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Pushover Analysis of Irregular Steel Structure with Varying Irregularity Ratios

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ABSTRACT

In this paper the seismic performance of irregular steel structure with varying irregularity ratio have been investigated. For the study purpose, two different models with vertical geometric irregularity and plan irregularity according to IS 1893 (part 1) -2002 have been considered. The irregularity ratio (A/L) where A is offset and L is base width has been varied from 0.2 to 0.8. Irregular structures have been modeled using ETABS, a finite element software and plastic hinges are assigned to incorporate the inelastic seismic behaviour of structures. Performance of eleven irregular structures has been compared with regular frame structure in terms of base shear carrying capacity, roof displacement and performance point, using pushover analysis. The results indicates that as irregularity ratio increases, base shear carrying capacity and performance point of irregular structure decreases.

Keywords : Irregularity ratio; plan irregularity; pushover analysis; seismic behaviour; vertical geometric irregularity.

I. INTRODUCTION

An earthquake is a natural phenomenon which induces seis-mic wave causing ground motion, Due to this lateral forces will act on structures which in turn cause severe damage or collapse of structures. When the structure is under seismic excitations, elements in structure reaches its inelastic zone. For seismic evaluation, nonlinear behaviour of structure in inelastic zone plays significant role. Hence elastic behaviour of structure is not sufficient to analyses and design the structures [1]. During seismic excitations considering inelastic behaviour with elastic behaviour, the real behaviour of structures can be studied.

In the last decade, pushover analysis is used to study performance of structure under seismic exaction. Pushover analysis is a sequential analysis method to study the inelastic behaviour of structures, when the structure pushed by providing monotonically increasing lateral force until a predefined target roof displacement is reached or till collapse of structure [2]. Also pushover analysis provides details regarding capacity curves and demand curves which represent ability of structure to resist the lateral loads and earthquake ground motion respectively [3]. Performance point can be obtained by superimposing capacity curves and demand curves on each other.

Irregular structures have been commonly used due to site restriction, various functional requirements and architectural demands. Researchers have shown that, irregular structure attracts more seismic forces compared to regular structures [4]. In an earlier research authors have study on the amount of eccentricity of structures effecting the seismic behaviour. Results indicates that as eccentricity increases, torsion increases. Due to which accuracy of seismic response is reduced [5]. Authors of the researcher studied seismic response considering various irregularities type of structural configurations.

Shows than seismic response of structure varies with the irregularities type [6]. When plan irregularity and vertical irregularity structures on a sloping ground is considered, the vertical irregularity structures are more critical in seismic performance [7]. Also various researches have been carried out in order to study the seismic performance of steel frame structures. Results show that steel structures have high seismic performance [8-10]. However, limited studies have been carried out in the effect irregularity ratio on irregular steel structures for seismic evaluation. So in this study, using pushover analysis, the effect of irregularity ratio on vertical geometric irregularity and plan.

II. METHODOLOGY

A 10 story structure with height of each story 3 m is considered as regular structure. The plan of dimension 15 m × 15 m of regular structure considered in the study is given in Fig. 1. The reinforced concrete slab considered is of 150 mm thick with M 20 grade of concrete. Eleven irregular models are considered by varying irregularity ratio. The irregularity ratio is varied by varying the offset and keeping the base width constant.

As per IS 1893 (part 1) – 2002 [11], Fig.2 shows, type (i) and type (ii) structures which are two types of vertical geometric irregularities. Fig.3 shows, type (iii) and type (iv) structures which are two types of plan irregularities. Fig. 4 to 6 shows the variation in irregularity ratio of type (i) structure. Fig. 7 and Fig. 8 shows the variation in irregularity ratio of type (ii) structure. Fig. 9 to 11 shows the variation in irregularity ratio of type (iii) structure. Fig. 12 to 14 shows the variation in irregularity ratio of type (iv) structure.

