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Performance of Flat Slab Structure with Different Ground Storey Height

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Abstract — *Flat slab systems in current construction practice are commonly used for relatively light residential loads and for spans from 4.5m to 6m. Earthquakes have the potential for causing the greatest damages amongst all natural hazards. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analysing structures under the action of these forces. When subjected to earthquake action, the unbalanced moments can produce high shear stresses in the slab. Hence it is necessary to study the performance of flat slab when subjected to earthquake. The pushover analysis is becoming popular method of predicting seismic force and deformation demands for the purpose of performance evaluation of existing and new structure. Now a day, according to demand of structure variation in height of ground storey is seen. In this study, 3 flat slab models with different ground storey height are analysed using design software ETABs (version 9.7.4) by pushover analysis. Results are shown in form of pushover curves, base shear, storey drifts, plastic hinges mechanism of flat slab building. Effect of increase and decrease in ground storey height is studied.*

Keywords*-Flat slab; ETABs; pushover analysis; pushover curves; base shear; storey drifts; plastic hinges mechanism*

I. INTRODUCTION

I.1 Flat Slab

The flat slab system since its inception in the USA by Turner in 1906 has been gained popularity all over the world, as evidence of the large portion of the newly constructed buildings which employ that system. Flat slab called beamless slab is a slab supported directly by columns without beams. A part of slab bounded on each of the four sides by centre line of column is called a panel. [5]

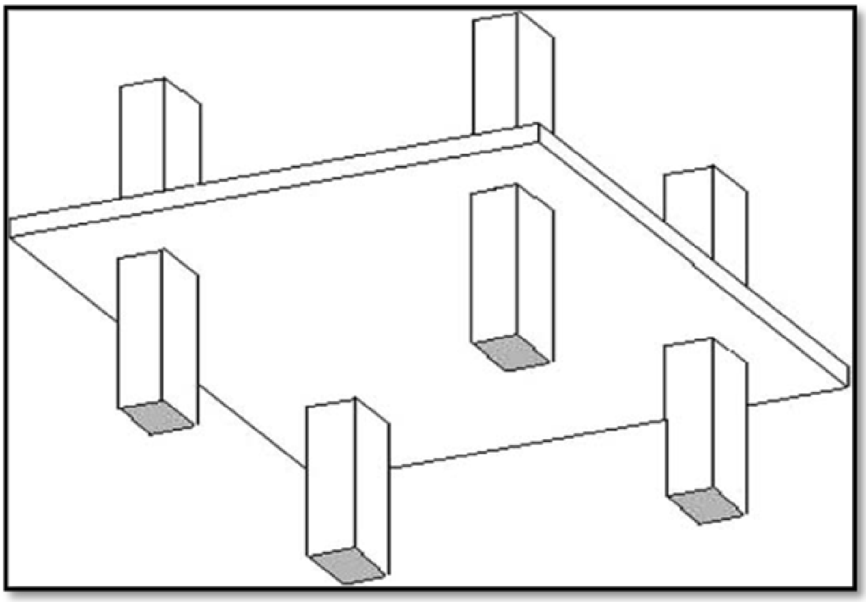

Figure 1: Illustration of a typical flat-slab structural form [5]

The flat slab is often thickened close to the supporting columns to provide adequate strength in shear. This thickened portion is called drop. In some cases, the top section of the column where it meets the floor slab or drop panel is enlarged which is known as column capital. Flat slab with drop has been used in the present study. Following Figure shows existing flat slab building with drop located in Pune.

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Figure 2: Flat Slab System with Drop

I.2. Pushover Analysis

The use of the non linear static analysis (pushover analysis) came in to practice in 1970's but the potential of the pushover analysis has been recognized for last 10-15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This procedure can be used for checking the adequacy of new structural design as well. The effectiveness of pushover analysis and its computational simplicity brought this procedure in to several seismic guidelines (ATC-40[3] and FEMA 356[4]) in last few years. Pushover analysis includes terms like capacity curve, capacity spectrum, demand curve, demand spectrum, performance point, non linear plastic hinges. These terms are explained below.

I.2.1 Capacity curve

The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of nonlinear analysis is required.

