Pushover Analysis of Sloping Ground Rc-Buildings

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***Abstract*--In the present scenario, most of the buildings are often Constructed on sloping ground due to increase in population and expansion of cities there is a lack of plane Ground, since the behavior of building on sloping ground During earthquake depends upon distribution of stiffness and mass in vertical and horizontal plane, both of which vary in case of building resting on sloping ground. This paper presents an overview performance of sloping ground building subjected to Pushover analysis as assessed in ATC-40 and FEMA-356.**

The analysis is carried out by Pushover analysis using ETABS software. The dynamic properties like Base shear, Roof displacement, Mode shapes, Fundamental natural periods, Ductility ratio and Hinge status induced in the building models have been studied to check performance of the building.

Keywords: Base shear, Roof displacement, Fundamental natural period, Ductility ratio and Hinge status.

1. INTRODUCTION

Earthquakes are natural hazards under which disasters are mainly caused by damage or collapse of buildings and other man-made structures. Past experience has shown that for new construction, establishing earthquake resistant regulations and their implementation is the critical safeguard against earthquake induced damage. Earthquake damage depends on many parameters, including earthquake ground motion characteristics (intensity, duration and frequency content of ground motion), soil characteristics (topography, geologic and soil conditions), building characteristics, and quality of construction, etc. Building must be designed such as to ensure that the building has adequate strength, high ductility, and will remain as one integral unit, even while subjected to very large ground motions. Social and other factors are also important, such as density of population, time of day of the earthquake occurrence and community preparedness for the possibility of such an event. Up to now we could do little risks and thereby reduce disasters provided we design and build or strengthen the buildings so as to minimize losses based on the knowledge of the earthquake performance of different building types during an earthquake. Observation of the structural performance of buildings

During an earthquake can clearly identify the strong and weak aspects of designs, as well as the desirable qualities of materials and techniques of construction, and site selection. The proposed work is made an attempt to study the behavior of structures constructed on sloping ground and design of these structures. In sloping regions, engineered construction is constrained by local topography resulting in the adoption of either a set-back, step-back or stepback setback configuration as a structural form for buildings. The behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in case of sloping buildings.

2. ANALYSIS SIGNIFICANCE

Pushover analysis is carried out on sloping ground buildings to check performance of the building. A performance evaluation check verifies that structural and non-structural components are not damaged beyond the acceptable limits of the performance objective for the forces and displacement implied by the displacement demand. This analysis is carried out using ETABS software by preparing models of the building using design data. The performance of the building is checked by observing the values of dynamic properties like base shear, roof displacement, fundamental natural period, ductility ratio and hinge status.

3. OBJECTIVE OF THE STUDY

3.1To evaluate the performance of sloping ground buildings.
3.2 To check the weaker elements of the building so that it can be retrofitted to increase the performance of the building.
3.3 Generation of 3D building models using ETABS software.
3.4 To perform lateral load analysis on different building models.

3.5 To evaluate these building models using Pushover analysis as given in ATC-40 and FEMA-356.

4. MODELING AND ANALYSIS

4.1 Introduction to ETABS

ETABS stands for Earthquake three dimensional analysis of building system. ETABS is a special purpose computer program developed specifically for building structures. It provides the Structural Engineer with all tools necessary to create, modify, analyze, design, and optimize building models.

4.2 Design data

Model 1

Description of Setback building

Type of structures: Multi-story RC frame structures
Occupancy: Residential building, office building
Number of stories: (G+3)
Ground storey height: 2m
Intermediate floor height: 4m
Type of soil: Hard soil
Site location: Goa

Materials

M25-Concrete
Fe-415 Steel

Member dimensions

Column size: 400 mm x 600 mm
Beam size: 300 mm x 500 mm
Slab thickness: 150 mm
Wall thickness: 250 mm

Load calculation

Dead load
Periphery wall load: (4 - 0.5) x 0.25 x 22 = 19.25 kN/m
Parapet wall load: 1.2 x 0.25 x 22 = 6.6 kN/m
Floor Finish load : 1 kN/m^2

Live load

Live load on floors: 3 kN/m^2 (IS: 875 (part 2) – 1987, Table1)
Live load on roof: 1.5 kN/m^2

Data for calculation

Seismic Zone: Zone-3 (As per IS: 1893 (part 1) – 2002 pp.35)
Site location: Goa
Type of structure: Setback building
Height of the building: 14 m
Damping ratio: 5% for RC frame structures
Seismic Zone factor (Z): 0.16 (As per IS: 1893 (part 1) – 2002 Table-2 pp.35)
Importance factor (I): 1.0 (As per IS: 1893 (part 1) – 2002 Table-6 cl., 6.4.2 pp.18)
Response reduction factor (R): 3
Fundamental Natural period of Vibration (Ta) (As per IS: 1893 (part-1-2002, pp24)
Ta=0.075x $h^{0.75}$ =0.075x $14^{0.75}$ =0.54 for RC frame building
Foundation soil type = Type-1 (Hard or Rock) (As per IS: 1893(part1-2002, pp.16)