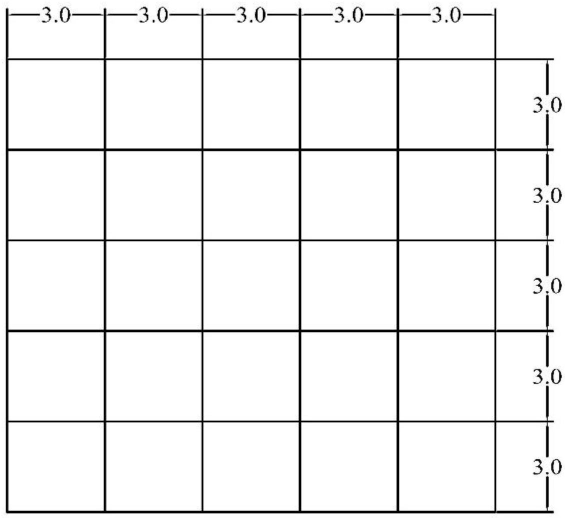

Fig. 1. Plan of the building

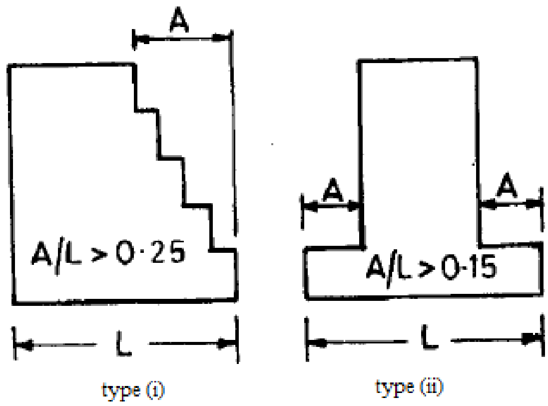

Fig. 2. Two types of vertical geometric irregularity as per IS 1893 (part 1) – 2002

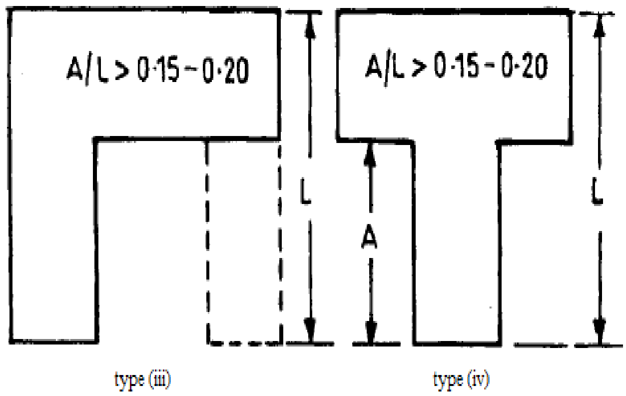

Fig. 3. Two types of plan irregularity as per IS 1893 (part 1) – 2002

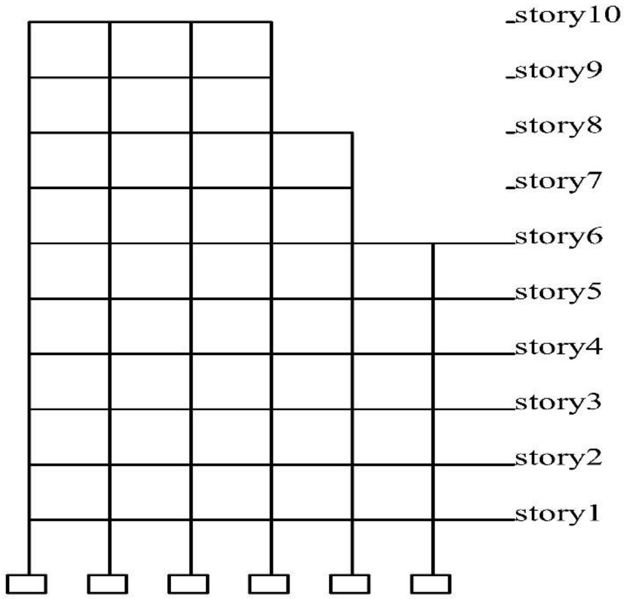

Fig. 4: Model 1, frame showing type (i) irregular structure with irregularity ratio of 0.4

