Performance Based Seismic Evaluation of Multi Storey R.C.C Building

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Abstract:- From the recent earthquakes, it is noticed that the seismic risk in urban areas is increasing and the infrastructure facility is far from socioeconomically acceptable levels. Performance based seismic design is an elastic design methodology done on the probable performance of the building under different ground motions. Thus the Performance-based seismic design is a process that permits design of new buildings or upgrade of existing buildings with a realistic understanding of the risk of life, occupancy and economic loss that may occur as a result of future earthquakes. Performance-based design begins with the selection of design criteria stated in the form of one or more performance objectives. In present study an attempt is made to understand the procedure and methodology adopted in performance based seismic evaluation of (G+10) and (G+20) storey RCC building with and without shear wall. Non linear static pushover analysis is performed by using SAP2000, a product of computers and structures international. The results of analysis have been compared in terms of base shear, storey drift, storey displacement and plastic hinge rotations, and found that both buildings satisfy strength as well as drift criteria.

Keywords : Performance Based Seismic Design, Non linear Static Pushover Analysis

INTRODUCTION

Earthquakes is one of the most devastating natural disasters that lead to catastrophic losses of lives and property around the world. According to the existing standard code of practice IS: 1893(part-1)-2002, more than 60% of existing land in india is susceptible to different kinds of earthquakes. Many existing structures are seismically deficient due to lack of awareness regarding seismic behavior of structures. Hence, we need to build structures that are capable to withstanding earthquakes with acceptable damage. The current seismic design codes in India and most of the other countries follow force-based design (FBD) method. Forced based approach does not give an idea about, how a building will perform under seismic loading, whereas displacement based approach is also known as performance-based seismic design (PBSD) evaluates how the building is going to perform under a given seismic loading. The concept of performance based seismic engineering using nonlinear analysis to evaluate the behavior of a building. The most accurate nonlinear analysis is time history analysis, but it is very complex, requires many computations, time and not practical for every design. So from a practical point of view nonlinear static analysis also known as pushover analysis gives acceptable result. Pushover analysis is an incremental static analysis used to determine the force-displacement relationship, or the capacity curve, for a structural element. The analysis involves applying horizontal loads to a computer model of the structure incrementally (i.e. pushing the structure), and plotting the total applied shear force and associated lateral displacement at each increment, until the structure reaches a limit state of collapse condition.

METHODOLOGY

Performance based seismic evaluation of buildings is carried out using pushover analysis. It is a static nonlinear procedure in which the magnitude of the structural loading is incrementally increased. With the monotonic increase in the magnitude of the loading, weak links and the failure modes of the structure are found. As the load and displacement increases, the element (beams, columns, etc.) begin to yield and deform inelastically. Pushover analysis requires capacity curve, demand curve, and performance objective. Capacity curve, which is roof displacement vs. base shear graph, is obtained from the nonlinear static analysis. Capacity curve depends upon stiffness and deformation capacity of the structure. The demand curve is estimated by reducing 5% damped design spectrum by special reduction method. Capacity curve and Demand curve is transformed into Acceleration Displacement Response Spectra (ADRS) which is acceleration vs. displacement graph. The transformed capacity curve is called capacity spectrum. Capacity curve, Demand Curve and ADRS is shown in figure-1.
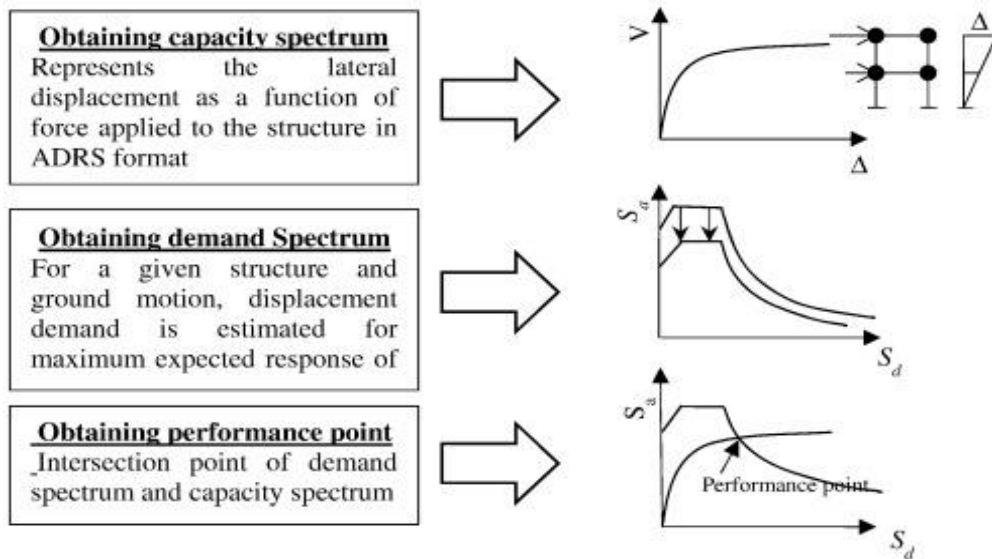
Figure 1. Capacity Curve, Demand Curve and ADRS.

