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PUSHOVER ANALYSIS OF TWO DIMENSIONAL STEEL BRACED STRUCTURE WITH TWO STORY HEIGHT BRACING

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ABSTRACT

In this paper the seismic performance of two dimensional braced steel frame structures with two story height bracings have been investigated. For the study purpose, Inverted V braced frames, Diamond braced frames and X braced frames are considered and seismic performance is compared with one story braced frame and bare frame structures. Varying aspect ratios (ratio of height of structure to base width) ranging from one to four are considered. Using ETABS, a finite element software, pushover analysis is performed to study the nonlinear behaviour of structure in inelastic zone. The results of the study indicate that, aspect ratio of one shows a better seismic performance when compared with rest of the models considered in the study. One story height braced frame structures have shown better seismic performance when compared to all other configurations considered.

Key words: aspect ratio, braced frame structure, nonlinear behaviour, pushover Analysis, seismic performance.

1. INTRODUCTION

During seismic excitations, surface waves generate ground motion which induces lateral forces on structures which causes severe damage or collapse of structures. This happens because, when structure subject to earthquake, nonlinear behaviour of elements in structure is not accounted in inelastic zone. Only the elastic linear behaviour is considered. Hence elastic linear behaviour of structure is not sufficient to analyse and design the structures [1]. For seismic evaluation, considering inelastic nonlinear behaviour accounts for the real behaviour of structures.

Pushover analysis is commonly used multiple level performance method to study performance of structure under seismic exaction. Pushover analysis is a method which consider inelastic behaviour, when the structure pushed by providing seismic forces i.e. structure subjected to monotonically increasing lateral force until a predefined target roof displacement is reached or till collapse of structure [2]. Also, pushover analysis predicates capacity of structure for seismic demand [3]. Capacity curves and demand curves represent ability of structure to resist the lateral loads and earthquake ground motion respectively. By superimposing capacity curves over demand curves, Performance point can be obtained.

During seismic exaction, when the structure is pushed beyond its yield point into inelastic zone, to account nonlinear behaviour in structure the hinges are applied on elements of structure. Plastic hinges are formed after the yielding of the elements and till collapse, elements will act as a plastic hinge. Considering the plastic hinges in elements of structure the performance of structures can be divided into four levels. In operational level, no damage should occur with full utility of the structure post-earthquake. In immediate occupancy level, very limited damage and after repairs the structure can reoccupied. In life safety level, the structure remains stable with major repairs or retrofit as to be done to reoccupy the structures. Whereas in collapse prevention level, the structure remains to be standing, but barely and structure has to be rebuilt. The damages beyond the collapse prevention level are not acceptable. For a better performance the structure is designed for a performance level in between the immediate occupancy to life safety. The structure with operational level of performance is uneconomical structure. Also, lesser the number of plastic hinges formed in the structure higher will be the seismic performance.

Researchers have shown that, bracing applied to one story height, have effectively reduced the roof displacement and increased base shear carrying capacity with reduction in inter-storey drifts and global damage index modal time period corresponding to applied earthquake [4-7]. The bracing section type is seen to have a global influence on the deformation and ductility capacities of structures with I section having higher seismic performance [8-9]. Hence, in this study I section is used for bracings. Till now researchers have studied the effect of frame which are two story heights on the response of X-braced frame structure. It was found that such structure undergoes significant vertical inelastic deformation [10-11]. In this study, pushover analysis technique is used to study the effect of two story height braced frame structure for varying aspect ratio.

2. DESCRIPTION OF MODELS

Using ETABS, a finite element software, Steel frame structure with and without braces are considered for analysis. Plan of the building is shown in Figure 1 with the frame element considered for two dimension analysis. In this study, four structures are considered with top story height of 9 m, 18 m, 27 m and 36 m, with height of each story is 3 m. The base width of the structure is 9 m, accordingly four aspect ratios are formed i.e. one, two, three and four respectively.

