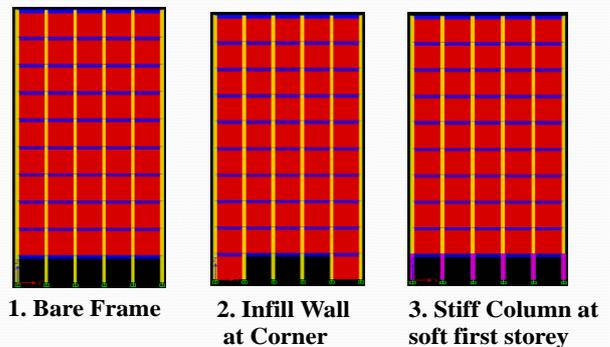


Fig. 2: ETABS Modeled 2D Frames

The Building is designed to resist Dead load, Live load & Seismic load. Various load combinations were tried as per IS 456 and the worst case was taken into account to design the respective member. Dead load consists of self-load and floor load. Self-weight was calculated automatically using the assigned density and dimension by ETABS itself.

Details of Modeled 2D Frame

ETABS Modeled 2D Frames are shown in Fig.3. Load transferred from slab to beams are calculated as follows:

Live load (LL)= 4.0 kN/m² at typical floor

Dead load (DL) = Load transferred from slab to beam in trapezoidal form.

$$= (1/2 \times h \times (a + b) \times D \times \gamma) = (1/2 \times 2.5 \times (5 + 5) \times 0.150 \times 25) = 9.375 \text{ kN/m (for each beam in 2D frame)}$$

Location= Zone II

Type of soil= Type II, Medium as per IS 1893:2002

Footing= isolated footings

Earthquake load (EQ)= As per IS-1893 (Part 1)

ASCE 7-05

The loaded frames using the calculated slab loads are shown in the Fig.4. It may also be noted that since $LL < (3/4) DL$ in all beams, the loading pattern as specified by IS 456:2000 is not necessary. Therefore design dead load plus design live load is considered on all spans as per recommendations of Clause 22.4.1 (b) of IS 456:2000. In design of columns, it will be noted that $DL + LL$ combination seldom governs in earthquake resistant design except where live load is very high.

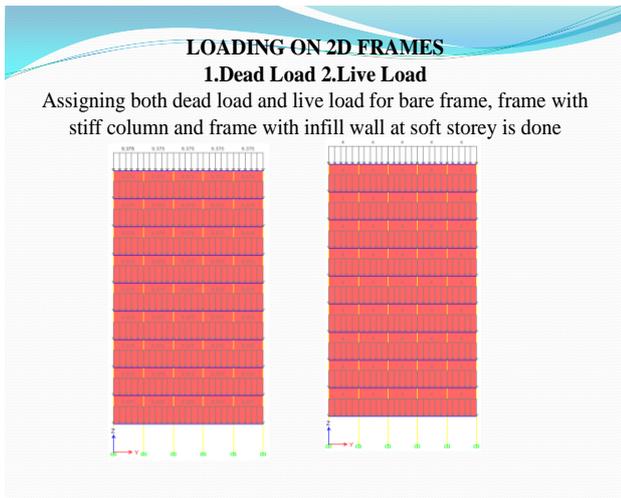
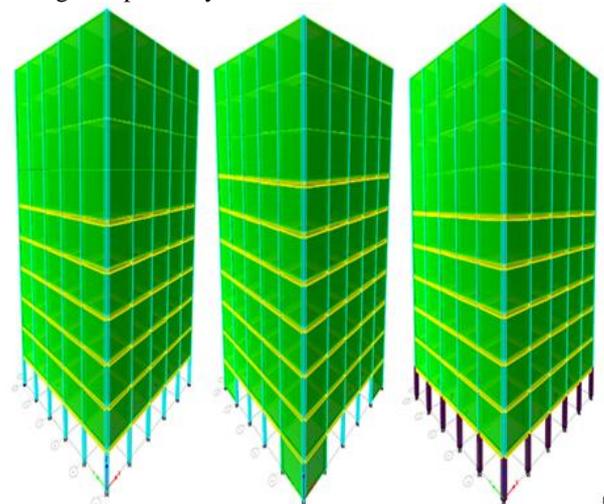


Fig. 3: Bare frame with Loading

NZS 1170-2004 and EUROCODE 8-2004 are as shown in Fig. 8 and Fig.9 respectively.