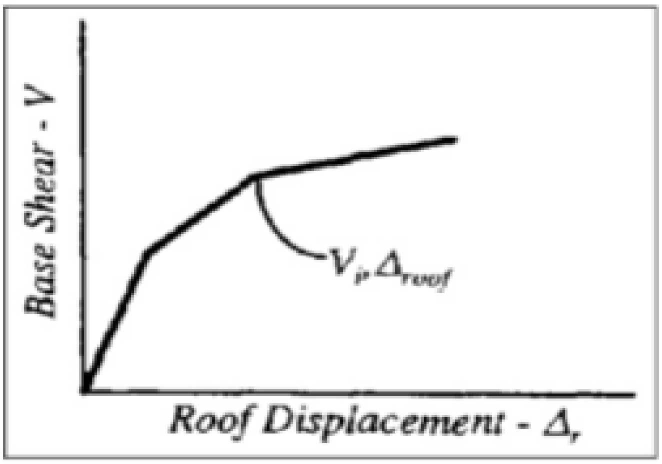

Figure 3: Capacity Curve

I.2.2 Capacity Spectrum

It is the spectrum transformed from shear force vs. roof displacement (V vs. Δ_r) coordinates into spectral acceleration vs. spectral displacement (S_a vs. S_d) coordinates [3].

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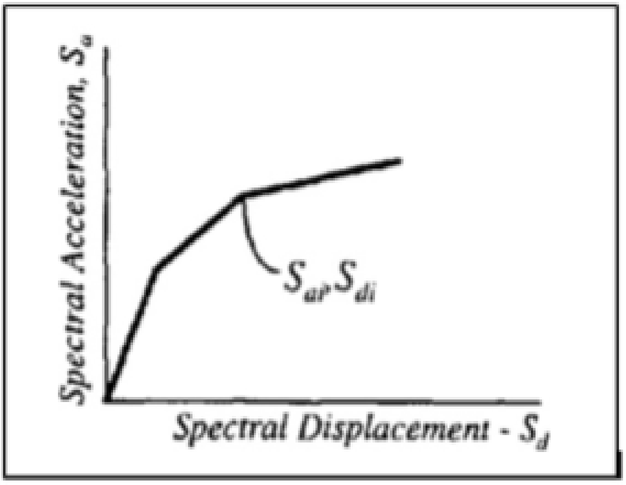

Figure 4: Capacity Spectrum

I.2.3 Demand Curve

Demand curve is a representation of the earthquake ground motion. It is given by spectral acceleration (S_a) Vs. Time period (T) as shown in Figure 5. [3]

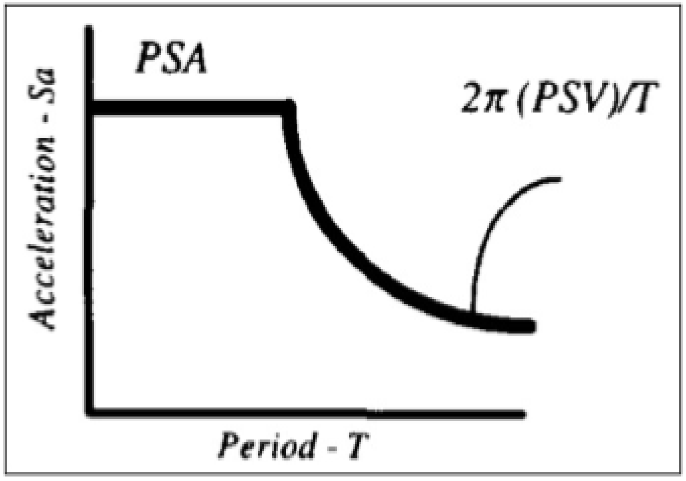

Figure 5: Demand Curve

I.2.4 Demand Spectrum

It is a spectrum that is converted from Demand curve (traditional spectrum - S_a Vs. T format) into demand spectrum (acceleration displacement response spectrum- S_a Vs. S_d format). [3]