The Nonlinear properties in beams and columns have to be introduced for analysis which can be introduced using predefined hinge properties in Sap 2000. The flexural default hinges (M3) to the beams at two ends was assigned. The interacting (P-M2-M3) frame hinges type a coupled hinge property was also assigned for all the columns at upper and lower ends. Sap 2000 take auto hinge property from ASCE41-13 tables. All buildings are designed as per IS 456:2000, for adequate main and shear reinforcements, corresponding to the ultimate moment capacity level. Flexural plastic hinges will be developed along with the predicted values of ultimate moment capacity when there is no prior failure in shear. Therefore, there is no need for shear hinge modeling as it is obvious for a code designed building to fail in flexure and not in shear. Two pushover loads Push X and Push Y were defined as displacement controlled. The maximum target displacement of the structure was kept at 4% of the height of the building. Both pushover loads were run from final conditions of dead load.

Description of Analyzed Buildings

In this paper (G+10) and (G+20) stories buildings are preliminary designed by Sap 2000 v.19 for seismic Zone V. Buildings were designed as Special Moment Resisting Frame (SMRF) as per IS1893-2002. Plan Dimensions of buildings kept as 20m x 15m with 5 bays in X-Direction and 3 Bays in Y-Direction (Figure-2).
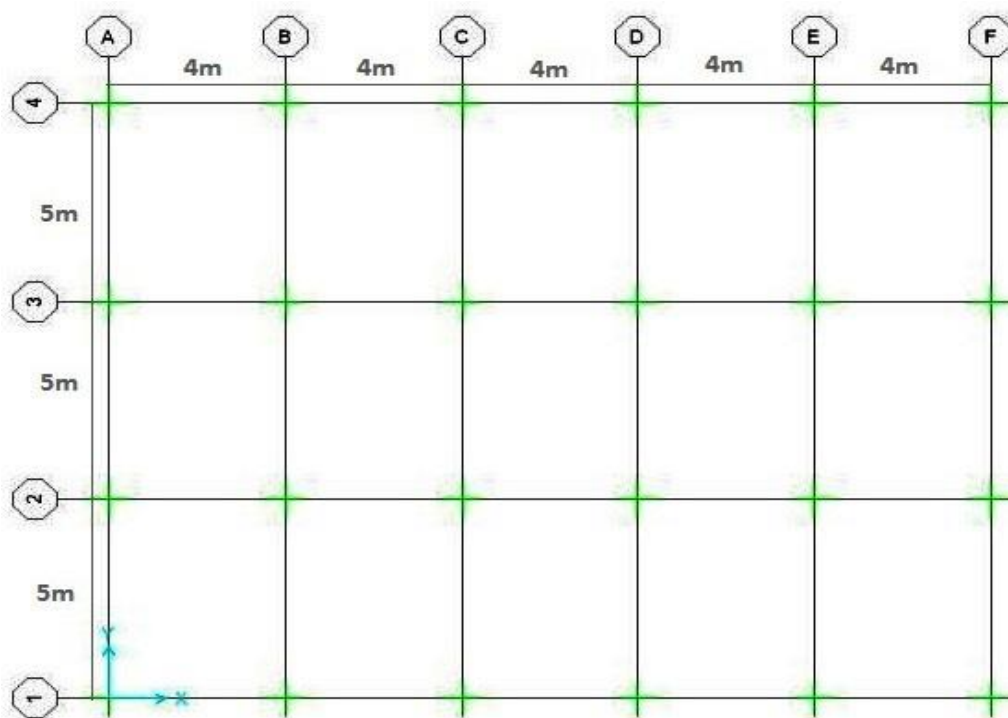

Figure 2. Plan of Building

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Storey height for ground floor is kept as 3.5 m and typical storey height is kept uniform for all stories i.e. 3 m. Slab thickness is kept 125 mm for all floors.. Shear wall is modeled as Mid pier frame element. Thickness of shear wall is taken equal to 200 mm. As the building is symmetric shear wall is provided in central bay of longer side of building frame. M25 Grade of Concrete and Fe415 Grade of steel are used in all members.

