Pushover Analysis of Multi-Storey RC Building with Different Structural Configuration

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ABSTRACT

The paper presents a simple computer - based pushover analysis technique for performance - based design of the building framework subject to earthquake loading. The technique used is nonlinear static pushover analysis. In this study G+10 multi-storey RC building with different structural configuration, bare frame, shear wall and infill wall is modeled and analyzed with the help of SAP2000 software. From output of analysis different parameters like base shear, displacement, effective damping, effective period, spectral acceleration and spectral displacement is obtained and compared. It is seen that at roof level displacement in bare frame is more than other two structural configurations and base shear is maximum in the frame with shear wall due to more self weight. Maximum hinges formed are between B - IO range.

Keywords – Pushover Analysis, Bare frame, Shear wall, Infill wall, Nonlinear.

1. INTRODUCTION

India has had a number of the world's greatest earthquakes in the last two decades. In fact more than fifty percent area in the country is considered prone to damaging earthquakes. The north eastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0, after 2001 Gujarat Earthquake and 2005 Kashmir Earthquake. There is a nation - wide attention to the seismic vulnerability assessment of buildings. Also, a lot of efforts were focused on the need for enforcing legislation and making structural engineers and builders accountable for the safety of the structures under seismic loading. The seismic building design code in India (IS 1893, Part-1) is also revised in 2002. The magnitudes of the design seismic forces have been considerably enhance in general, and the seismic zone's of some regions has also been upgraded. There are many literatures available that presents step-by-step procedures to evaluate multi-storey buildings. This procedure follows nonlinear static (pushover) analysis as per FEMA 356.

1.1 Pushover Analysis

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified.

1.2 Target Displacement

The fundamental question in the execution of the pushover analysis is the magnitude of the target displacement at which seismic performance evaluation of the structure is to be performed. The target displacement serves as an estimate of the global displacement of the structure is expected to experience in a design earthquake. It is the roof displacement at the center of mass of the structure. In the pushover analysis it is assumed that the target displacement for the MDOF structure can be estimated as the displacement demand for the corresponding equivalent SDOF system transformed to the SDOF domain through the use of a shape factor. Under a Non-linear Static Procedure, a model directly incorporating inelastic material response is displaced to a target displacement, and resulting internal deformations and forces are determined. The mathematical model of the building is subjected to monotonically increasing lateral forces or displacements until either a target displacement is exceeded, or the building collapse. The target displacement is intended to represent the maximum displacement likely to be experienced during earthquake.

1.3 Non-linear Static Analysis using SAP2000

The ATC-40 and FEMA-273 documents have developed modeling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force deformation criteria for hinges used in pushover analysis. As shown in Figure 1, five points labeled A, B, C, D, and E are used to define the force deflection behavior of the hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.) The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-273 documents.

SAP2000, a state-of-the-art, general-purpose, three-dimensional structural analysis program, is used as a tool for performing the pushover. The SAP2000 static pushover analysis capabilities, which are fully integrated into the program, allow quick and easy implementation of the pushover procedures prescribed in the ATC-40 and FEMA-273 documents for both two and three-dimensional buildings.

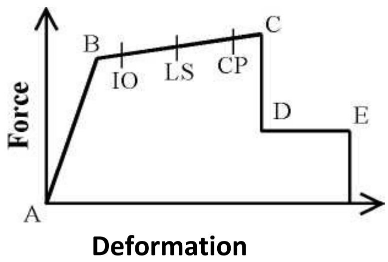


Fig. 1 Force v/s Deformation Curve

2. MODELLING AND ANALYSIS

2.1 Material Properties

M-20 grade of concrete and Fe-415 grade of reinforcing steel are used for all the frame models used in this study. Elastic material properties of these materials are taken as per Indian Standard IS 456 (2000). The short-term modulus of elasticity (*Ec*) of concrete is taken as:

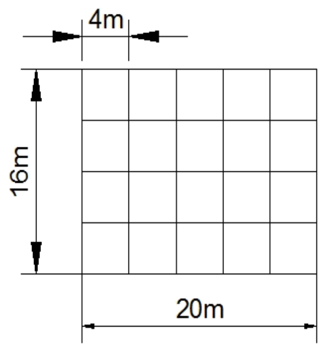
$$Ec = 5000\sqrt{fck} \text{ MPa.}$$

Where *fck* = characteristic compressive strength of concrete cube in MPa at 28-day (20 MPa in this case). For the steel rebar, yield stress (*fy*) and modulus of elasticity (*Es*) is taken as per IS 456 (2000).

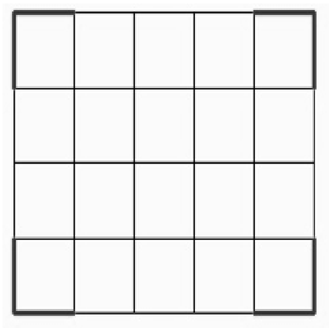
The concrete possessed the following properties:
(a) Modulus of Elasticity (E) = 22360680 kN/m^3
(b) Poisson Ratio (U) = 0.15
(c) Density = 25 kN/m^3
(d) Coefficient of thermal expansion (A) = 5.500E-06
(e) Shear Modulus (G) = 9722035
The reinforcing steel possessed the following properties:
(a) Modulus of Elasticity (E) = 1.999 E+08 kN/m^3
(b) Poisson ratio (U) = 0.3
(c) Density = 76.9729 kN/m^3
(d) Coefficient of thermal expansion (A) = 1.170E-05
(e) Shear Modulus (G) = 76923077
The masonry infill has the following material properties:
(a) Density – 20 KN/m^3
(b) Young's Modulus (E) – 11000000 KN/m^3
(c) Poisson's Ratio – 0.3
(d) Alpha – 1.170E-05
(e) Shear Modulus (G) – 4230769

2.2 Building Geometry

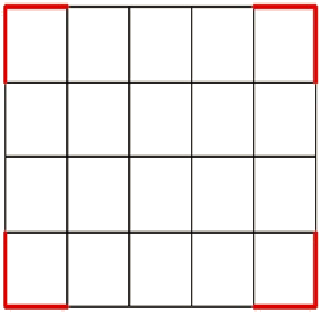
G+10 building with bare frame and L type shear wall and infill wall at corner were taken for the study. Building models with a uniform bay width of 4m (X and Y direction) and storey height equal to 3.3m were considered for this study. The structures are modeled by using computer software SAP-2000 (v18.2.0). The column sections defined for the frames satisfy both the requirements for strength and stiffness. All the selected models were designed with M-20 grade of concrete and Fe-415 grade of reinforcing steel as per Indian Standards. Shear wall is modeled as a shell element and infill wall as equivalent diagonal strut. Fig. 2 shows different types of building models taken for the study.



Model 1 (Bare Frame)



Model 2 (L Type Shear Wall at Corner)



Model 3 (L Type Infill Wall at Corner)

Fig. 2 Different Building Models Taken For the Study

TABLE - I

Particular	Details
Plan Size	20m x 16m
No. of Bays in X Direction	5
No. of Bays in Y Direction	4
No. of Floors	G+10
Storey Height	3.3m
Depth Of Foundation Below Ground	1.8m
Type Of Soil	Type II, Medium As Per IS:1893
Grade of Concrete	M-20
Grade of Steel	Fe415
Column Size	500mm x 500mm
Beam Size	450mm x 300mm
Slab Thickness	150mm
External Wall	230 mm (Brick Masonry Wall)
Internal Wall	150 mm (Brick Masonry Wall)
Shear Wall	230 mm (Reinforced Concrete Wall)
Infill Wall	230 mm (as equivalent strut)
Dead Load External Wall	13.11KN/m^2
Dead Load Internal Wall	8.55 KN/m^2
Dead Load Parapet Wall	6.9 KN/m^2
Dead Slab Load	3.75 KN/m^2
Live Load on typical floors	3 KN/m^2
Roof Live Load	1.5 KN/m^2
Floor Finish Load	1.0 KN/m^2
Roof Treatment Load	1.5 KN/m^2
Earthquake Load	As Per Is-1893 (Part 1) – 2002
Wind Load	As Per Is: 875-Not Designed For Wind Load, Since Earthquake Loads Exceed The Wind Loads.
Building Importance Factor	1
Response Reduction Factor	5
Zone Factor	0.36