Model 2

Description of Stepback building

Type of structures: Multi-story RC frame structures
Occupancy: Residential building, office building
Number of stories: (G+4)
Ground storey height: 2m
Intermediate floor height: 4m
Type of soil: Hard soil
Site location: Goa

Materials

M25-Concrete
Fe-415 Steel

Member dimensions

Column size: 400 mm x 600 mm
Beam size: 300 mm x 500 mm
Slab thickness: 150 mm
Wall thickness: 250 mm

Load calculation

Dead load
Periphery wall load: (4 - 0.5) x 0.25 x 22 = 19.25 kN/m
Parapet wall load: 1.2 x 0.25 x 22 = 6.6 kN/m
Floor Finish load: 1 kN/m^2

Live load

Live load on floors: 3 kN/m^2 (IS: 875 (part 2) – 1987, Table1)
Live load on roof: 1.5 kN/m^2

Data for calculation

Seismic Zone: Zone-3 (As per IS: 1893 (part 1) – 2002 pp.35)
Site location: Goa
Type of structure: Setback building
Height of the building: 18 m
Damping ratio: 5% for RC frame structures
Seismic Zone factor (Z): 0.16 (As per IS: 1893 (part 1) – 2002 Table-2 pp.35)
Importance factor (I): 1.0 (As per IS: 1893 (part 1) – 2002 Table-6 cl., 6.4.2 pp.18)
Response reduction factor (R): 3
Fundamental Natural period of Vibration (Ta) (As per IS: 1893 (part-1-2002, pp24)
Ta=0.075x $h^{0.75}$ =0.075x $18^{0.75}$ =0.655 for RC frame building
Foundation soil type = Type-1 (Hard or Rock) (As per IS: 1893(part1-2002, pp.16)

Model 3

Description of Setback-Stepback building

Type of structures: Multi-story RC frame structures
Occupancy: Residential building, office building
Number of stories: (G+4)
Ground storey height: 2m
Intermediate floor height: 4m
Type of soil: Hard soil
Site location: Goa

Materials

M25-Concrete
Fe-415 Steel

Member dimensions

Column size: 400 mm x 600 mm

Model	Design Base Shear V_b(kN-m)	Performance Point	
		V_b(kN-m)	d(m)
Setback	462.67	2172.83	0.050
Stepback	663.15	2408.16	0.035
Setback-Stepback	718.18	2448.92	0.012

Beam size: 300 mm x 500 mm
Slab thickness: 150 mm
Wall thickness: 250 mm

Load calculation

Dead load
Periphery wall load: (4 - 0.5) x 0.25 x 22 = 19.25 kN/m
Parapet wall load: 1.2 x 0.25 x 22 = 6.6 kN/m
Floor Finish load: 1 kN/m^2

Live load

Live load on floors: 3 kN/m^2 (IS: 875 (part 2) – 1987, Table1)
Live load on roof: 1.5 kN/m^2

Data for calculation

Seismic Zone: Zone-3 (As per IS: 1893 (part 1) – 2002 pp.35)
Site location: Goa
Type of structure: Setback building
Height of the building: 20 m
Damping ratio: 5% for RC frame structures
Seismic Zone factor (Z): 0.16 (As per IS: 1893 (part 1) – 2002 Table-2 pp.35)
Importance factor (I): 1.0 (As per IS: 1893 (part 1) – 2002 Table-6 cl., 6.4.2 pp.18)
Response reduction factor (R): 3
Fundamental Natural period of Vibration (Ta) (As per IS: 1893 (part-1-2002, pp24)
$Ta=0.075xh^{0.75}=0.075x18^{0.75}=0.655$ for RC frame building
Foundation soil type = Type-1 (Hard or Rock) (As per IS: 1893(part1-2002, pp.16)

5. RESULT AND DISCUSSIONS

The results obtained for different building models are considered in the form of tabulation and graphs. Also discussions are made on the results obtained. The modeling and analysis is carried out in ETABS software by considering pushover analysis and the results are presented.

5.1 Base shear and Roof displacement at performance point

The seismic performance evaluation comprises of comparison between some of the 'demand' that earthquake places on structure to measure of the 'capacity' of the building to resist. Base Shear (total horizontal force at the lower level of the building) is the normal parameter that is used for this purpose. The base shear demand that would be generated by a given earthquake or intensity of ground motion and compare this to the base shear capacity of the building.

Model	Design Base Shear V_b(kN-m)	Performance Point	
		V_b(kN-m)	d(m)
Setback	462.67	1535.91	0.0019
Stepback	663.15	2257.00	0.0070
Setback-Stepback	718.18	2601.40	0.0059

Table 5.1: Performance point Base shear of models along push-X

Table 5.2: Performance point Base shear of models along Push-Y

From Tables 5.1 and 5.2, it can be observed that the base shear at performance point is higher for all models than design base shear. The tables also suggest that Setback-Stepback building has higher base shear at performance point and low roof displacement as compared to other buildings.

5.2 Mode shapes

Mode shapes of different modes of vibration of the buildings are determined. Though higher mode shapes are more of a theoretical topic, these do indicate the dynamic characteristics of a building. Mode shapes of Setback, Stepback, Setback-Step back buildings are given below.