Loads Considered

Following loads are considered for analysis of all buildings.
Live load: 3.5 kN/m2 on all floors. As per IS 875 (Part-2)
Dead Load: 3 kN/m2 on all floors and 16.8 kN/m wall load on all beams.
Earthquake load: as per IS1893:2002 (Part1)
Type of Soil: Medium Soil (Type II) as per IS1893 (2002)
Importance factor, I : 1
The time period for both buildings is program calculated as per IS 1893(2002) was used to calculate the earthquake force for both buildings. For earthquake force analysis in Sap 2000 following loads were considered in the mass source: Dead load plus 0.5 times live load. The building is designed according to IS456:2000 using SAP 2000 v.19 considering live load, dead load and Earthquake load in both directions X and Y with minimum eccentricity. The dimensions of beams and columns and designed reinforcement details of columns are mentioned in Table-1 and Table-2. Columns A1,A2,A3,A4,B1,B2,B3,B4,C1,C2,C3,C4,D1,D2, D3,D4,E1,E2,E3,E4, and F1,F2,F3,F4 can be identified from figure-2.

Table-1 (G+10) Structural Details as per Analysis and Design in Sap2000

Storey	Height m	Beam Size (BxD) mm	Column Size (BxD) mm	Reinforcement Percentage in Column %					
				A1,A4 F1,F4	A2,A3 F2,F3	B1,B4 E1,E4	B2,B3 E2,E3	C1,C4 D1,D4	C2,C3 D2,D3
11th	33.5	200 x 325	325 x 325	0.8	0.8	0.8	0.8	0.8	0.8
10th	30.5	200 x 325	325 x 325	0.8	0.8	0.88	0.8	0.85	0.8
9th	27.5	200 x 375	375 x 375	0.8	0.8	0.83	0.8	0.81	0.8
8th	24.5	200 x 375	375 x 375	0.8	0.8	0.96	1.51	0.86	1.37
7th	21.5	200 x 375	375 x 375	0.8	1.32	1.72	2.69	1.62	2.54
6th	18.5	275 x 425	425 x 425	0.8	0.8	0.81	1.67	0.8	1.65
5th	15.5	275 x 425	425 x 425	0.8	0.92	0.99	2.4	0.95	2.65
4th	12.5	275 x 425	425 x 425	0.8	1.5	1.49	3.34	1.47	3.65
3rd	9.5	300 x 450	450 x 450	0.8	1.41	1.14	3.46	1.14	3.77
2nd	6.5	300 x 450	450 x 450	0.8	1.82	1.49	4.3	1.64	4.65
1st	3.5	300 x 450	450 x 450	1.69	2.98	2.22	5.29	2.31	5.6