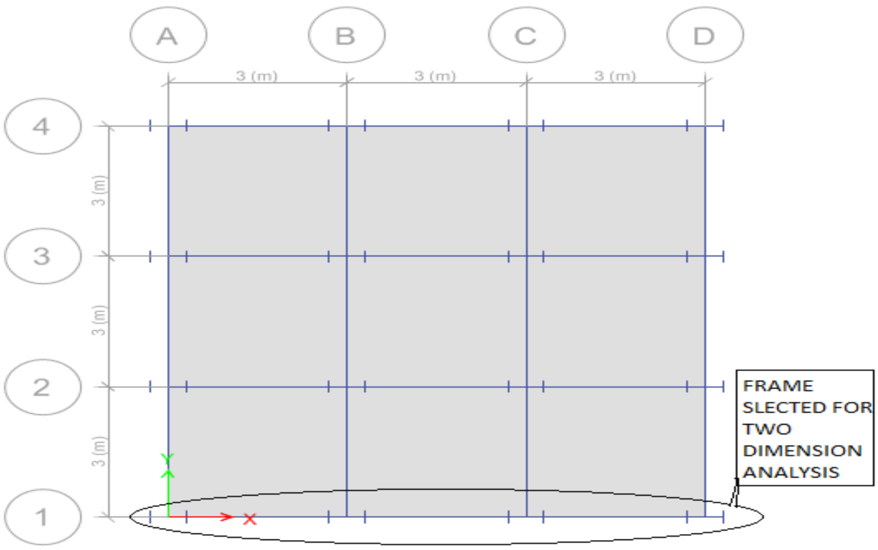

Figure 1 Plan of frame structure

The dead and live are considered on structure are based on IS 875 (Part I) [12] and IS 875 (Part II) [13] respectively. The gravity loads are applied on the beams of the frame structures. Live load considered is 3 kN/m^2 and on roof is 1.5 kN/m^2 with Dead load is 1 kN/m^2.Beams and columns are modelled as frame element. The dead load and portion of live load is applied as forced controlled pushover load case. The grade of steel used is Fe 250. The steel section used for beams, columns and bracings are ISMB 200, ISWB 600-2 and ISLB 175 respectively and designed according to IS 800 (2007) [14].

3. PUSHOVER ANALYSIS OF FRAME STRUCTURE

The frame structure is assumed to be fixed at the base for the simplicity of analysis. The target displacement considered for the study is 4% the height of the structure for all the structural configurations considered. Using ETABS software, auto hinges M3, coupled P-M2-M3 and P are assigned to beams, columns and bracings respectively as per to ASCE 41-13 [15]. For accounting geometric nonlinearity in structures, the P- δ (P- delta) effect is considered.

4. NONLINEAR SIMULATION

For seismic demand, importance factor of all structural model is one and type of soil is medium. Structure is considered to be situated in seismic zone III with response reduction factor as four. The earthquake loading is applied as displacement controlled pushover load case. Performance of two story height braced frame structures are compared in terms of base shear capacity, roof displacement, performance point and the formation number of the hinges with one story height braced frame structures and bare frame structure. The two story height of the bracing in inverted braced frames, diamond braced frames and X braced frames are shown in Figure 2 to 4 respectively for aspect ratio of one.