Table-1: Particular and Details for All Building Models

3. RESULT AND DISCUSSION

3.1 Capacity Spectrum

"Base acceleration was plotted with respect to Roof displacement is known as capacity spectrum". Capacity spectrum has capacity curve and demand curve. Performance point values are found out when capacity curve crosses or intersects the demand curves (the performance point is the point where the capacity curve crosses or intersects the demand curves). From capacity spectrum the performance point of the structure and roof displacement are obtained. In fig. 3, 4 and 5 capacity spectrum for Model 1, 2 and 3 are shown, green line in the fig. showing capacity curve and the orange line showing demand curve and the point where this lines intersect is called as performance point, which shows global behavior of the structure. By the help of the capacity spectrum, performance point of the building is found in terms of base shear and displacement (V, D), capacity and demand (S_a, S_d) and effective period, effective damping (T_{eff}, B_{eff}). For the present work demand curve is plotted for seismic coefficient of 0.4 (Value of C_a and C_v), this value of seismic coefficient for RCC building is taken from ATC-40.

Fig. 3 Capacity Spectrum for Model 1 (Bare Frame)

Fig. 4 Capacity Spectrum for Model 2 (L Type shear wall at corner)

Fig. 5 Capacity Spectrum for Model 6
(L Type infill wall at corner)

3.2 Characteristics of Performance Point

For Model 2 (L Type shear wall at corner) the performance point of the building is found to be 1.095 seconds which is the least effective period for all the building models and for Model 1 (Bare Frame) the performance point of the building is found to be maximum i.e. 6.215 seconds, the reason for increasing period of the building is the increase in displacement of the building. Displacement increase damping and reduce the demand hence optimum point should have a higher capacity for lesser displacement. Position of the shear wall and infill wall also plays an important role in the performance of the building, as position of walls changes performance of the building changes and due to that capacity spectrum changes.
Table 2 shows the characteristics of performance point of the models as per ATC40.

TABLE - II

Model No.	Base Shear (V) KN	Displacement at roof (D) m	Effective Damping (B_{eff}) Unit less	Effective Period (T_{eff}) sec	Spectral Acceleration (S_a) Unit less	Spectral Displacement (S_d) m
Model 1	2260.783	0.214	0.399	6.215	0.027	0.259
Model 2	5024.549	0.032	0.075	1.095	0.07	0.022
Model 3	4058.973	0.046	0.085	1.641	0.053	0.035

