Pushover Analysis of Reinforced Concrete Structures

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ABSTRACT
Earthquakes have severely damaged the structures which are already built. Due to this there is large number of deaths, injuries and economic loss. Therefore there is an urgent need for seismic evaluation of structures. The concept of performance based seismic engineering using pushover analysis is a modern and popular tool to earthquake resistant design due to its simplicity and better seismic assessment of existing and new structures. It gives better understanding of the structural behavior during the strong earthquake ground motion.The present study gives an effect of increase in number of storey on seismic responses by performing pushover analysis. Reinforced concrete structures of G+4, G+5 and G+ 6 storey have been modeled and analyzed using CSi ETABS 9.7.4 software. Comparison of seismic responses of the structure in terms of base shear, time period and displacement has been done by performing nonlinear static pushover analysis. From analysis results it has been observed that base shear and spectral acceleration is reduced, whereas displacement, time period, spectral displacement is increased as the number of storey increases. Analysis also shows location of plastic hinges at performance point of the structures with different number of storey.

Keywords
nonlinear static analysis; pushover analysis; performance based seismic assessment

1. INTRODUCTION
The sudden release of energy in the earth's crust creates seismic waves which arrive at various instance of time with different intensity levels are called as earthquake. It causes the random ground motion in all directions, radiating from epicenter, which causes structure to vibrate due to which induce inertia forces in them.Many existing structures are seismically deficient due to lack of awareness regarding seismic behavior of structures. Due to this, there is urgent need to reverse this situation and do the seismic evaluation of existing and new structures.

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. The equivalent static lateral loads approximately represent earthquake induced forces. Pushover analysis 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. The resulting graphic curve is an easy to visualize representation of the capacity of the building unlike in the case of conventional methods. Using this method, structures with predictable seismic performance can be produced.The three basic elements of this method are:-

Capacity: - It represents ability of the structures to resist the seismic demand.
Demand: - It represents the earthquake ground motion.
Performance: - It is an intersection point of capacity spectrum and demand spectrum.The performance of a building is depended upon the performance of the structural and the nonstructural components. After obtaining the performance point, the performance of the structures is checked against these performance levels.

Immediate occupancy: It is a damage state due to earthquake in which limited structural damages has occurred. There are negligible chances of life threatening injury due to structural failure.Life safety: It is a state in which damage to the structure due to earthquake may have occurred but in which some margin against either total or partial collapse remains. Injuries during the earthquake may occur, but the risk of life threatening injury from structural damage is very low. Collapse prevention: In this state the building has experienced extreme damage with large permanent drifts. The structure may have little residual strength and stiffness with extensive damages occurred to nonstructural elements.

In the present study bare reinforced concrete building without infill wall of G+4, G+5 and G+ 6 storeyhas been modeled and analyzed using CSi ETABS 9.7.4 software. The analysis is performed using "Nonlinear static pushover analysis" for understanding the effect of increase in number of storey of building. The results obtained from the analysis are compared in terms of seismic responses such as base shear, time period, displacement, spectral acceleration and spectral displacement along with the location of plastic hinges at the performance point of all the building structures considered respectively.

2. NUMERICAL PROBLEM
In this present study, a 3D building structures of G+4, G+5 and G+6 storeys has been modeled and analyzed using CSi ETABS 9.7.4 software. Building structures are modeled as a bare frame without infill walls.

Table 1 General description and parameters of the structures

Story height	3.2 m
Beams size	300x450 mm
Column size	300x450 mm
Slab thickness	120 mm
Live load	3 kN/m^2
Floor finish load	1 kN/m^2
Concrete grade	M25
Steel	Fe415
Seismic zone	V
Seismic zone factor	0.36
Importance factor	1
Response reduction factor	5
Type of soil	Medium soil

The general description and parameters considered for the modeling and analysis of the structures is as shown in table 1 above.