Table 5.3: Mode shapes of building models

Mode Shape	Fundamental natural periods (sec)		
	Setback building	Stepback building	Setback-Stepback building
1	0.6337	0.5896	0.4147
2	0.5418	0.4919	0.2956
3	0.4238	0.4409	0.2700
4	0.2151	0.2000	0.1957
5	0.1876	0.1431	0.1337
6	0.1871	0.1414	0.1192
7	0.1309	0.1216	0.0951
8	0.1046	0.0945	0.0928
9	0.0973	0.0912	0.0876
10	0.0565	0.0792	0.0769

5.3 Fundamental natural periods

The natural periods obtained from seismic code IS: 1893 (Part 1)-2000 (referred to as "Codal" in the discussion) and free vibration analysis using ETABS (referred to as "Analysis" in the discussion) are shown in Table 5.4

Table 5.4: Codal and Analytical Fundamental Natural Period for Different Models

Model	Fundamental Natural Periods T(sec)	
	Code	Analysis
Setback	0.540	0.633
Stepback	0.655	0.589
Setback-Stepback	0.655	0.414

Codal and analytical values are not identical. The natural period computed analytically for Setback building is higher than that of codal value and the natural period computed analytically for Stepback, Setback-Stepback buildings are lower than that given by codal value provisions.
The analytical natural period depends on the mass and stiffness of each model in addition to its height and is different for models with different amounts of eccentricity.

5.4 Ductility ratio

Ductility of a structure, or its member, is the capacity to undergo large inelastic deformation without significant loss of strength. This is important for an earthquake resisting system because if the structure is incapable of behaving in ductile fashion then the structure collapses without yielding. Reinforced Concrete structures for earthquake resistance must be designed, detailed and constructed in such a way that the ductility factor will be at least 3 up to the point of beginning of visible damage and even greater, to point of beginning of structural damage and limitations.
The selected ductility ratio for building models are tabulated below.

Table 5.4: Ductility Ratio for the Models along Push-X

Model	Δ_{max}	Δ_y	μ
Setback	0.276	0.107	2.57
Stepback	0.186	0.020	9.30
Setback-Stepback	0.118	0.010	11.60

Table 5.5: Ductility Ratio for the Models along Push-Y

Model	Δ_{max}	Δ_y	μ
Setback	0.0239	0.003	7.96
Stepback	0.020	0.003	6.70
Setback-Stepback	0.0156	0.0046	3.39

Table 5.6: Codal values of Ductility Ratio

Maximum value of displacement ductility	Classification
<2	Low ductility demand
2 to 4	Moderate ductility demand
>4	High ductility demand

From the table 5.4, the ductility ratio for the models in push-X case ranges from 2.57 to 11.60. The Setback Buildings have moderate ductility demand and Stepback & Setback-Stepback buildings have high ductility ratio which shows high ductility demand. In push-x case the ductility demand of setback building is less compared to other models and Setback-Stepback building have high ductility of 11.60 as compare with Stepback and Setback buildings.

From the table 5.5, the ductility ratio for the models in push-y case ranges from 3.39 to 7.96. The Setback, Stepback buildings have high ductility demand, and Setback-Stepback building have moderate ductility demand. In push-y case the ductility demand of Setback-Stepback building is less compare to other models and setback building have high ductility of 7.96 as compared with and setback-stepback, stepback buildings.

5.5 Hinge status at Performance point

Performance point determined from pushover analysis is the point at which the capacity of the structure is exactly equal to the demand made on the structure by the seismic load. The performance of the structure is assessed by the state of the structure at performance point. This can be done by studying the status of the plastic hinges formed at different locations in the structure when the structure reaches its performance point. It is therefore important to study the state of hinges in the structure at performance point. The status of hinges at performance point for different models ie for set-back building, step-back building and setback-stepback building are considered for analysis.

5.5.1 Retrofitting measures

The Setback, Stepback, and Setback-Stepback buildings have some weaker elements which can be retrofitted by any of the following measures, so as to increase the performance of the building.

1. Concrete Jacketing
2. Steel Jacketing
3. Fibre Reinforced Polymer Composites (FRPC) Jacket
4. Steel braces

6. CONCLUSION

The following conclusions are drawn based on the study.
1. The maximum base shear is induced in Setback-Step back building. The base shear obtained by pushover analysis increases the performance point as compared to the design base shear.

2. The Roof displacement is found to be within permissible limits for all building models.

3. Stepback-Setback building may be favored on sloping ground which increases the performance and has less weak elements

4. The fundamental natural periods decreases as the stiffness of the building increases and there by leading to increase in base shear.

5. For the buildings studied, it is found that the plastic hinges are more in case of Setback and Stepback buildings compared to Setback-Stepback building. Hence the structural elements which lies in the range of collapse point increases the seismic vulnerability of the structure and such elements requires retrofitting.

6. The Stepback and Setback-Stepback buildings possess high ductility demand.

7. The performance of the structure increases as less hinges are formed in the structure.

8. The weaker elements in a structure can be retrofitted which increases the performance of the structure to meet the required demand.

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