Table-2(G+20) Details as per Analysis and Design in Sap2000

Storey	Height m	Beam Size (BxD) mm	Column Size (BxD) mm	Reinforcement Percentage in Column %					
				A1,A4 F1,F4	A2,A3 F2,F3	B1,B4 E1,E4	B2,B3 E2,E3	C1,C4 D1,D4	C2,C3 D2,D3
21st	63.5	225 x 375	400 x 400	0.85	0.8	0.88	0.8	0.84	0.8
20th	60.5	225 x 375	400 x 400	0.8	0.8	0.8	0.8	0.8	0.8
19th	57.5	225 x 375	400 x 400	0.8	0.8	1.45	1.58	1.29	1.29
18th	54.5	300 x 450	450 x 450	0.8	0.8	1.41	1.63	1.25	1.35
17th	51.5	300 x 450	450 x 450	0.8	1.04	1.65	2.31	1.53	2.08
16th	48.5	300 x 450	450 x 450	1.18	1.82	2.38	3.25	2.27	3.03
15th	45.5	325 x 500	500 x 500	0.8	1.35	1.78	2.63	1.71	2.48
14th	42.5	325 x 500	500 x 500	1.05	1.93	2.12	3.14	2.05	3.11
13th	39.5	325 x 500	500 x 500	1.72	2.77	2.78	4.01	2.74	4.03
12th	36.5	375 x 550	550 x 550	1.13	2.06	2.03	3.08	1.98	3.45
11th	33.5	375 x 550	550 x 550	1.58	2.61	2.38	3.74	2.37	4.17
10th	30.5	375 x 550	550 x 550	2.16	3.25	2.86	4.37	2.86	4.95
9th	27.5	400 x 600	600 x 600	1.56	2.62	2.15	3.72	2.28	4.19
8th	24.5	400 x 600	600 x 600	1.96	3.13	2.5	4.28	2.78	4.86
7th	21.5	400 x 600	600 x 600	2.5	3.75	2.89	4.93	3.3	5.53
6th	18.5	450 x 650	650 x 650	1.93	3.09	2.35	4.14	2.72	4.7
5th	15.5	450 x 650	650 x 650	2.38	3.66	2.77	4.67	3.16	5.32
4th	12.5	450 x 650	650 x 650	2.78	4.16	3.18	5.26	3.64	5.89
3rd	9.5	500 x 700	750 x 750	2.3	3.57	2.64	4.47	2.99	5.18
2nd	6.5	500 x 700	750 x 750	2.68	4.04	2.98	5.04	3.44	5.71
1st	3.5	500 x 700	750 x 750	3.04	4.52	3.44	5.6	3.84	5.07

RESULTS & DISCUSSION

The seismic performance of a building is evaluated in terms of capacity curve, performance point and plastic hinge formation and storey drift.

Capacity Curve

Pushover Analysis gives an idea of the maximum base shear that the structure can resist at the time of the seismic load. For regular buildings, it can also give a rough idea about the global stiffness of the building. Capacity Crve obtained after pushover analysis is plotted in Figure-3 and Figure-4. It is observed that Buildings with shear wall is capable to resist larger base shear as compared to bare frame buildings. Maximum Displacement was also observed in bare frame building.

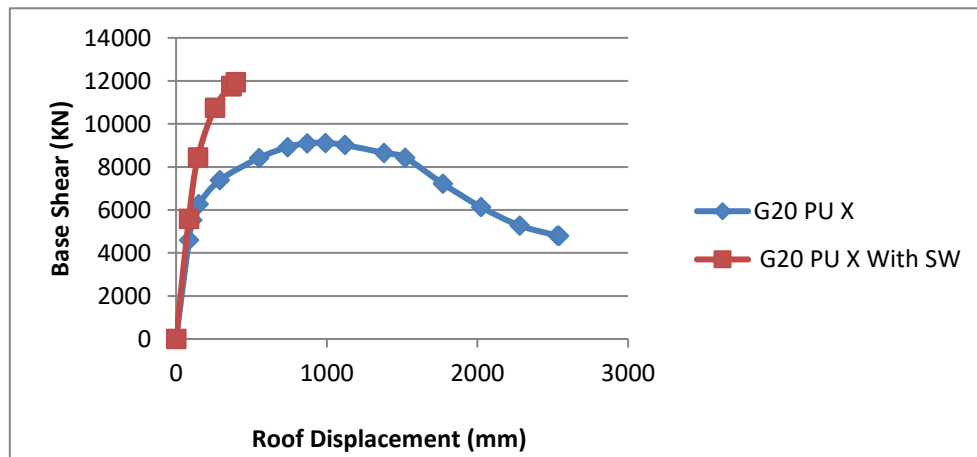Figure 3. Capacity Curves of (G+10) Buildings for Pushover in X-Direction