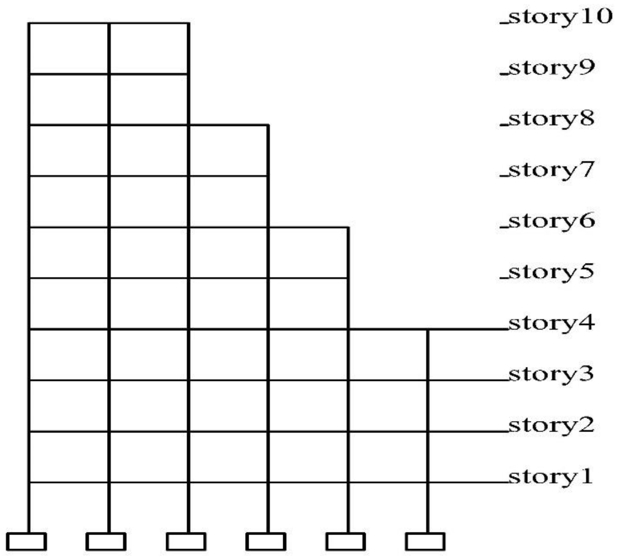

Fig. 5: Model 2, frame showing type (i) irregular structure with irregularity ratio of 0.6

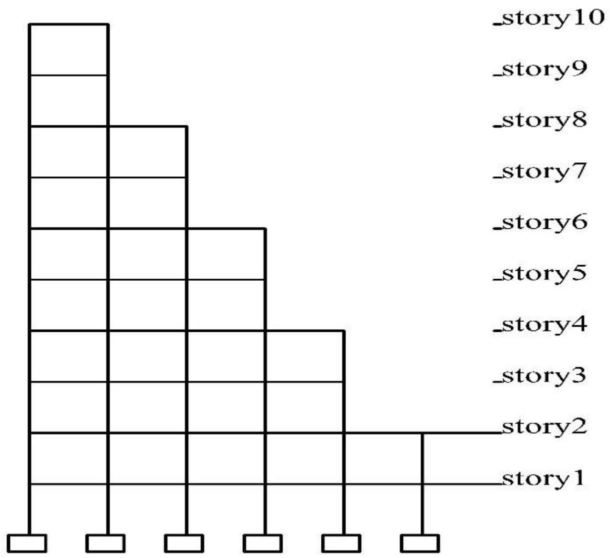

Fig. 6: Model 3, frame showing type (i) irregular structure with irregularity ratio of 0.8

The dead and live loads are considered on structure is based on IS 875 (Part I) [12] and IS 875 (Part II) [13] respectively. Live load considered on all floors is 3 kN/m^2 and on roof is 1.5 kN/m^2 with Dead load on floor is 1 kN/m^2 on all structural models. For seismic evaluation, structural models considered is situated in seismic zone III with response reduction factor as four. All the structural configurations are having importance factor of one with soil type medium. Using ETABS, a finite element software, beams and columns are modelled as frame elements with slab considered as membrane element. For the seismic analysis simplicity structural models are considered fixed at the base. The structural models both regular and irregular structures are designed according to IS 800 (2007) [14].

The designed steel section used for beams, columns and bracings are ISMB 200, ISWB 600-2 and ISLB 175 respectively with grade of steel used is Fe 250. The auto hinges for incorporation of inelastic behaviour of structures, M3, P-M2-M3 and P hinges are assigned to beams, columns and bracings respectively according to ASCE 41-13[15]. For seismic performance evaluation, the base shear carrying capacity, roof displacement and performance point are considered in both the direction of applied earthquake loading i.e. X and Y direction.