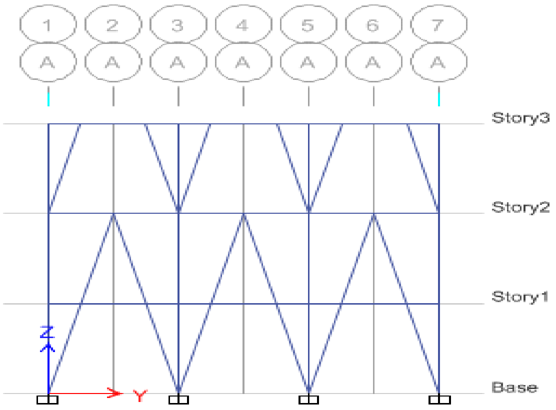

Figure 2 Two story Inverted V bracing

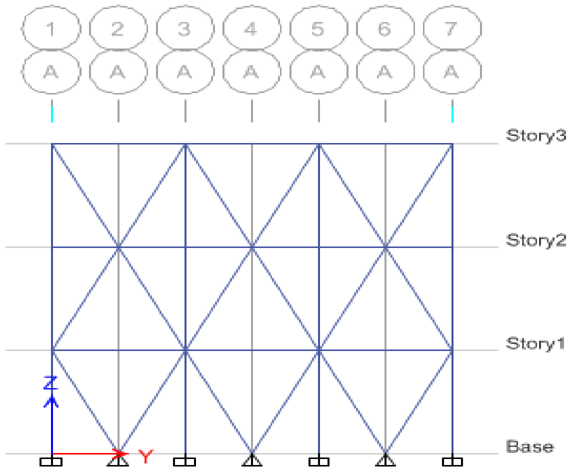

Figure 3 Two story Diamond bracing

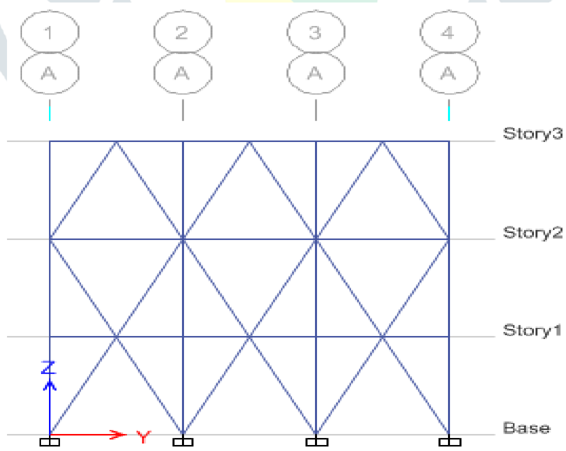

Figure 4 Two story X bracing

5. RESULTS AND DISCUSSIONS

The results obtained from nonlinear pushover analysis are dis-cussed here. Fig. 5 to 8 shows the capacity curves comparing the irregular structural models with regular structural model.