Figure 4. Capacity Curves of (G+20) Buildings for Pushover in X-Direction

Status of Hinges at Ultimate Stage

Status of plastic hinges at the ultimate stage for (G+10) and (G+20) is shown in figure 5 and 6.
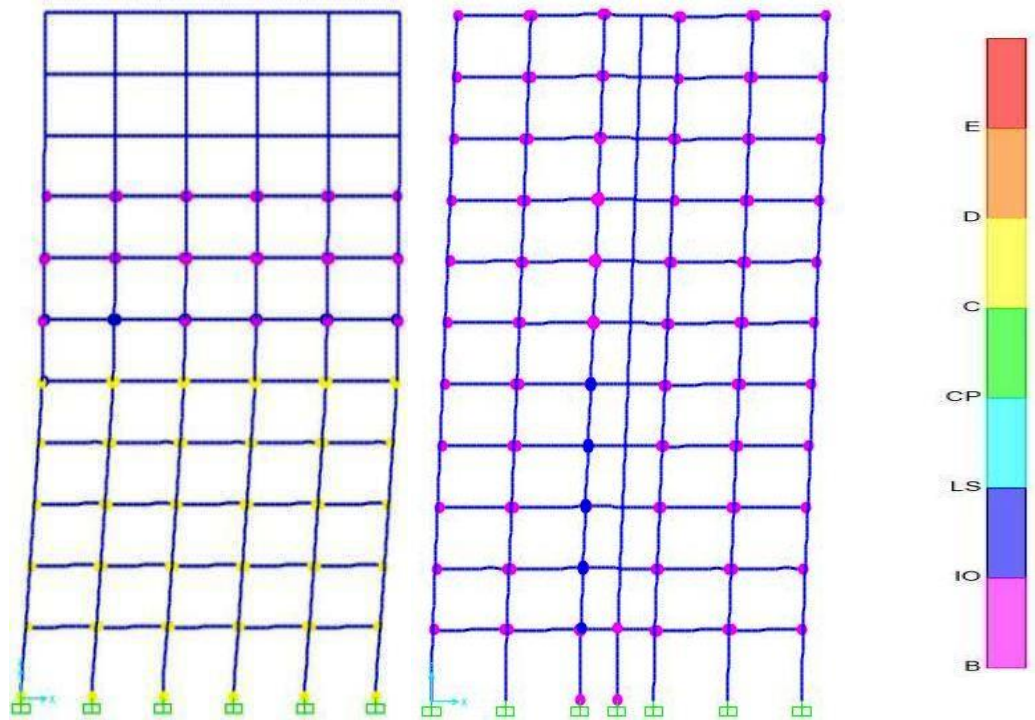
Figure 5. Status of Hinges at Ultimate Stage in Pushover-X Case

A table of hinge status at the ultimate stage is shown in Table-3. It was observed that in (G+10) building without shear wall 74 hinges are formed between immediate occupancy and life safety range and 228 hinges are formed beyond collapse range, by addition of shear wall only 18 hinges are formed between immediate occupancy and life safety range .So there is considerable decrease in hinge formation by addition of shear wall and building lies between immediate occupancy and life safety range.

Table 3. Status of Hinges at Ultimate Stage

Building	Monitored Displacement (mm)	Base Force (KN)	O-IO (Nos.)	IO-LS (Nos.)	LS-CP (Nos.)	>CP (Nos.)	Total (Nos.)
G10 P X	1340	2753.549	1062	74	0	228	1364
G10 P X SW	226	5687.324	1390	18	0	0	1408
G20 P X	2540	4998.35	2084	96	0	424	2604
G20 P X SW	395	11937.755	2688	0	0	0	2688

O: Operational Level, IO: Immediate Occupancy Level, LS: Life Safety Level, CP: Collapse Prevention Level