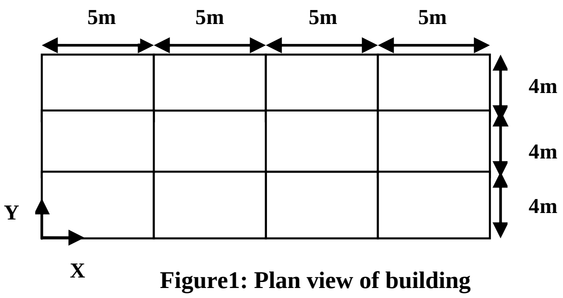


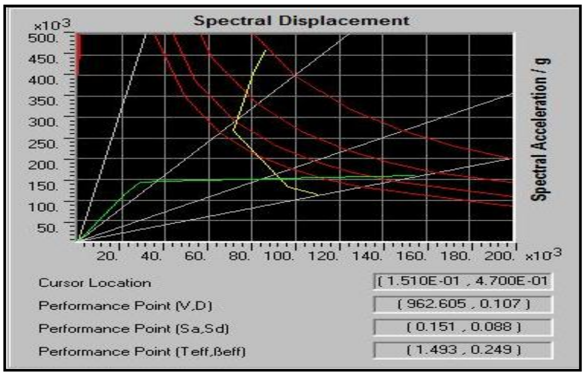
Figure1: Plan view of building

Plan view of the considered structures for analysis is as shown in figure 1 respectively.

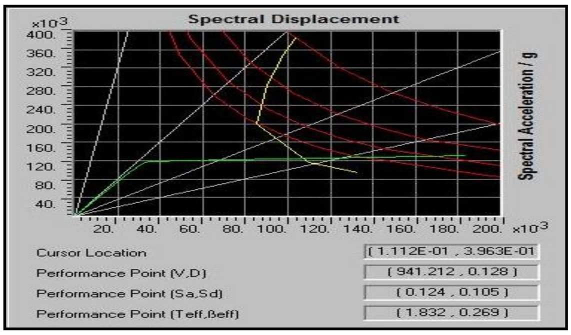
3. PUSHOVER ANALYSIS PROCEDURE

1. 3D models are created for all the considered building structures.
2. All the material properties, frame sections, load cases are defined and assigned.
3. Select all the beams and columns and assign hinge properties as per ATC-40 to the frame elements. For beams default hinge of flexure (M3) and shear (V2) is assigned and for column default hinges of axial force and bending moment (P M2 M3) is assigned.
4. Two static pushover cases are defined. Initially gravity load is applied to the structure and then lateral load along longitudinal direction is applied to the structure.
5. Initially linear static analysis is performed and building is designed as per IS 456-2000 for defined load combinations.
6. After the design of building, static nonlinear analysis is performed to determine the pushover curve and performance point.

