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Effect of Plan Irregularity in RC Framed Buildings

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ABSTRACT
The performance of a building to the forces applied is dependent on many factors, such as shape, size of elements of the building, materials used, etc. Considering shape as a factor, a building structure can be classified as regular or irregular. Irregularity in a structure either in plan or elevation or both, makes the structure more vulnerable to damage compared to a
regular structure. This paper presents a study of fifteen bare frame buildings (G+5) having the same weight, one being the reference model which is a regular structure, other fourteen having irregularity in their plan. These Moment resisting frame buildings with no infill walls, have been modelled and analysed using STAAD-PRO software by Response Spectrum Analysis (RSA) for seismic conditions by the guidelines of IS-1893 (Part 1): 2016. Earthquake force have been applied in X-direction and Z-direction. Results have been plotted in the form of graphs depicting the response of each model in terms of base shear, frequency and displacement at each storey. It has been concluded that due to the presence of plan irregularity there is an increase in either base shear or displacement or both, in comparison to the reference model. The increase in the values of base shear and displacement makes these structures more prone to damage.
Keywords*: Plan Irregularity, displacement, eccentricity, base shear, natural frequency*

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I. INTRODUCTION

The performance of a building to the seismic forces applied is dependent on many factors, such as shape, size of elements of the building, materials used, structural characteristics, etc. (Arnold, 2000). Irregularity in a structure either in plan or elevation or both, makes the structure more vulnerable to damage compared to a regular structure. Irregularity in plan may give rise to torsion due to the asymmetry of the structure as the centre of mass (CM) and centre of stiffness (CS) does not coincide with each other. According to IS-1893 (Part 1): 2016, torsional irregularity in a building structure occurs when the ratio of the maximum displacement at one end in the direction of the lateral force to the minimum displacement at the far end is mora than 1.5. It can also occur when the natural period of the first two translational mode of oscillation along each of their principle plan directions is less than natural period of fundamental torsional mode of oscillation. Plan irregularity can also give rise to the formation of re-entrant corners such as in the cases of L-shaped, U-shaped buildings, etc., which can prove to be highly vulnerable places for cracking in a structure. This paper presents the comparative study of seismic response of 15 buildings, one of which is a regular structure, taken as the reference model and other fourteen are the plan irregular models. Response spectrum method has been used for the analysis of the models using STADD-PRO. Comparative studies have been carried out between the responses in terms of eccentricity, base shear, displacement, frequency of all the models with the help of the graphs.

II. METHODOLOGY

In the present paper, analysis using STAAD-PRO has been done for regular structure and 14 plan irregular structure, having the same seismic weight and stiffness has been done. Due to the change in plan shape, there is change in number of columns, beams and walls. To keep the weight of all the models same, the weight of increased columns, beams and walls has been deducted from the floor load of the slab in each model accordingly. To keep the stiffness same in all the models the size of columns has been considered accordingly. The beams dimension for all the models is 0.45 m × 0.6 m and column dimension for the reference model is 0.65 m × 0.65 m.

The reference building is a five-bay × five-bay MRF building. The column to column distance in each bay of all the buildings is 4m i.e. the length of the beam. Plinth storey is of height 1.5m whereas, all the storeys above are of 3.5m height. M25 grade of concrete has been used for all the models having modulus of elasticity as 25×10^6 KN/m^2, unit weight of 25 KN/m3, poisons ratio of 0.17 and critical damping of 7.90066×10^{033}. The damping ratio for seismic analysis has been taken as 5 percent. Dynamic analysis has been carried out by

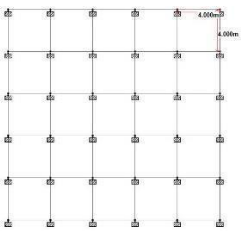
Response Spectrum Analysis described in code IS-1893 (Part 1): 2016. RSA has been applied for seismic forces applied in both X-direction and Z-direction. Response of the structure as base shear, displacement, frequency has been plotted by graphs for force acting in both x-direction and zdirection.