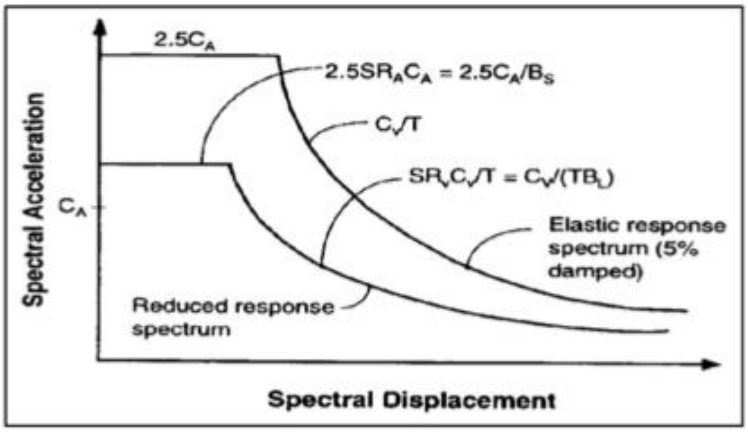

Figure 6: Reduced Response Spectrum

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I.2.5 Performance Point

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two spectra known as performance point. Figure 7 shows superimposing demand spectrum and capacity spectrum.

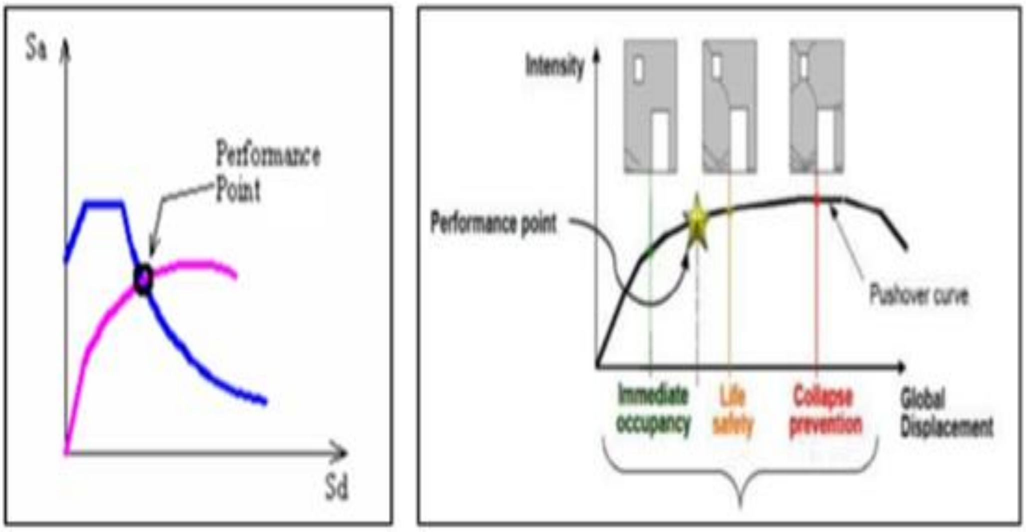

Figure 7: Performance Point

Check performance level of the structure and plastic hinge formation at performance point. A performance check verifies that structural and non-structural components are not damaged beyond the acceptable limits of the performance objective for the force and displacement implied by the displacement demand

I.2.6 Non Linear Plastic Hinges

Pushover Analysis requires the development of the force-deformation curve for the critical section of beams and column. Such a curve is presented in Figure 8.

