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Pushover Analysis of RC Building

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Abstract: ***Pushover analysis is one of the most-used nonlinear static procedures for the seismic assessment of structures, due to its simplicity, efficiency in modeling and low computational time. The previous studies about pushover analysis are almost based on symmetric building structures and unidirectional earthquake excitation. This analysis is conducted to evaluate the seismic capacities of an existing asymmetric-plan building. The seismic response of RC building frame in terms of performance point and the effect of earthquake forces on multi storey building frame with the help of pushover analysis is carried out in this paper. In the present study the building frame is designed as per 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 (version 15).***

Keywords: Pushover analysis, RC building, Performance Point, Capacity Curve**.**

1. Introduction

Pushover analysis is stated as a nonlinear analysis in which, the nonlinear load-deformation characteristics are determined directly by incorporating the mathematical model of the building frame [1]. The response of individual components and elements of buildings can be calculated separately. Each element shall be exposed to monotonically increasing lateral loads. During an earthquake, the inertia forces generated act as the lateral loads. As the intensity of the load increases, the structure is pushed. Due this, cracks are generated at various locations. When it exceeds the elastic limit, yielding occurs and it leads to plastic hinge formations along the span of the member. The deformations are recorded as a function of the increasing lateral load up to the failure of various structural components. This load incremental process is discontinued when the target displacement is reached at the roof level [2]. Target displacement is the maximum expected displacement by combining both elastic and inelastic responses of the building under selected earthquake ground motion. Pushover analysis evaluates the structural performance by computing the force, drift capacity and seismic demand by a nonlinear static analysis algorithm. The analysis accounts for material inelasticity, geometrical nonlinearity and the redistribution of internal forces [3]. The seismic demand parameters are component deformations, component forces, global displacements (at roof or any other reference points), storey drifts and storey forces [4],[5],[6],[7],[8].

The static pushover analysis is mainly based on the assumption that the response of the structure is regulated by the first mode of vibration and mode shape, or by the first few modes of vibration, and that this shape remains constant throughout the elastic and inelastic response of the structure [1],[9],[10]. This provides the basis for transforming a dynamic problem into a static problem.

Capacity spectrum method is another approach for getting the target displacement [1]. The basic assumption is that, for the nonlinear SDOF system, the maximum inelastic deformation can be approximated from corresponding value of the linear elastic SDOF system with an equivalent period and damping, and it is same as the displacement coefficient method. In this method the term ductility is incorporated in calculation of effective period and damping. In the capacity spectrum method the pushover curve is considered in the form of acceleration-displacement response spectrum (ADRS) format [3], and is termed as capacity spectrum. The Figure 1. shows the ADRS format for the capacity spectrum method.

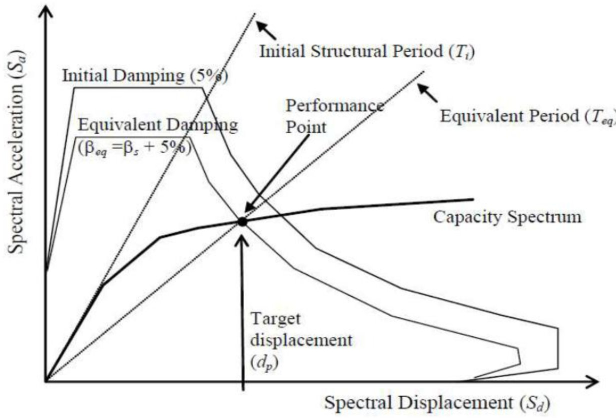

Figure 1: ADRS format

2. Analysis of the Existing RC Building

2.1. General

To check the seismic performance, an educational building situated in Kerala, India was considered. The main block is a four storey I shaped building and it consist of three portions, a central portion and left and right straight wing portions. The three portions are to be joined by expansion joints. The architectural plan of the left section is shown in Figure 2. and beam layout is as shown in Figure 3. The storey height is 4.05m. The soil type found at the site is hard laterite so isolated square footings are provided for the columns [11]. Design was carried out as per IS 456:2000 [12] and IS13920:1993 [13] for detailing.

