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Seismic Performance Assessment of Irregular RC Building

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ABSTRACT

Damage to irregular structures caused by asymmetry in plan has been observed during many major and minor earthquakes during the past. The non-coincident center of mass and stiffness in a structure generate plan asymmetry which causes torsional vibration resulting in severe damage to structural components in the more laterally flexible regions of the structure. Modelling plays a very important role in design and analysis of structures. In the present study, a typical irregular plan of building with 5-storey is considered and is assumed to be located on medium soil condition and seismic zone V. The building is analyzed by using response spectrum analysis and designed as special moment resisting frame as per the specifications of Indian Standard. Further, the performance of building is assessed using Non-linear static procedure i.e. static pushover analysis as per ASCE-41. In addition to this the response reduction factor (R) of considered model is also evaluated. It is concluded that, for irregular buildings considering response reduction factor R same as that provided in Indian seismic code is inappropriate and the value should be less than 5.

Keywords: Asymmetric building, Response Spectrum Method, Non-linear Static analysis, Response Reduction factor.

I. INTRODUCTION

So far irregularity has been studied by many researchers and important recommendations has also been laid in the Indian codes, so as to avoid the major devastation during seismic actions. Different types of irregularity seen practically

a. Vertical stiffness irregularity
b. Mass irregularity
c. Vertical geometric irregularity
d. In plane discontinuity
e. Out of plane offsets
f. Discontinuity in capacity (weak storey)
g. Torsional sensitivity

This causes obstruction in the flow of forces and stress concentration increases in the critical areas. Torsional forces occurs as CM and CR (Centre of mass and rigidity) do not lie at same points. The torsional stresses are quite dangerous, causing complete failure of the structure. Static method i.e seismic coefficient method mentioned in IS 1893: 2016 Part I may not be useful as it is based on regular distribution of stiffness and mass in a structure, and hence it becomes less accurate. Figure 1 shows different plan irreguality arrangements which are observed, which are proved to be dangerous, Indian codes on earthquake resistant design laid some stringent clauses for the design of irregualr buildings.

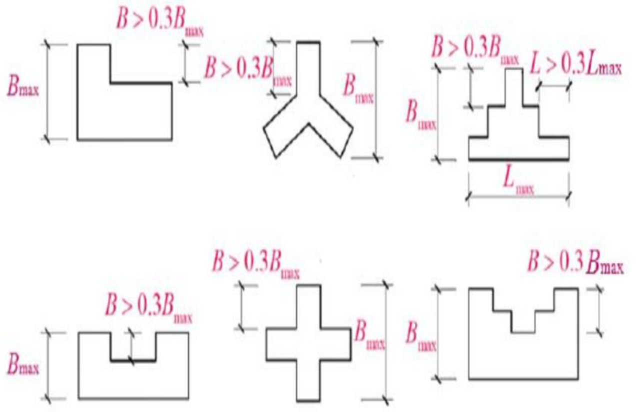

Figure 1. Plan irregularity in buildings, (google search)

Shelke and ansari, 2007 considered the irregularities of the structure namely mass, stiffness and vertical geometric irregularity. It was obsreved that the structure with mass irregualrity experience large base shear than regualar structures. Stiffness irregularity structures experience large storey drifts, further, darshale and Shelke, 2016 studied the to control the effect of irregualrity by using base isolation. Base isolation reduced the lateral displacement, shear forces, bending moments, base shear, storey acceleration, interstorey drift as compared to the conventional fixed base structure. Which shows the effectiveness of base isolation and concluded that base isolation is very effective seismic response control device.

Sheikh and Shinde, 2016, studied about the seismic analysis by considering mass irregularities given in the specific codes and investigated the proportional distribution of lateral forces evolved through seismic action in each storey level due to changes in mass of frame on vertically irregular frame. Bhosale, et al. (2016) examined the seismic performance of buildings with irregular distribution of mass, stiffness, and strength along the height may be significantly different from that of regular buildings. Stepped and setback buildings under the category of vertical geometric irregularity needs to be investigated in detail to validate the special design requirements recommended by design codes. Further, Mohod, 2015, examined the effect of shape and the plan of the structural building on the response of seismic analysis. Buildings with irregular geometry respond differently against seismic action. . It has been observed from the research that simple plan and configuration must be adopted at the planning stage to minimize the effect of earthquake. Mahesh and Rao, 2014, presented a paper in which a G+11 multistorey building with regular and irregular configuration had been considered for earthquake and wind loads using ETABS and STAAD PRO V8i. Different response like the storey drift, displacement, base shear were plotted and the inference was that when both regular and irregular configurations were compared, the storey drift and the base shear value were found to be more for regular configuration. Athanassiadou C.J. (2008) addressed multistorey reinforced concrete (R/C) frame buildings, irregular in elevation. Two ten-storey two-dimensional plane frames with two and four large setbacks in the upper floors respectively, as well as a third one, regular in elevation, have been designed to the provisions of the 2004 Eurocode 8 (EC8) for the high (DCH) and medium (DCM) ductility classes, and the same peak ground acceleration (PGA) and material characteristics. As expected, DCM frames are found to be stronger and less ductile than the corresponding DCH ones. The overstrength of the irregular frames is found to be similar to that of the regular ones, while DCH frames are found to dispose higher overstrength than DCM ones. Sarkar (2010) studied about how to deal with the vertical irregularities in stepped building. Stepped building frames, with vertical geometric irregularity, are now increasingly encountered in modern urban construction.

