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EFFECT OF BAY WIDTH ON THE HEIGHT OF THE STRUCTURE USING PUSHOVER ANALYSIS

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ABSTRACT

Configuration is critical to good structural performance of buildings earthquakes. The important aspects affecting structural configuration of buildings is overall geometry, structural systems, and load paths. The buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations. The geometry of the building consists of height of the structure, width of the structure, number and size of columns, location and orientation of columns which affects the building performance. For tall buildings the bay width of a building is one of the important considerations than just the height alone.

In the present study nonlinear performance of different height of the structures with constant bay width and same number of bays is investigated. Six models are categorised based on the different aspect ratios, they are 0.62, 1.25, 1.87, 2.5, 3.12, and 3.75 for a varying height of 15m, 30m, 45m, 60m, 75m, and 90m are considered. The base width is taken as 24m fixed in both length and breadth side with 4m of bay width and storey height is taken as 3m for all buildings. The results for effects of different aspect ratios of buildings are presented in terms of roof displacements, base shear, drift and plastic hinge formations.

KEYWORDS: *Aspect Ratio, Base Shear, Pushover Analysis, Plastic Hinge, Displacements, Drift, SAP2000*

Article History

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INTRODUCTION

The structural resistance of buildings is directly related to building configuration. In considering building configuration in relation to structural design we need a method of classification that can serve as a reference for the discussion and analysis of configuration on a systematic basis. Building configurations are extremely varied but are not random. There are three major influences they are the requirements of site, the requirements of the building occupancy, and the requirements of imagery, or aesthetic aims. In order to illustrate the interaction of these determinants it is useful to study building configuration. Building configuration may be defined as the overall geometry of the building which includes plan shape, horizontal aspect ratio or plan aspect ratio.

In this research, an attempt is made to study the effects of an aspect ratio on damage level of the structure under nonlinear behaviour. Pushover analysis is a simplified procedure to determine the displacement capacity of a building expected to deform inelastically. It is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution, until a target displacement is reached. Pushover analysis methodologies are under continuous development to predict behaviour of a structure under real earthquake. [4] The effects of building configuration on seismic performance of RC buildings by taking three buildings with three different plans having same area and height and did pushover analysis.[6] Presented about limitations of too long and too tall structures by nonlinear analysis.[3] An investigation was done by comparing four 2D frames with different aspect ratios like 2 and 4 and the frames were designed for gravity loading as well as for earthquake loading. [2] Experimented on effects of seven different aspect ratios ranging from 1 to 3.75 for the ten storey steel frame building with concentric X bracing and without bracing system. [7] Developed G+ 3 structure to evaluate the performance of frames buildings under future expected earthquakes by conducting nonlinear static pushover analysis.

In the present study to observe the behaviour of the structure in each incremental load step of pushover analysis a displacement control method is used. Based on the capacity curve of a structure, the damage state of the structure can be seen in four ranges. Point A indicates elastic state of the structure, point B a state in between elastic state and ultimate strength state, point C an ultimate strength state, point D a state in between ultimate strength state and collapse state, point E the collapse state. Along range O to C (the force-control region), strength of the structure increases nonlinearly with displacement, and along C to E (the displacement-control region), displacement increases but strength reduces.

In this paper investigation is carried out to study the effect of bay width on the height of the building. For this purpose, six models are used with differentaspect ratios. The bay width and number of bays are kept constant and height of the building is increased by increasing number of stories. 3D modelling is employedand nonlinear performance and damage pattern is studied using pushover analysis.

Details of the Structure

To study the effects of aspect ratios, six models are considered like 5, 10, 15, 20, 25, 30 storey models with an aspect ratio of 0.62, 1.25, 1.87, 2.5, 3.12, and 3.75 as shown in figure 2. Plan area for all models is 24x24m with typical floor-to-floor height is 3m. The plan area view for all buildings, are shown in figure 1. There are 6 bays with 4m bay width in both the directions and buildings are designed according to Indian codes of practice for plain and reinforced concrete (IS: 456) and earthquake resistant design (IS: 1893). The buildings are assumed to be situated in seismic zone V of IS: 1893–2002, with an intensity of 0.36g ground acceleration. Material properties are assumed to be 25 MPa for the concrete compressive strength, and 415 MPa for steel yield strength, for both, longitudinal and transverse reinforcement.