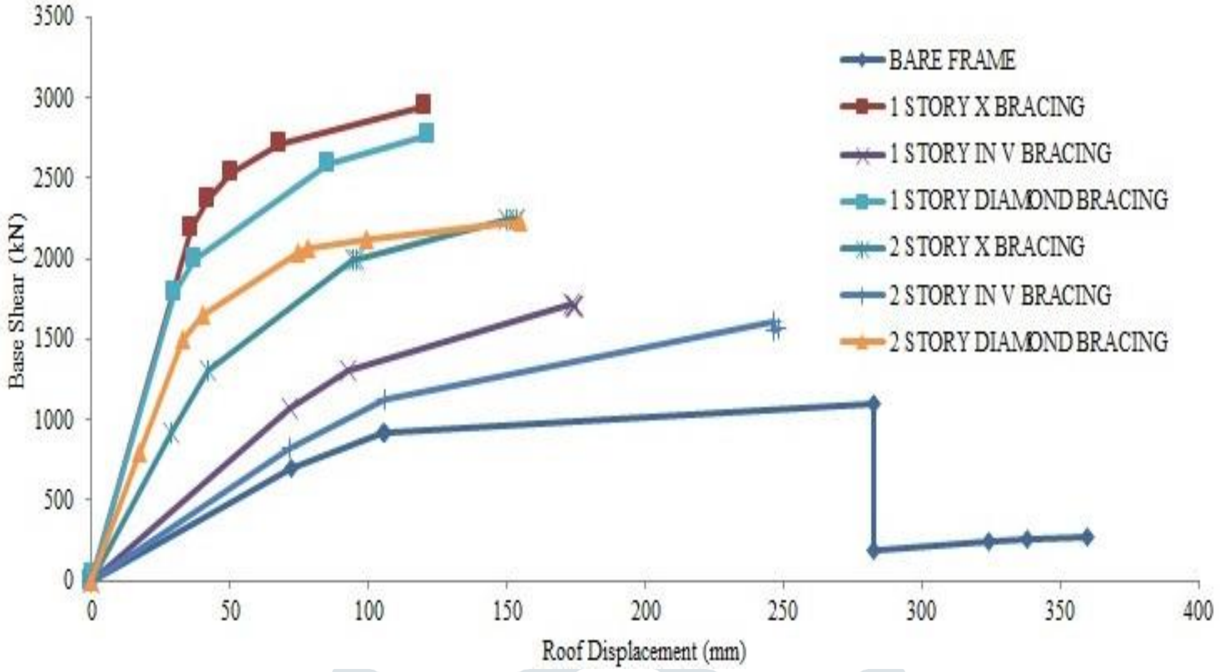

Figure 5 Capacity curves, comparing two story height bracing with one story height bracing and bare fame for aspect ratio of one

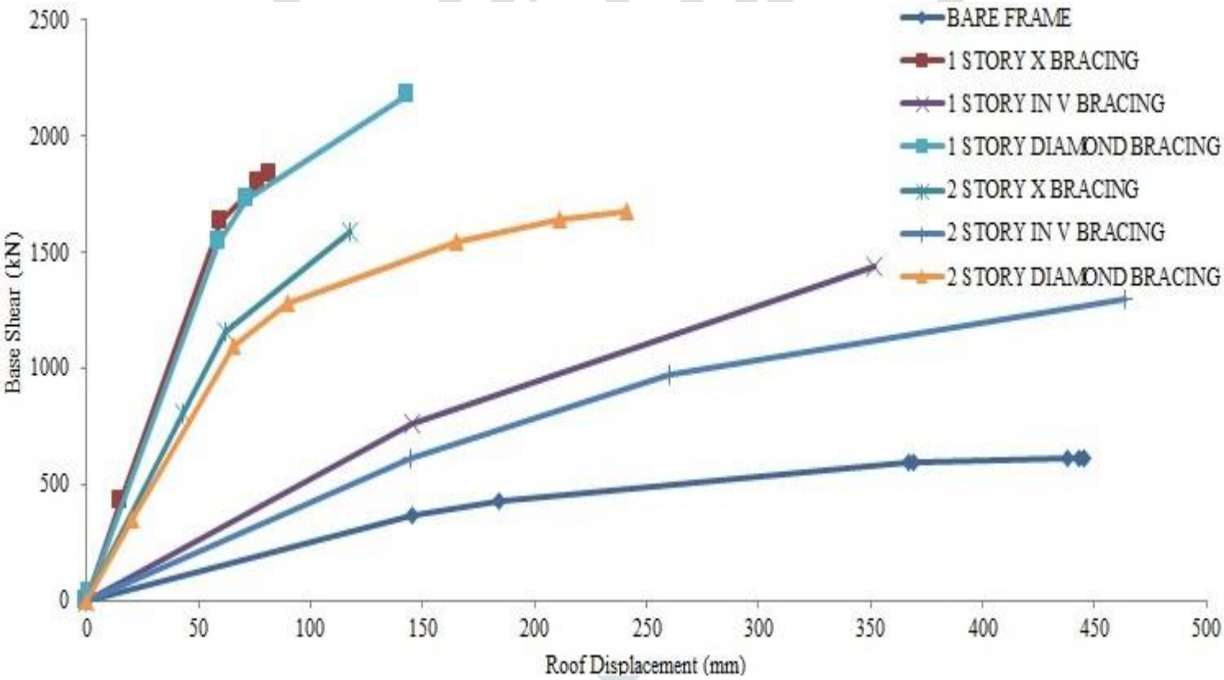

Figure 6 Capacity curves, comparing two story height bracing with one story height bracing and bare fame for aspect ratio of two