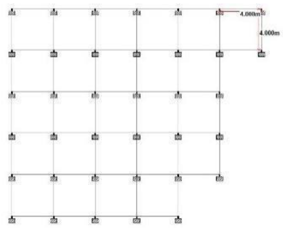
III. ANALYSIS OF REGULAR AND IRREGULAR STRUCTURE

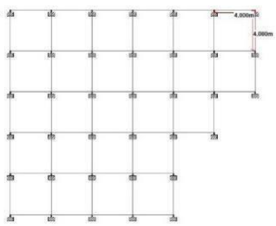
A regular building and 14 buildings having re-entrant corners due to plan irregularity have been analysed. The regular building is taken as the reference building. Dead load of all the beams and columns has been considered automatically by the software during the analysis according to the dimension which remains same for all the models. A live load of 4 KN/m^2 has been applied on all the storeys except for the top storey and the ground storey. A load of 2 KN/m^2 has been applied on the top floor and no live load has been applied on the ground floor. Seismic load in x-direction ELx and z-direction ELz has been applied by the STAADPRO software.

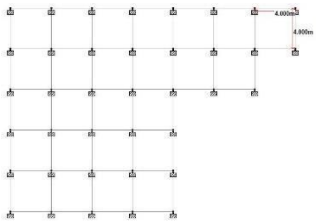
Guidelines from code IS 1893-2016 (Part-I) were followed for the calculation of the seismic parameters. Analysis was carried out for all the models considering them to be normal RC buildings with ordinary moment resisting frame (OMRF) located in Zone V area having medium stiff soil type. Keeping in view the description of the models and their location, suitable parameters has been considered according to IS-1893 (Part 1): 2016, and design horizontal acceleration coefficient (A_h) has been calculated. Then the value of A_h is multiplied by seismic weight of the structure and base shear is calculated according to IS1893 (Part 1): 2016, clause 7.6.1.

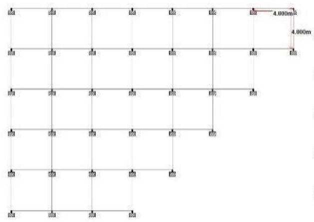
Wall load of 15.29 KN/m^2 has been considered, taking thickness of wall to be 230mm for all the floors except the top storey. Parapet wall of 2m has been considered on the top storey, its wall load being 8.74 KN/m^2. The floor load for the reference model is 4.75 KN/m^2 taking slab thickness of 150mm.