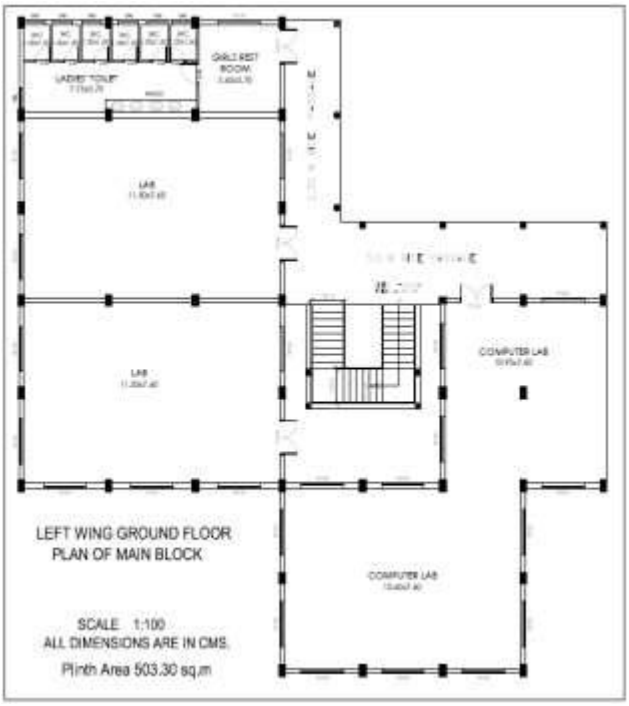

Figure 2: Ground floor plan of the building.

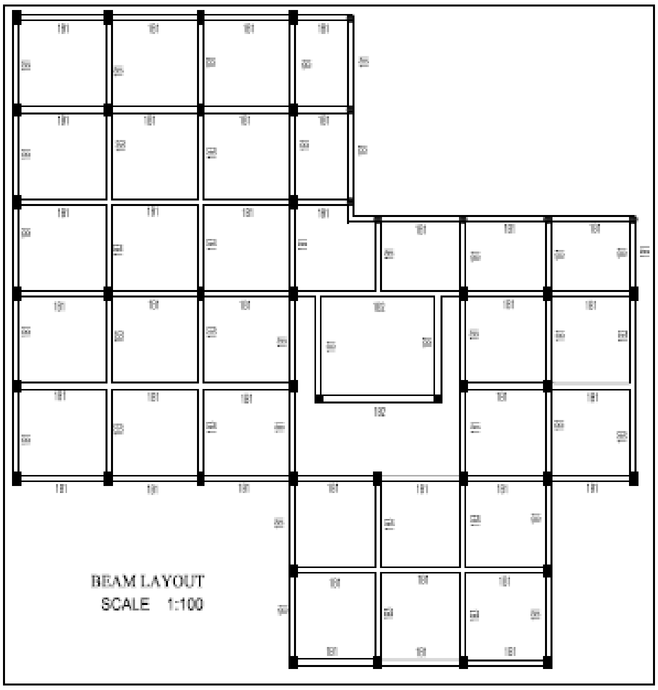

Figure 3: Beam layout of the building.

The structure analyzed is a four-storied unsymmetrical building frame, constructed with moment resisting frame of reinforced concrete with properties as specified below. The concrete floors are modelled as rigid. The floor plan is same for all floors. The concrete slab is 120 mm thick in each floor level.

2.2. Material Properties

The material used for construction is reinforced concrete with M-25 grade concrete and Fe-500 grade reinforcing steel. The Stress-Strain relationship used is as per IS 456:2000. The basic material properties used are as follows:

- Modulus of Elasticity of steel, E_s = 21,0000 MPa
- Modulus of Elasticity of concrete, E_C = 24890 MPa
- Characteristic strength of concrete, f_{ck} = 25 MPa
- Yield stress for steel, f_y = 500 MPa
- Ultimate strain in bending of concrete, ε_{cu} = 0.0035

The structure is made of various sections whose dimensions are enlisted in table 1 below. In the identification of beams, the starting number indicate the floor level and number at third place is represent the type of beam. The beam layout in plan is same for all floors. Similarly, 'C' represents column while the first numeral after it stands for the column type.