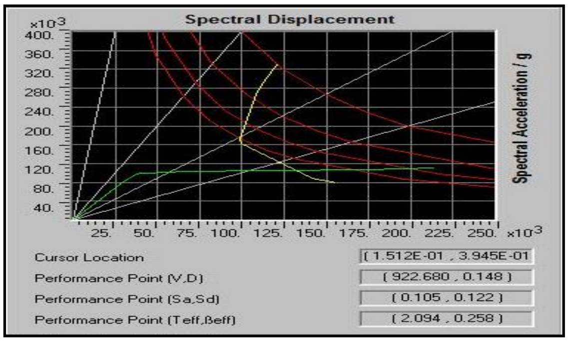
4. RESULTS



(a) G+4



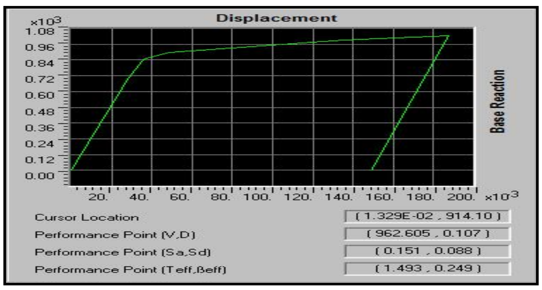
(b) G+5



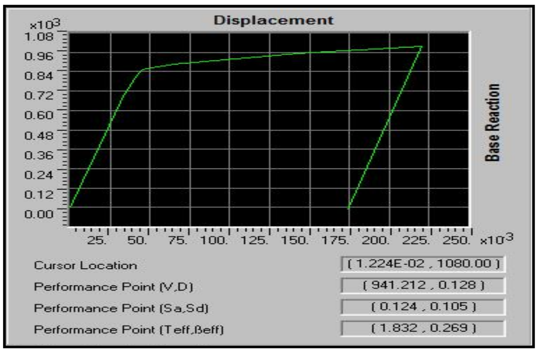
(c) G+6

Figure2: Comparison of performance point

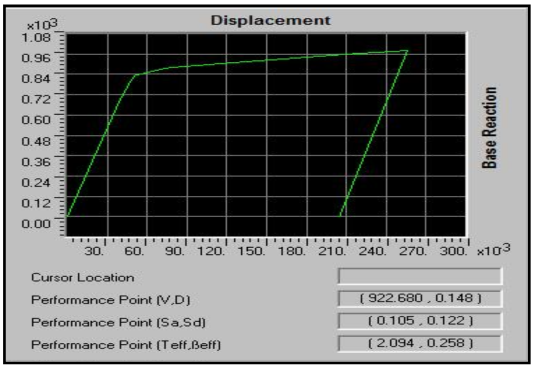
Comparison of performance point for G+4, G+5 and G+6 storey building structure is shown in figure 2 above. Performance point is obtained by intersecting capacity and demand spectrum, where demand curve is shown in yellow color and capacity curve is shown in green color. Performance point represents the global behavior of the structures.



(a) G+4



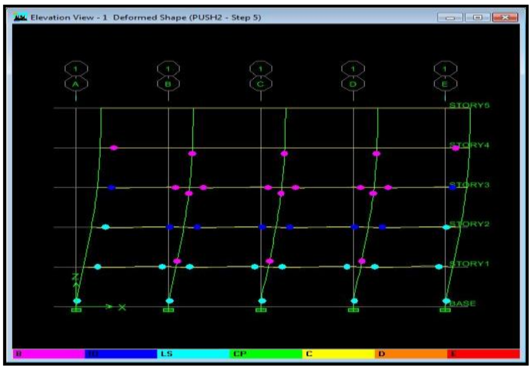
(b) G+5



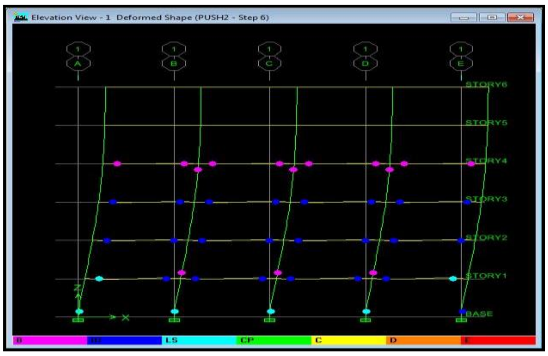
(c) G+6

Figure3: Comparison of pushover curve

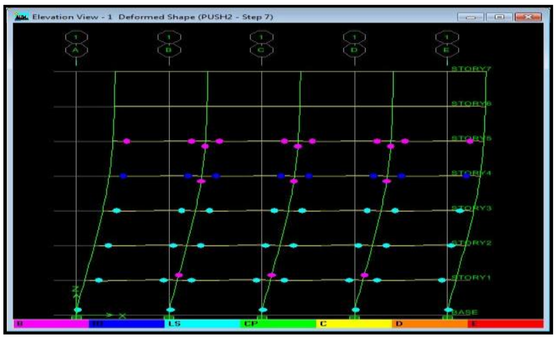
Comparison of pushover curves which are obtained from performing nonlinear static pushover analysis is shown in figure 3 above. Pushover curve shows base shear vs. displacement obtained from pushover analysis.



