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Comparative Study on Effect of Aspect Ratio on Performance of Steel Frame Structure with and without infill using Pushover Analysis

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Abstract: This paper focuses on the effect of different aspect ratios i.e. H/B ratio, where H is the total height of the building frame and B is the base width of the building frame, on the seismic performance of the steel frame structure with and without infill. Here, height of the building is kept constant and the base width is varied. In the present study, seven different aspect ratios ranging from 1.0 to 3.75 have been considered for the ten storey steel frame building. Two types of frames are considered for the study, one with similar steel sections for maximum strength required for beam and column and the other with varying steel sections conforming to the strength and serviceability requirements to withstand the specified loading. For this analytical study, ETABS is used and the comparison between the performances of frames with different aspect ratios is made using pushover curves and performance point. It is found that the presence of infill stiffness contributes significantly to the performance of the structure compared to bare frame.

Keywords: Aspect Ratio, Pushover analysis, Steel Frame, Type 1 section, Type 2 section.

I. INTRODUCTION

In the past years, steel structures have played a vital role in construction industry. Because of its large strength to weight ratio, it tends to be more economical than concrete structures. Steel structures are amongst the most popular structures all over the globe because of higher load carrying capacity, reduced size, ease and speed of construction, ability to enhance ductile characteristics, capacity to withstand dynamic loads and possibility to adopt for tall structures etc. Masonry infills in buildings are normally considered as non-structural elements and their stiffness contributions are generally ignored in practice. But, infill walls tend to interact with the frame when the structure is subjected to lateral loads, and also reveal energy-dissipation characteristics under seismic loading. The term "infilled frame" is used to represent a composite structure shaped by the combination of a moment resisting plane frame and infill walls. Uva et al.,(2012) have considered the participation of masonry infill panel to overall seismic resistance of building. They have modeled the infill panel as equivalent strut of width bw using different mathematical models and compared the result [1]. FEMA 273(1997) recommends the elastic in-plane stiffness of a solid unreinforced masonry infill panel before cracking may be signified with an equivalent diagonal compression strut of width, Weff, calculated using equations given below.

The equivalent strut considered in the study has the same thickness and modulus of elasticity as the infill panel.

$$W_{eff} = 0.175(\lambda_h h_{col})^{-0.4} r_m \quad (1)$$

where, $\lambda_h = \sqrt[4]{(E_m t \sin 2ø)/(4 E_c I_c h_m)} \quad (2)$

Where h_{col} is column height between centre to centre distance of beams, hm is height of infill section, E_c is modulus of elasticity of frame material, E_m is expected modulus of elasticity of infill section, I_c is column moment of inertia, r_m is diagonal length of infill section ø is angle whose tangent is the infill height-to length aspect ratio in radians, t is the thickness of infill section[2]. Khan and Khan, (2014) studied on the typical 15^{th} – storey regular steel frame building with different pattern of bracing system. This building is designed for various types of concentric bracings like V, X, Diagonal and Exterior X and performance of each frame is carried out through nonlinear pushover analysis. Three types of sections i.e. ISA, ISMC, ISMB are used to compare for same patterns of bracing and results are compared with roof displacement and performance point [3]. Kalibhat et al., (2014) studied on the effect of a provision of concentric bracings on the seismic performance of the steel frames with two different types of concentric bracings (viz. X and inverted-V type bracing) for the different storey levels. They found that inclusion of bracing increased the base shear capacity and decreased the roof displacement and also reduced the inter storey drift.

The lateral storey displacements of the building are reduced by the use of inverted-V bracing in comparison to the X bracing system [4]. Babu and Vijayakumar, (2012) assessed the behavior of G+2 reinforced concrete bare frame subjected to earthquake forces in zone III. The reinforced concrete structures were analyzed by nonlinear static analysis using SAP2000 software. The results obtained in terms of pushover curves, capacity curve, performance point and number of hinges gave an insight into the real behavior of structures. Most of the hinges have developed in the beams in the form of immediate

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occupancy, Life safety, Collapse prevention and few in the columns. The column hinges have limited the damage [5]. Poluraju and Rao, (2011) assessed the performance of G+3 building using pushover analysis. Observations showed that properly designed frame will perform well under seismic loads. It was found that the hinges developed more in the beams than the columns; thereby column had limited damage [6].

