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Non-linear static analysis of multi-storey building by using SAP2000

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Abstract — *Pushover analysis is a static, nonlinear procedure using simplified nonlinear technique to estimate seismic structural deformations. It is an incremental static analysis used to determine the force-displacement relationship, or the capacity curve, for a structure or structural element. In technique a computer model of the building is subjected to a lateral load of a certain shape (i.e., inverted triangular or uniform). This study aims at evaluating and comparing the results of different methodologies namely the ones described by the ATC-40 and the FEMA-273 using nonlinear static procedures, with described acceptance criteria. The methodologies are applied to an existing building designed as per the IS 456-2000 and IS 1893-2002 (Part II) in the context of Performance Based Seismic Design procedures. It gives clear idea about the performance of building by applying different load combination .*

Keywords*-Non-linear static analysis, performance based design, capacity curve, performance point, base shear, literature review*

I. INTRODUCTION

The term earthquake can be used to describe any kind seismic event which may be either natural or initiated by humans, which generates seismic waves. Earthquake generally occurs by rupture of geological faults but they can also occur due some natural as well as un natural activities like volcanic activity, mine blasts, landslides and nuclear tests. A sudden release of energy in the earth's crust creates seismic wave which ultimately results into earthquake. In recent years, substantial amount of study has been carried out in order to evaluate building's performance during a seismic event. During seismic action, the building is expected to deform in-elastically and therefore seismic performance evaluation is required considering post-elastic behavior of the structure. Performance based seismic design is a modern approach to earthquake resistant design of RC buildings.

One of the procedures is the static pushover analysis which is becoming a popular tool for seismic performance evaluation of existing and new structures. In particular, the seismic rehabilitation of older concrete structures in high seismicity areas is a matter of growing concern, since structures venerable to damage must be identified and an acceptable level of safety must be determined. To make such assessment, simplified linear-elastic methods are not adequate. Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based structures and are moving away from simplified linear elastic methods towards a more non linear technique.

II. LITERATURE REVIEW

1. Pushover curve :

Govind M., Shetty K.K. and Hegde A.K. have studied non linear static pushover analysis of irregular space frame structure with and without t shaped columns. In the present study, the behaviour of G+20 storied R.C frame buildings (H shape in plan, with and without T shaped column) subjected to earthquake, located in seismic zone III is discussed briefly using ETABS software. Gravity loads and laterals loads as per IS 1893-2002 are applied on the structure and it is designed using IS 456. Displacement control pushover analysis is carried out.
The results of pushover analysis of reinforced concrete frames designed according to the IS1893:2002 has been presented. The behaviour G+20 storied R.C frame buildings (H shape in plan, with and without T shaped column) subjected to earthquake, located in seismic zone III is also discussed briefly using ETABS software.
RCC frame model is developed using ETABS software and pushover analysis is done on the H shaped plan model with rectangular column (with and without T shaped column). The result obtained from the analysis is analyzed and compared each other.

Table 1 : Detail and dimension of building

Type of structure	Ordinary moment resisting RC frame
Grade of concrete	M 40 (fck= 40 N/mm2)
Grade of reinforcing steel	Fe 415 (fy = 415 N/mm2)
Plan area	960 m2
Number of stories	G + 20
Floor height	3.5m
Column size:	230 × 1500 mm
	300 × 1500 mm
	230 × 1800 mm
	300 × 1800 mm
	T shape B=1.5m, D=1.5, tw &tf =0.3m
Beam size	230 × 600 mm
Slab thickness	130 mm
Wall thickness	230mm
Density of concrete	25 N/mm3
Live Load on Floor and roof	3 KN/m2 and 1.5 KN/m2
Density of wall	20 N/mm3
Diaphragm	semi rigid diaphragm
Plan irregularity:	H shape