1) Bare Frame 2) Infill wall at Corner 3) Stiff Column at soft storey

Fig. 6: Modeled 3D Frame

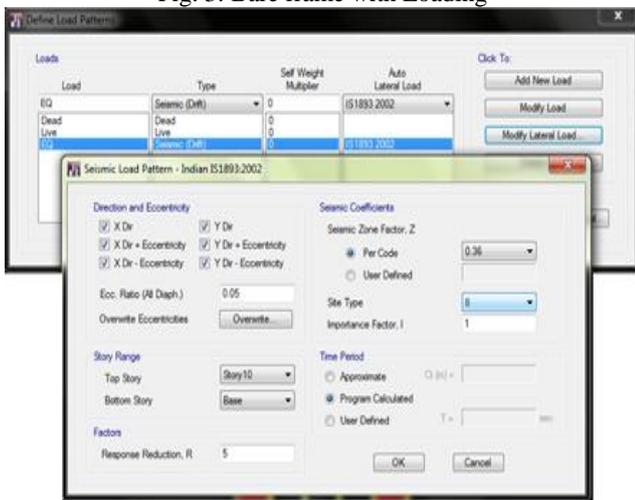


Fig. 4: Defining Seismic Load Pattern as per IS:1893(2002)

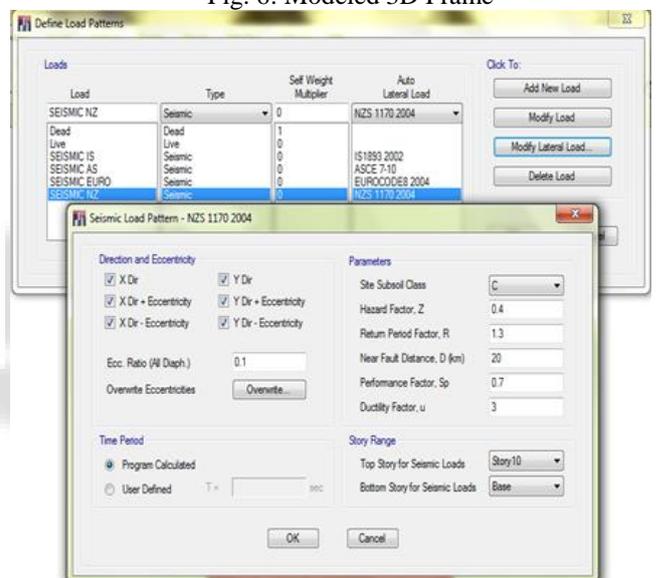


Fig. 7: Defining Seismic Load Pattern as per NZS 1170 2004

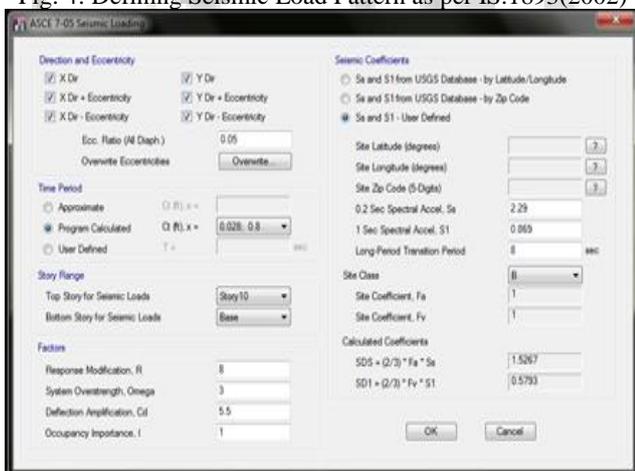


Fig. 5: Defining Seismic Load Pattern as per ASCE 7-05

The lateral force on the structure is calculated by using IS1893:2002 and ASCE 7-05 as shown in Fig.5 and Fig.6 respectively. Seismic load pattern defining for frame structure was done by choosing 'program calculated' option. Here Response reduction factors, Importance factor, System over strength, Deflection amplification are predefined values as per Standards.

