

# Seismic Evaluation of G+3 Story Reinforced Concrete Structure by Non-Linear Static Pushover Analysis

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## 1.1 GENERAL

The term earthquake can be used to describe any kind of seismic event which may be either natural or initiated by humans, which generates seismic waves. Earthquakes are caused commonly by rupture of geological faults; but they can also be triggered by other events like volcanic activity, mine blasts, landslides and nuclear tests. An abrupt release of energy in the Earth's crust which creates seismic waves results in what is called an earthquake, which is also known as a tremor, a quake or a temblor). The frequency, type and magnitude of earthquakes experienced over a period of time defines the seismicity (seismic activity) of that area. The observations from a seismometer are used to measure earthquake. Earthquakes greater than approximately 5 are mostly reported on the scale of moment magnitude. Those smaller than magnitude 5, which are more in number, as reported by the national seismological observatories are mostly measured on the local magnitude scale, which is also known as the Richter scale. There are many buildings that have

primary structural system, which do not meet the current seismic requirements and suffer extensive damage during the earthquake. The buildings at College were designed by primary structural system and the reason behind this is Rourkela lies in ZONE II of Seismic Zone Map of 2002 i.e. according to Seismic Zoning Map of IS: 1893-2002, which says the region is least probable for earthquakes. The institute building is a G+3 story building designed without considering the design factors of IS: 1893-2002. At present time the methods for seismic evaluation of seismically deficient or earthquake damaged structures are not yet fully developed.

The buildings which do not fulfill the requirements of seismic design, may suffer extensive damage or collapse if shaken by a severe ground motion. The seismic evaluation reflects the seismic capacity of earthquake vulnerable buildings for the future use. According to the Seismic Zoning Map of IS: 1893-2002, India is divided into four zones on the basis of seismic activities. They are Zone II, Zone III, Zone IV and Zone V. Rourkela lies in Zone II.

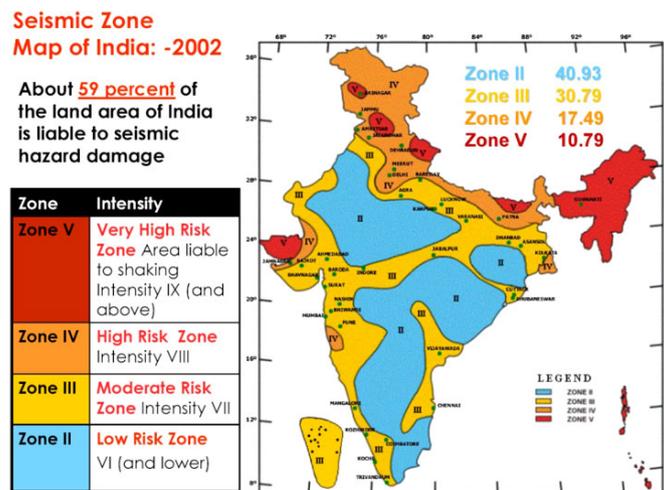


Fig. 1 Seismic zonation and intensity map of India

Fig 1.1 Seismic Zoning Map of India

The methodologies available so far for the evaluation of existing buildings can be divided into two categories-(i) Qualitative method (ii) Analytical method.

The qualitative methods for evaluation are based on the background data of the building and its construction site available, which requires some or few documents like drawings, visual inspection report, past performance of the analogous buildings under seismic activities, and certain non-destructive test results.

The analytical methods for evaluation are centered on the consideration of the ductility and capacity of buildings on the grounds of drawings which are already available.

Pushover analysis is an estimated analysis method where the structure is subjected to different monotonically increasing lateral forces, with a distribution which is height-wise invariant, until the target displacement is touched. Pushover analysis comprises of a series of successive elastic analysis, superimposed to estimate a force-displacement curve of overall structure.

First, a two or three dimensional model that includes bi-linear or tri-linear load-deformation figures of all the lateral force resisting elements is created and gravity loads are applied. Then, a predefined lateral load pattern that is distributed along the building height is applied. Until some members yield, the lateral forces are amplified. The structural model is modified in order to account for reduced stiffness of the yielded members and the lateral forces are increased again till additional members yield. This process is continued till a control displacement at top of the building reaches a particular level of deformation or else the structure becomes unsteady. The roof displacement is plotted with respect to the base shear so as to get the global capacity curve.