- **Results :**

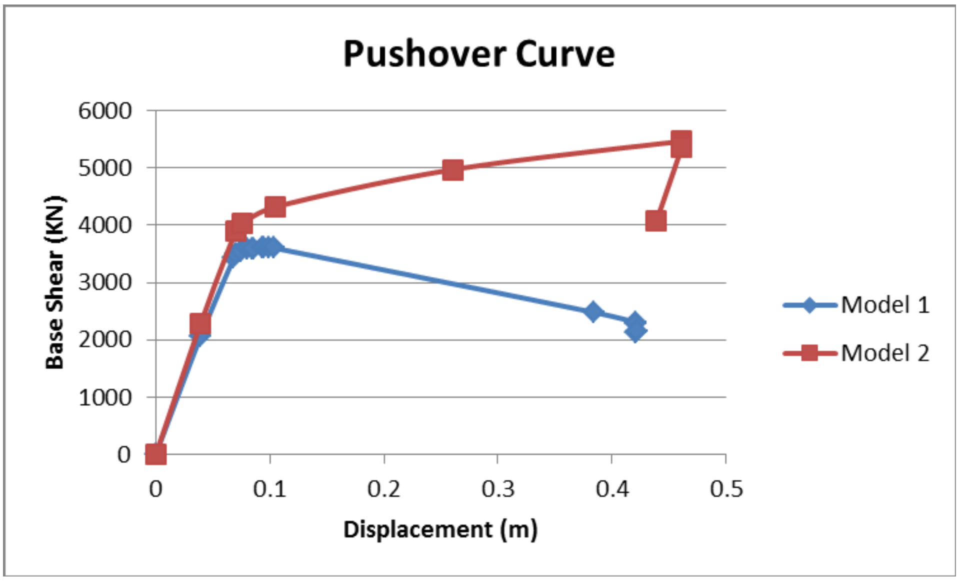

Chart 1 : Post elastic behaviour of bare frame for Pushover Load – EQY

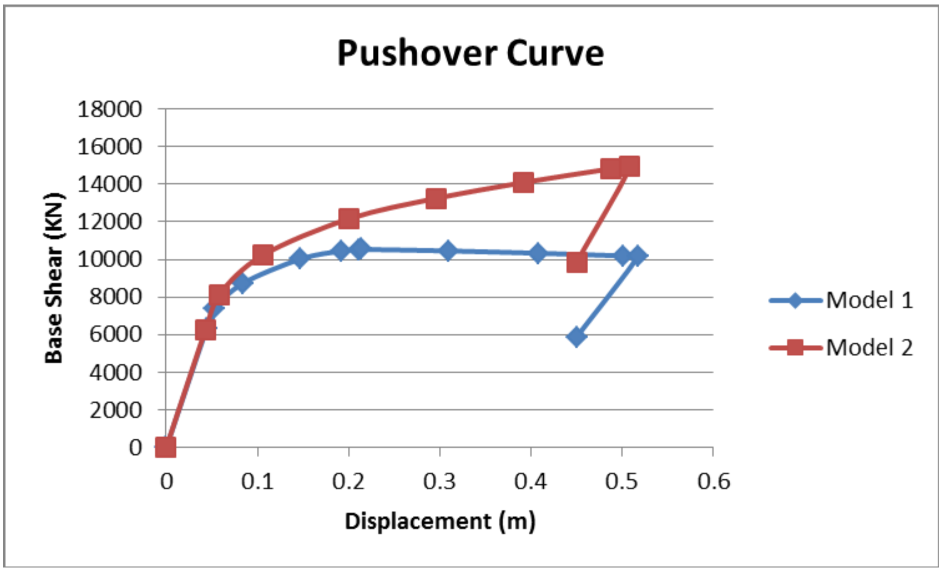

Chart 2 : Post elastic behaviour of bare frame for Pushover Load – EQX

When earthquake load is applied in X direction, it is found that model with T shaped column can resist more base shear than Model with rectangular column. When earthquake load is applied in Y direction, it is found that model with T shaped column can resist more base shear than Model with rectangular column. But the percentage increment is acceptable. The results obtained in terms of demand, capacity spectra shows real behaviour of structures.