Details of Modeled 3D Structures The modeled 3D frames of Bare Frame, Infill Wall at Corner and Stiff Column at soft storey are shown in Fig.7. The lateral force on the structure was calculated by using IS:1893(2002), ASCE 7-05 as shown in Fig. 5 and Fig.6 respectively and seismic load patterns per

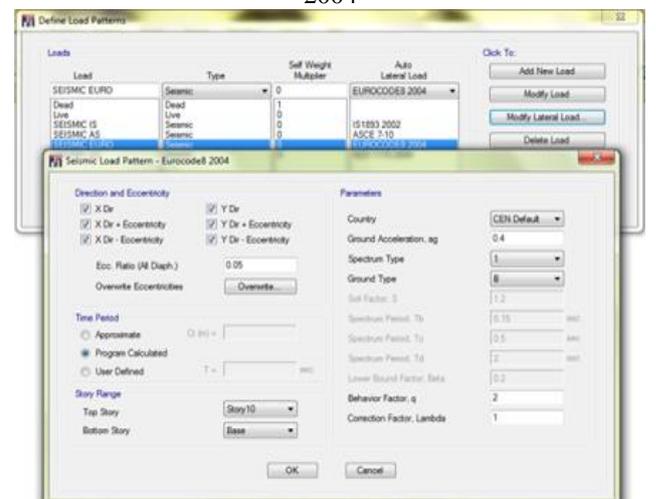
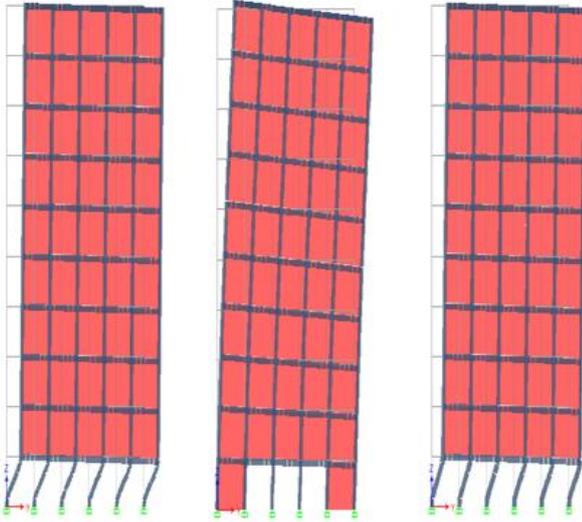


Fig. 9: Defining Seismic Load Pattern as per EUROCODE 8 2004

III. RESULTS OF 2D FRAME ANALYSIS

The deflected shape of bare frame (BF), Stiff columned at ground storey frame (SF) and Infill Wall at corner in ground storey frame (IF) are shown in Fig. 9. It is observed that deflection of bare frame (Fig.9.a) and stiffened column frame (Fig.9.c) cause the formation of a soft storey plastic mechanism which will lead to failure of structure. Infill wall at corner frame (Fig.9.b) deflects in a bending mode.