In (G+20) building without shear wall 96 hinges are formed between immediate occupancy and life safety range and 424 hinges are formed beyond collapse prevention state, but with shear wall addition hinges are not formed beyond immediate occupancy state. Building lies at immediate occupancy state, thus both buildings performed well up to design seismic load and it can be easily said that performance of high rise building is more affected than medium rise building with addition of shear wall.
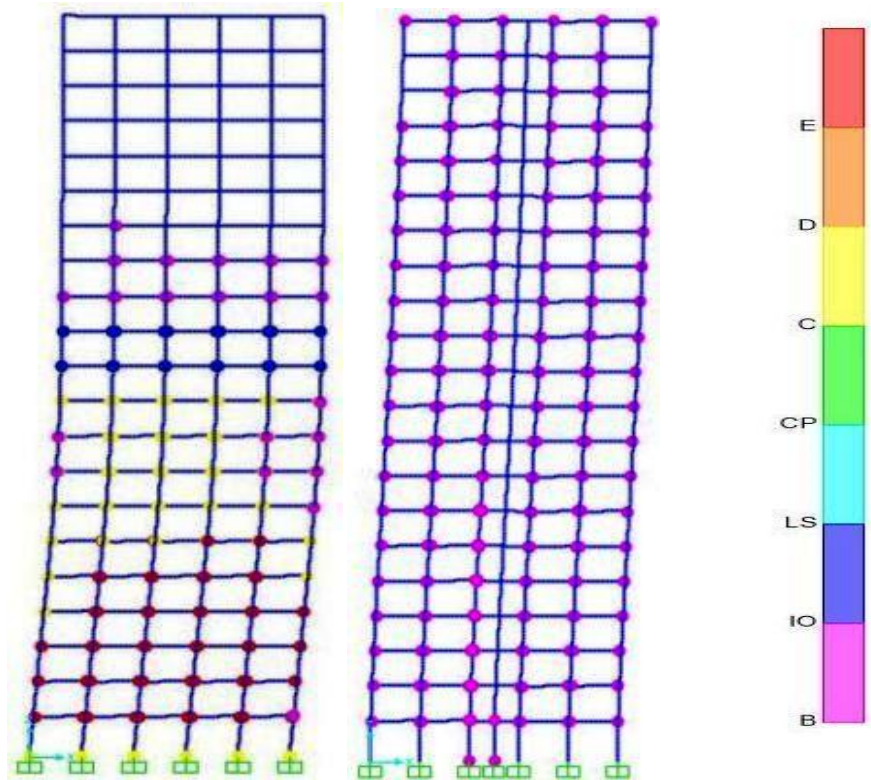
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Figure 6. Status of Hinges at Ultimate Stage in Pushover-X case

Capacity Demand Spectrum

Capacity demand spectrum is the representation of structures ability to resist the seismic demand. The point of intersection of capacity spectrum and demand spectrum is required performance point. Figure 7 and 8 shows the capacity spectrum curve as per ATC-40 of (G+10) and (G+20) buildings with shear wall respectively. Table 4 shows the performance point in terms of different structural parameter like base shear (V), displacement (D), spectral acceleration (Sa), spectral displacement (Sd), effective time period (Teff), effective damping (βeff).

Table 4. Performance Point in terms of (V, D) (Sa, Sd) (Teff, βeff)

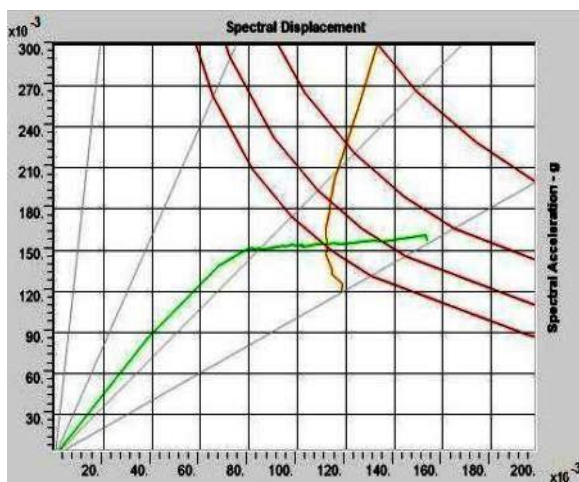| Performance Point	G10 P	G10 P SW	G20 P	G20 P SW
Performance Point (V, D)	(3297.138, 0.222)	(5563.003, 0.165)	(7393.275, 0.287)	(10806.918, 0.262)
Performance Point (Sa, Sd)	(0.081, 0.179)	(0.155, 0.112)	(0.062, 0.223)	(0.099, 0.184)
Performance Point (Teff, βeff)	(2.969, 0.243)	(1.707, 0.196)	(3.814, 0.261)	(2.732, 0.182)