Modelling

Analyses have been performed using SAP2000, which is a general-purpose structural analysis program for static and dynamic analyses of structures. In this study, SAP2000 Nonlinear Version 20 has been used. A description of the modelling details is provided in the following. A three dimensional model of each structure is created in SAP2000 to carry out nonlinear static analysis. Beam and column elements are modelled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of the beams and columns. The hinges are located at 5% from beam and column end. SAP2000 implements the plastic hinge properties described in FEMA-356 (or ATC-40). As shown in Fig 3. Five points labelled A, B, C, D, and E define the force–deformation behaviour of a plastic hinge. The values assigned to each of these points vary depending on the type of element, material properties, longitudinal and transverse steel content, and the axial load level on the element. SAP2000 provides default-hinge properties and recommends PMM hinges for columns and M3 hinges for beams. Once the structure is modelled with section properties, steel content and the loads on it, default hinges are assigned to theelements (PMM for columns and M3 for beams). There is no extensive calculation for each member.

RESULTS AND DISCUSSIONS

Base Shear

Figure 4shows the base force results for six different aspect ratios with bare frame models. The Ultimate base shear for six different aspect ratios was observed. By increasing aspect ratio, the base shear increases linearly with the displacement, after reaching certain base shear the building yields. After reaching the ultimate strength the base shear decreases gradually and the maximum base shear is observed for higher aspect ratio.The reason for the increase in displacement and increase in base force is due to change in height with fixed base width.

Roof Displacement

The roof displacement of bare frame structures with six different aspect ratios is shown in figure 5. It has been observed that the increase in aspect ratio increases the displacement of the structure. Comparing displacement of all bare frame structures, it is observed that bare frame with an aspect ratio 3.75 shows maximum displacement of 1.017m and bare frame with an aspect ratio 0.62 shows minimum displacement of 0.236m.From this, we can observe thatcompared to bare frame with an aspect ratio 3.75, there is 13.76%decrease in displacement in case of a bare frame with an aspect ratio 3.12,20.45% decrease in displacement in case of a bare frame with an aspect ratio 2.5,35.79% decrease in displacement in case of a bare frame with an aspect ratio 1.87, 54.08% decrease in displacement in case of a bare frame with an aspect ratio 1.25 and 76.79% decrease in displacement in case of bare frame with an aspect ratio of 0.62. This happens due to the change in height and change in plastic hinge formations.

Drift

The story drift is the ratio of relative horizontal displacement of two adjacent floors and corresponding story height. It is observed that, 5 storey building in Y direction shows maximum drift than in X direction. In X direction maximum drift percentage shown is about 1.57% and in Y direction 1.61%. This shows the building is better in X direction as shown in figure 6. While comparing with other buildings with increase in aspect ratio to 1.25, 1.875, 2.5, 3.125, and 3.75 of aspect ratio the percentage of drift goes on decreases to 1.55%, 1.45%, 1.34%, 1.16%, and 1.15% respectively in X direction and 1.65%, 1.49%, 1.36%, 1.22%, and 1.17% respectively in Y direction. In this case the structure does not reached to 4% of drift and it is going to unstable state before reaching Ultimate state.

Plastic Hinge Patterns

The hinge patterns for 5 storey modelat performance point the hinge formations first starts with beam and later to columns at lower stories with a roof displacement of 0.140m and base shear is about 6139.62kN, then hinges propagate to upper stories. Here, lower stories are formed with immediate occupancy and hinges are evenly distributed to upper stories. At a base shear and roof displacement of 6612.15kN and 0.236m the first storey beams are in ultimate strength. When the structure went to collapse state at displacement of 0.236m and base shear is 6022.42kN the hinges are formed in beams at first floor which are in critical state, mostly middle frames and in ground floor the columns at 2^{nd}, 3^{rd}, 4^{th}, and 6^{th} frames are in life safety level.