(a) G+4



(b) G+5



(c) G+6

Figure4: Comparative location of plastic hinges at performance point

The above figure 4 shows location of plastic hinges at performance point of the structures which is at step 5 for G+4, step 6 for G+5 and at step 7 for G+6 storey buildings.

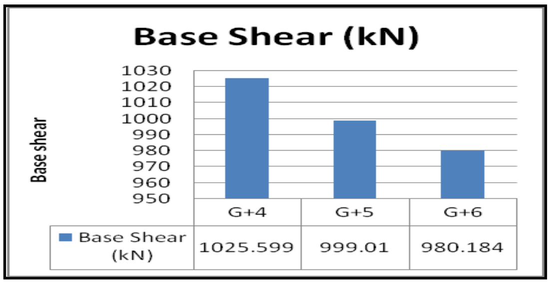


Figure5: Comparison of maximum base shear

Comparison of maximum base shears from the pushover analysis of G+4, G+5 and G+6 storey buildings is shown in figure 5 above.

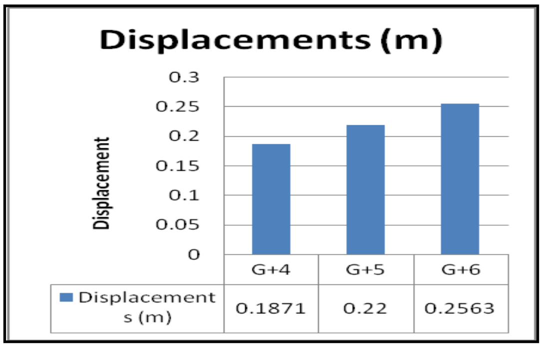


Figure6: Comparison of maximum displacement

Comparison of the maximum displacements obtained from performing pushover analysis on all the structures considered is shown in figure 6 above.

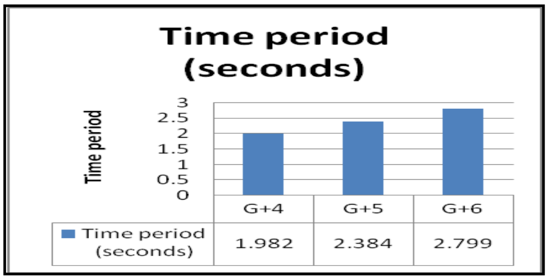


Figure7: Comparison of maximum time period

Comparison of maximum time periods obtained from performing pushover analysis on all the structures considered is shown in figure 7 above.

Table 2 Comparison of performance points

Storey number	G+4	G+5	G+6
Spectral acceleration	0.151	0.124	0.105
Spectral displacement	0.088	0.105	0.122
Damping	0.249	0.269	0.258
Base shear (kN)	962.606	941.212	922.680
Time period (seconds)	1.493	1.832	2.094
Displacement (m)	0.107	0.128	0.148

Comparison of performance points in terms of base shear, time period, displacement, spectral acceleration, spectral displacement and damping for all the structures considered for the analysis is shown in table 2 above.

5. CONCLUSION

The major objective of the present study was to understand the effect of increase in number of storey of the reinforced concrete building structure. From the analysis results, it has been observed that the base shear decreases with the increase in number of storey of the building. Whereas time period and displacement of the structure increases with the increase in number of storey. It has also been observed that spectral acceleration is reduced and spectral displacement is increased as the number of storey increases. Location of plastic hinges at performance point of the structures is also determined and it has been observed that most of the hinges lies within life safety performance level i.e. most of the hinges have moderate damage to the structural elements, but still there is residual strength and stiffness in all storey which means there will be probably no collapse locally at this level of earthquake. Pushover analysis showed actual nonlinear behavior of the structure which helps in performance based seismic design of structure.

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