Pushover analysis can be performed as force-controlled or displacement-controlled. In force controlled pushover procedure, full load combination is applied as specified, i.e, force-controlled procedure should be used when the load is known (such as gravity loading). Also, in force controlled pushover procedure some numerical problems that affect the accuracy of results occur since target displacement may be associated with a very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects.

Pushover analysis has been the preferred method for seismic performance evaluation of structures by

the major rehabilitation guidelines and codes because it is conceptually and computationally simple. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as the progress of overall capacity curve of the structure.

Equivalent static method is used to seismically design most of the low and medium-rise building structures. In this method, design forces are acquired from elastic spectra that are reduced using a response modification factor. This coefficient signifies the structure's inelastic performance and specifies hidden ductility and strength of those structures in inelastic phase. The ratio of eventual deformation of the structure and its deformation in yielding is referred to as the ductility coefficient which expresses inelastic deformation capacity of these structures. The larger the value of this coefficient is, the higher the level of energy absorption is and the more the number of plastic joints formed are, as compared to before. Thus accurate determination of the yielding points and the ultimate displacements is very important. Certain failure criteria are used to evaluate the building's seismic demands in this paper. The maximum drift of the structure without total collapse under seismic loads is called the target displacement.

If the Nonlinear Static Procedure (NSP) is selected for seismic analysis of the building, a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a target displacement is exceeded. The target displacement is intended to represent the maximum displacement likely to be experienced during the design earthquake. Because the mathematical model accounts directly for effects of material inelastic response, the calculated internal forces will be reasonable approximations of those expected during the design earthquake. The relation between base shear force and lateral displacement of the control node shall be established for control node displacements ranging between zero and 150% of the target displacement,  $\delta_t$ . In order to obtain performance points as well as the location of hinges in different stages, we can use the pushover curve. In this curve, the range AB being the elastic range, B to IO being the range of instant occupancy, IO to LS being the range of life safety and LS to CP being the range of collapse prevention.

When a hinge touches point C on its force-displacement curve then that hinge must start to

drop load. The manner in which the load is released from a hinge that has reached point C is that the pushover force or the base shear is reduced till the force in that hinge is steady with the force at point D.

As the force is released, all of the elements unload as well as the displacement is decreased. After the yielded hinge touches the point D force level, the

magnitude of pushover force is again amplified and the displacement starts to increase again.

If all of the hinges are within the given CP limit then that structure is supposed to be safe. Though, the hinge after IO range may also be required to be retrofitted depending on the significance of structure.

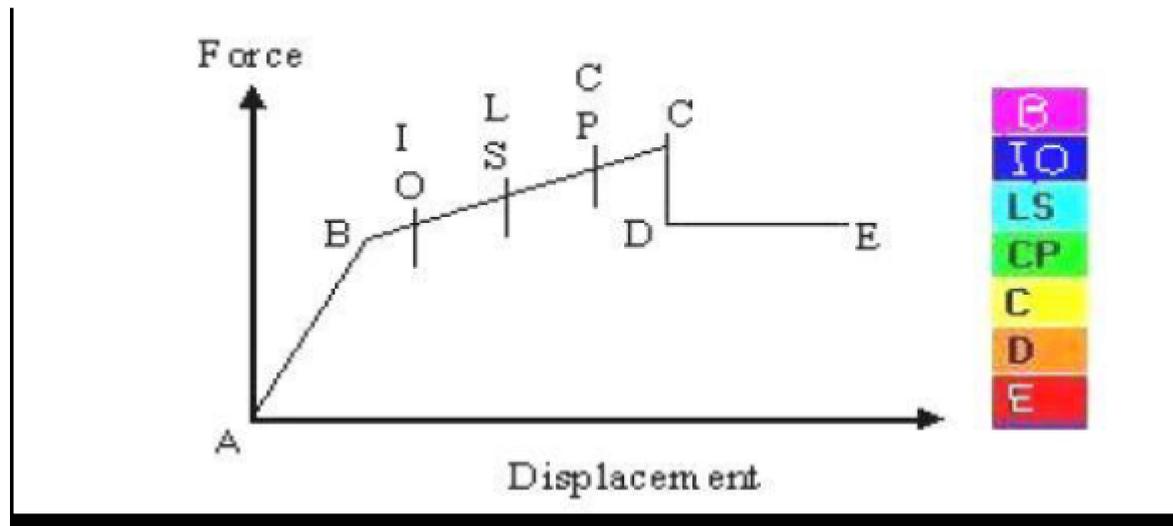


Fig. 1.2 Different stages of Plastic Hinges

The basic seismic response parameters taken into consideration are-

- (i). Stiffness
- (ii). Strength
- (iii). Ductility.