(a) Bare Frame (BF) (b) Infill Wall at Corner Frame (IF)
(C) Stiff columned at Soft Storey (SF)

Fig. 9: Deformed Shape

Table. 1 and Table.2 gives the storey response of maximum storey displacement and maximum storey drift infill wall at corner frame and stiffened column frame due to lateral loading as per IS 1893:2002 respectively. From Table 1, it has been noted that roof deflection of SF and IF deflects 17.4% and 61.1% less when compared to BF. Storey drift of first storey at top of BF is 1.96 and 21.32 times higher than SF and IF respectively as per IS:1893 (2002). Deflection of BF as per IS:1893 (loading 54.2% less when compared to ASCE 7. Fig.11 shows maximum storey displacement and maximum storey drift as per IS: 1893(2002) and ASCE 7 (c) Stiff Columned at Soft Storey (SF) Fig .9. Deformed Shape of bare frame, and ASCE 7-05 as 2002) lateral 7-05.Fig.11 and 7-05 respectively.

Storey	Maximum storey displacement (m)		
	Bare frame	Stiff columned frame	Infilled frame
Storey10	0.003715	0.003068	0.001445
Storey9	0.003609	0.002870	0.001284
Storey8	0.003503	0.002667	0.001117
Storey7	0.003396	0.002461	0.000948
Storey6	0.003290	0.002256	0.000779
Storey5	0.003184	0.002057	0.000617
Storey4	0.003078	0.001869	0.000466
Storey3	0.002972	0.001696	0.000331
Storey2	0.002866	0.001546	0.000216
Storey1	0.002761	0.001410	0.000130
Base	0	0	0

Table 1. Maximum Storey Displacement (Is 1893:2002)

Comparison of values of maximum storey drift with various conditions of 2D soft storey building due to lateral loading using IS 1893:2002.

Storey	Maximum storey drift (m)		
	Bare frame	Stiff columned frame	Infilled frame
Storey10	0.00003	0.000057	0.000046
Storey9	0.00003	0.000058	0.000048
Storey8	0.00003	0.000059	0.000049
Storey7	0.00003	0.000059	0.000049
Storey6	0.00003	0.000057	0.000047
Storey5	0.00003	0.000054	0.000044
Storey4	0.00003	0.000050	0.000039
Storey3	0.00003	0.000044	0.000033
Storey2	0.00003	0.000039	0.000031
Storey1	0.000789	0.000403	0.000037
Base	0	0	0

Table 2. Maximum Storey Drift (Is 1893:2002)

Comparison of values of maximum storey displacement with various conditions of 2D soft storey building due to lateral loading using ASCE 7-10.

Storey	Maximum storey displacement (m)		
	Bare frame	Stiff columned frame	Infilled frame
Storey10	0.008107	0.004236	0.000023
Storey9	0.007896	0.004090	0.000020
Storey8	0.007685	0.003945	0.000018
Storey7	0.007474	0.003800	0.000015
Storey6	0.007263	0.003654	0.000012
Storey5	0.007052	0.003509	0.000010
Storey4	0.006841	0.003364	0.000007
Storey3	0.006631	0.003219	0.000005
Storey2	0.006421	0.003074	0.000003
Storey1	0.006211	0.002930	0.000002
Base	0	0	0

Table 3. Maximum Storey Displacement (Asce 7-10)

Comparison of values of maximum storey drift with various conditions of 2D soft storey building due to lateral loading using ASCE 7-10.

Storey	Maximum storey drift (m)		
	Bare frame	Stiff columned frame	Infilled frame
Storey10	0.00006	0.000042	0.000001
Storey9	0.00006	0.000042	0.000001
Storey8	0.00006	0.000042	0.000001
Storey7	0.00006	0.000042	0.000001
Storey6	0.00006	0.000042	0.000001
Storey5	0.00006	0.000041	0.000001
Storey4	0.00006	0.000041	0.000001
Storey3	0.00006	0.000041	0.000001
Storey2	0.00006	0.000041	0.000000409
Storey1	0.001774	0.000837	0.000001
Base	0	0	0

Table 4. Maximum Storey Drift (Asce 7-10)

Storey drift of first storey at top of bar frames is 1.96 and 21.32 times higher than stiff columned at soft storey(SF) and infill at corner frame(IF) respectively as per IS:1893 (2002).

- Deflection of Bare frame as per IS:1893(2002) lateral loading 54.2 % less when compared to ASCE 7-10.