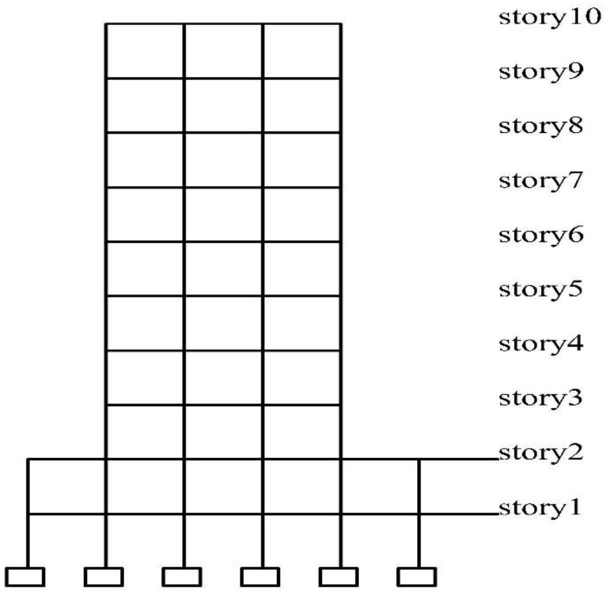

Fig. 7: Model 4, frame showing type (ii) irregular structure with irregularity ratio of 0.2

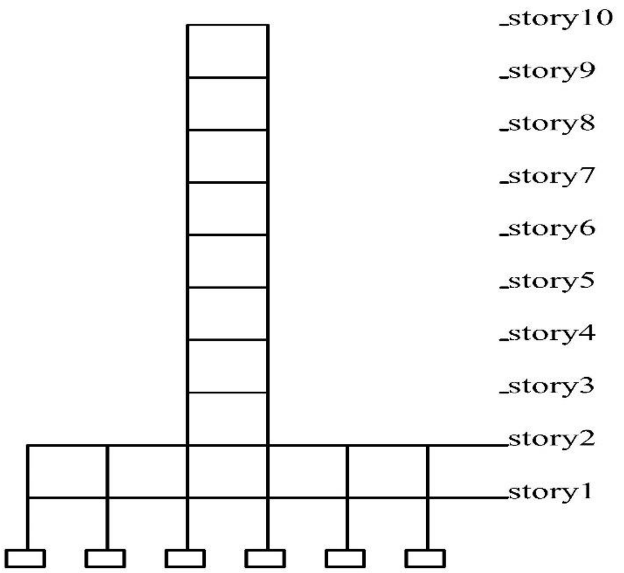

Fig. 8: Model 5, frame showing type (ii) irregular structure with irregularity ratio of 0.4

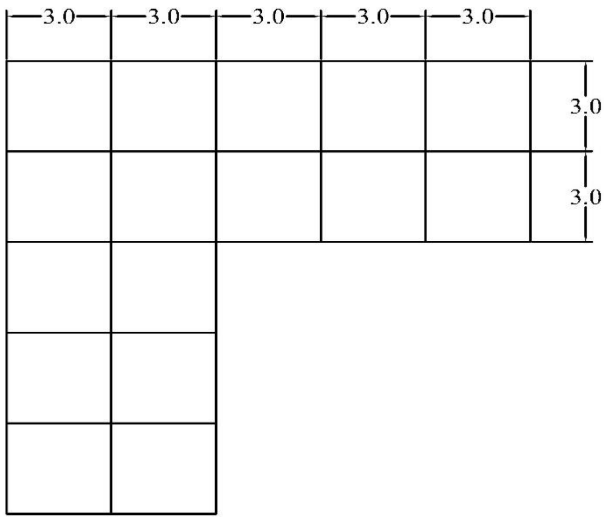

Fig. 10: Model 7, frame showing type (iii) irregular structure with irregularity ratio of 0.6