For 10 storey model the plastic hinge patterns at performance point the hinges are formed first at 2nd and 3rd floor in beams with immediate occupancy and rest of the floors are evenly distributed. When the structure is in ultimate state at 3rd floor significant strength degradation starts with a displacement of 0.467m and base shear is about 7820.38kN. The initial failure of structure started at a base shear of 7142.10kN with a displacement of 0.459m, where the structure in 3rd floor for beams they are in critical state. Here, the hinges are distributing with immediate occupancy up to 6th floor in beams and in ground the columns are occupied hinges with immediate occupancy.

For 15 storey model the plastic hinge pattern the first yeild is occurred to beams in 2nd floor. At performance point the hinges in 3rd, 4th, and 5th are in immediate occupancy and rest of the floors are evenly occupied with a base shear and displacement of about 7161.53kN and 0.410m respectively. When the structure is in ultimate state with a displacement of 0.653m and base shear is 8193.41kN, the structure is in 4th floor for beams went to strength degradation and at ground floor the column just occupied the hinges. In collpase state the structure in 4th floor is in failure conditions for beams at a displacement of 0.612m with base shear 6722.05kN. the stresses are more concentrating at the middle of the structure, where maximum number of beams in immediate occupancy.

For 20 storey model the hinge patterns at performance point the hinges are formed first at 3rd, 4th, 5th and 6th floor in beams with immediate occupancy and rest of the floors are evenly distributed. When the structure is in ultimate state at 5th floor significant strength degradation starts with a displacement of 0.809m and base shear is about 10740.54kN. The initial failure of structure started at a base shear of 9946.86kN with a displacement of 0.789m, where the structure in 5th floor for beams they are in critical state. Here, the hinges are distributing with immediate occupancy in top floors for beams and for ground floor columns occupied hinges at edges.

For 25 storey model the hinge patterns are shown. For a given target displacement of 3.0m,direction the first yeild is occurred to beams in 1st floor. At performance point the hinges in 4th, 5th, and 6th are in immediate occupancy and rest of the floors, hinges are evenly occupied with a base shear and displacement of about 11914.16kn and 0.427m respectively. When the structure is in ultimate state with a displacement of 0.877m and base shear is 13985.54kn, the structure is in 6th floor for beams went to strength degradation. In collapse state the structure in 5th, 6th, and 7th floor is in failure conditions for beams at a displacement of 0.875m with base shear 13284.99kn. the stresses are more concentrating at the middle of the structure, where maximum number of beams in immediate occupancy.

For 30 storey model the hinge patterns at performance point the hinges are formed first at 4th, 5th, 6th, and 7th floor in beams with immediate occupancy and rest of the floors are evenly distributed. When the structure is in ultimate state at 7thfloor significant strength degradation starts with a displacement of 1.01m and base shear is about 15782.77kN. The initial failure of structure started at a base shear of 15405.19kN with a displacement of 1.03m, where the structure in 7th, 8th, and 9th floor for beams are in critical state.

CONCLUSIONS

- The base shear of six models has been compared. The building with aspect ratio of 0.62 shows least base shear, thereafter base shear significantly increases with increase in aspect ratio.
- The roof displacements of six models has been compared. The building with aspect ratio of 0.62 shows least displacement.The displacement increases with increase in aspect ratio.

- Based on Different aspect ratios drift is compared in terms of percentage.From this we can observethat the six models does not reached to 4% before reachingit, the structure went to unstable state.
- The formation of hinges for six models are observed in sequential bases. In this we can observe the maximum hinges are formed for middle frames and mostly beams are ultimate state.
- By increasing the aspect ratio, the total number of hinges formed at different performance levels also increases, which may lead to building deficiency to resist lateral loads.

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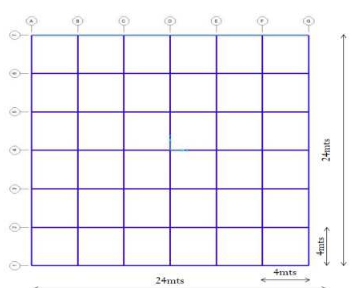


Figure 1: Plan View of Six Models.