From the study of literature, it has been concluded that irregularity is detrimental for the structures during earthquake, hence preventive measure need to be considered while designing structures and irregularity must be avoided.

II. MODELLING AND ANALYSIS

- **Selection of plan of the building**

In order to thoroughly analyze the building with plan irregularity, various shaped building having different plan shapes will be undertaken. From the literature thorough idea regarding plan irregularity has been studied and L Shaped building is considered with irregularity of more than 50%. The plan area of the considered 5 storey building is 15 x 15 m with 3 m of storey height. The sizes of each component of the building is decided by designing the building for gravity and earthquake loading. Figure 2 and 3 shows the plan and elevation of the building. Preliminary sizes of the frame members have been considered based on the deflection criteria given as per Indian standard IS 456-2000 and IS 13920-2016. Response spectrum analysis of structure has been performed as per IS 1893 part 1 (2016). Building is assumed to be situated on medium soil in seismic zone V, having zone factor 0.36. Structure is subjected to gravity loads as per the clauses mentioned in Indian standards (IS 456, IS 875 part I and II). In the proposed structure slab thickness and wall thickness is assumed equal to 100 mm and 230 mm (outer) and 115 mm (internal) respectively. Structural modelling, analysis and design have been performed in SAP 2000 version 14.2.4. Detailed mathematical model has been prepared to represent the distribution of structural geometry of elements and loading in plan as well as in elevation.

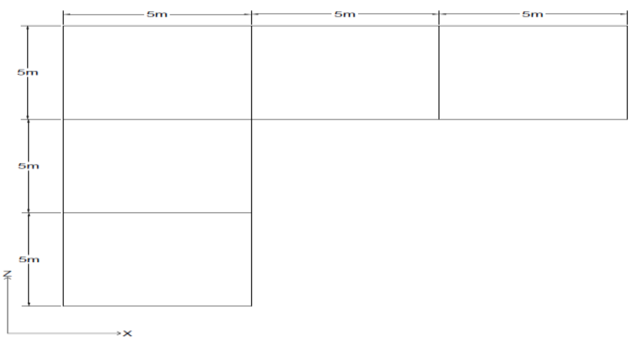

Figure 2. Plan of the building

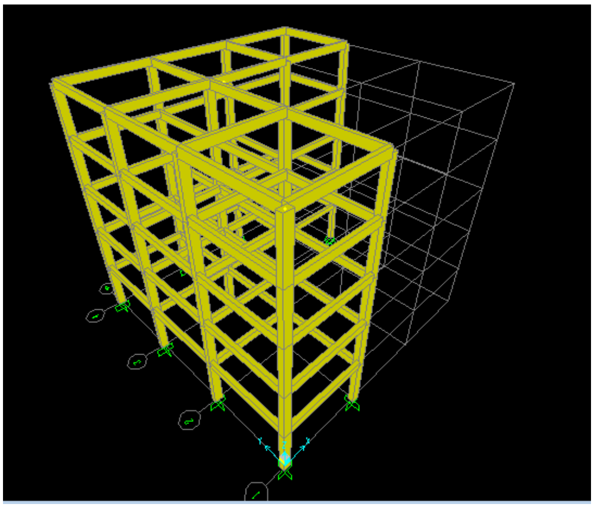

Figure 3. 3D view of the building

Thickness of slab at all floor level and roof level have been assumed to be same and modeled as rigid diaphragm. Archetype building has been analyzed by using response spectrum analysis and designed as special moment resisting frame as per the specifications IS 456:2000 and IS 13920:2016 code. The beams have been assigned with moment (M3) hinges and columns with coupled axial moment (P-M2-M3) hinges at the two ends. To access the performance of building nonlinear static analysis i.e. static pushover analysis have been performed.

III. RESULTS AND DISCUSSION

Pushover analysis is performed for the considered model under study. The different pushover curves in terms of base shear and roof displacement in longitudinal as well as transverse directions has been obtained. Capacity curves of building model are linear initially, after certain point it start deviating from linearity to non-linearity. Non-linearity comes in picture due to inelastic action start takes place in structural elements. All curves are approximated by means of bi-linearization method as per FEMA 356.

