A study of Stiffness and Mass Irregularity of Reinforced Concrete Building

Sunil B. Makhare[1], Abhishek V. Sonawane[2] and Ajay G. Dahake[3]
[1]PG Student, [2]PG Student, [3]Professor & Head
Department of Civil Engineering, G H Raisoni College of Engineering and Management, Pune

***Abstract*— Irregular building forms a significant section of modern urban infrastructure. The occurrence of several major earthquakes has brought the shortcoming in the building, which had cause them get damage and fall down. In a vertical irregular structure failure start at a point of weakness. This weakness occure because of discontinuity in mass and stiffness. The structure having this discontinuity is term as irregular structure. This research is an attempt to study the stiffness and mass irregularities along with seismic response of vertically irregular building and its validation. In the present study stiffness and mass irregularities of G +10 storeys building frame is checked and method of seismic analysis studied. The soft computing tool and commercial software CSI-ETABS is used for modeling and analysis purpose.**

***Index Terms*— Irregular building, earthquake, seismic response, stiffness and mass**

I. INTRODUCTION

Earthquakes are the most uncertain and destructive among all natural disasters. The behavior of structure during earthquake depends on different factors such as ductility, stiffness, adequate lateral strength, simple and regular configuration. As per IS 1893-2016 The building configurations are of two types regular and irregular configurations. Building is said to be regular when its configuration almost symmetrically about its axis and it called irregular when it is not symmetric and discontinuity in mass, geometry. Regular structure has no physical discontinuity in plan and their vertical configuration or in their lateral force resisting system. Irregular structure has discontinuity in configuration or in lateral force resisting system. As per IS 1893-2016 irregular structure having vertical irregularity and plan irregularity or both in their structural configuration.

Building irregularities are classify into two parts plane irregularities and vertical irregularities. Vertical irregularities considered for present study is Stiffness irregularity

Soft storey: It is storey in which lateral stiffness at any floor is less than 70% of above floor or if it is less than 80% of the average lateral stiffness of the three storey above.

Extreme soft storey: It is storey whose lateral stiffness is less than 60% of the above storey and less than 70% of the average stiffness of three storey above.

Mass irregularity: Mass irregularity considered when the weight at any storey is more than 150% of that storey above and below.

Poudel[1] have done a case study on irregularities present in tall building and reviewed the provisions on Indian standard. He identified the irregularities present in existing commercial cum residential building and complications on adaptation of mitigation measures. Merajuddin and Azeem[2] have done study of estimating the stiffness irregularities in reinforced concrete building. They analysed the three-dimensional storey frame with 5,10,15 storey regular and irregular with equivalent lateral force analysis after analysis they came to conclusion that the effect of irregularities on storey stiffness, displacement, storey drift, base shear and percentage of steel. They found that it is not possible to determine threshold in between regular and irregular building based on storey stiffness ratio. Poncet and Tremblay[3] studied the mass irregularities of eight storey concentrically steel braced frame with different setback configurations for regular and irregular building both by equivalent static load method and response spectrum analysis method. They found that mass irregularities have a small impact on collapse prevention when method of static analysis used. Also, performance of irregular frame is lower than the regular frame. Naveen et.al.[4] have modified a nine-storey regular frame by incorporating irregularities in various form in both plan and elevation. They found that stiffness irregularities have a maximum influence on the response among the case having combination of irregularities configuration with stiffness, mass, and vertical geometric irregularities have a maximum response. Bharvase and Patil[5] have done similar study on the vertically regular and irregular steel structure considering wind force computed the parameters like storey stiffness, displacement and drift. Pathan and Dhamge[6] highlights the effect of mass irregularity on different floor in RCC building using response spectrum method of seismic analysis. Ahmed and Tahera[7] have done study on seismic behavoir of multistorey structure with vertical irregularities in stiffness and mass under various soil condition such as soft, medium and hard soil. They came to conclusion that the soft soil model has a higher maximum displacement, storey drift. Tiwari and Adhikari[8] have done study of seismic analysis of reinforced concrete building with varation in stiffness and mass by numerical modeling in SAP 2000 and computed the seismic parameter like displacement, base shear and storey drift. They found that with increasing stiffness of the column axial force in column and base shear of the building increases. Also they found that frame of irregular floor with large floor height is critical than building of same floor height. Ravikumar et.al.[9] have studied the two kinds of irregularities in the building namely plan irregularities and vertical irregularities. In order to identify the most susceptible building among the model considered, they perform different analytical ways to identify the seismic demand in linear and nonlinear way. Chandurkar and pajgade[10] have done the seismic analysis of reinforced concrete building with or without shear wall. They determined the solution for shear wall location in multistorey building. They also studied the effectiveness of shear wall with help of four diffrerent models. Shaikh and Rahman[11] studied the multistorey building with stiffness irregularity at ground floor at carried out seismic analysis. They found that building with stiffness irregularity are not stable and carry more storey shear. Tomer and Bhandari[12] have done study of seismic behaviour of vertically irregular building . Seismic performance can be found out by using time history analysis. They found that building with soft storey having variation in the storey stiffness yield large interstorey drift value and showing more damage. Costa et. al.[13] have done study the seismic behavior of reinforced concrete building exhibiting vertical irregularities. They studied 16 storey building for three different horizontal layouts and for five vertical configurations. Ambrisi et. al.[14] studied the seismic performance of irregular mass eccentric 3D reinforced concrete frame subject to seismic action. Very detailed model set through the computer code zeus and seismic response expressed in terms of displacement and drift. Chauhan and Banerjee[15] computed the seismic response of irregular building on sloping ground. They analysed the irregular building with horizontal angle of inclination at 20,30,40 and 45 degree on sloping ground using a method of response of seismic analysis.