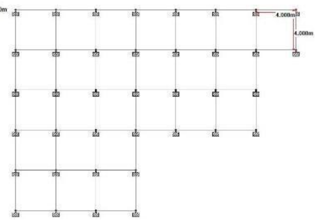

(a) Reference Model

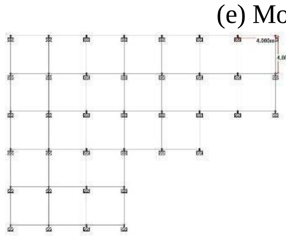

(b) Model 1

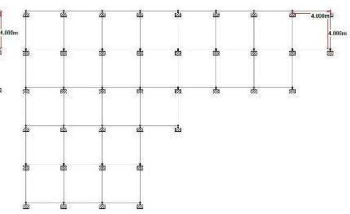

(c) Model 2

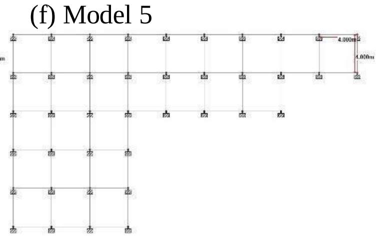

(d) Model 3

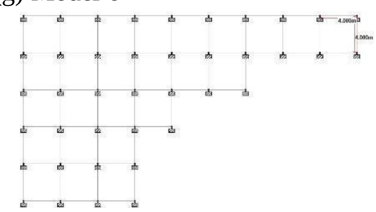

(e) Model 4

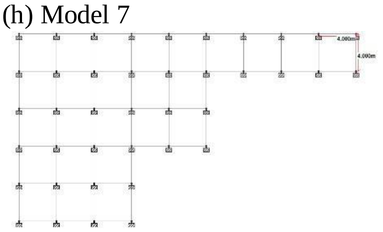

(f) Model 5

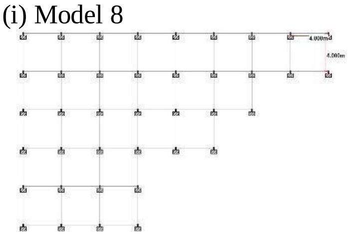

(g) Model 6

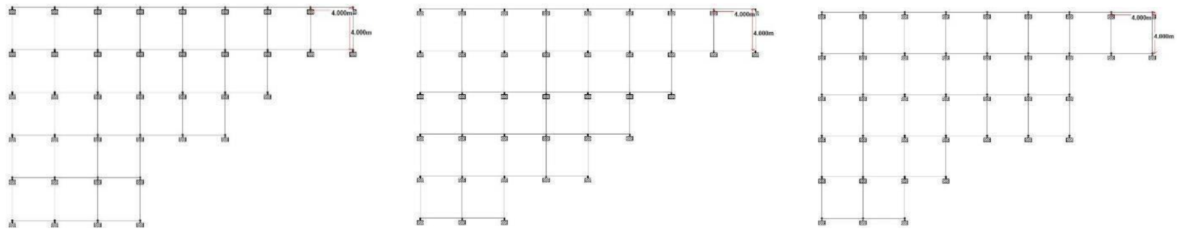

(h) Model 7


(i) Model 8


(j) Model 9


(k) Model 10


(l) Model 11



(m) Model 12 (n) Model 13 (o) Model 14

Fig.1 (a) shows the reference model which is a regular structure, (b) to (o) shows plan irregular structure namely Model1 to Model10 respectively.

The floor load of slab for irregular models have been applied accordingly so that the mass. To keep the stiffness of all the models same, the size of the columns has also been designed accordingly. The floor load for slab and column dimensions for each model has been tabulated in Table 1.

Table 1. Floor load of slab and column dimension

MODEL NUMBER	FLOOR LOAD (KN/m^2)	COLUMN DIMENSION
Reference model	4.75	0.65 m × 0.65 m
Model 1, Model 2	4.456	0.645 m × 0.645 m
Model 3, Model 4, Model 5, Model 6	4.153	0.641 m × 0.641 m
Model 7, Model 11, Model 12, Model 13, Model 14	3.85	0.637 m × 0.637 m
Model 8, Model 9, Model 10	3.551	0.633 m × 0.633 m

IV. RESULTS AND DISCUSSIONS

The results for the response of the structure has been plotted with the help of graphs in a comparative manner with respect to the reference model.