The nonlinear performance of structure depends on stiffness, strength and ductility of structure. The approximate estimation of aforementioned parameters can be found from the capacity curve result of building obtained from nonlinear static pushover analysis. Pushover analysis also give insight of weak links present in the structure or highlight the region of inadequate capacity. In the present case the comparative study of change in over strength, storey displacement, yield and ultimate base shear capacity of structure due to irregularity scenario has been performed.

The results of non-linear static pushover analysis obtained in the form of capacity curve for considered irregularity in the model in longitudinal and transverse direction are shown in Fig. 4 and Fig. 5 respectively.

The response reduction factor (R) is calculated from the formulations given in Lakhade et al. (2017) for collapse prevention level. The formulation adopted for determining response reduction factor of the considered models is given by equation (1) (Lakhade et al. 2017).

$$R = R_S R_\mu \qquad \text{......(1)}$$

As mentioned in IS 1893(1):2016, value of R for considered model is taken as 5. But the value of R obtained for model is 5.77 (i.e., greater than 5) in longitudinal direction whereas in transverse direction, R is less than 5. This shows that for irregular buildings considering response reduction factor R same as that of R equals to 5 is inappropriate and the value should be less than 5.

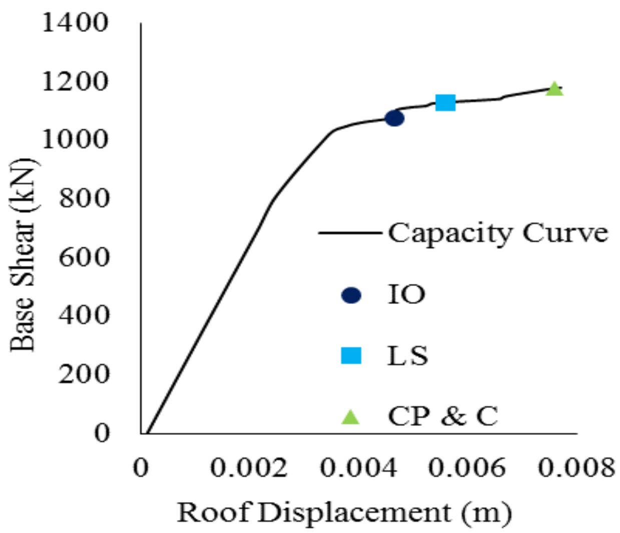

Figure 4. Capacity curve in longitudinal direction

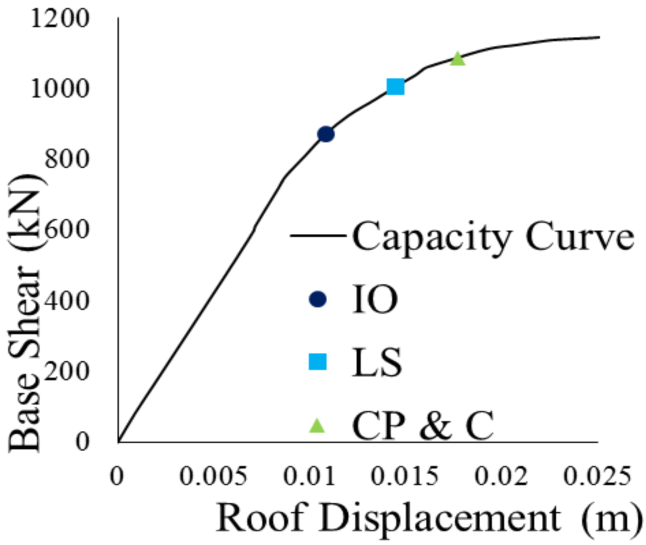

Figure 4. Capacity curve in transverse direction

Table 1. Capacity curves results

Direction	X	Y
Initial stiffness	300411	92222
Ductility	2.22	1.75
Overstrength	2.1	2.13
Response reduction factor (R)	5.77	4.147

IV. CONCLUSION

Irregularity imparts torsional forces, since CG and CM doesn't coincides with each other. The stress concentration increases at severe locations and hence complete failure of the structure is possible. Hence, stringent clauses have been recommended regarding the design of irregular structures for earthquake. Indian codes prohibits the use of such structures in earthquake prone areas. In the present L-shaped building is considered and the performance is evaluated based on non-linear static pushover analysis. Following conclusions have been made

1. Response reduction factor is found to be more than 5 in X-direction and less than 5 in Y-direction.
2. Pushover curves gives the capacity of the building.
3. For the considered model, ductility is less in Y-direction as compare to X-direction.

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