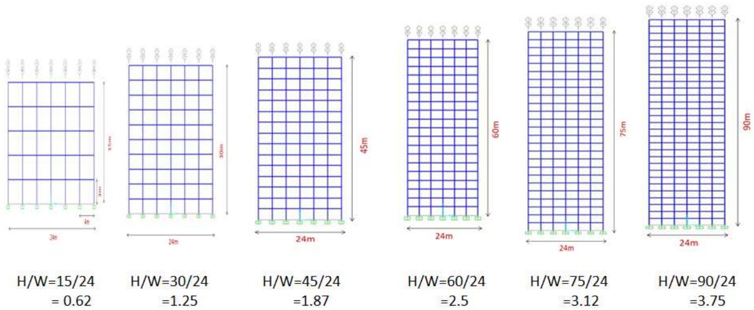


Figure 2: Elevation view of Six Models.

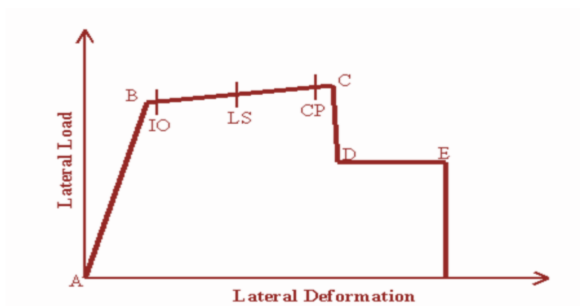


Figure 3: Performance Levels of a Load Deformation Curve.

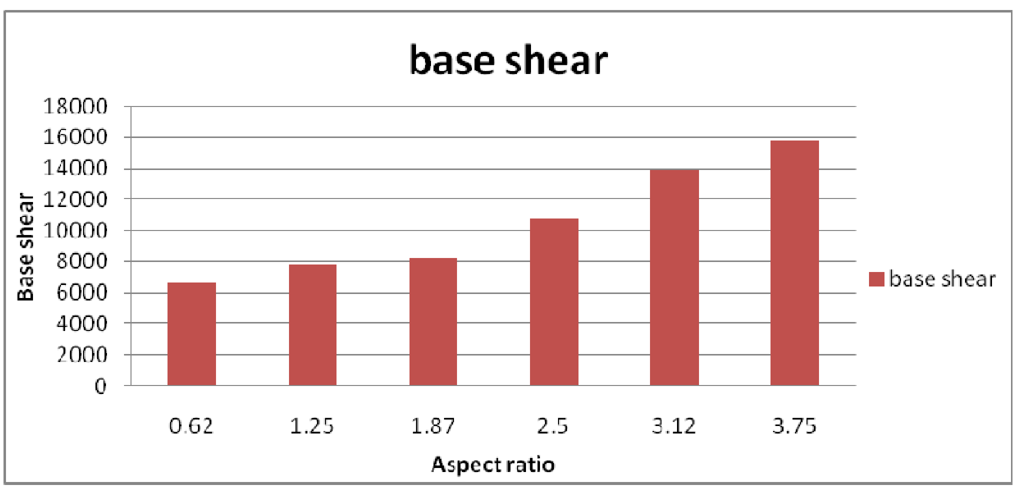


Figure 4: Base Shear Results for Six Aspect ratios.

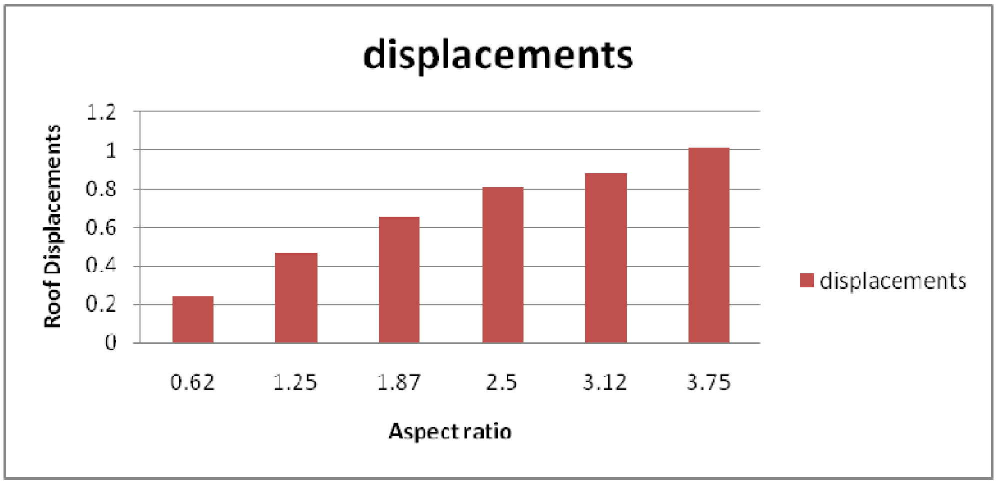


Figure 5: Roof Displacement Results for Six Aspect Ratios.