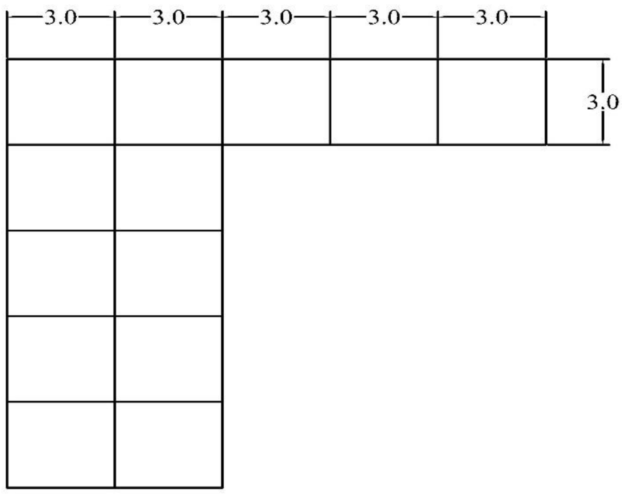

Fig. 11: Model 8, frame showing type (iii) irregular structure with irregularity ratio of 0.8

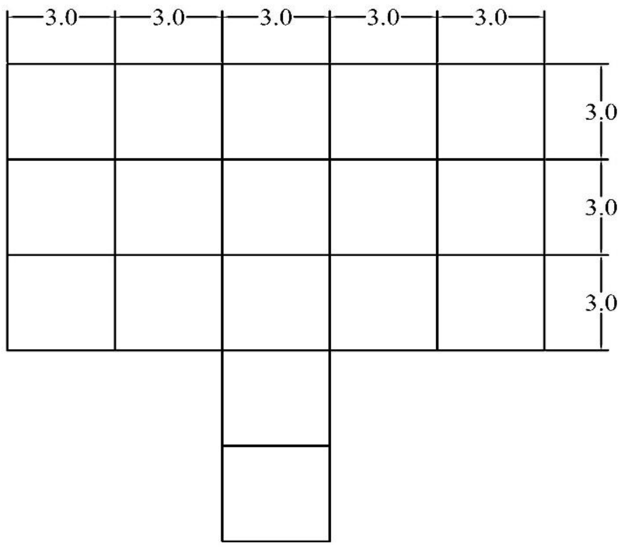

Fig. 12: Model 9, frame showing type (iv) irregular structure with irregularity ratio of 0.4

III. RESULTS AND DICUSSION

The results obtained from nonlinear pushover analysis are dis-cussed here. Fig. 15 to 20 shows the capacity curves comparing the irregular structural models with regular structural model. The variation of capacity curves in Y direction for irregular structures of type (ii) and type (iv) follows the similar trend as shown in Fig. 17 and Fig. 20 respectively.

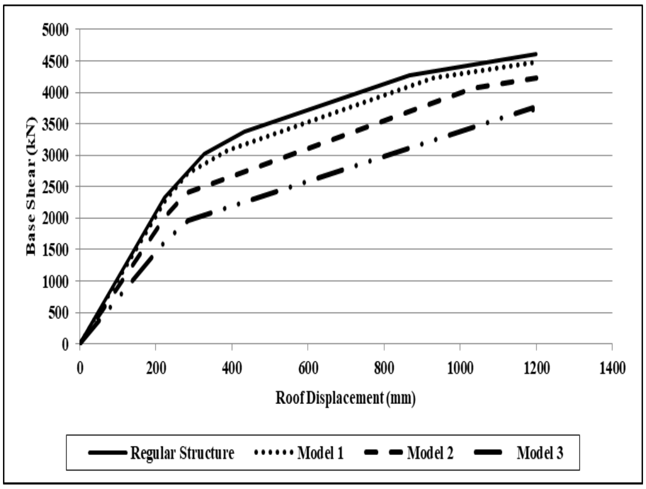

Fig. 15: Capacity curves, comparing vertical geometric irregularity of type (i) structures with regular structure in X direction of earthquake

