Assessment of Location of Centre of Mass and Centre of Rigidity for Different Setback Buildings

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***Abstract*— Buildings are mainly classified into regular and irregular buildings. Nowadays due to our requirements and aesthetic point of view, we are making the buildings more irregular than regular. An irregular building is as a building that lacks symmetry and has a discontinuity in geometry (setback), mass or load resisting elements. The presence of structural irregularities has an adverse effect on the seismic response of the structure. The structural irregularity can be broadly classified as plan irregularities and vertical irregularities. In this present study, the effect of vertical irregularity on seismic response of a structure is studied. In particular, a setback in buildings are considered and behavior of the structure with respect to the location of the center of mass and center of rigidity is assessed using pushover analysis. The analysis tool used to assess the building is ETABS 2015.**

Keywords*— Vertical irregularities, Centre of mass, Centre of rigidity, Setback, pushover, ETABS 2015.

I. INTRODUCTION

In the present scenario, structures are becoming manmade astonishing wonders. By considering the aesthetical point of view and based on our requirements structures are designed. While designing the structure, it is essential to consider earthquake load because it most dangerous unpredictable natural disaster. It is been observed that as the irregularity in the building increases deformation due to earthquake load also increases hence it is most important to design structure for earthquake load. As per IS 1893(Part-1):2002 for earthquake resistant design of structure, there are two types of irregularities namely

1) Plan Irregularity
2) Vertical Irregularity

1) *Plan Irregularity*

The condition of being non-uniform in the plan of a structure is called plan irregularity. These can be characterized by five different types such as torsional, re-entrant corners, diaphragms discontinuity, out of plane offset and nonparallel system for plan irregularity.

2) *Vertical Irregularity*

Structures having significant physical discontinuities in a vertical configuration or in their lateral force resisting systems are termed as vertically irregular structure. The vertical irregularities in structures are Stiffness irregularity, Mass irregular, Vertical geometric irregularity, Discontinuity in capacity.

A. *Centre of Mass*

The centre of mass is a position defined as the average position of all the parts of the system, weighted according to their masses. The distribution of mass is balanced around the centre of mass and the average of the weighted position coordinates of the distributed mass defines its coordinates. During an earthquake, acceleration-induced inertia forces will be generated at each floor level and it will act at a point, where the mass of entire story may be assumed to be concentrated. In a building having a symmetrical distribution of mass the positions of the centers of floor masses will not differ from floor to floor. However, irregular mass distribution over the height of a building may result in variation in centers of masses at various floors.

B. *Centre of Rigidity*

The centre of rigidity is a point at a particular story as the location of application of lateral load at that point will not produce rotation of that story. This definition is valid when the slab is modeled as a rigid diaphragm. A Diaphragm Constraint causes all of its constrained joints to move together as a planar diaphragm that is rigid against membrane deformation.
As a function of structural properties, the center of rigidity is independent of loading.

C. *Setback Buildings*

The Setback buildings are characterized by an immediate reduction in floor area with respect to the height of the building, with results in drop in stiffness, mass and strength. Height-wise changes in stiffness and mass provide the

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dynamic characteristics of these buildings different from the regular building. Setback buildings show more deformation on seismic action than any other structure. These buildings exhibit more deformation even though the structure is designed under current seismic codes. This inferior performance due to seismic load has been allocated to the combined action of structural irregularities i.e., to the combined non-uniform distribution of mass, stiffness, and strength along the height of setback frames, and to concentrate on the inelastic action at setback level.

In this present study, we are focusing on the behavior of buildings with respect to the center of mass and centre of rigidity under the action of seismic load using pushover analysis on a setback buildings. Here we can observe the shifting of centre of mass and centre of rigidity with respect to different setback buildings as shown in figure 1. It is possible to evaluate the seismic performance of setback building accurately using ETABS 2015 software.

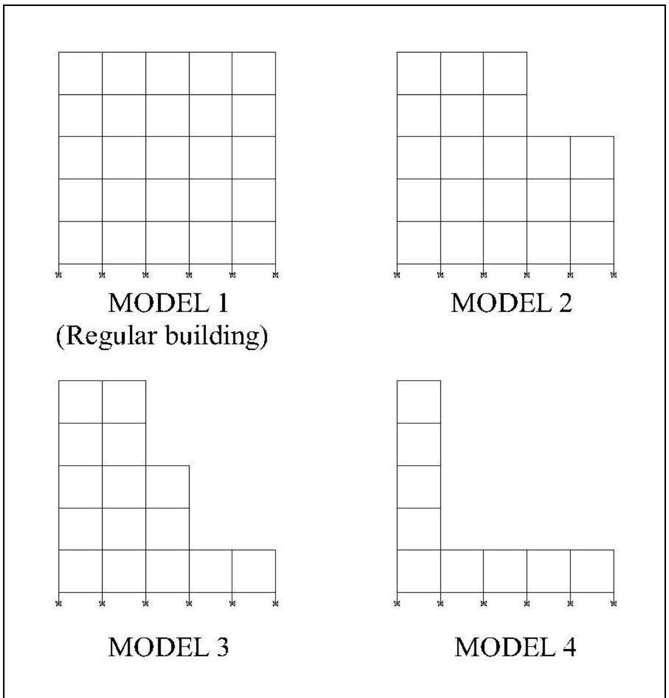

Fig 1: Elevation of regular building (model 1) and setback buildings (model 2, 3 and 4)

For a given floor diaphragm, centre of rigidity is calculated through the following process:

Case 1 applies a global-X unit load to an arbitrary point, perhaps the centre of mass, such that the diaphragm rotates R_{zx}.