3.1 ECCENTRICITY

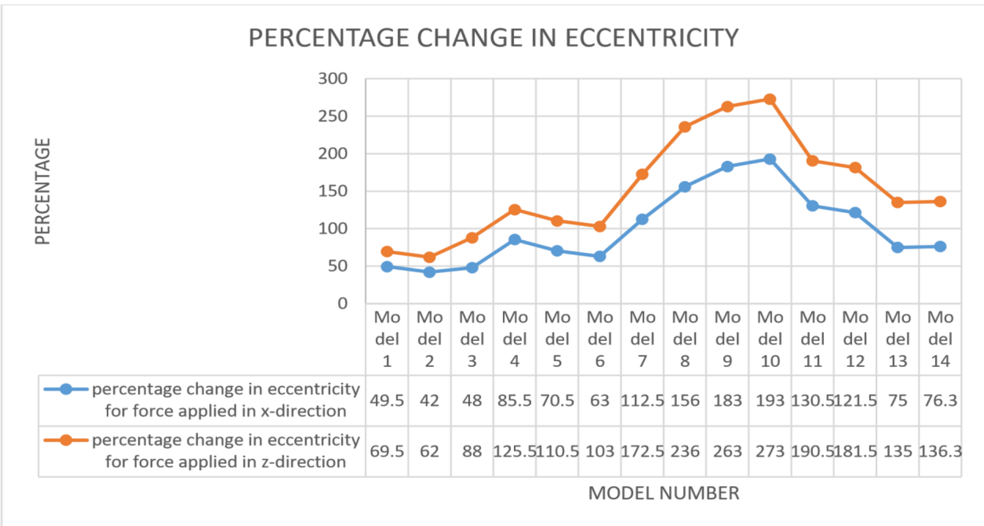


Fig. 2 PERCENTAGE CHANGE IN ECCENTRICITY FOR ALL THE MODELS FOR FORCE APPLIED IN X-DIRECTION AND Z-DIRECTION

Fig.2 shows that the values of eccentricity for force is applied in x-direction is less than the eccentricity for force is applied in z-direction. This suggests that the building is more vulnerable when the direction of force is along the z-direction as compared to when the direction of force is along the x-direction.

It has been concluded that there is an increase of percentage from Model 6 to Model 10, then it decreases from there on. In model 10 there is a major percentage increase of 193 percent for force applied in x-direction and 273 percent for force applied in z-direction, which is the maximum. It is most vulnerable to damage. The minimum percentage increase of 42 percent for force applied in x-direction and 62 percent for force applied in z-direction, in Model 2 makes it least vulnerable to damage.