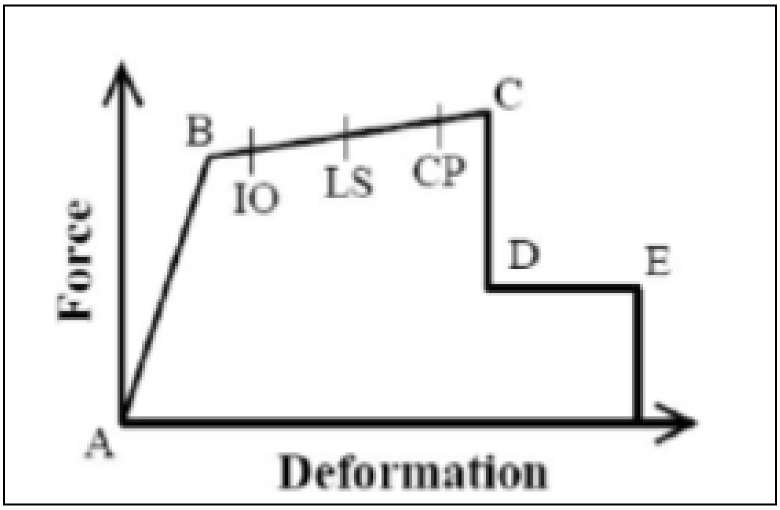

Figure 8: Typical Load-Deformation Relation

Point A denotes the unloaded condition. Load deformation relation shall be described by linear response from A to an effective yield B. Then the stiffness reduce from point B to C. Point C has resistance equal to the nominal strength then sudden reduction in lateral load resistance to point D, the response at reduced resistance to E, final loss of resistance thereafter. The slope of line BC, ignoring effects of gravity effects of gravity loads acting through lateral displacement, is usually taken between 0 and 10% of the initial slope. Line CD corresponds to initial failure of the member. Line DE represents the residual strength of the member. These points are specified according to FEMA to determine hinge rotation behaviour of RC members. The points between B and C represent acceptance criteria for the hinge, which is Immediate Occupancy (IO), Life Safety (LS), and CP (Collapse Prevention).

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Table 1: Performance Levels of Building

Performance Levels	Description
Operational	Very light damage, no permanent drift, structure retains original strength and stiffness, all systems are normal
Immediate Occupancy (IO)	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety (LS)	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention (CP)	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

II. STRUCTURAL MODEL

The three flat slab building models are taken in this study. All flat slab models are having 3 stories and 4 bays. The height of ground storey is varying i.e. 2.5m, 3.5m and 5.5m. A model having ground storey height 2.5m is named an GL2.5, model having ground storey height 3.5m is named an GL3.5, model having ground storey height 5.5m is named an GL5.5.

Table 2: Details of other properties of structure

1.	Grade of concrete	M25
2.	Grade of steel	Fe415
3.	Normal storey height	3.5m
4.	Thickness of slab	200mm
5.	Size of panel	6m X 6m
6.	Size of drop	3m X 3m
7.	Thickness of drop	250mm
8.	Seismic zone	IV
9.	Zone factor	0.24

The structural analysis program, ETABs Version (9.7.4) is used to perform analyses. A three dimensional model of each structure has been created to undertake the non linear analysis. ETABs provide default hinge properties and recommends P-M-M hinges for columns as described in FEMA 356. As flat slab is beamless slab so hinges are assigned to columns only.

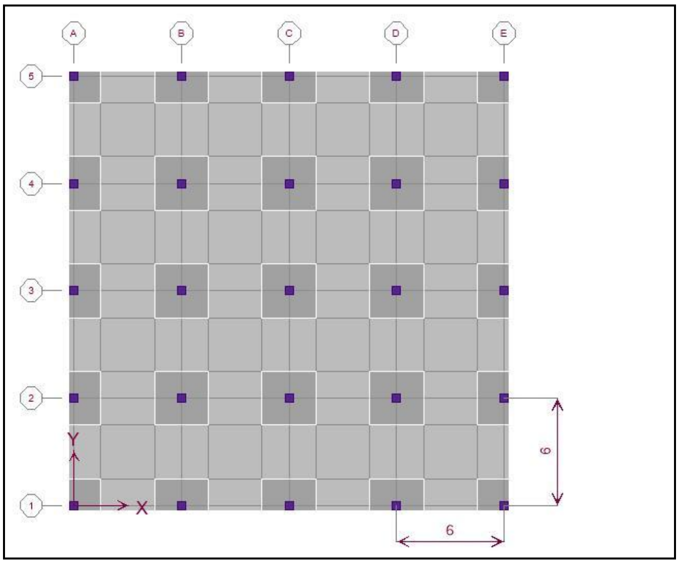

Figure 9: Plan of flat slab building

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An elevation view for flat slab models GL2.5, GL 3.5, GL 5.5 is shown in following figure.