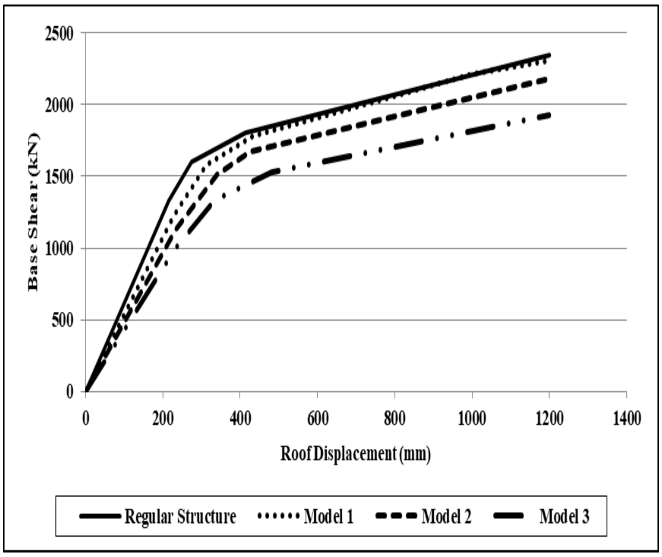

Fig. 16: Capacity curves, comparing vertical geometric irregularity of type (i) structures with regular structure in Y direction of earthquake

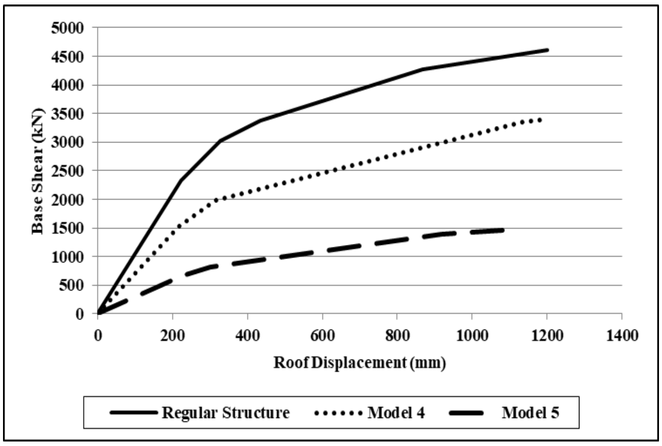

Fig. 17: Capacity curves, comparing vertical geometric irregularity of type (ii) structures with regular structure in X direction of earthquake

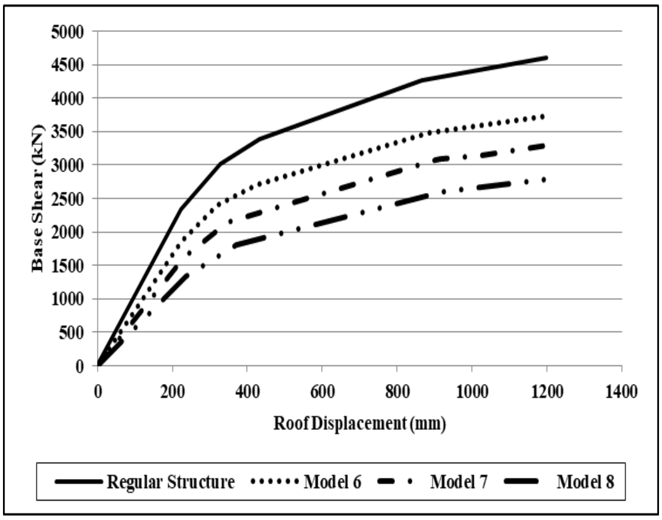

Fig. 18: Capacity curves, comparing plan irregularity of type (iii) structures with regular structure in X direction of earthquake