3.2 BASE SHEAR

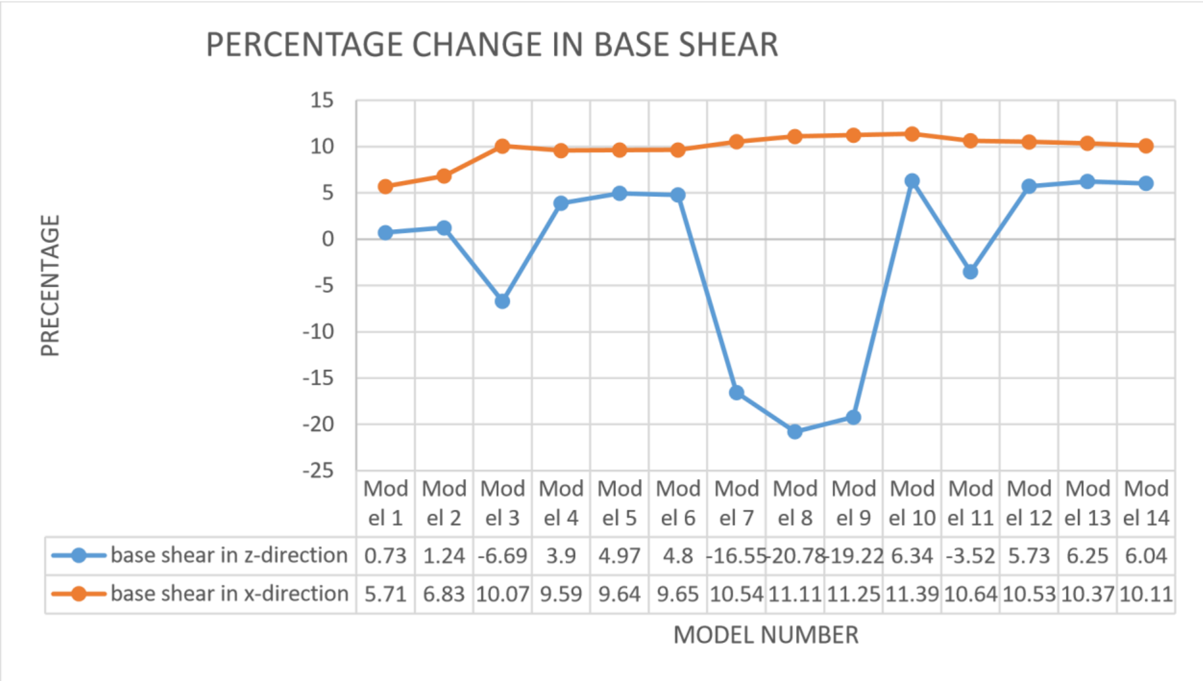


Fig.3 PERCENTAGE CHANGE IN BASE SHEAR FOR ALL THE MODELS FOR FORCE APPLIED IN X-DIRECTION AND Z-DIRECTION

Fig.3 shows the variation of percentage change of base shear in each model with respect to the reference model, for force acting in x-direction and z-direction. When the force is acting in the x- direction, there is an increase of 5.71 percent in Model 1, 6.83 percent in Model 2 and 10.07 in Model 3. From Model 3 to Model 6, the change becomes almost constant. Then there is an increase in the values of percentage change till Model 10 the it starts decreasing till Model 14. Model 10 has the highest percentage increase of 11.39 for force acting in xdirection. We can also conclude from this graph that there is only increase in values of base shear for all the models with respect to the reference model.

Also suggests, when the force is acting in the z-direction, there is a percentage decrease in values of base shear of 6.69 percent Model 3, 16.55 percent Model 7, 20.78 percent Model 8, 19.22 percent Model 9 and 3.52 percent Model 11. These buildings are least vulnerable with respect to shear failure. Percentage change of 6.34 in Model 10, makes it most vulnerable.

Model 13 and model 14 with percentage change of 6.25 and 6.04 respectively are also very vulnerable.