Mohammad A., Nikhade A.R. have studied the pushover analysis on reinforced concrete structure. In which G+10 building was subjected to push in x and push in y direction analysis was done in sap2000 15. They have evaluate G+10 multistory building subjected to earthquake forces in zone II and III. pushover analyses are performed on case study frames using SAP2000.

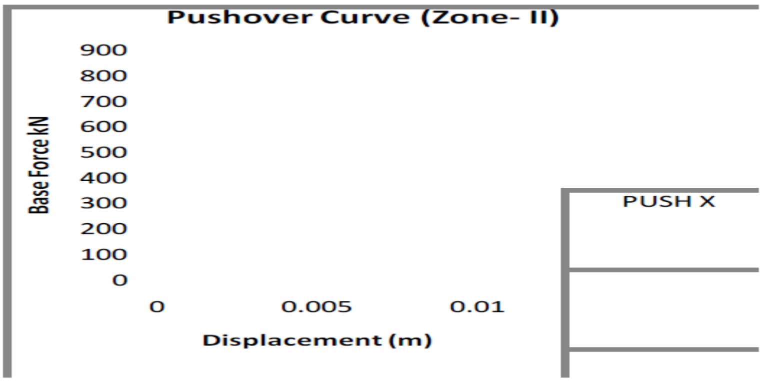

Chart 3 : pushover curve zone II- Push-X

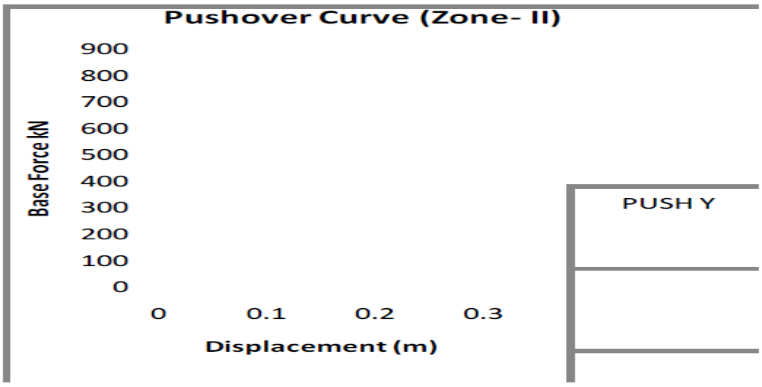

Chart 4 : pushover curve zone II- Push-Y

Raut A.V., Prof. Prasad RVRK have studied pushover analysis of G+3 reinforced concrete building with soft storey. They highlights the importance of explicitly recognizing the presence of the open first storey in the analysis of the building and also for immediate measures to prevent the indiscriminate use of soft first storeys in buildings. Modeling for such analysis requires the determination of the nonlinear properties of each component in the structure, quantified by strength and deformation capacities, which depend on the modelling assumptions. Pushover analysis is carried out for either user-defined nonlinear hinge properties or default-hinge properties, available in some programs based on the FEMA-356 and ATC-40 guidelines. This paper aims to evaluate the zone –II selected reinforced concrete building to conduct the non-linear static analysis (Pushover Analysis). The pushover analysis shows the pushover curves, capacity spectrum, plastic hinges and performance level of the building. This non-linear static analysis gives better understanding and more accurate seismic performance of buildings of the damage or failure element.
The pushover analysis is a simple way to explore the nonlinear behaviour of the buildings. The results obtained in terms of pushover demand, capacity spectrum and plastic hinges the real behaviour of structures. In a four storey building seismic zone –II is designed and constructed using IS-456-1978 and the revised code IS-1893- 2000 provisions. Hinges have developed in the beams and columns showing the three stages immediate occupancy, Life safety, Collapse prevention. The column hinges have limited the damage.

We can conclude that from the results of pushover curve as the storey increases the value of base shear as well as displacement value increases. From that we can change the design of building, as per different zone.