Bhatta et. al.[16] have done several case studies consist of different configuration of vertical irregular structure and they carried out the seismic behavior of vertical irregular structure using response spectrum method of seismic analysis. They found that irregular structure have greater chances of high stress concentration as well as high displacement demand in vicinity of irregularity. Raut et. al.[17] analysed the irregular reinforced concrete building with three type of irregularities such as vertical, mass and plan irregularty and they compare the three parameter namely shear force, bending moment and deflection. Tarta and Pintea[18] evaluated the seismic performance of multistorey building having moment resisting steel frames with stiffness irregularites using standard and pushover method. They present comparison between standard, advanced pushover analysis and exact result obtained by nonlinear time history analysis. Sayyed et. al[19] studied the seismic performance of regular and irregular building by considering two type of vertical irregularities namely stiffness and setback irregularity. They modeled total eight regular and irregular building and response spectrum method of seismic analysis used. They found that building having stiffness and setback irregularity are not stable during seismic loading. Shashiknath et. al.[20] have done the analysis of mass irregular structure subjected to wind load. They analaysed vertically irregular structure with mass irregularity subject to wind load and compare the result of maximum roof displacement, storey drift and base shear. Dhakal and Rathor[21] have done seismic analysis of vertical irregular reinforced concrete building frame with or without shear wall using NBC 105:2020. They compare the seismic behavoir of building with regular and irregular floor plan. Georgoussis et. al.[22] have done approximate seismic analysis of muiltistorey building with mass and stiffness irregularities. The approximate method is based on the analysis of two equivalent, single storey asymmetric model system. Tabassum et. al.[23] studied the mass irregular structure situated in mysuru using SAP-2000 software. Chabokan and Faridmehr[24] have done seismic assessment of steel moment frame with irregularity in mass and stiffness. They considered three frames with variation in mass on different storey and evaluated the seismic performance.

II. METHODOLOGY

The problem addressed for current study is taken from IS 1893:2016 (Part-1) in which a 10-storey building frame consider with 2 type of vertical irregularities mass and stiffness irregularities taken from IS 1893:2016 check for stiffness and mass irregularities is given as per IS code. Seismic analysis is also carried out assuming seismic zone III. Seismic analysis is done using software CSI-ETABS.