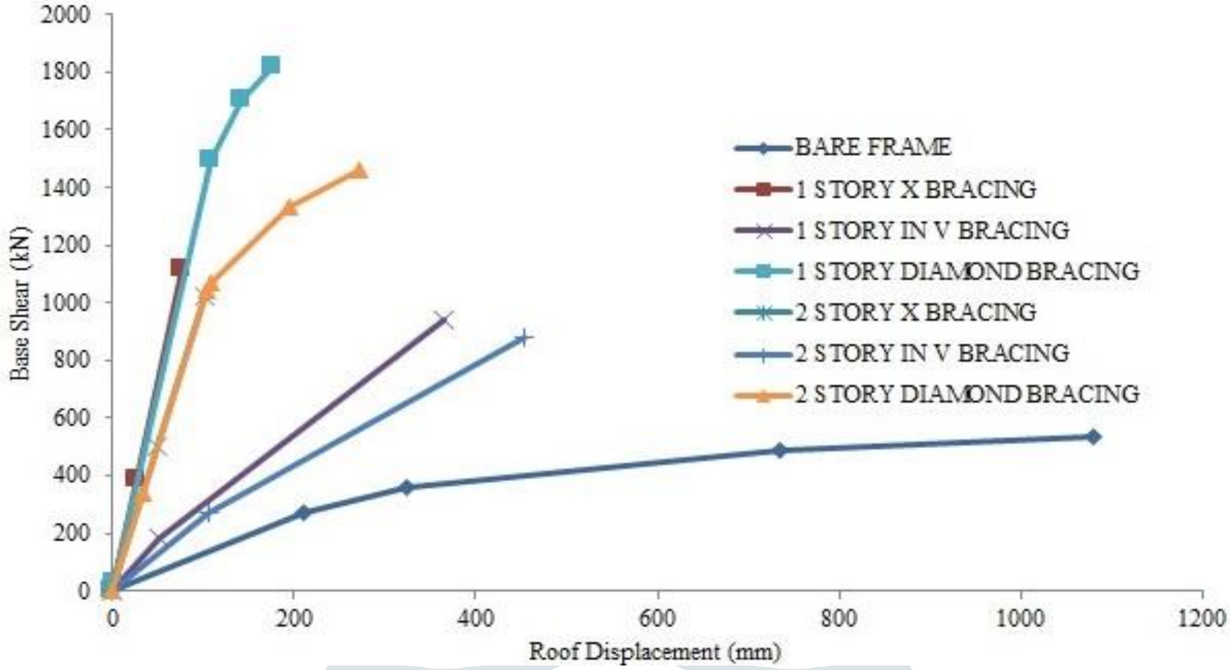

Figure 7 Capacity curves, comparing two story height bracing with one story height bracing and bare fame for aspect ratio of three