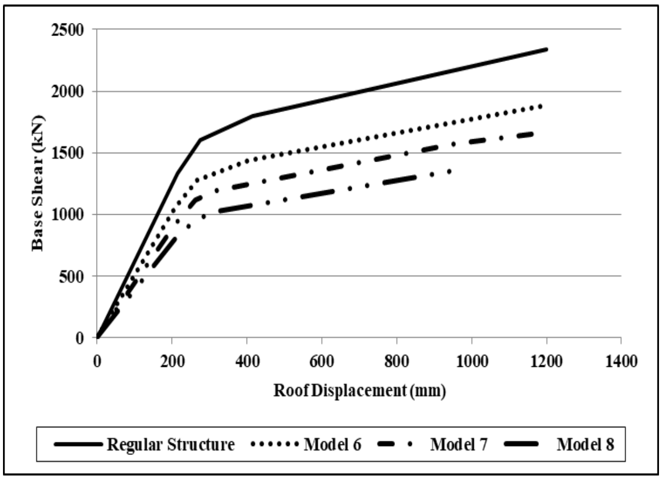

Fig. 19: Capacity curves, comparing plan irregularity of type (iii) structures with regular structure in Y direction of earthquake

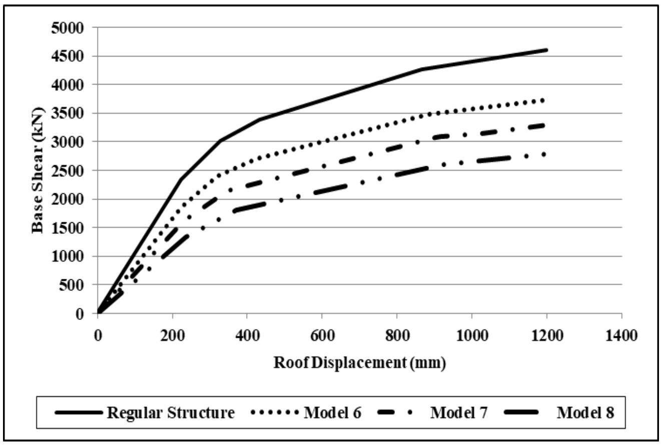

Fig. 18: Capacity curves, comparing plan irregularity of type (iii) structures with regular structure in X direction of earthquake

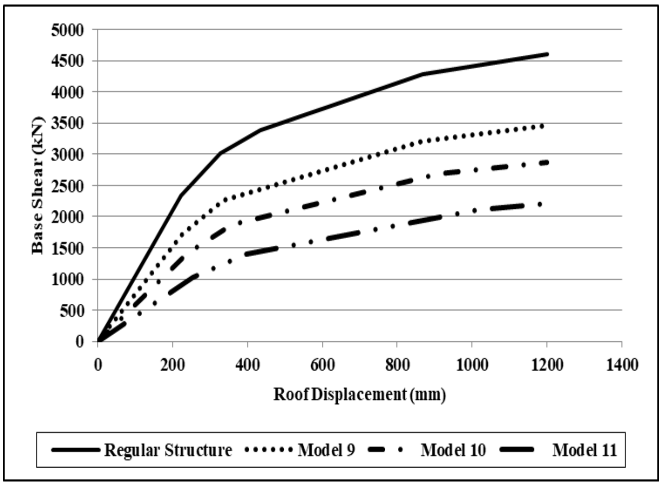

Fig. 20: Capacity curves, comparing plan irregularity of type (iv) structures with regular structure in X direction of earthquake

From Fig. 15 to 20, graph indicates that, as irregularity ratio increases, base shear carrying capacity of irregular structure decreases. Comparing roof displacement of all irregular structural models with roof displacement of regular structure, the values are almost same with few exception. There is reduction of 6.5% and 9% of roof displacement occurring in model 5 compared to regular structure in X and Y direction respectively. Whereas roof displacement is reduced by 18% in Y direction of model 8 compared to regular structure. The irregularity ratio of 0.4 have higher base shear carrying capacity compared to all other irregularity ratios considered in the study. The stiffness in all structural configurations along X direction is more compared to Y direction, hence base shear carrying capacity of all the models in X direction is higher. From Fig. 15 to 20, base shear carried by the irregular structures is considerably reduced when compared to regular structure. Table 1 shows percentage decrease in base shear along X and Y direction.