Now, if we consider any Reinforced Concrete frame building, we can summarize the sources of weakness as:

- (i). Discontinuous load path/interrupted load path/irregular load path.
- (ii). Lack of deformation capability of structural members.
- (iii). Quality of workmanship and materials.

## 1.2 PROPOSED WORK AND OBJECTIVE

My research project aims at doing seismic evaluation for the institute main building using nonlinear static analysis method. The institute main building is currently the most prominent building in the institute area. However, since it was constructed some 50 years earlier, it wasn't designed to withstand earthquakes.

A thesis done earlier using Equivalent Static Method reveals that the structure will invariably fail when subjected to earthquake loads. Except

beams of corridors which fail in both sagging and hogging moments, all other beams were found to pass in hogging moments only. In case of columns, the ground floor columns of classrooms pass in flexural strength but the ground floor column of corridor fails in flexure. Most beams and columns were found to pass in shear.

Taking the above results into consideration, our objective is to:

- (i) Analyze the seismic performance of the existing structure with more degree of accuracy by using Non-linear Static Analysis Method.
- (ii) Simulate the structure in SeismoStruct Version 5.2.2 in accordance to the design generated by STAAD.Pro v8i and run Pushover analysis for the limiting case of the structure to generate a pushover curve.
- (iii) Find the target displacement of the structure by using Idealized Force-Displacement Curve and Displacement Coefficient Method in accordance with ASCE 41-06.
- (iv) Studying the behaviour of the structure when subjected to the Pushover Analysis by limiting the maximum displacement of the top node to the calculated target displacement

### 1.3 CALCULATION

#### Calculation of Seismic Weight:

Section	Length	Number	Volume
0.43x0.37	24.12	5	19.18746
0.40x0.33	24.12	5	3.18384
0.40x0.30	24.12	5	14.472
0.62x0.40	8.89	45	99.2124
0.35x0.20	2.95	10	2.065
0.57x0.47	15.0	4	16.074
0.28x0.45	15.0	9	17.01
0.55x0.52	15.0	4	17.16
0.55x0.34	15.0	2	5.61
0.55x0.45	15.0	8	29.7

(Table 3.3 Beam and Column Section Details: Seismic Weight Calculation)

$$\text{Total volume} = 223.6747\text{m}^3$$

$$\text{Seismic weight due to dead load (beam + column)} = (223.6747\text{m}^3) \times (24\text{kN/m}^3) = 5368.2\text{kN}$$

$$\text{Seismic weight due to dead load (slab)} = (238.1\text{m}^2) \times (3.7\text{kN/m}^2) = (880.97\text{kN}) \times 4 = 3523.88\text{kN}$$

$$\text{Seismic weight due to imposed load} = (238.1\text{m}^2) \times (4\text{kN/m}^2) \times 0.5 \times 3 = 1428.6\text{kN}$$

$$\text{Hence, total seismic weight, } W = 10320.68\text{kN}$$

### 1.4 SUMMARY OF REVIEW

Pushover analysis yields insight into elastic and inelastic response of structures under earthquakes provided that adequate modeling of structure, careful selection of lateral load pattern and careful interpretation of results are performed. However, pushover analysis is more appropriate for low to mid-rise buildings with dominant fundamental mode response. For special and high-rise buildings, pushover analysis should be complemented with other evaluation procedures since higher modes could certainly affect the response.

### 1.5 CONCLUSION

- The pushover analysis is a useful tool for assessing the inelastic strength and deformation demands and for exposing design weakness. The pushover analysis is a relatively simple way to explore the non-linear behaviour of the structure.
- The pushover analysis is undertaken by loading the structure to the calculated base shear for limiting displacement, then the structure is pushed to a state of complete collapse and a pushover curve is obtained using SeismoStuct Version 5.2.2.
- Taking into account the low level of seismicity of Rourkela and the characteristic features of the structure and using ASCE 41-06, the target displacement is calculated.

- Upon loading the structure to the calculated base shear and limiting the displacement of control node, the pushover analysis reveals the structure is SAFE and hence the building does NOT need to be retrofitted.

### 1.6 FUTURE SCOPE OF STUDY

- An inclusion of shear failure limits in the performance criteria may lead to a better and more comprehensive understanding of the building's behaviour.
- Non-linear time history analysis can be used for the structure to have a more accurate assessment of the structure's capacity and understanding a more realistic demand scenario.

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