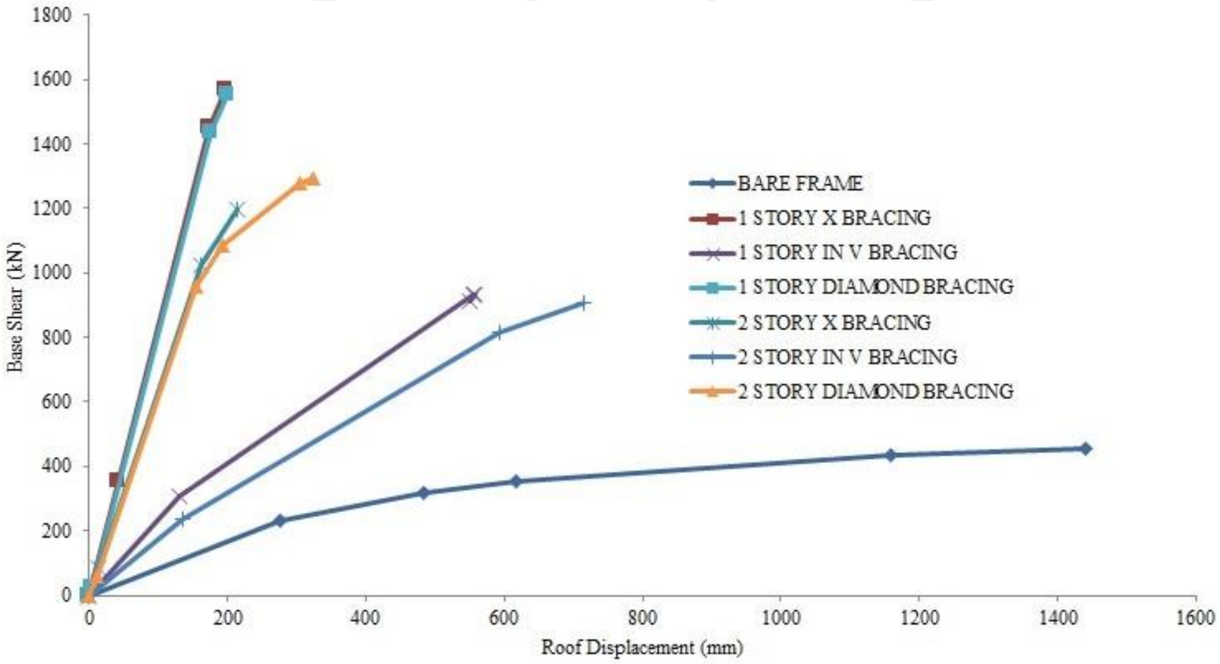

Figure 8 Capacity curves, comparing two story height bracing with one story height bracing and bare fame for aspect ratio of four

From the Figure 5 to 8 the graph indicates that, braced frame structures have reduction in the roof displacement with higher base shear capacity compared to bare frame. The braced frame structure with one story bracing has higher base shear capacity with least roof displacement when compared with two story bracing for all aspect ratios and for all the configurations. It was found that, the one story X braced, two story diamond braced structures, have higher base shear capacity when compared to all braced structures respectively. The aspect ratio of one has higher base shear capacity compared to other aspect ratios for all the bracing configurations. Hence the braced frame has provided the stiffness to the structure by reducing the roof displacement and increasing the base shear carrying capacity. The Figure 9 to 15 shows the formation maximum number of hinges formed with the maximum pushover load cases i.e., till the target displacement reached or collapse of structure for aspect ratio of one.

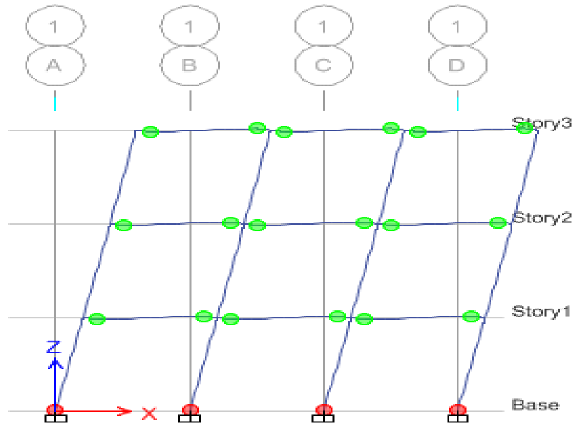

Figure 9 Hinges formed in bare frame structure.

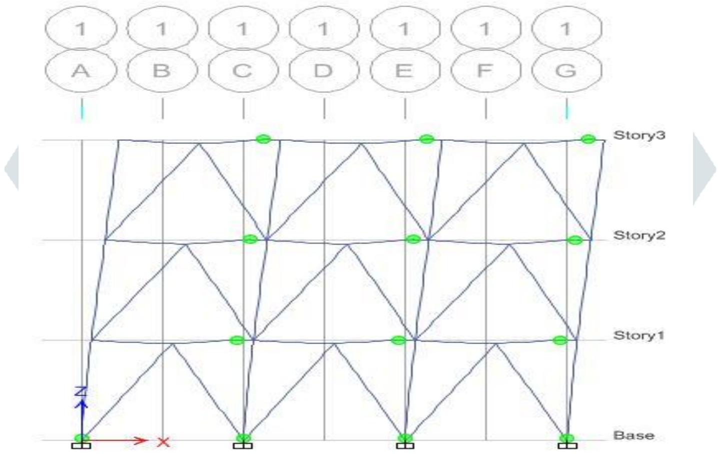

Figure 10 Hinges formed in one story height Inverted V Braced frame structure.