2. Base shear

Bansal A., Patidar A. have studied pushover analysis of multistory buildings having flat slab and grid Slab. They compare the results of multi-storey buildings having flat slab with that of having grid slab and to study the effect of base shear, storey drift and maximum displacement on it under seismic forces. three cases of multi-storey buildings are considered with area 20 m x 20 m having 4 storey, 8 storey and 12 storey with 3.6 m storey height considered. All the three cases are considered having flat slab and grid slab, and also analyzed by using software SAP2000.

Base Shear and Displacement				
No. Of Storeys	Flat Slab		Grid Slab	
	Displacement	Base Shear	Displacement	Base Shear
4	90.65	5439.03	80.45	5434.70
8	116.31	6732.87	90.72	6799.41
12	161.09	8428.65	106.31	8469.65

Table 2 : Base shear vs. displacement

From the result we can say that resultant displacements for flat slab are quite larger than in grid slab models. Base shear in both types of slabs is almost similar. For seismic loadings flat slab is deflected more than that of grid slab models for all the three stories considered. Lateral displacement in flat slab model is more than that in grid slab model.

Shinde D.N., Nair V.V. and Pudale Y.M. have carried their work on pushover analysis of multy story building. In the present study a building frame is designed as per Indian standard i.e. IS 456:2000 and IS 1893:2002. The main objective of this study is to check the kind of performance a building can give when designed as per Indian Standards. The pushover analysis of the building frame is carried out by using structural analysis and design software SAP 2000. The analysis involves applying horizontal loads, in a prescribed pattern, to 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 or collapse condition.
They were taken a case study of building frame of G+10 floors is considered. It is consisting of two bays in both the directions. The spacing along X and Y directions is 5m and the story height is taken as 3m. The frame is located in seismic zone III.

Results :

The design Base shear, VB = $A_h \times W$, IS: 1893 (Part 1): 2002,clause 7.7.1 VB = 0.022x 32677 = 720 KN .

For pushover analysis the various pushover cases are considered such as push gravity, push X (i.e. loads are applied in X direction), push Y (i.e. loads are applied in Y direction). The various load combinations are also used for this purpose. After pushover analysis the demand curve and capacity curves are obtained to get the performance point of the structure.

The performance point is obtained as per ATC 40 capacity spectrum method. The base shear for PUSH X load case is (904.612 KN). And for PUSH Y base shear at performance point is (915.197) as shown in figure