III. STRUCTURAL MODELLING

A symmetric building plan of dimension of 20 m x 20 m, spacing of bay is 4 m in both direction and height of storey is 3 m. Building structure are modeled and analysed using ETAB. Total three different building geometries, one regular and two vertical irregular is considered. Figure below shows plan and elevation of regular building frame.

A. Model-1

This is the basic regular structure of building with no irregularity and has 10 storey with storey height of 3 m and bay width 4 m.

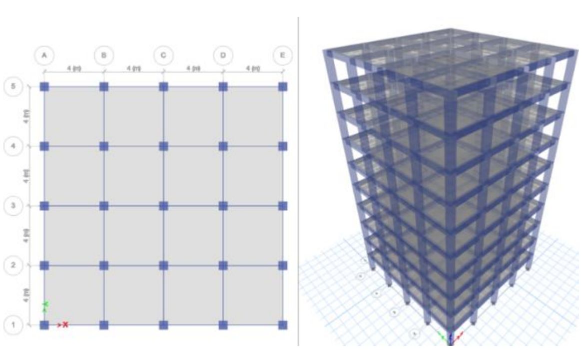

Fig. 1. Plan and elevation of regular building

B. Model-2

This is the frame having stiffness irregularity with storey No.7 having storey height 5 m

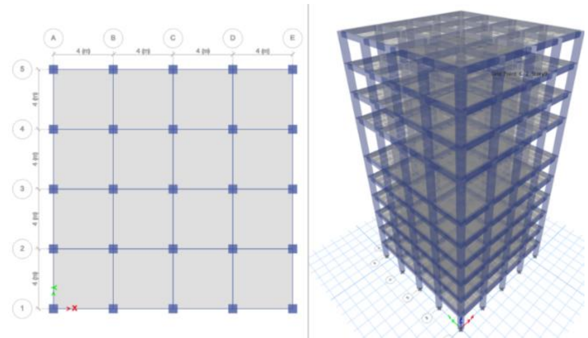

Fig. 2. Plan and elevation of stiffness irregular building

C. Model-3

This is the frame having mass irregularity above storey No.8

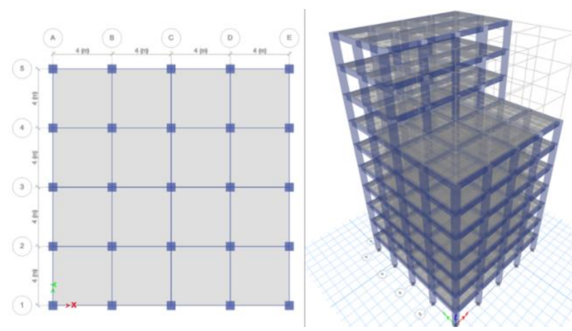

Fig. 3. Plan and elevation of mass irregular building

The seismic analysis is carried out corresponding to seismic zone III of IS 1893:2016 analysis.

The material and geometric properties are shown in table.

Table 1: Properties of material

Properties of concrete	
Grade of concrete	M35
Modulus of elasticity	29580 N/mm^2
Poissons ratio	0.2
Concrete density	25 KN/m^3
Properties of reinforcement steel	
Grade of steel	Fe500
Modulus of elasticity	20000 MPa
Poissons ratio	0.3

A. Dimension of structural elements

Beam dimension: 450 mm x 450 mm

Column dimension: 600 mm x 600 mm

Slab thickness: 150 mm

Storey height: 3 m

B. Seismic parameter
Zone: III
Importance factor: 1
Response reduction factor: 1
Type of soil: Medium

IV. RESULT AND DISCUSSION

Results of all different type of model according to study of vertical irregularity and seismic analysis are obtained and mentioned here.