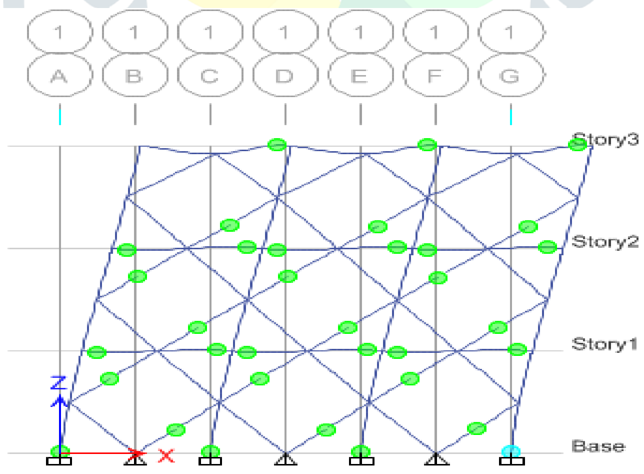

Figure 11 Hinges formed in one story height diamond braced frame structure.

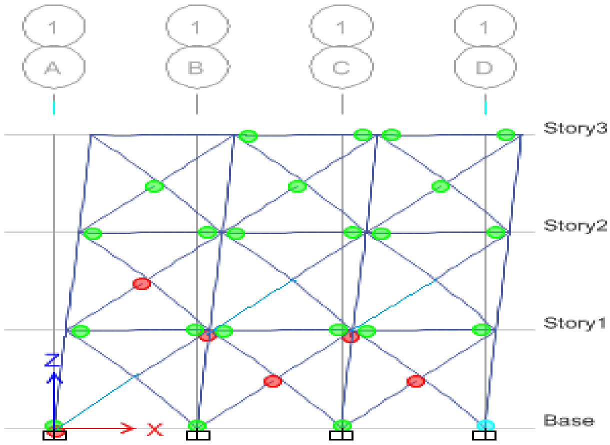

Figure 12 Hinges formed in one story height X braced frame structure.

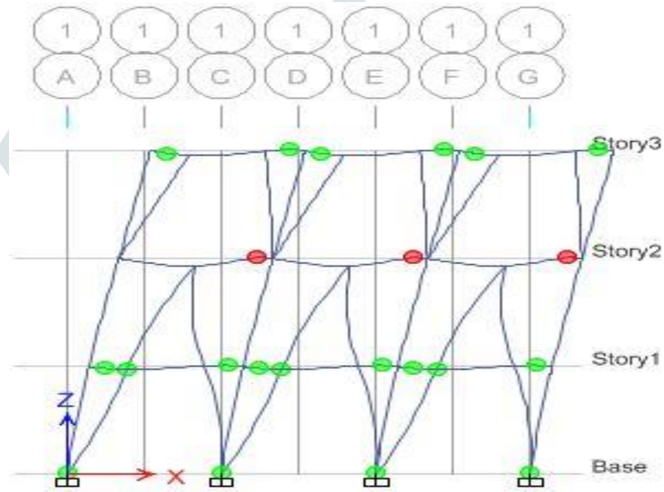

Figure 13 Hinges formed in two story height Inverted V braced frame structure.

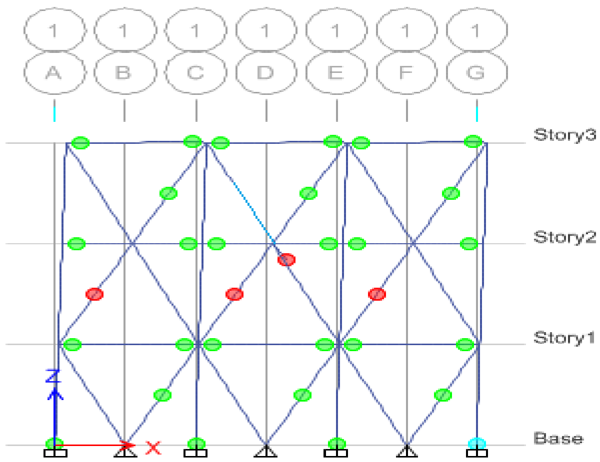

Figure 14 Hinges formed in two story height Diamond braced frame structure.