– Fig.8 and Fig.9 shows maximum storey displacement and maximum storey drift as per IS:1893(2002) and ASCE 7-10 respectively.

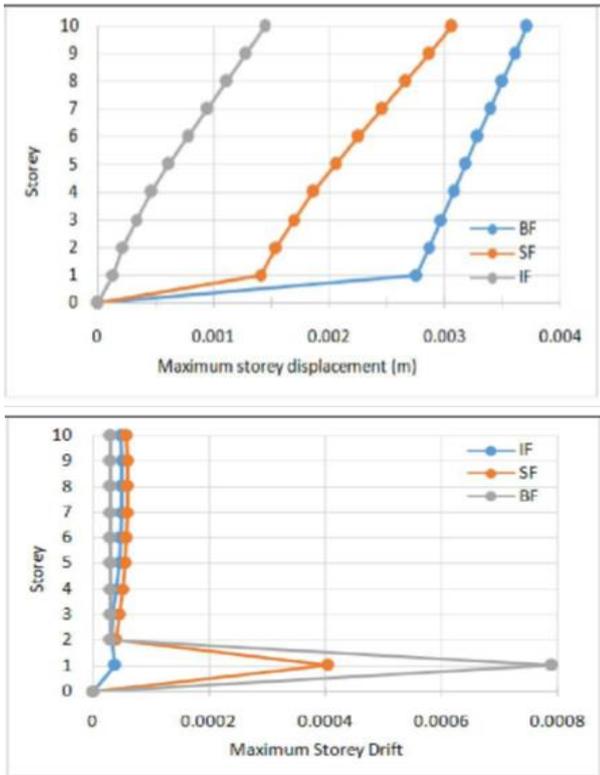


Fig. 10: Maximum storey displacement and maximum storey drift as per IS: 1893(2002)

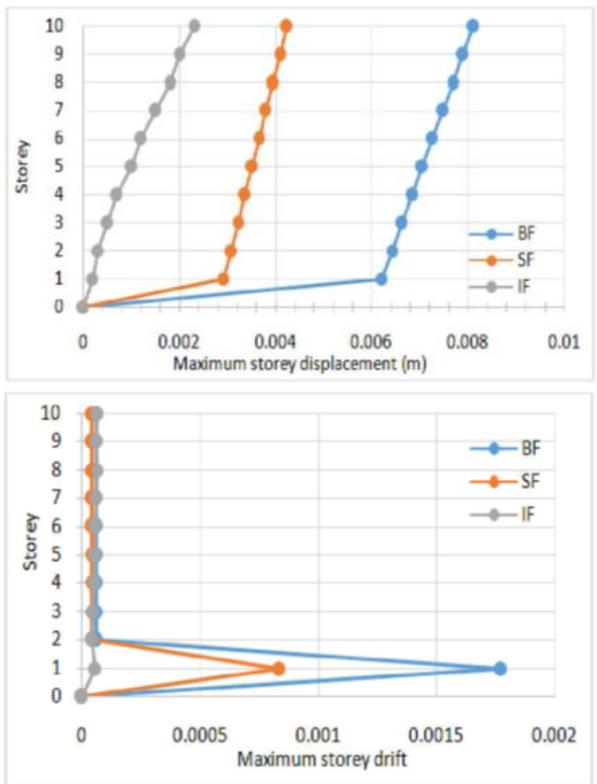


Fig. 11: Maximum storey displacement and maximum storey drift as per ASCE 7-05

IV. RESULTS OF 3D FRAME ANALYSIS

Results of maximum storey displacement and the various curves resulting from the analysis are briefed in the following text. Fig. 12 shows the deflected shape of three frames under seismic loading. From deflected shape, it has been noticed that storey failure mechanism as expected is more in BF when compared to other two frames. It has been also seen that deflection of corner columns of IF with infill differs from other free columns in soft storey.