A. Check for irregularity

Table 2: Model-1 (Check of stiffness irregularity for regular building)

Check for Stiffness irregularity in X direction				
Storey	Stiffness (KN/m)	Value	Soft storey check	Extreme Soft storey check
Storey10	367343.3	-	-	-
Storey9	461844.4	1.2573	OK	OK
Storey8	482346.0	1.0444	OK	OK
Storey7	489846.7	1.0156	OK	OK
Storey6	494291.8	1.0091	OK	OK
Storey5	498389.2	1.0083	OK	OK
Storey4	504329.8	1.0119	OK	OK
Storey3	518734.4	1.0286	OK	OK
Storey2	574286.0	1.1071	OK	OK
Storey1	1015878.0	1.7689	OK	OK

Table 3: Model-1 (Check of mass irregularity for regular building)

Check for Mass irregularity					
Storey	Mass (kg)	Value	Value	Check	Check
Storey10	104376.3	-	0.7629	OK	OK
Storey9	136813.7	1.3108	1	OK	OK
Storey8	136813.7	1	1	OK	OK
Storey7	136813.7	1	1	OK	OK
Storey6	136813.7	1	1	OK	OK
Storey5	136813.7	1	1	OK	OK
Storey4	136813.7	1	1	OK	OK
Storey3	136813.7	1	1	OK	OK
Storey2	136813.7	1	1	OK	OK
Storey1	136813.7	1	-	OK	OK

Table 4: Model-2
(Check of stiffness irregularity for stiffness irregular building)

Check for Stiffness irregularity in X direction				
Storey	Stiffness (KN/m)	Value	Soft storey check	Extreme Soft storey check
Storey10	387067.0	-	-	-
Storey9	479601.0	1.2391	OK	Ok
Storey8	461766.0	0.9628	OK	Ok
Storey7	214380.2	0.4643	Not ok	Not Ok
Storey6	492040.7	2.2952	OK	Ok
Storey5	539773.5	1.097	OK	Ok
Storey4	556595.8	1.0312	OK	Ok
Storey3	574421.0	1.032	OK	Ok
Storey2	631640.9	1.0996	OK	Ok
Storey1	1090073	1.7258	OK	Ok

Table 5: Model-2
(Check of mass irregularity for stiffness irregular building)

Check for Mass irregularity					
Storey	Mass (kg)	Value	Value	Check	Check
Storey10	106298.5	-	0.7662	Ok	Ok
Storey9	138735.9	1.3052	1	Ok	Ok
Storey8	138735.9	1	0.8651	Ok	Ok
Storey7	160360.8	1.1559	1	Ok	Ok
Storey6	160360.8	1	1.1559	Ok	Ok
Storey5	138735.9	0.8651	1	Ok	Ok
Storey4	138735.9	1	1	Ok	Ok
Storey3	138735.9	1	1	Ok	Ok
Storey2	138735.9	1	1	Ok	Ok
Storey1	138735.9	1		Ok	Ok

Table 6: Model-3
(Check of stiffness irregularity for mass irregular building)

Check for Stiffness irregularity in X direction				
Storey	Stiffness (KN/m)	Value	Soft storey check	Extreme Soft storey check
Storey10	221740.0	-	-	-
Storey9	283400.6	1.2781	OK	OK
Storey8	314309.9	1.1091	OK	OK
Storey7	475060.2	1.5114	OK	OK
Storey6	495368.8	1.0427	OK	OK
Storey5	502459.2	1.0143	OK	OK
Storey4	508822.5	1.0127	OK	OK
Storey3	523046.1	1.028	OK	OK
Storey2	578357.8	1.1057	OK	OK
Storey1	1020614.0	1.7647	OK	OK

Table 7: Model-3
(Check of mass irregularity for mass irregular building)

Check for Mass irregularity					
Storey	Mass (kg)	Value	Value	Check	Check
Storey10	58740.51	-	0.75	OK	OK
Storey9	78202.94	1.3313	1	OK	OK
Storey8	78202.94	1	0.63	OK	OK
Storey7	123838.8	1.5836	0.90	Not OK	OK
Storey6	136813.7	1.1048	1	OK	OK
Storey5	136813.7	1	1	OK	OK
Storey4	136813.7	1	1	OK	OK
Storey3	136813.7	1	1	OK	OK
Storey2	136813.7	1	1	OK	OK
Storey1	136813.7	1	-	OK	OK