Case 2 applies a global-Y unit load at the same point, causing rotation R_{zy}.

Case 3 applies a unit moment about global-Z, causing rotation R_{zz}. These three load cases are shown in Figure 2.

Centre of rigidity (X, Y) is then computed as $X = -R_{zy} / R_{zz}$ and $Y = R_{zx} / R_{zz}$.

During analysis, ETABS automatically calculates this coordinate for each floor diaphragm. The diaphragm must be present and defined in the model.

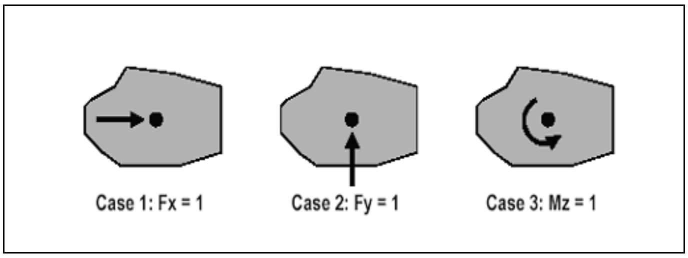

Fig 2: Centre of rigidity

II. MATERIAL AND METHODS

The software used in the present study is ETABS-2015 (Extended 3D Analysis of Building System). ETABS software was developed by CSI, Berkeley California. The method of analysis used is Nonlinear Static Analysis also known as Pushover Analysis. The first model is a regular model with equal elevation (figure 1 model 1). The second model is the setback model with floors are reduced at top right corner of its front elevation, in the similar manner model 3 and 4 are setbacked by reducing its floors. Both centre of mass and centre of rigidity models consist of 5 floors i.e., (G+4), with the floor heights being 3.5m each. Totally five bays are provided in x-direction and 3 bays are provided in y-direction with each bay size being 5m.The dimension of the columns being fixed at 230mm x 600mm and that of the beams at 230mm x 450mm at top stories and 230x300 at plinth level as shown in table 1. The beam and column dimensions are fixed as per IS 456: 2000. The column positions have so been fixed, that the spans of all the beams in both X and Y directions are kept same and equal to 5m. The roof modeling considered in the present study is a rigid diaphragm. For analyzing the center of mass and centre of rigidity of structure, the loading and the other parameters are kept same. Also, both the centre of mass and centre of rigidity models have been analyzed for rigid diaphragm condition.

III. ANALYSIS

In this study, ETABS-2015 software is used for the analysis of building model.

The structure was modeled in ETABS by considering the parameters shown in table.1. Model shown in figure 1 was subjected to both dead load and live loads to check the capacity of preliminary dimensions of the structural members of the building model. The seismic analysis is carried out only if all the members are safe with design check. If members are not safe, then the dimensions of the members are revised (should be as per IS 456: 2000). To carry out the pushover analysis, the non-linear static load patterns and load cases are defined along X and Y directions. The mass source is defined by taking percentage of impact load (As per 1893-part1 2002) for the calculation of seismic load. Then the columns and beams are assigned with hinges based on the hinge properties taken from ASCE 41-13 table. After

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assigning hinges the model is checked for errors. Then the model is analyzed which is subjected to lateral pushover loads as per displacement control method. Run analysis after selecting to calculate centre of mass and rigidity. After the pushover analysis is complete, the push over results like centre of mass and centre of rigidity for all storeys is tabulated and reviewed.

TABLE I. PARAMETERS CONSIDERED IN THE PRESENT STUDY

Structure Type	Ordinary moment resisting frame
No. of storey	G+4
Typical storey height	3.5m
Type of building use	Public cum office building
Foundation type	Isolated footing
Seismic zone	V
Material properties	
Grade of concrete	M_{20}
Grade of steel	Fe500
Density of concrete	25 kN /m^2
Member properties	
Slab thickness	0.150m
Beam size	0.230m x 0.450 m
Plinth beam size	0.230m x 0.300 m
Column size	0.230m x 0.600m
Wall size	0.230m
Dead load intensities	
Roof finishes	2.0 kN/m^2
Floor finishes	1.0 kN/m^2
Live load intensities	
Roof	3.0 kN/m^2
Floor	4.0 kN/m^2
Earthquake live load on slab as per clause 7.3.1 and 7.3.2 of IS: 1893(Part-1) 2002	
Roof	0.25 x 3.0 = 0.75 kN/m^2
Floor	0.5 x 4.0 = 2 kN/m^2

But in the present study, we are analyzing the movement of centre of mass and centre of rigidity for setback buildings for the top storey obtained from pushover analysis.