Table 1: Section properties

Identification	B mm	D mm	Top cover	Bottom cover	Top steel no - dia	Bottom steel no - dia	Dia of stirrups	Spacing of stirrups
1B1	250	400	30	30	3 no- 16	2 no- 16	8	150
1B2	250	500	30	30	4 no - 20	2 no - 20	8	150
1B3	250	750	30	30	6 no - 20	2 no-20	8	150
C1	300	300	40	40	6 no - 20	6 no - 20	8	150
C2	300	500	40	40	8 no - 20	8 no - 20	8	150
C3	300	700	40	40	8 no - 25	8 no - 25	8	150

2.3. Seismic Loads on the Building

The base shear force is calculated based as per IS-1893 (Part-1) 2002 [14], by using the formula,

$$V_B = \frac{ZI(S_a/g)}{2R}W \tag{1}$$

Here, Z = Zone factor = 0.16
I= Importance factor = 1.5 (Educational building)
R= Response reduction factor = 3 (Ordinary RC moment-resisting frames)
Sa/g = Average response acceleration coefficient for soil
(Sa/g) at x- direction = 2.06
(Sa/g) at y- direction = 2.04
W = Total Seismic weight of the building.
The dead load intensity on each floor, D.L= 17.69 kN/m^2
The live load intensity on each floor, L.L= 4.0 kN/m^2
The total floor area on each floor = 503.30 m^2
Total seismic load, W = 39639.56 kN.
The base shear, V_B = 3963.60 kN.

The base shear force is distributed as a lateral force, which affects the joint, at each level of the building. For this study, the distribution of the lateral seismic loads along the height of the building as per IS 1893 is shown in Table 2 for both directions.

Table 2: Lateral load distribution with heights

Story level	Wi (kN)	Hi (m)	Wi×Hi^2	(Wi×Hi^2)/ (∑Wi×Hi^2)	Lateral Force, Qi (kN)
4	9909.89	16.2	2600752	0.53334	2113.94
3	9909.89	12.15	1462923	0.30001	1189.11
2	9909.89	8.1	650188	0.13334	528.50
1	9909.89	4.05	162547	0.03334	132.15
		Sum	4876409		3963.70

2.4. Analysis in SAP2000

The building is a portion of a four storey educational building in seismic zone III. For the analysis of the building, the basic computer model in the usual manner was created [11]. The figure 4 shows the 3-D model of the building Frame.

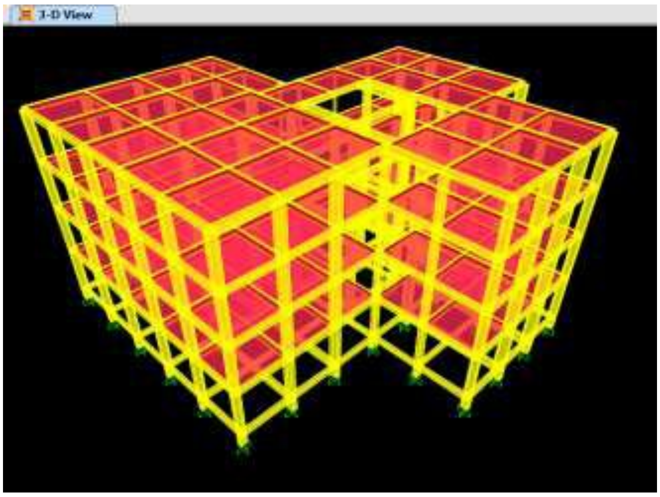

Figure 4: 3-D model of the building frame

For the pushover analysis of the building the properties of the various plastic hinges such as flexural, shear, torsional and joint hinges are defined. For every beam and column the hinge length is calculated as half of their effective depth. Shear failure mostly occur in beams and columns owing to inadequate shear design. There are a lot of existing buildings which are not detailed as per IS 13920: 1993. Also, poor construction practice may lead to shear failure in framed building in the event of severe earthquakes [4],[5]. This particular existing educational building was designed as per IS 456:2000 and detailed as per IS 13920:1993, for adequate main and shear reinforcements, corresponding to the ultimate moment capacity level. When there is no prior failure in shear, flexural plastic hinges will be developed along with the predicted values of ultimate moment capacity. Therefore, it is obvious for a code designed building to fail in flexure and not in shear and there is no need of shear hinge modelling.