From previous work we can observe that many experimental and analytical works have been done in the area of the pushover analysis of the RC frames and few works on steel frames with different types of bracing systems. Since no work is done on aspect ratios of steel frames, the present work is focused on the effect of different aspect ratios on the seismic performance of the steel frame structure with and without infill using ETABS and results are analyzed through pushover analysis.

II. PUSHOVER ANALYSIS

Linear elastic analysis gives a good indication of elastic capacity of structures and indicates where the first yielding will occur but it cannot predict failure mechanisms and accounts for redistribution of forces due to progressive yielding. Among different approaches described in ATC-40, Nonlinear Static Pushover analysis is very popular because of its simplicity and ability to estimate component and system level deformation demands with acceptable accuracy without intensive computational and modeling effort as dynamic analysis. Pushover analysis is a static nonlinear technique in which the degree of the structural loading is incrementally increased in accord with a certain predefined pattern.

Pushover analysis may be categorized as displacement controlled pushover analysis when lateral movement is executed on the building and its equilibrium designates the forces. In the same way, when lateral forces are enforced, the analysis is termed as force-controlled pushover analysis. The target force or target displacement is estimated to signify the maximum force or maximum displacement expected to be qualified by the structure during the design earthquake. Response of structure beyond full strength can be bent on only by displacement controlled pushover analysis. Hence, in the study, displacement-controlled pushover method is used for analysis of structural steel frames. A plot of the total base shear versus top roof displacement in a building is attained by this analysis that would specify any early weak areas of the element. The analysis is executed up to failure, thus it permits purpose of collapse load and ductility capacity. A typical pushover curve is shown in Fig. 1. Force versus displacement is plotted for gradually increasing lateral loads till failure. Beyond elastic limit, different states such as Immediate Occupancy (IO), Life Safety (LS), Collapse prevention (CP), Ultimate capacity (C), C to D- between C and residual strength, D to E- between D and collapse >E collapse are defined as per ATC 40 and FEMA 356.

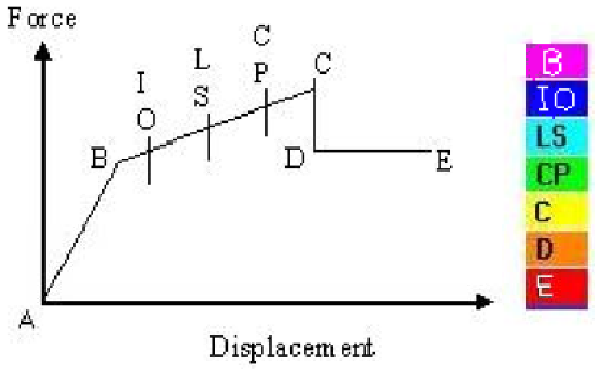

Fig. 1. Typical pushover curve

III. DESCRIPTION OF STEEL FRAME STRUCTURE

In the present study, a 2- bay two dimensional steel frame structure with and without infill with different aspect ratios has been modeled and analyzed using ETABS. Two types of frames are considered for the study, one with similar steel sections (Type 1) for maximum strength required for beam and column and the other with varying steel sections (Type 2) confirming to the strength and serviceability requirements to withstand the specified loading.