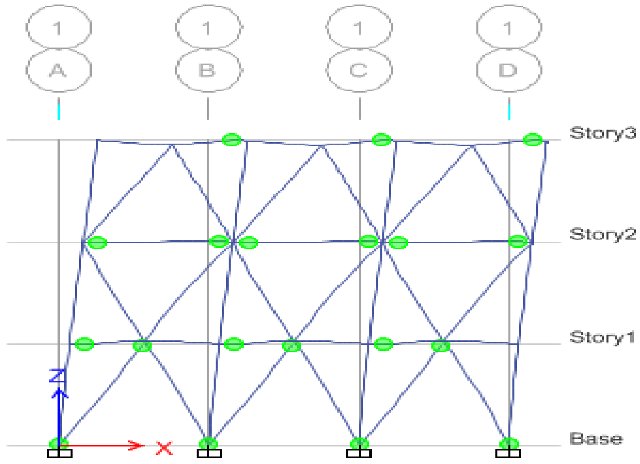

Figure 15 Hinges formed in one story height X braced frame structure.

The formation of plastic hinges for all other aspect ratios considered follow similar trends as that of aspect ratio of one. The Figure 9 to 15 shows the formation maximum number of hinges formed with the maximum pushover load cases i.e. till the target displacement reached or collapse of structure for aspect ratio of one. In bare frame structure hinges formed in beams are in between immediate occupancy level and life safety level with column hinges at the bottom story are in collapse prevention level. However, in braced frame structures, hinges formed in beams, columns and bracings are in between immediate occupancy level and life safety level and few hinges in the bracing are found to have formed in collapse prevention level (Figure 12 to 14). From the plastic hinges results, the seismic performance of braced frame structures considered are more than bare frame structure. Two story level bracing has shown maximum number of plastic hinges compared to one story bracings indicating a good performance with the plastic hinges being in between immediate occupancy level and life safety level. Hence the one story Inverted V braced and Diamond braced framed structure is safer compared to all the other models considered in the study for the given earthquake. Table 1 shows the performance point of the frame structure in both X and Y direction.

Table 1 Base Shear and displacement at performance point

Bracing height in terms of story level	Aspect Ratio	Performance Point							
		Bare frame		Inverted V bracing		Diamond bracing		X bracing	
		base shear (KN)	displacement (mm)	base shear (KN)	displacement (mm)	base shear (KN)	displacement (mm)	base shear (KN)	displacement (mm)
One story bracing	1	66.90	6.92	74.44	5.01	59.45	1.05	60.72	1.01
	2	145.71	58.02	168.89	32.40	184.40	7.73	181.10	6.46
	3	198.89	153.64	265.06	76.62	279.82	22.88	274.20	18.79
	4	185.50	220.19	329.18	139.54	372.33	53.39	361.43	42.64
Two story bracing	1	66.90	6.92	73.58	6.49	62.87	1.37	57.46	1.82
	2	145.71	58.02	165.39	39.03	176.11	10.37	117.47	9.42
	3	198.89	153.64	258.88	101.39	271.18	26.35	269.41	26.81
	4	185.50	220.19	282.91	160.20	363.36	63.00	362.35	59.66

From the table 1 it can be seen that, as the aspect ratio increases the base shear carrying capacity and displacement at performance point increases for all configurations. The x braced frame and diamond braced frame structures carry higher base shear at performance point compared to bare frame structure for all aspect ratios. For all configurations one story bracing system carries higher base shear with least displacement at performance point.

6. CONCLUSION

From the pushover analysis results it can be observed that, the two story height braced frame have enhanced base shear capacity compared to bare frame. From the study, the conclusion can be obtained that bracing increase the seismic performance of the structure as there is increasing in rigidity and stiffness of the structure. The flexibility of the structure is reduced in the braced frame structure. Aspect ratio of one has shown better performance for all the structural models considered. One story height braced frame structure has higher seismic performance compared to two story bracing for all configurations. Also, X bracing and diamond bracing with one story shows highest seismic performance. The bracing can be used for retrofitting and rehabilitation of civil old infrastructures to enhance the seismic performance of the structure without altering the existing structure.

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