B. Storey displacement

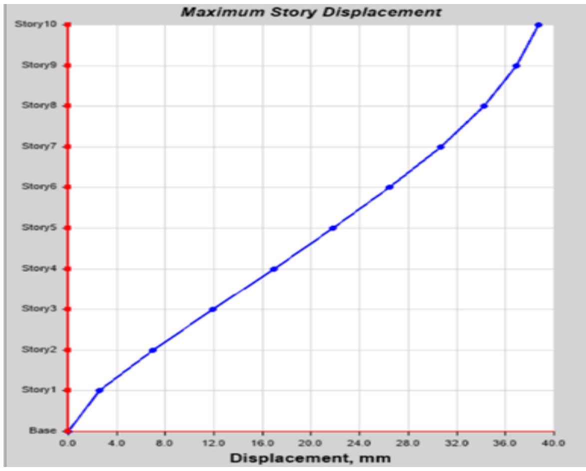

Fig.4. Model-1
(Graph of storey displacemet vs storey)

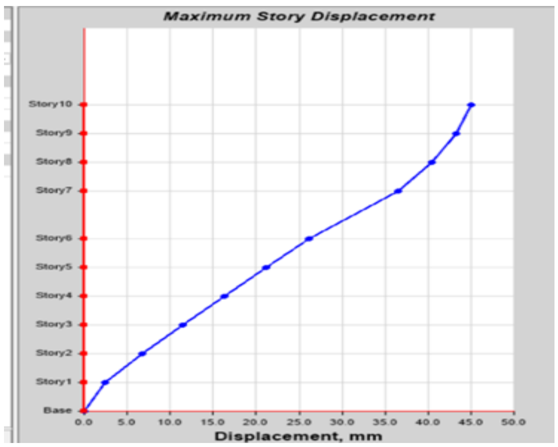

Fig.5. Model-2
(Graph of storey displacemet vs storey)

Fig.6. Model-3
(Graph of storey displacemet vs storey)

C. Storey drift

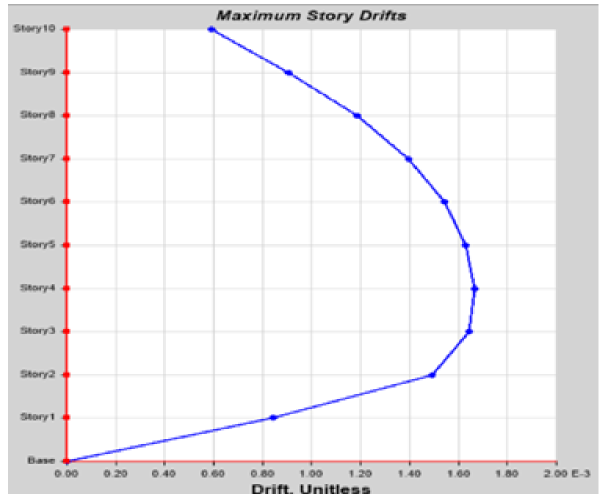

Fig.7. Model-1
(Graph of storey drift vs storey)

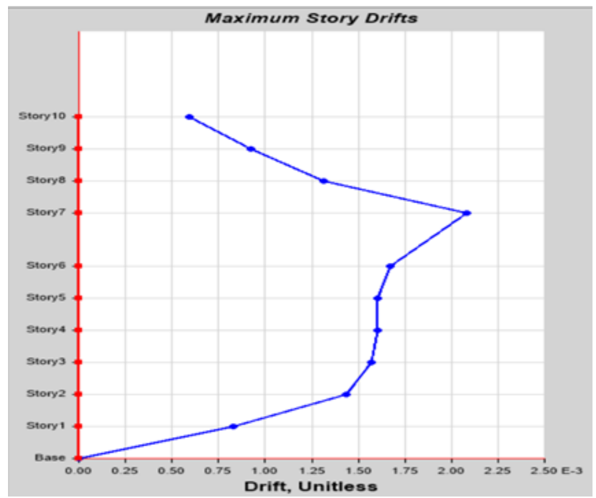

Fig.8. Model-2
(Graph of storey drift vs storey)

Fig.9. Model-3
(Graph of storey drift vs storey)