3.3 DISPLACEMENT

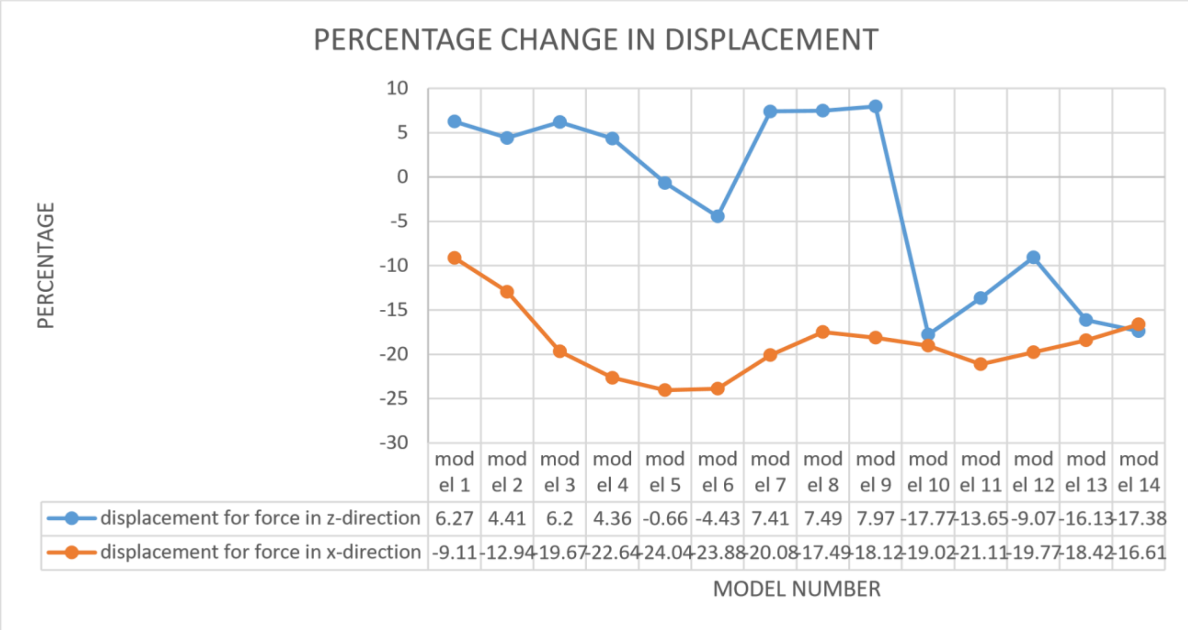


Fig.4PERCENTAGE CHANGE IN DISPLACEMENT OF TOP STOREY FOR ALL THE MODELS FOR FORCE APPLIED IN X-DIRECTION AND Z-DIRECTION

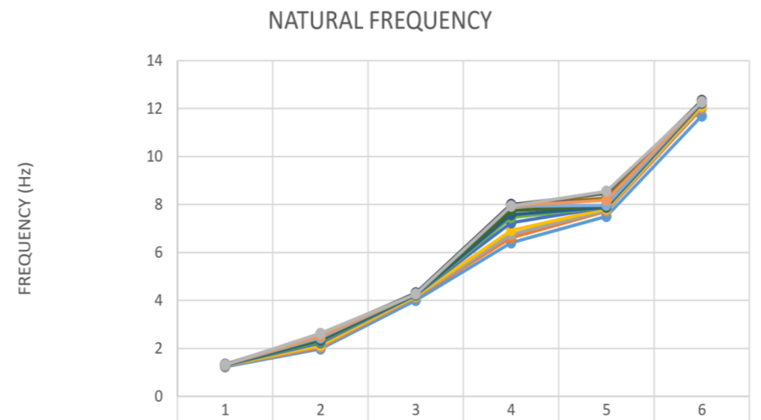
From Fig.4 we can note that, when the force is acting in the x-direction, firstly there is a decrease in percentage change from Model 1 to Model 5. Displacement in Model 5, decreases by 24.04 percent with respect to the reference model. This is the maximum value for decrease in percentage change in displacement. Then the value starts increasing form Model 6 to Model 8 in comparison to Model 5. Then further, there is a decrease in values from Model 9 to Model 11. Then again there is an increase of values with respect to Model 11.

From this graph we can conclude that there is an increase and decrease of percentage change of displacement with respect to each other. Although, there is only decrease in values in all the models, when compared with the reference model. This means that, when the force is acting in x-direction, all the models are safe from the failure due to displacement as it is less than the reference model which is a regular structure.

When the force is acting in the z-direction, there is both increase and decrease in values of percentage change with respect to the reference model. There is a notable increase of 7.41 percent in Model 7, 7.49 percent in Model 8 and 7.97 percent in Model 9. Whereas, Model 10, Model 11 and Model 12 experience decrease in values of percentage change by 17.77 percent, 13.65 percent and 9.07 percent respectively. This concludes that Model 9 is most vulnerable to damage due to displacement as it has maximum value of percentage increase in displacement with respect to the reference model. Whereas, Model 10 being least vulnerable to damage due to displacement as it has minimum value of percentage decrease with respect to the reference model.

3.4 NATURAL FREQUENCY

The natural frequency of the structure is the rate at which it vibrates when no external for has been acting on it. It depends only on the mass and stiffness of the structure. We can conclude from Fig.5 that there is only a slight change in values in Mode 4 but in all other modes the value of natural frequency is almost same, for the force applied in x-direction. This is because the mass and stiffness of each model is same.