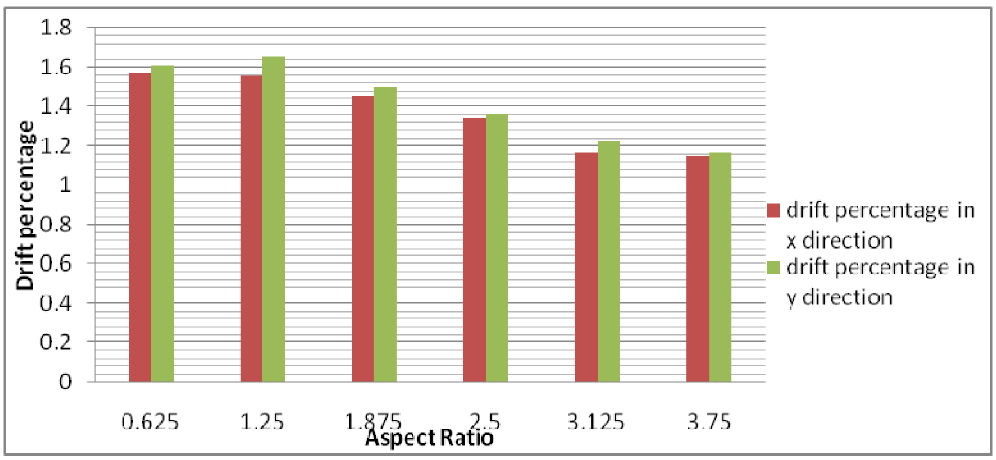


Figure 6: Comparison of Drift in X and Y Direction for Six Aspect ratios.

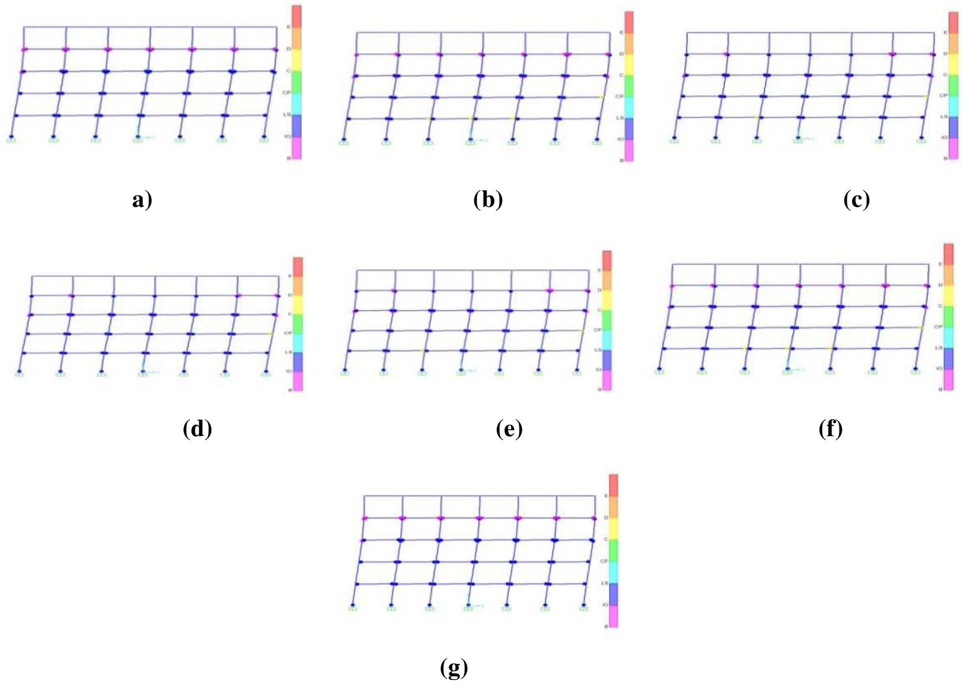


Figure 7: Sequential Formation of Plastic Hinges for 5 Storey Model.