3. Result and Discussion

A static non-linear (pushover) analysis of the existing educational building was carried out using SAP2000. The maximum roof displacement of 0.64 m was chosen to be applied. 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. On the above educational building frame the non-linear static pushover analysis was performed to investigate the performance point of the building frame in terms of base shear and displacement. After pushover analysis the demand curve and capacity curves are plotted to get the performance point of the structure. The performance point is obtained as per ATC 40 [1] capacity spectrum method. The base shear for PUSH X load case is 5125.533 kN and for PUSH Y base shear at performance point is at 5341.196 kN as shown in figure 5 and 6.

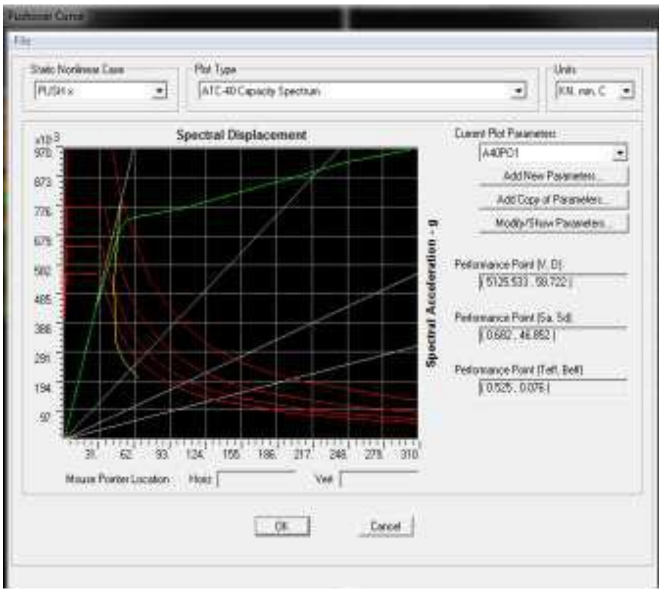

Figure 5: Performance point due to PUSH X

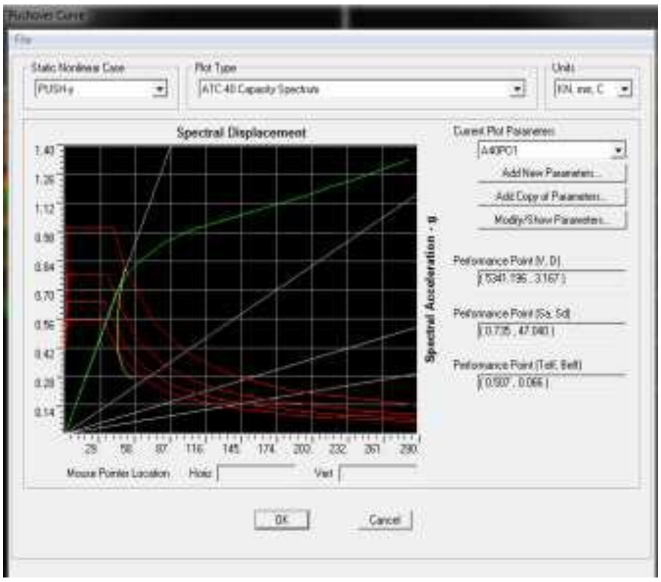

Figure 6: Performance point due to PUSH Y

The design base shear of the building frame is found to be 3963.60 kN as per calculation. After performing the analysis the base shear at performance point is found to be 5125.533 kN for X directional loading and 5341.196 kN for Y directional loading, 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. Both the pushover curves show no decrease in the load carrying capacity of buildings suggesting good structural behavior. Also due to the demand curve intersects the capacity curve near the elastic range, the structure has a good resistance.

4. Conclusions

The performance of reinforced concrete frames was investigated using the pushover analysis. As a result of the work that was completed in this study, the following conclusions were made:

- It is concluded that the existing building frame used for pushover analysis is seismically safe, because of the performance point base shear is greater than design base shear.
- Since the demand curve intersects the capacity curve near the elastic range, the structure has a good resistance and high safety against collapse.
- The behaviour of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves.

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