D. Storey shear

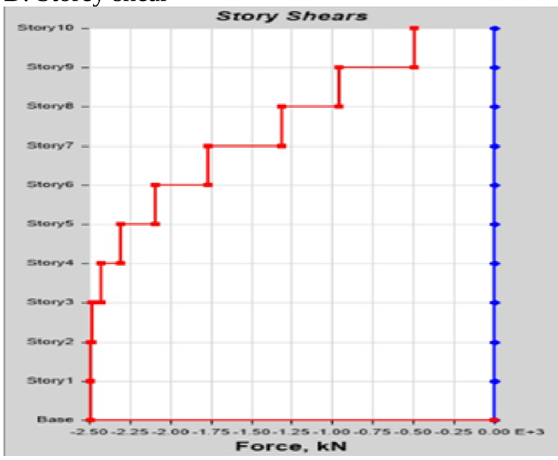

Fig.10. Model-1
(Graph of storey shear vs storey)

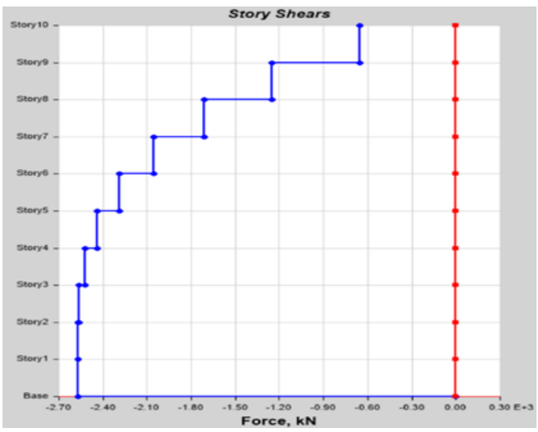

Fig.11. Model-2
(Graph of storey shear vs storey)

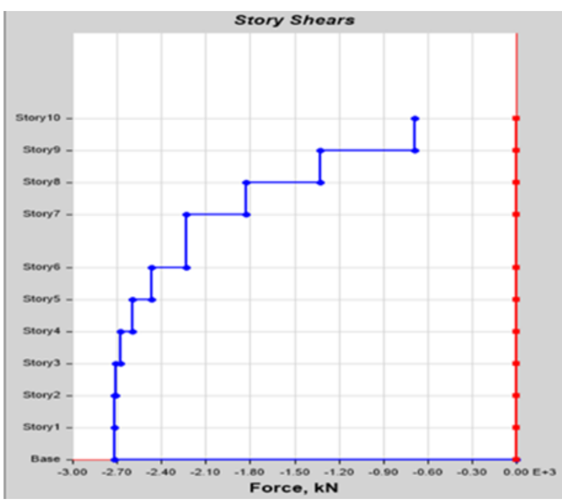

Fig.12. Model-3
(Graph of storey shear vs storey)

From above graph it is observed that

1) Of all three models storey displacement is maximum at top storey. Maximum storey displacement of model-1 is 38.67 mm, model-2. is 45 mm, and model-3 is 39.40 mm. Storey displacement is minimum for model-1.

2) Storey drift is maximum at stroey No. 4 of model-1 and its value is 1.67. For model-2 it is maximum at storey No. 7 and its value is 2.083 For model-3 it is maximum at storey No. 3 and its value is 1.6

3) Similarly it is observed that of all three models storey shear is maximum at base and it decreases from storey 1 to top storey. Storey shear of model-1 is 2.55 KN, model-2 is 2.7 KN and model-3 is 2.50 KN

IV. CONCLUSION

The current study is focus on the study of stiffness and mass irregularities and their effect on seismic performance of building. The performance was study in terms of storey displacement, storey drift and storey shear.

The study leads to following conclusion

1. Maximum storey displacement is more for building with stiffness and mass irregularity than building with regular configuration.
2. Maximum storey drift is more for building with stiffness irregularity than building with regular configuration.
3. Storey shear is maximum for irregular building than regular building.
4. Seismic performance of regular building better than irregular building.

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