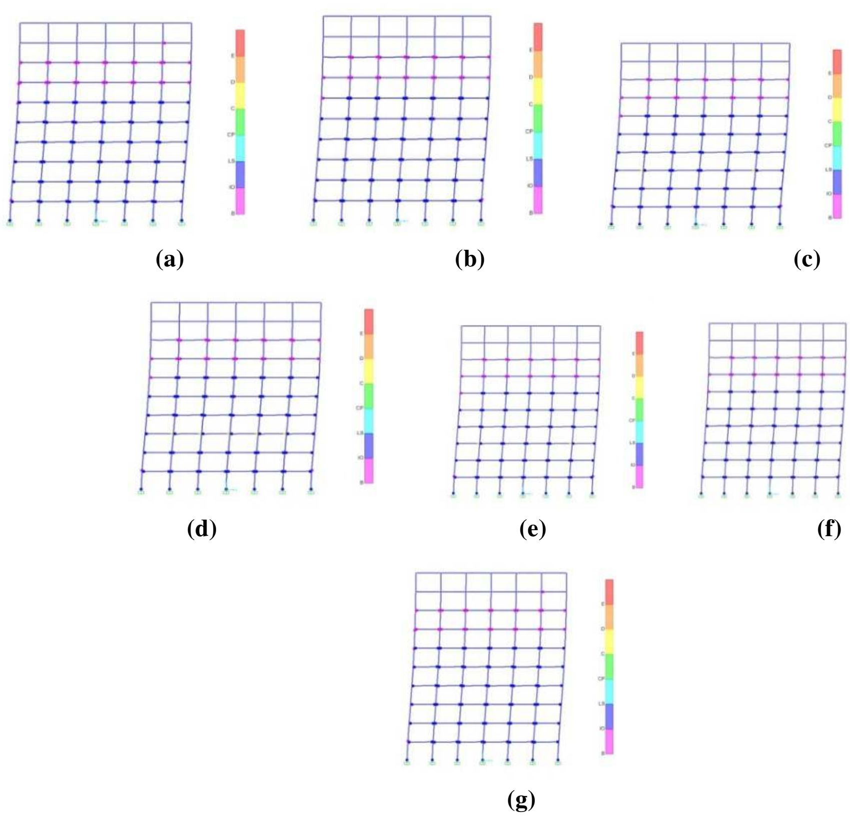
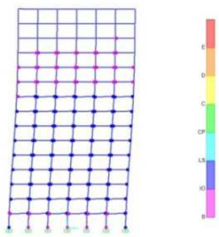
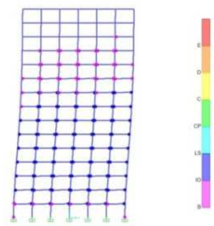


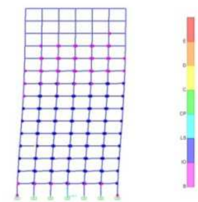
Figure 8: Sequential Formation of Plastic Hinges for 10 Storey Model.



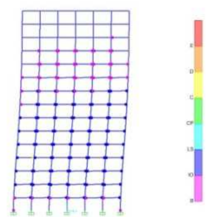
(a)



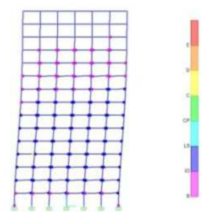
(b)



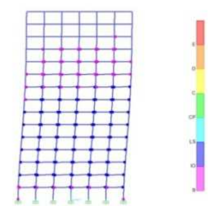
(c)



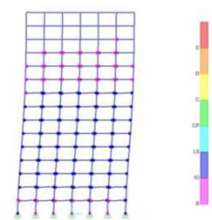
(d)



(e)



(f)



(g)

Figure 9: Sequential Formation of Plastic Hinges for 15 Storey Model.