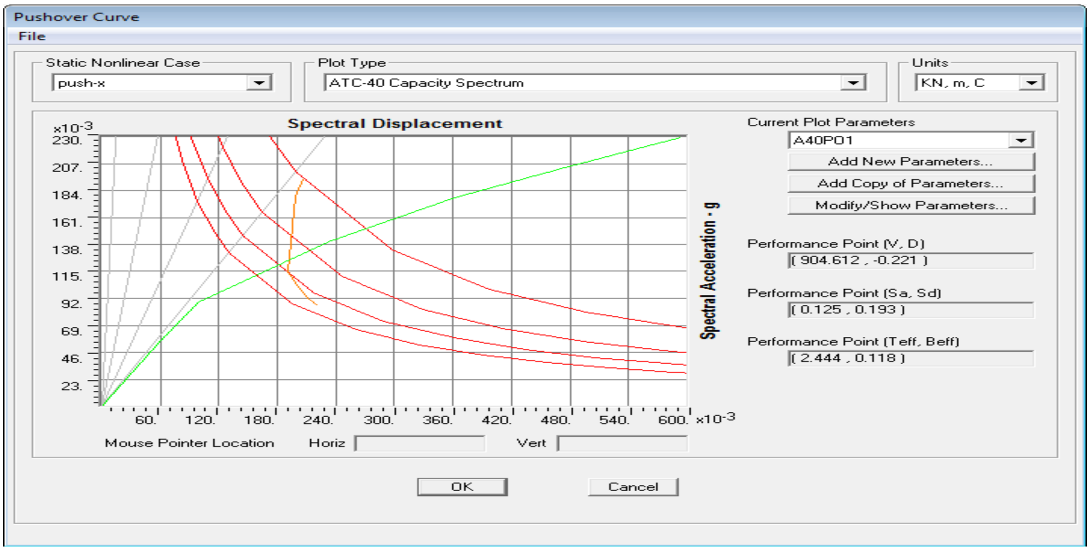

Figure 3 : Capacity and demand curves for PUSH X load case

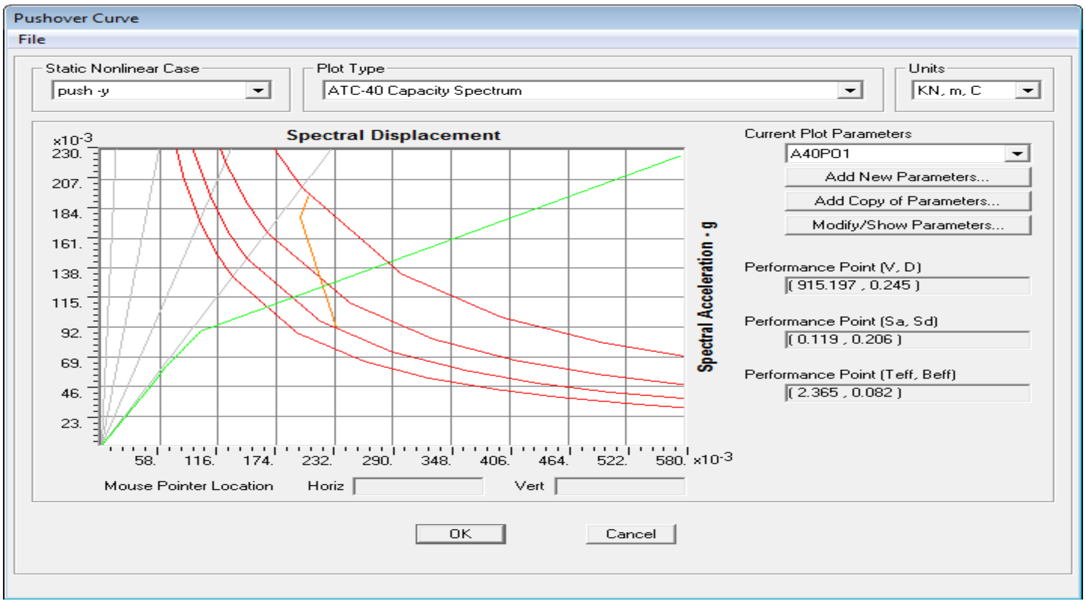

Figure 4 : Capacity and demand curves for PUSH Y load case

Building designed with IS 1893:2002 found to have a better performance under given earthquake. The design base shear of the building frame is found to be 720 KN as per calculation. After performing the analysis the base shear at performance point is found to be 915KN which is greater than design base shear. Since at the performance point base shear is greater than the design base shear the building frame is safe under the earthquake loading.

From the results we can say that base shear value in both types (flat slab and grid slab) of slab is almost similar. But for lateral displacement flat slab has higher value than grid slab. There is minor difference between manual and software calculation for base shear, it may be acceptable. The value of performance point is higher than the design value so our design is safe.

3. Storey drift

Rahman M.K., Ajmal M. and Baluch M.H. have presents a 3D nonlinear static analysis for seismic performance evaluation of an existing eight-story reinforced concrete frame-shear wall building in madinah. The building has a dome, reinforced concrete frame, elevator shafts and ribbed and flat slab systems at different floor levels. The 3D static pushover analysis was carried out using SAP2000 incorporating inelastic material behaviour for concrete and steel. The structure is an existing municipality building located in madinah, Saudi Arabia constructed in 1996.The building has eight stories with typical story height 3.2m for five stories and the rest of three story height are 4.2m,2.4m and 5m.Plan area of the building is 40 x 40 m. The building has a dome, reinforced concrete frame, elevator shafts and ribbed and flat slab systems at different floor levels. From the available design data, the strength of concrete is 30 MPa and reinforcement is 420 MPa. The slab load composed of self-weight and superimposed load (D) and 25 % of the live load (L),where D= self-weight + 1.435 kN/m²,L= 4.8 kN/m² for all story and for roof D= self-weight + 1.925kN/m² , L= 2.4kN/m² ,respectively.