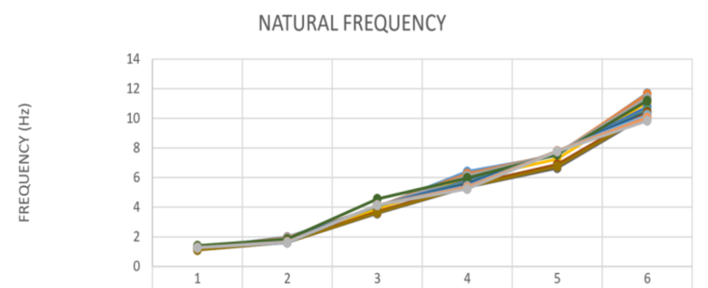


	1	2	3	4	5	6
reference model	1.233	1.983	4.005	6.406	7.504	11.692
model 1	1.275	2.043	4.135	6.611	7.727	12.001
model 2	1.281	2.087	4.154	6.75	7.763	12.057
model 3	1.296	2.133	4.194	6.922	7.82	12.117
model 4	1.307	2.23	4.232	7.237	7.889	12.221
model 5	1.307	2.299	4.233	7.455	7.892	12.226
model 6	1.307	2.338	4.233	7.578	7.894	12.23
model 7	1.322	2.44	4.275	7.923	7.964	12.29
model 8	1.334	2.595	4.307	7.995	8.459	12.328
model 9	1.335	2.53	4.311	7.999	8.262	12.334
model 10	1.336	2.506	4.314	8.003	8.188	12.34
model 11	1.323	2.38	4.277	7.747	7.957	12.293
model 12	1.322	2.442	4.275	7.932	7.97	12.29
model 13	1.321	2.514	4.271	7.946	8.181	12.284
model 14	1.319	2.631	4.265	7.937	8.55	12.271

MODEL NUMBER

Fig.5 NATURAL FREQUENCY FOR ALL MODLES FOR FORCE APPLIED IN X-DIRECTION

Fig.6 shows that when the force is acting in z-direction, the natural frequency for all the models in each mode is almost the same. Also in both the cases, the frequency increases with increase in the Mode.



	1	2	3	4	5	6
reference model	1.233	1.983	4.005	6.406	7.504	11.692
model 1	1.24	1.938	4.035	6.261	7.584	11.644
model 2	1.244	1.898	4.048	6.133	7.605	11.404
model 3	1.202	1.805	3.893	5.885	7.259	11.086
model 4	1.248	1.782	4.069	5.772	7.663	10.773
model 5	1.254	1.744	4.084	5.649	7.688	10.544
model 6	1.266	1.731	4.123	5.604	7.755	10.452
model 7	1.145	1.675	3.702	5.487	6.888	10.407
model 8	1.108	1.628	3.578	5.355	6.647	10.22
model 9	1.126	1.633	3.637	5.382	6.756	10.295
model 10	1.272	1.606	4.145	5.251	7.783	9.944
model 11	1.397	1.837	4.557	5.973	7.558	11.19
model 12	1.271	1.671	4.142	5.434	7.792	10.213
model 13	1.273	1.645	4.145	5.351	7.789	10.059
model 14	1.272	1.609	4.137	5.235	7.759	9.84

MODE NUMBER

Fig.6 NATURAL FREQUENCY FOR ALL MODLES FOR FORCE APPLIED IN Z-DIRECTON

V. CONCLUSIONS

Comparing the absolute values of eccentricity of all the models, it has been seen that the structures are more vulnerable when seismic forces act in the direction where the depth of the building is less in plan i.e. z-direction.

Percentage change in the values of eccentricity for force acting in both x-direction and zdirection for all models has been considered. There is only increase in the values with respect to the reference model due to the presence of irregularity.

The base shear is more in all the models in the direction where the depth of the building is more in plan due to increased stiffness.

The values of displacement for force acting in z-direction is more in comparison to force acting in x-direction. This may be because the values of width in plan hence stiffness in the z-direction is the less. Model 10 has the maximum decrease in top storey displacement for force acting in z-direction, this also may be due to the fact that model 10 has the maximum value of eccentricity. Due to this more rotation may develop in the structure and less lateral displacement.

The values of natural frequency and natural time period, for all the models and seismic force acting in both the directions, are varying by some degree. This may be due to the fact that both of these parameters are dependent on the stiffness of the structure.

Model 10 has may be most vulnerable out of all the models as it has the highest value of eccentricity and base shear. The structure is most vulnerable when force is acting in the direction in which the width of the building in plan is less as compared to the other dimension. In this case it was z-direction.

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