Table 5 gives the maximum storey displacement three frame due to lateral loading in one direction (Y-direction) as per IS 1893:2002 and ASCE 7-10. Table 6 gives the maximum storey displacement three frame due to lateral loading in one direction (Y-direction) as per NZS 1170 2004 and Eurocode 8 2004 respectively. Displacement in X-direction is very negligible. Comparison of deflection of three frames due to IS 1893:2002, ASCE 7-10, NZS 1170 2004 and Eurocode 8 2004 lateral loading is shown in Fig. 13. Comparisons of frames BF and SF deflection response to various standard loading is shown in Fig. 14. Table. 7 gives structure response in terms of maximum storey displacement at top (mm), drift ratio ($=\Delta/H$) and total base shear for various standards loading condions.

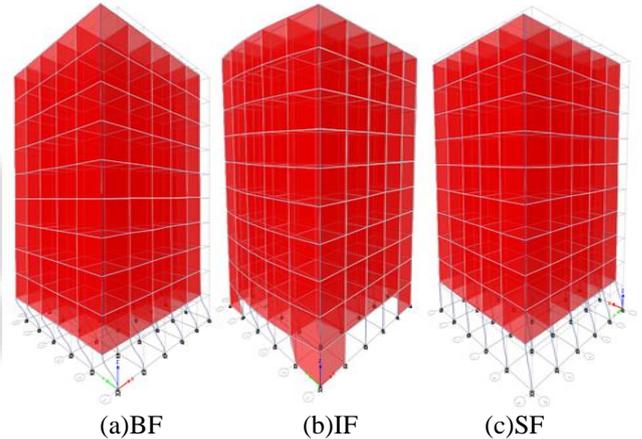


Fig.12.Deformed Shape of the Frames to Lateral Loading

Structural response	frame	IS:1893 (2002)	ASCE 7-10	NZS 1170 2004	Eurocode 8 - 2004
Maximum storey displacement at top (mm)	BF	8.8	12.8	24	52.8
	SF	5.2	9.1	19.6	33.6
	IF	0.2	0.2	0.3	0.3
Drift Ratio $=\Delta/H$ of ground storey	BF	0.00025	0.00036	0.0006	0.0006
	SF	0.00015	0.00026	0.0005	0.0005
	IF	0.00000	0.00000	0.0000	0.0000
Total Base shear (kN)	BF SF IF	16053.2	17019.4	35752.7	53370.6
Comparison of Base shear of other standards with IS	BF SF IF	-	1.06	2.227	8.817

Table 7. Structure Response For Loading As Per IS 1893:2002, ASCE 7-10, NZS 1170 2004 AND Eurocode 8-2004

V. CONCLUSION

In this study, G+9 Reinforced Concrete framed soft storey building was designed as per IS1893:2002 and was then analyzed for seismic lateral loading as per IS 1893:2002, ASCE 7-10, NZS 1170-2004 and EUROCODE 8-2004 methods using ETABS 2013 v 13.1.1. Following are the salient conclusions observed: The obtained result from ETABS software shows infill wall acts as the diagonal bracing in structure and the storey displacement in soft storey column transfers lateral force to adjacent infill wall panel. Stiffen columned frame also shows little soft storey mechanism when compared to Bare frame. Maximum storey displacement in 3D frame structure in descending order of (1) Bare frame model > (2) stiffen columned in soft first storey > (3) Infill wall at corners of soft first storey for Indian, American, New- Zealand and European Standards loading. Similarly in 2D frame structure maximum storey displacement and maximum storey drift values gives the same result. Hence use of infill walls at corners of soft first storey gives good resistant to lateral force. When comparing ETABS results of Indian, American, New- Zealand and European Standards, Base Shear values are in descending order of (1) European > (2) New Zealand > (3) American > (4) Indian standards. Base shear value as per Eurocode is about 9 times greater than Indian Standard. Factors like Seismic zone factor, Importance factor, Response reduction factor, Fundamental period and Total mass of the structure differs from Standard to Standard. Hence the Base shear values also differ. Thereby affecting deformation of building.

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