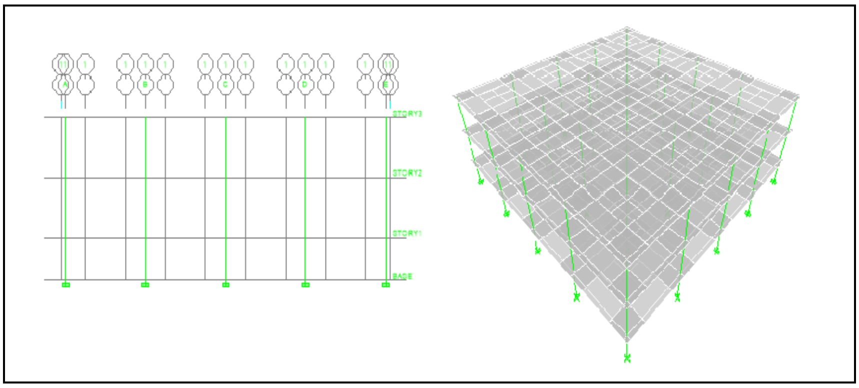

Figure 10: Elevation and 3D view of model GL2.5

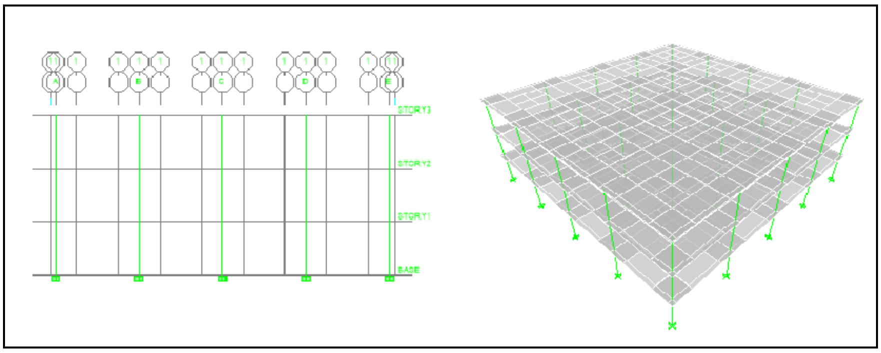

Figure 11: Elevation and 3D view of model GL3.5

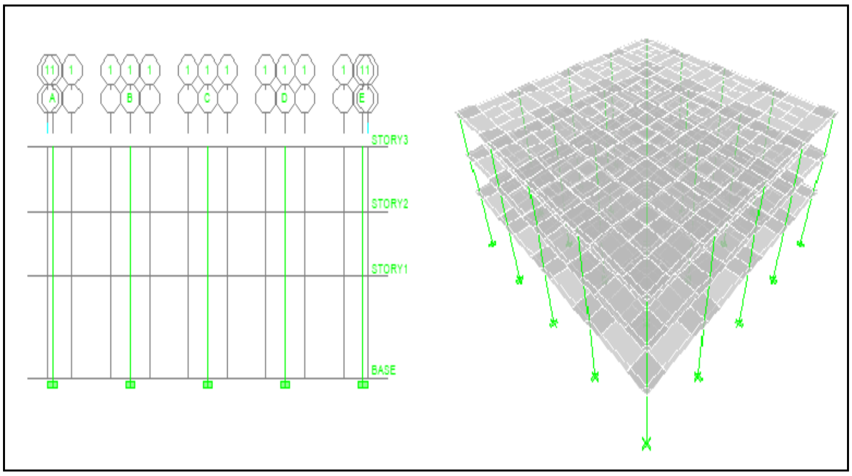

Figure 12: Elevation and 3D view of model GL5.5

III. RESULTS FROM PUSHOVER ANALYSIS

Standard pushover analysis is performed according to the ATC 40 and results for all the buildings in the form of capacity curve, storey drift, plastic hinge formation are plotted and the performance of flat slab building with different ground storey height is studied.

III.1. Capacity Curve

The pushover analysis generates the relationship between base shear (V) and roof displacement (Δ_{roof}) which is known as pushover curve or capacity curve. Following graph shows the capacity curve for models GL2.5 , GL3.5 and GL5.5 . It is observed that the nature of capacity curve for all 3 models is same. The variation can be seen when yielding occurs.