From Table 1, vertical geometric irregularity of type (i), the models 1, 2 and 3 shows an average reduction in base shear carrying capacity of 2%, 9% and 18.5% when compared to regular structure respectively. Whereas vertical geometric irregularity of type (ii), the average reduction in base shear carrying capacity of model 4 and model 5 are 26% and 64% when compared to regular structure respectively. Hence vertical geometric irregularity of type (i) models have shown higher base shear carrying capacity compared to type (ii) From Table 1, plan irregularity of type (iii), the models 6, 7 and 8 shows an average reduction in base shear carrying capacity of 19%, 28% and 40% when compared to regular structure respectively. Whereas plan irregularity of type (iv), the average reduction in base shear carrying capacity of models 9, 10 and 11 are 25%, 38% and 52% when compared to regular structure respectively. Hence plan irregularity of type (iii) models have shown higher base shear carrying compared to type (iv) models for all irregularity ratios. The vertical geometrical irregularity of type (i) has higher base shear carrying capacity compared to all irregular configurations considered in the study.

Table 2 and Table 3 shows the base shear carried and displacement at performance point of structures for earthquake in X and Y direction respectively. From the Table 2 and Table 3 the base shear carrying capacity at the performance point of regular structure is higher compared to all irregular models considered. As the irregularity ratio increases the base shear carrying capacity at performance point decreases for both X and Y direction of earthquake.

In irregular models the model 2 carried higher base shear capacity compared to all configurations considered in the study.

TABLE 1: PERCENTAGE DECREASE IN BASE SHEAR FOR CORRESPONDING DIRECTION OF EARTHQUAKE

Structural models	**Percentage decrease in base shear along in X direction (%)**	**Percentage decrease in base shear along Y direction (%)**
Model 1	2.61	1.44
Model 2	8.20	7.05
Model 3	19.30	17.62
Model 4	26.13	26.47
Model 5	67.88	60.48
Model 6	18.77	19.34
Model 7	28.59	29.03
Model 8	39.34	41.66
Model 9	24.80	25.91
Model 10	37.56	38.85
Model 11	52.00	51.81

TABLE 2: THE BASE SHEAR CARRIED AND ROOF DISPLACEMENT AT PERFORMANCE POINT OF STRUCTURE FOR EARTHQUAKE IN X DIRECTION

Structural models	Performance point	
	Base shear (kN)	Base shear (kN)
Model 1	3639.88	360.22
Model 2	3196.81	354.53
Model 3	2552.29	348.74
Model 4	2481.46	351.81
Model 5	961.55	328.74
Model 6	3030.24	365.72
Model 7	2619.79	373.43
Model 8	2206.91	393.84
Model 9	2760.60	362.50
Model 10	2206.94	372.26
Model 11	1643.24	409.63

TABLE 3: THE BASE SHEAR CARRIED AND DISPLACEMENT AT PERFORMANCE POINT OF STRUCTURE FOR EARTHQUAKE IN Y DIRECTION

Structural models	Performance point	
	Base shear (kN)	Base shear (kN)
Model 1	2829.74	526.64
Model 2	2495.44	516.19
Model 3	2057.33	477.22
Model 4	2030.35	449.27
Model 5	954.54	369.85
Model 6	2363.28	468.39
Model 7	2041.52	458.85
Model 8	1720.31	450.24
Model 9	2152.02	471.53
Model 10	1720.90	458.09
Model 11	1287.26	436.65

IV. CONCLUSION

Based on the result and discussion it can be concluded that, as irregularity ratio increases, base shear carrying capacity and performance point of irregular structure decreases. Regular structural model showed higher seismic performance in both X and Y direction compared to all irregular structural models considered. The vertical geometrical irregularity models of type (i) has higher seismic performance compared to all the irregular configurations considered in the study. Also vertical geometrical irregularity of type (ii) has least seismic performance compared to all the irregular configurations considered in the study

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