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# Damage capacity on RC structures using performance based analysis

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**Abstract**: Performance based analysis is conducted on a structure to know the performance of building under severe earthquake loads with limited and well-distributed damage. To do this analysis a non-linear static analysis called pushover analysis had conducted on the structure. In this paper, an RC building with both 5 storey and 10 storey is designed for both gravity loads and earthquake resistant loads using SAP2000 software. Analysis is done in both X and Y direction to get a damage curve (pushover curve). By studying the damage curve, the results that obtained are earthquake resistant designed building had more strength when compared to gravity load designed building and it is better to consider earthquake in building design , because gravity loads alone cannot give the adequate results.

## 1 Introduction

Disasters are the unexpected events that effect the human life since our existence. Earthquakes are one among the natural disasters, which occur due to vibration of ground. Due to earthquake, many structures have being damaged and collapsed throughout the world, which results in huge loss of money and life. As the earthquakes are unpredictable and unpreventable, the only option left with us is to design an earthquake resistant structure. Generally, in seismically active zones, a structure has to resist both gravity loads and seismic loads. Even though if we design a structure for both gravity and seismic loads, the attempt is only to prevent the structure from collapse by allowing it to undergo some damage [1].

From past few years, there are many developments in designing an earthquake resistant building. According to present design codes, structure is designed by using traditional design approach called force-based design approach, which means the design of a structure for an elastic response for forces under design basic earthquakes. The response of a building under strong ground motion results in non-linear behavior of the structure, so that an elastic analysis is insufficient because it cannot realistically predict force and deformation after the initiation of damage in the building. So that a capacity design approach was used to improve the response of a structure under severe earthquakes but some of, the studies show that the inter-story drift and damage are not properly distributed among the structure, when designed using force-based design approach. Therefore, an alternative to force-based design approach, performance-based design approach was developed based on probable performance of building to resist the building from severe earthquake ground motion, which limited and well distributed damage [4]. So to perform a non-linear static analysis using a performance based design approach both static pushover analysis and dynamic time history analysis are most popular methods to predict the structural non-linear response under seismic loads [5].

Non-linear static analysis is not a recent development;many researchers from past few years used this analysis to analyze the structure. Ahmed Ghobarah [6] research indicated the state of development of performance based design and shows that the performance-based design has a possibility of achieving seismic assessment with uniform risk at multiple performance levels and hazard levels. To improve the seismic performance of a building, bracing systems are introduced in the building elements, such as M.R.Maheri [7] used steel X and knee braces, Macro Valente [8] used a dissipative bracing system known as braced ductile shear panel system which is composed of concentric X braces and ductile shear panels and A.Rahimi et al. [9] used X braces to retrofit the designed RC building. All these studies shows that by using the bracing system the seismic performance of the building has increased by decreasing the lateral displacement and ductility demand. Shuang Li et al. [10] conducted a non-linear time history analysis and pushover analysis on a RC frame and compared the results to know the accuracy and applicability of pushover analysis on structure, which is under collapse stage. Masood M.M.Irheem et al. [11] conducted pushover analysis using SAP2000 software on a structure with 8 different boundary conditions , different story heights and bay numbers , to know there effect on the parameters like response modification factor, over strength and ductility reduction factor. A. Ismail [12]attempted to investigate the seismic behavior of a typical existing building by conducting pushover analysis before and after retrofitting the columns by reinforced concrete, steel sections and carbo fiber reinforced polymer. To estimate seismic performance of an RC building, several developed analysis called mass proportional pushover procedure (Sun-pil kim [13] ), new multimode pushover procedure( Grigorious E.Manoukas [14]) and multi-mode adaptive displacement based pushover analysis ( Maysam Jalikhanl et al.[15] ) are used and some studies like Triantafyllos K.Makarios [16] also shows the performance of pushover analysis in determining the seismic performance of the building.

In the present study, a building with a plan of 17.5x14m is designed with two different heights of 5 and 10 story by using SAP2000 software. The buildings are designed according to the Indianstandard designcode IS 456:2000 [25] for both gravity loads and earthquake resistant loads. Then the pushover analysis is done for both models and the results are compared in between the models. The parameters observed in the results are the strength and ductility from the capacity curve we obtained after the analysis.