IV. RESULTS AND DISCUSSIONS

Results obtained from the analysis with regards to the shift in the position of center of mass and center of rigidity with respect to different models considered in the analysis. Table 2 shows the location of centre of mass with respect to X and Y directions for different models and table 3 shows the location of centre of rigidity with respect to X and Y directions for different models. In the tables, XCM and YCM represent the location of centre of mass with respect to X and Y directions respectively and similarly XCR and YCR represent the location of centre of rigidity with respect to X and Y directions respectively.

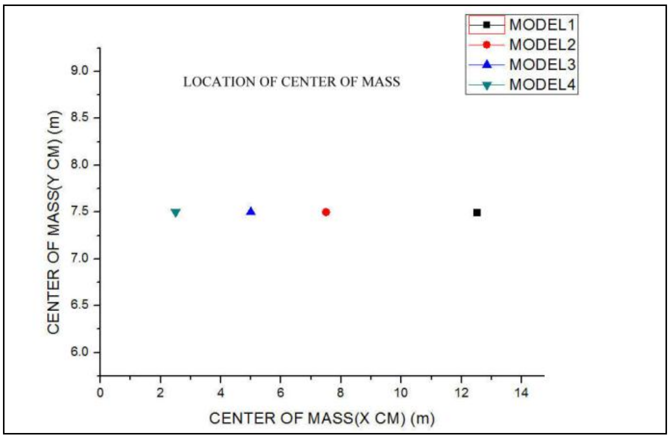
TABLE II. LOCATION OF CENTRE OF MASS FOR DIFFERENT MODELS

MODEL TYPE	LOCATION OF CENTRE OF MASS(m)	
	XCM	YCM
MODEL 1	12.5	7.5
MODEL 2	7.5	7.5
MODEL 3	5	7.5
MODEL 4	2.5	7.5

TABLE III. LOCATION OF CENTRE OF RIGIDITY FOR DIFFERENT MODELS

MODEL TYPE	LOCATION OF CENTRE OF RIGIDITY(m)	
	XCR	XCR
MODEL 1	12.5	7.5
MODEL 2	9.9432	7.5
MODEL 3	6.794	7.5
MODEL 4	3.0192	7.5

Also, the Graph 1 and Graph 2 show the plots of locations/positions of centre of mass and center of rigidity for models 1, 2, 3 and 4 respectively. Both the plots i.e. graph 1 and 2 have been plotted with respect to the location of the center (i.e. centers of mass and rigidity) at top storey along X and Y directions for the respective models.



Graph 1. Location of Centre of Mass with Respect to X and Y Axes

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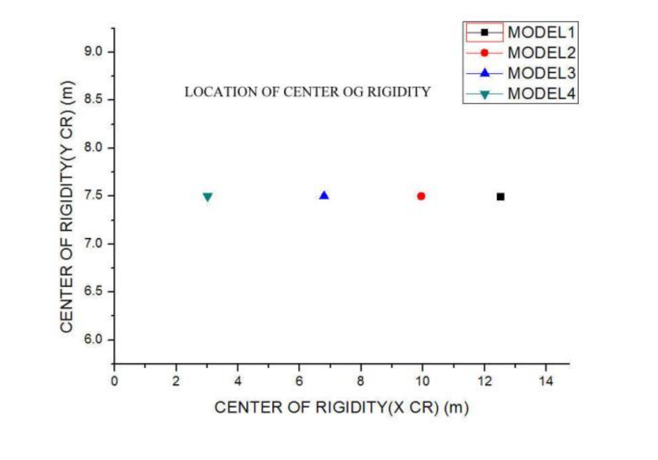

Graph 2. Location of Centre of Rigidity with Respect to X and Y Axes

From Graph 1 it can be observed that the value of centre of mass goes on reducing for model 1 to model 4 as the mass and the area of the models goes on reducing from model 1 to model 4. This due to the concentration of building towards the origin of the building. Similarly, Graph 2 indicates that the value of centre of rigidity goes on reducing for model 1 to model 4 as the mass and the area of the models goes on reducing from model 1 to model 4. This due to the concentration of building towards the origin of the building.

V. CONCLUSIONS

Nowadays the buildings with irregularities are more common because of the need or requirement of the individual and due to aesthetic appearance of the buildings. Also, the consideration of centre of mass and centre of rigidity while designing a structure for seismic loads plays a major role. From the present study it can be seen that for a vertical regular building the centre of mass and centre of rigidity were exactly at the centre of building in plan view. Whereas for a structure with vertical irregularities like setback buildings the location of centre of mass and centre of rigidity moves to a concentrated region or in other words the point moves towards the region of more area.

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