Figure 7

Figure 8

Storey Drift

Storey Drift of (G+10) and (G+20) storey buildings for push x case with and without shear wall designed for dead load, live load and the earthquake load is presented in figure-9 and 10. All buildings satisfy the strength requirements as well as satisfy inter-story drift criteria. As per 1893: 2002 clause no. 7.11.1 maximum permissible inter-storey drift is 0.004 times the storey height.
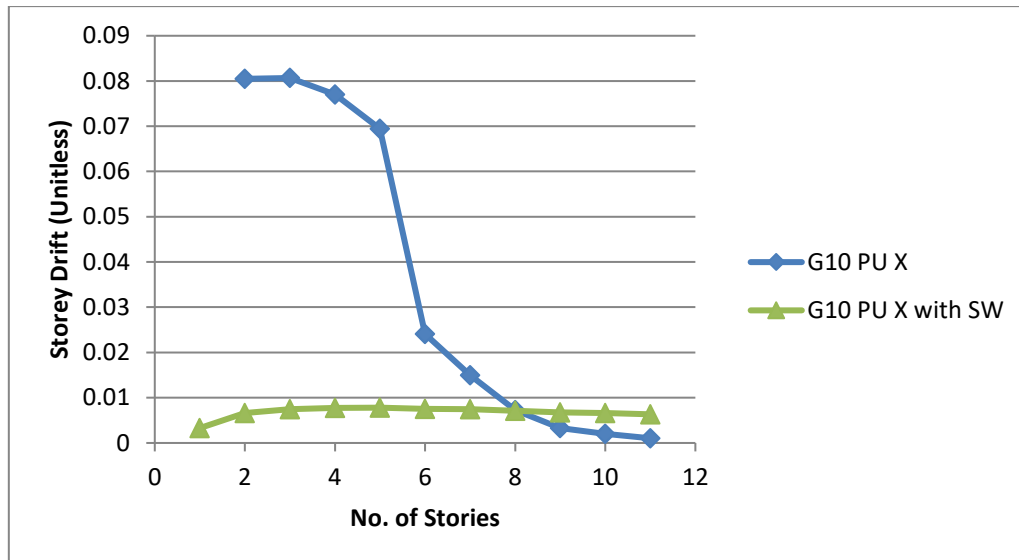

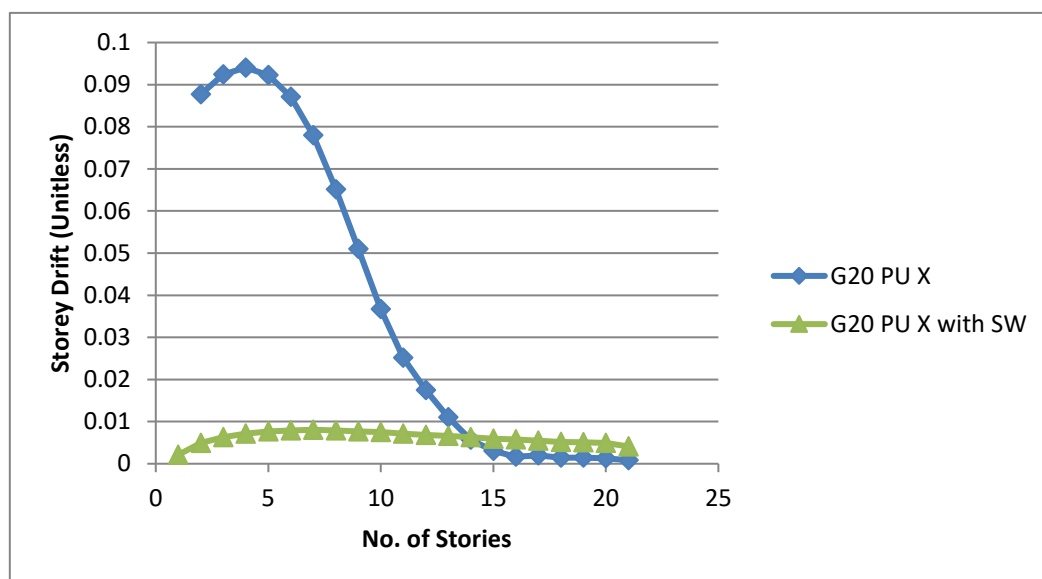Figure 9. Storey Drift in X-Direction for (G+10)

Figure 10. Storey Drift in X-Direction for (G+20)

CONCLUSIONS

In this work (G+10) and (G+20) stories buildings with and without shear wall have been taken for their seismic performance evaluation. Both buildings were designed for seismic zone V of India as per IS1839:2002 and IS456:2000 . Pushover analysis of buildings was carried out using Sap 2000 nonlinear software tool. Based on the present study, the following conclusion can be drawn.

1. From pushover analysis it is seen that capacity of structure increases with the introduction of shear walls in both G10 and G20 buildings.
2. There is a considerable reduction in hinge formation between immediate occupancy and life safety range and no hinge formation above life safety range with addition of shear wall.
3. As per IS 1893-2002 allowable storey drift requirement is 0.004 times storey height which is satisfied by both G10 and G20 buildings.

It is concluded that pushover analysis gives a better view of building performance under seismic load and its failure mechanism.

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