## 2 Pushover analysis

Pushover analysis is a non-linear static analysis, which is used to find the seismic demand of a building. A capacity curve also known as pushover curve is developed by a series of incremental static analysis. This analysis allows a keen observation of progressive yielding of each structural element when subjected to lateral load. This lateral load magnitude increases until the target displacement of the building reaches. The target displacement is nothing but it represents the top or roof displacement of the building when it is subjected to design level ground excitation. Then capacity curve represents the capacity of a structure under particular forces. It represents the relationship between base shear and roof displacement. It mainly depends on the strength and deformation capacities of the structure. It shows the building performance after the elastic zone that means once the yielding is started. According to FEMA356 [27], capacity curve of a building shows the critical position of structural elements. These critical points are known as hinges, which are nothing but point where there is a initial form of damage started. These hinge points are formed only after the yielding point.

## 3 Details of the structure

A building model with plan of 17.5x14m is modeled with 2 different building heights of 5 story and 10 story, with each story height of 3m. The column and beam dimensions of 2 buildings are given below in the table 1 and the material properties considered for building are also shown in the table 2. Following is the building plan view and elevation view, which is show in the figure 1.

**Table 1**. Beam and Column Dimensions

| Stories | Beam(mm) | Column(mm) |
|---|---|---|
| **5 story** | B1=230x300<br>B2=230x350 | C1=230x400<br>C2=400x400 |
| **10 story** | B1=300x500<br>B2=300x600 | C1=750x750<br>C2=600x600 |

**Table 2**. Building Parameters

| | |
|---|---|
| Concrete | M30 |
| Steel | HYSD415 |
| Supports | fixed |
| Diaphragm | Shell elements for slab |

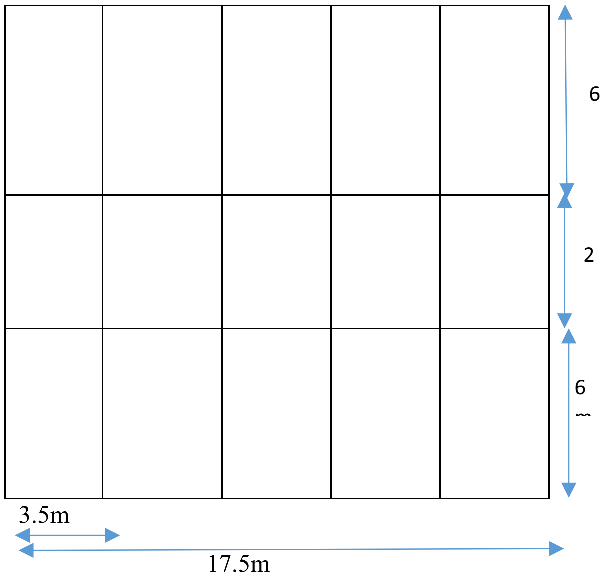
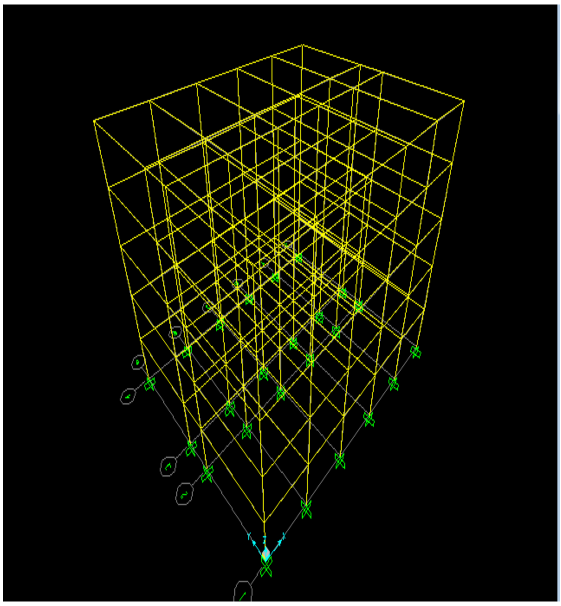