Table-2: Characteristics of Performance Point of the Models as per ATC-40

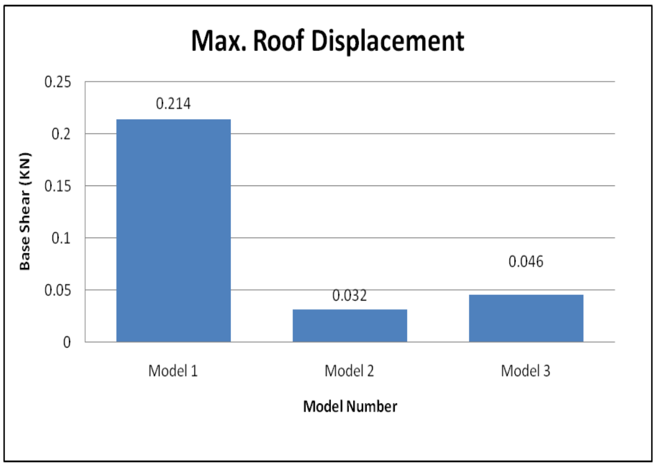


Fig. 6 Comparison of Maximum Roof Displacement at Performance Level

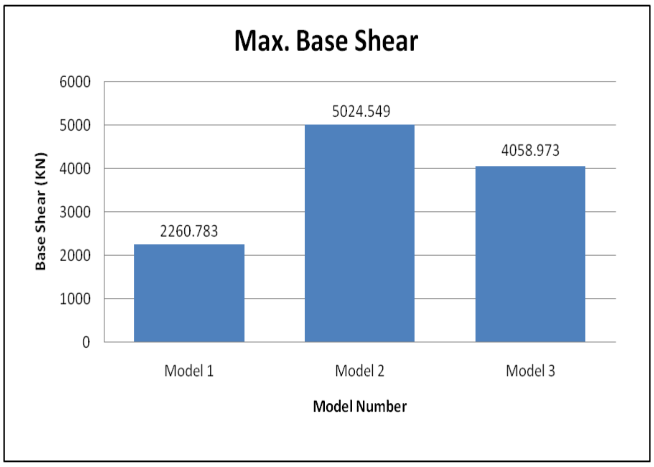


Fig. 7 Comparison of Maximum Base Shear at Performance Level

Minimum roof displacement 0.032 m is obtained in Model number 2 (L Type shear wall at corner) because shear wall is present at the corner of building which give more strength, stiffness and resistance to displacement to the building, Maximum roof displacement 0.214 m is obtained in Model number 1 (Bare Frame) as there is no infill wall or shear wall present to support the structure.

Due to more self weight maximum base shear at performance level is higher 5024.549 KN in Model 2 (L Type shear wall at corner) and least maximum base shear is 2260.783 KN obtained in the Model 1 (Bare Frame) as there is no shear wall and infill present so the weight of the structure is less.

4. CONCLUSION

Following are the important conclusion made from the present study:

1. The performed pushover analysis for the present work clearly shows that there is an important difference in the displacement of the bare frame, frames with different configuration of shear wall and infill wall.

2. Maximum roof displacement at performance level is obtained in Model 1 (Bare Frame) which is 85.05% higher than the minimum roof displacement obtained in Model 2 (L Type shear wall at corner).

3. Maximum Base Shear at performance level is obtained in Model 2 (L Type shear wall at corner) which is 55% higher than the minimum base shear obtained in Model 1 (Bare Frame).

4. Roof displacement at performance level of Model 3 (L Type infill wall at corner) is 0.046 m which is in between Model 1 and Model 2 and base shear at performance level is 4058.973 KN which is higher than the Model 1 but lower than Model 2.

5. Maximum effective period (T_{eff}) 6.215 sec is found in Model 1 (Bare Frame) which is 82.38% higher than the minimum effective period 1.095 sec found in Model 2 (L Type shear wall at corner).

6. Effective period (T_{eff}) 1.641 sec is found in Model 3 (L Type infill wall at corner) which is 33.2% higher than Model 2 but 73.6% less than Model 1.

7. The results obtained in terms of pushover demand, capacity spectrum gave an insight into the real behavior of structures.

8. The result shows that, Capacity of the buildings may be significant but the seismic demand varies with respect to the different configuration of shear wall and infill wall in building.

9. Result from the pushover analysis on the different models indicates that the shear wall have considerable strength while infill wall has lower strength. Infill wall have considerable strength as lateral resisting element and can prevent collapse of buildings in moderate earthquakes.

10. Infill walls can be used to provide supplemental stiffness for structures where existing shear wall are inadequate. Performance of a concrete infill is depend on adjacent elements especially columns, so premature failure in columns due to strong axial forces must be considered.

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