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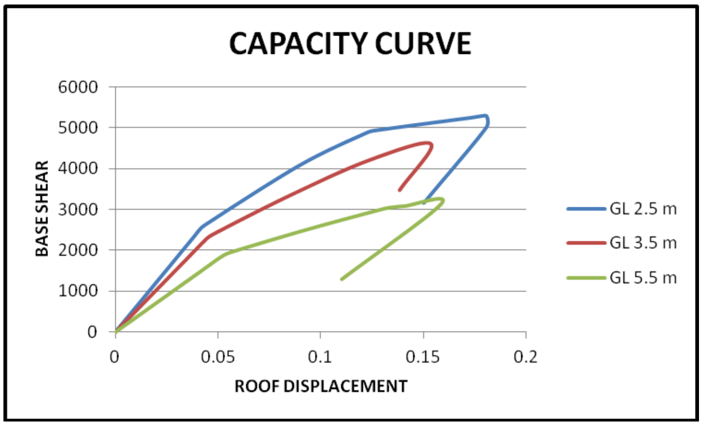

Figure 13: Capacity curve

III.2. Storey drift

Resulting storey drifts for X-direction are studied and performance of flat slab building with modified storey height at ground levels is evaluated.

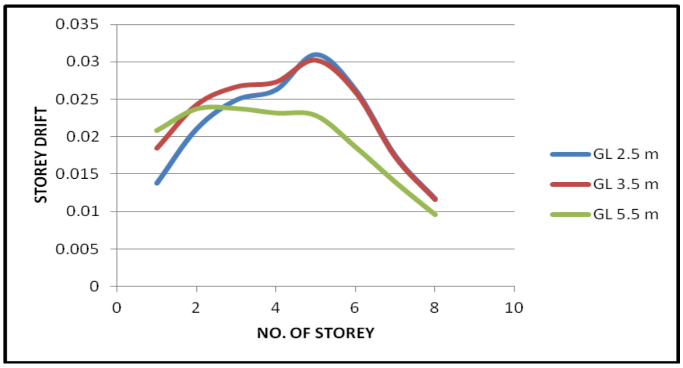

Figure 14: Storey drift

III.3 Demand capacity curve

The effect of modified ground storey height is shown by considering the demand capacity curve of models having 3 stories 4 bays. Number of stories and bays are kept constant. Only the height of ground storey is varying i.e. 2.5m, 3.5m and 5.5m. Following figure shows the demand capacity curve for models GL2.5 , GL3.5 and GL5.5.