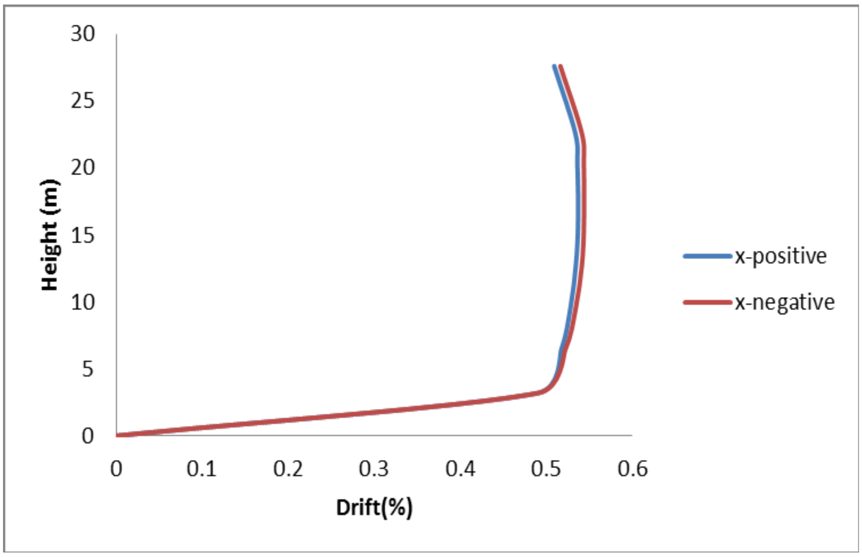

Chart 5 : Storey drift ratio of the building

Pushover analysis of the madinah municipality building showed the building is deficient to resist seismic loading. Formation of hinges clearly shows that the members of the building are designed purely for gravity loads as with a small increment of displacement, most of the members start yielding. Pushover curves show non-ductile behavior of the building, because almost all the seismic load is carried by the shear walls and at very small displacement, hinges start forming in shear walls.

From storey shear results give the idea about the performance of building in different zones. As the floors increases the storey drift increases and it identify the weak point of the building. From the results we can say that storey drift in positive X and negative X direction is almost same. That indicates the strengthening of the shear wall in the building is required.

III. SUMMARY

From all the review of above papers we can say that pushover analysis was very useful method for checking the performance of the building by subjecting the buildings in different seismic zones. By adopting the results of pushover curve, demand curve, base shear, storey drift etc. gives the clear idea about the performance of building. It shows that non-linear static analysis was very useful tool for checking the performance of building. As the floor increases , the storey drift increases. Pushover curve show non-ductile behavior of the building. Base shear was calculated by IS: 1893 (Part 1): 2002, clause 7.7.1.

IV. CONCLUSION

All the above reviews conclude that to understand the seismic behaviour of building subjected in different seismic zone. Pushover analysis for the buildings were carried out by the guidelines given in the code ATC40 and FEMA356. They compare the results like base shear, performance point, storey drift etc. From that they conclude that as the building goes higher means increase in floor, it may reduced the performance of building. The results shows that the base shear decreases as the no. of storey increases. But for time period and displacement of the structures increase with the increase in floors. By conducting pushover analysis for different buildings, pushover curve and demand curve can be obtained and compared with models. The pushover analysis is a simple way to explore the nonlinear behavior of building. Pushover analysis can identify weak elements by predicting the failure mechanism and account for the redistribution of forces during progressive yielding. It may help engineers take action for rehabilitation work.

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