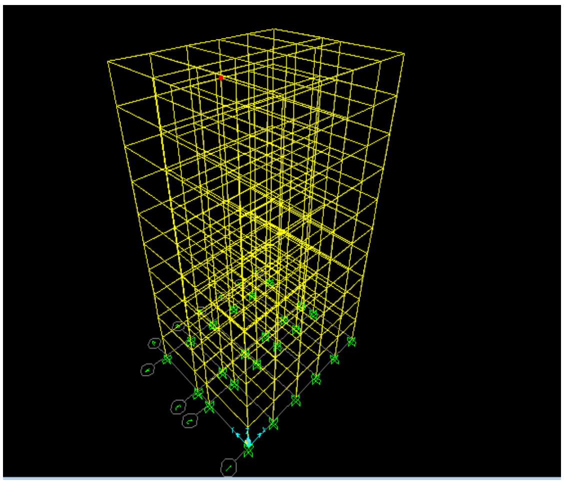

**Fig.1.** Plan for 5 story and 10 story Building

## 4 Modelling details

A building model with plan dimension of 17.5m x 14m, with two different building heights of 5 story and 10 story are modeled, with each story height as 3m. The model is designed as shown in figure 2 and analyzed using the SAP2000 software. The support conditions are fixed with building material properties as, the grade of concrete considered is M30and grade of steel considered is Fe 415. The section properties of the building elements are defined and assigned by deciding the sizes of the elements according the deflection criteria prescribed in the Indian standard codes (IS 13920:2016,IS 456-2000) [25]. Constraint type for Reinforced concrete slab and roofs are considered as a diaphragm. The modeled building analyzed by using linear dynamic analysis and designed for critical load combination as per Indian standard code (IS 456-2000) [25]. For conducting the pushover analysis, the beams and columns are assigned with default moment (M3) hinges and coupled axial moment(P-M2-M3)hinges respectively. The building model is defined with new load cases as push X and push Y, by considering minimum number of save steps as 500 and maximum number of save steps as 1000 and maximum number of null steps per stage as 500.The building is designed and analyzed for both gravity loads and seismic loads separately. The seismic load combinations are considered according to the Indian design code(IS 1893: 2016) [26].



**(a) 5 story**



**(b) 10 story**

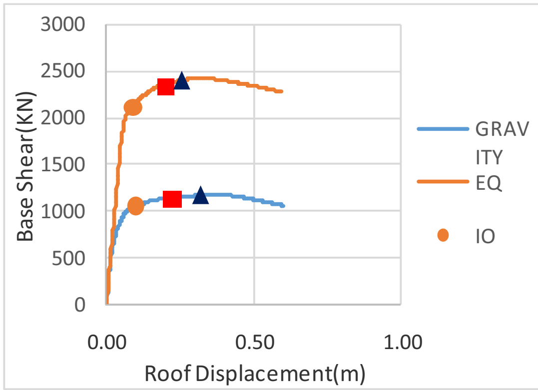
**Fig.2**. 3D building model in SAP2000

## 6 Results

A RC building with two different story heights of 5 story and 10 story, with a building plan of 17.5 x 14m is modeled and designed by using SAP2000 software. Each individual model is designed for both gravity loads and earthquake loads respectively. Then the pushover analysis is done for both gravity design structure and earthquake resistant design structure for two different load cases, such as PUSH X and PUSH Y. By analyzing, the building models we get a capacity curve also known as damage curve, which helps in defining the strength and deformation capacity of the structure. Following are the capacity curves obtained for 5 story and 10 story model for both PUSH X and PUSH Y load cases, which are designed for both gravity and earthquake loads shown in figure 3 and 4. The capacity curve represents base shear on X axis and roof displacement on Y-axis. Capacity analysis of these structures can be done by using these capacity curves and the three points IO (immediate occupancy), LS and C obtained from the curve. According to the FEMA 356 [27], these points on the curve indicates the formation of hinges in the structure after the formation of the yield point.