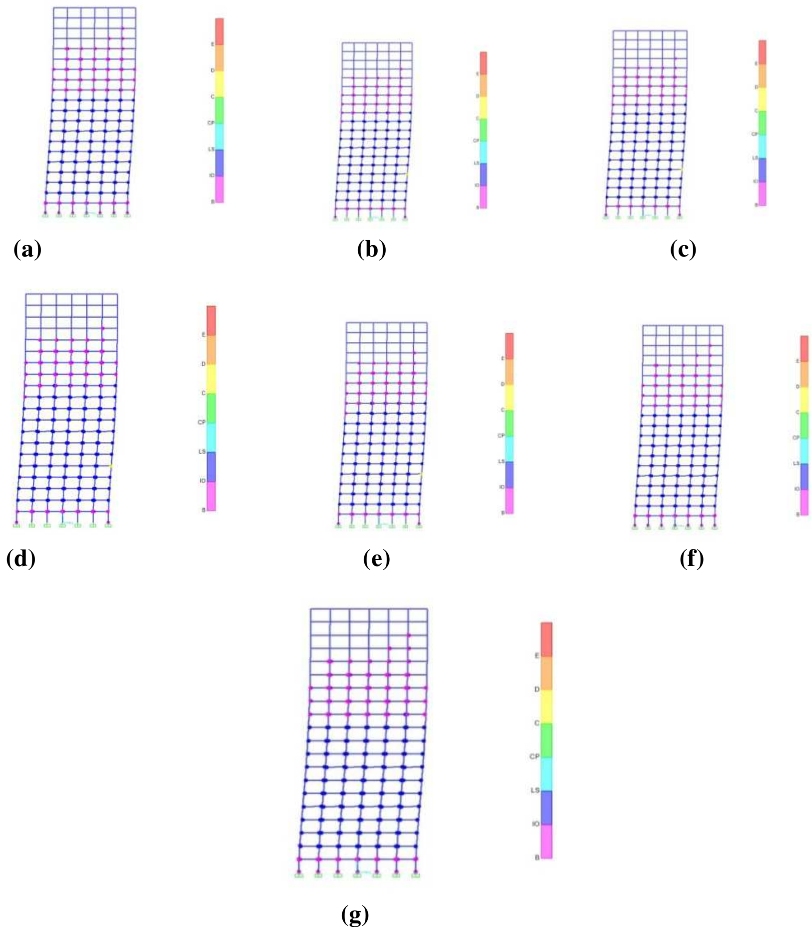
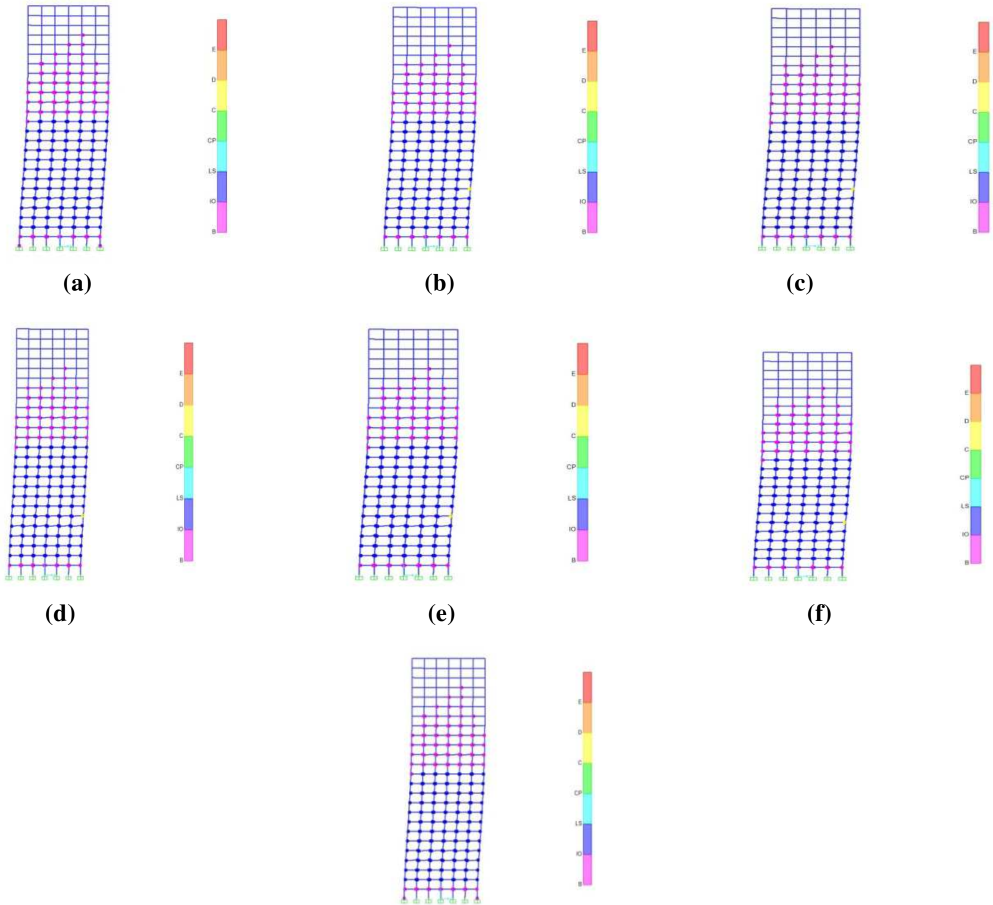