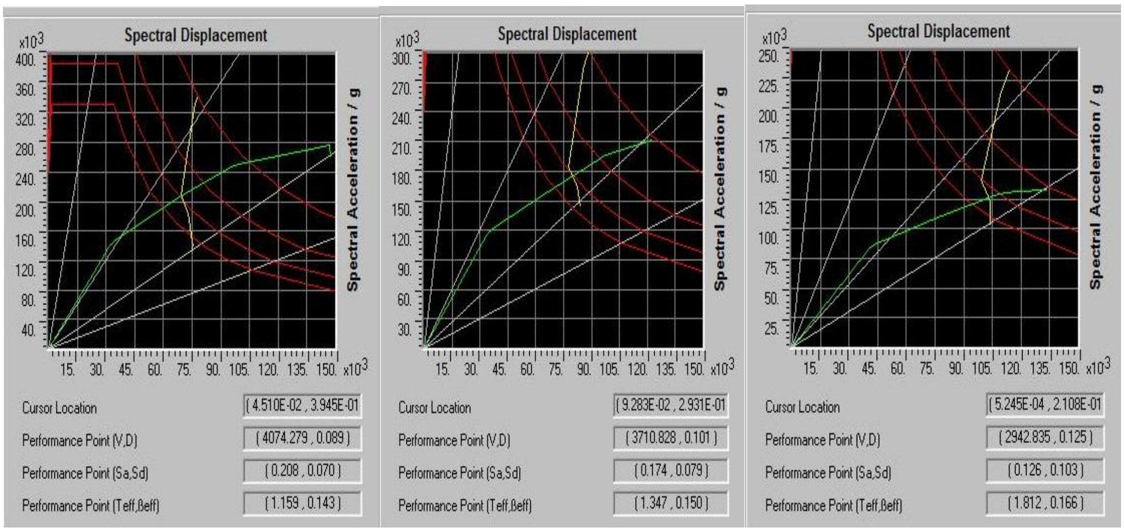

Figure 15: Demand capacity curve for models GL2.5 , GL3.5, GL5.5

III.4 Plastic hinge mechanism

The level of hinges for modified ground storey height is shown by considering the demand capacity curve of models having 3 stories 4 bays. Following figure shows plastic hinge formation at performance point for models GL2.5 , GL3.5 and GL5.5.

Table 3: Number of Plastic Hinges Formation at Performance Point

Model No.	Step	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
GL2.5	3	104	21	25	0	0	0	0	0	150
	4	61	55	9	25	0	0	0	0	150
GL3.5	4	92	33	0	25	0	0	0	0	150
	5	70	13	42	25	0	0	0	0	150
GL5.5	4	98	27	0	25	0	0	0	0	150
	5	93	32	0	25	0	0	0	0	150

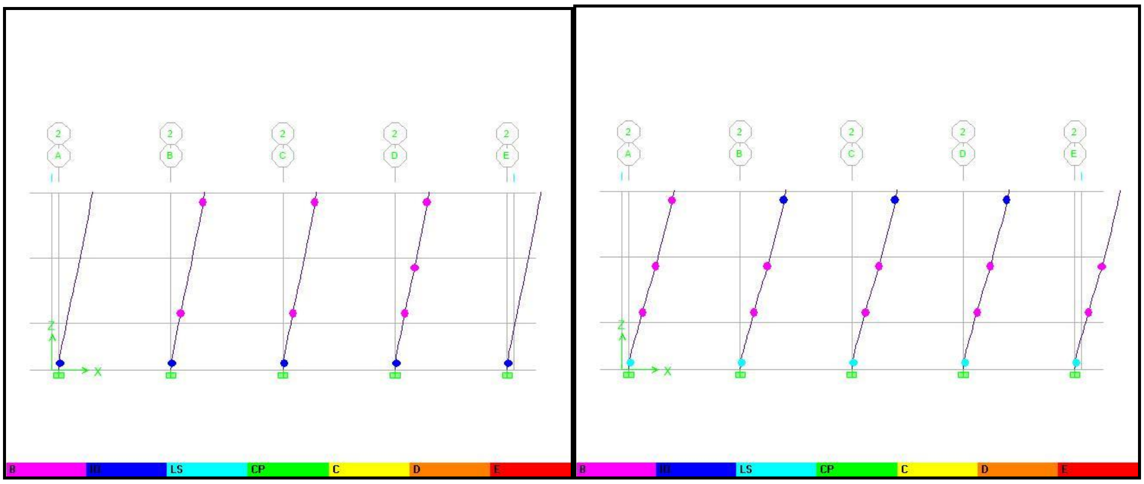

Figure 16: Elevation of Plastic Hinge Formation in model GL2.5 at step 3 and step 4