**5 Story**

**Push X**




**Push Y**

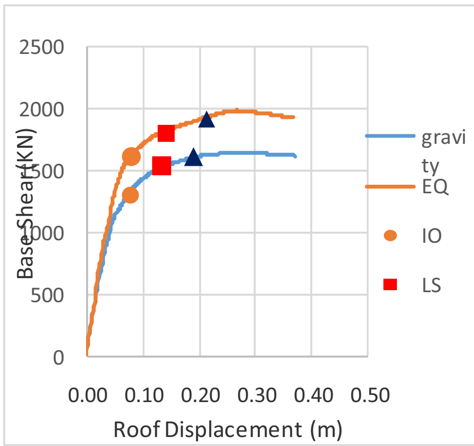



**Fig.3.** Pushover curve for 5-storybuilding

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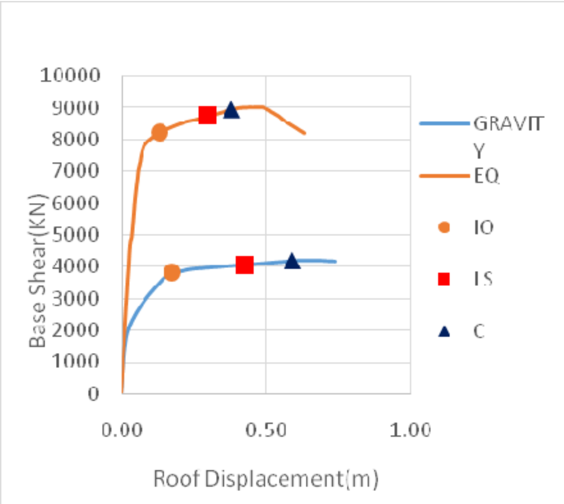
**10 Story**

**Push X**




**Push Y**

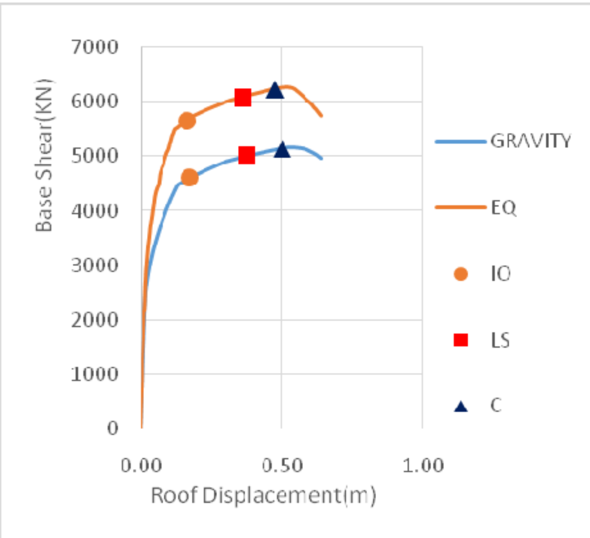



**Fig. 4**. Pushover curve for 10-story building

Capacity analysis of the building can be done, by using these capacity curves and the three points IO (immediate occupancy), LS (life safety) and C (collapse) obtained from the graphs. According to the FEMA 356 [27], these points on the curve indicates the formation of hinges in the structure, which only form after the formation of yield point. These hinge points shows the critical positions in the building elements. Hinge positions of a 5-story building after analysis is as shown in the figure 5.

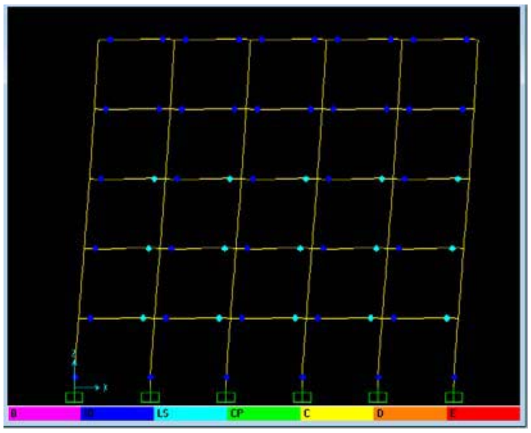


**Fig. 5.** formation of hinge points

## 7 Conclusions

In this study, by comparing the capacity curves obtained from the pushover analysis, we conclude that

1. Stiffness of the frame is larger in the earthquake resistant design building when compared to the gravity load design. That means the earthquake resistant design building has a greater capability to resist lateral loads that the gravity load design structure.
2. At every deformation steps of the pushover analysis, it determines the plastic hinge location in the elements and hinges reaches the FEMA limit states , which are IO, LS and C
3. By predicting failure mechanism, we can identify the week elements using pushover analysis. Therefore, it helps in redistribution of forces during progressive yielding and helps engineers to take action on rehabilitation work.
4. From the Results obtained, we can say that a structural engineer should consider earthquake during building design, because the design considering only gravity load was found inadequate.

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