Figure 10: Sequential Formations of Plastic Hinges for 20 Storey Model.



(a) **(b)** **(c)**

(d) **(e)** **(f)**

(g)

Figure 11: Sequential Formations of Plastic Hinges for 25 Storey Model.

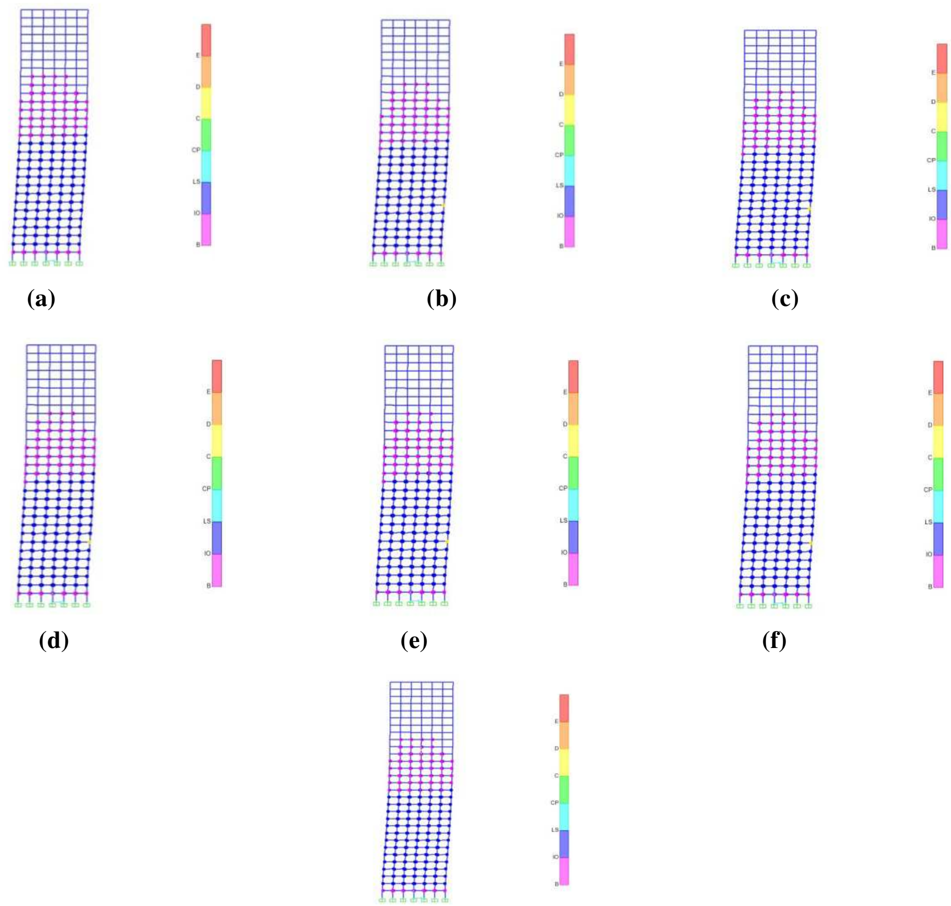


Figure 12: Sequential Formations of Plastic Hinges for 30 Storey Model.