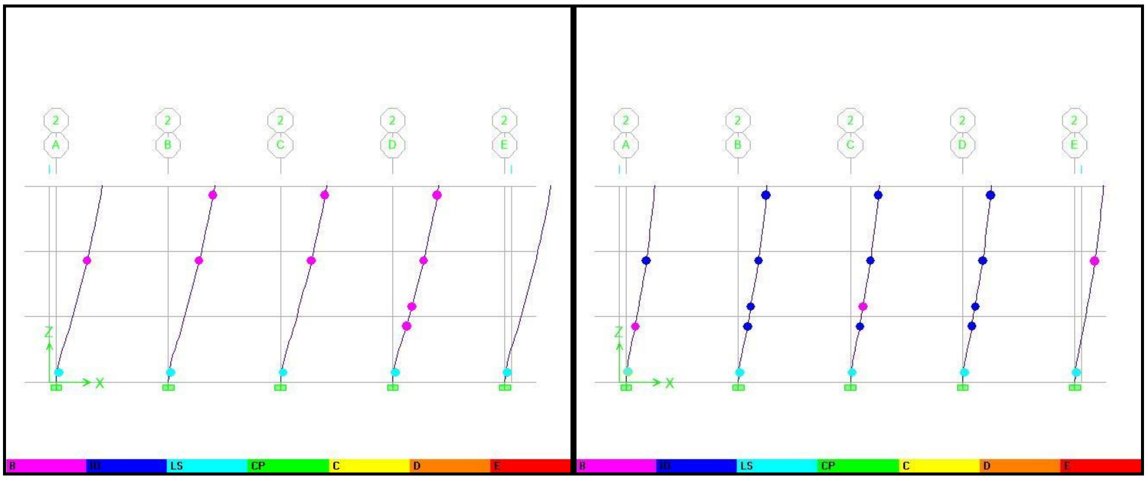

Figure 17: Elevation of Plastic Hinge Formation in model GL3.5 at step 4 and step 5

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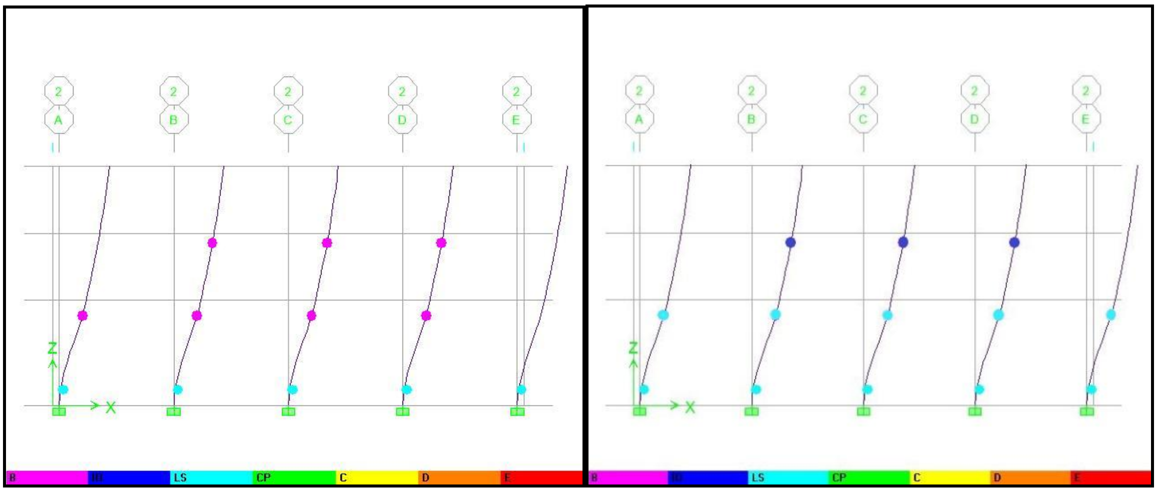

Figure 18: Elevation of Plastic Hinge Formation in model GL5.5 at step 4 and step 5

IV. CONCLUSIONS

1. The results obtained in terms of capacity curve concluded that nature of pushover curve is same when ground storey height is modified. It can be concluded when ground storey height decreases from 3.5m to 2.5m load carrying capacity increases by 15%. When storey height decreases column size also decreases hence stiffness increases and may be because of this load carrying capacity increases.
2. When ground storey height increases from 3.5m to 5.5m load carrying capacity decreases by 30%. When storey height increases column size also increases hence stiffness decreases and may be because of this load carrying capacity decreases.
3. Storey drift of mid storey increases by 3% when the ground storey height decreases to 2.5m. Storey drift of mid storey and top storey are 23% and 16% less respectively for model having 5.5m ground storey height as compare to model having 3.5 m ground storey height.
4. The overall performance level for all building models at performance point was found between LS-CP (life safety to collapse prevention). The hinge status and location has been determined and it is noted that most of the hinges begin to form in B-IO (Operational to Immediate Occupancy) range onwards.

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