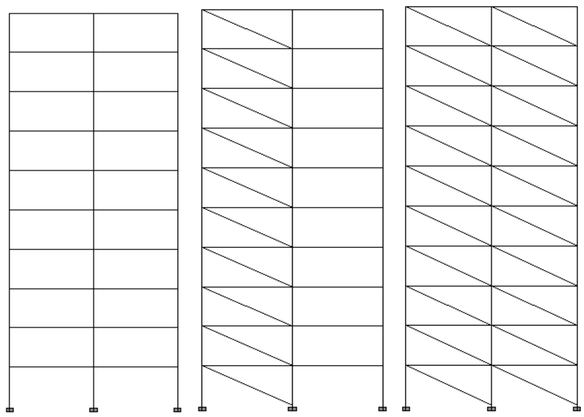
(i) (ii) (iii)

Fig. 2. (i) Steel bare frame, (ii) One Bay infilled frame, (iii) Two Bay infilled frame for aspect ratio1.0

Structural configuration of aspect ratio 1.0 for bare frame, one bay infilled frame and two bay infilled frame are shown in the Fig. 2.The building consists of G+9 stories. All columns in all models are assumed to be fixed at the base for simplicity. The height of each floor is 3.0m. Live load on floor is taken as 3kN/m^2 and that of roof is 1.5kN/m^2. Floor finish on the floor is 1kN/m^2. Weathering course on roof is 2kN/m^2. In the seismic weight calculation only 25% of floor live load is considered. The unit weights of concrete and masonry are taken as 25kN/m3 and 20kN/m3 respectively. Modulus of elasticity of masonry is 5500MPa.The building is steel moment resisting frame considered to be situated in seismic zone III. The medium type of soil is considered and time period of the building in X-direction is considered based on base

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dimension of the building. The sizes used for beam is Girder Section1 and that of column is Girder Section2 for Type 1 section. Beam and column sizes for Type 2 sections as per SP 6 (1) 1964 are tabulated in Table 1.

Girder Section1: Web plate (800x12) mm, Flange angle (150x150x18) mm, Flange plates (400x40) mm
Girder Section2: Web plate (800x12) mm, Flange angle (150x150x18) mm, Flange plates (500x32) mm
Girder Section1: Web plate (800x12) mm, Flange angle (150x150x18) mm, Flange plates (400x16) mm

Table 1. Beam and column sizes of Type 2 section for different aspect ratio

Aspect Ratio	Base Width B in m	Type 2 Section	
		Beam Size	**Column Size**
1.00	30	Girder Section1	Girder Section2
1.25	24	Girder Section3	ISWB600 C.P 32mm
1.50	20	ISMB550 C.P 40mm	ISWB600 C.P 32mm
2.00	15	ISMB 600 C.P 25mm	ISWB400 C.P 32mm
2.50	12	ISMB 600	ISWB600
3.00	10	ISMB 450	ISWB600
3.75	08	ISMB 400	ISWB550

C.P: Cover Plate

A. Modeling of Masonry Infill

In the study, infill is modeled as single equivalent diagonal strut connected between two compressive diagonal corners. Linear and nonlinear static analysis is carried out to investigate its response to earthquake. The diagonal compression strut is assumed to be pin connected to the corners of frame at both ends. The modeling of infill panel as single diagonal strut is based on the assumption that the masonry is weak in tension. The cross section area of diagonal strut is a function of the width of strut, as thickness of the strut is taken equal to that of infill panel. Width of infill depends on the stiffness of column (Ip).Width of strut is calculated using the eqn (1) are tabulated below.

Table 2. Width of infill of Type 1 and Type 2 sections for different aspect ratio

Aspect Ratio	Type 1 Section	Type 2 Section
	Weff(m)	**Weff(m)**
1.00	2.426	2.426
1.25	1.922	1.765
1.50	1.597	1.477
2.00	1.208	1.001
2.50	0.989	0.811
3.00	0.851	0.703
3.75	0.724	0.569

IV. RESULTS AND DISCUSSION

Linear static and pushover analysis is conducted on all the models for seismic loads defined as per IS 1893-2002 (Part-I) using ETABS. The pushover analysis signifies an insight into the structural behaviour, which reins the performance of the structure during earthquakes. It also estimates the data on the strength and ductility of a building. The results obtained from analysis are compared and discussed as follows.

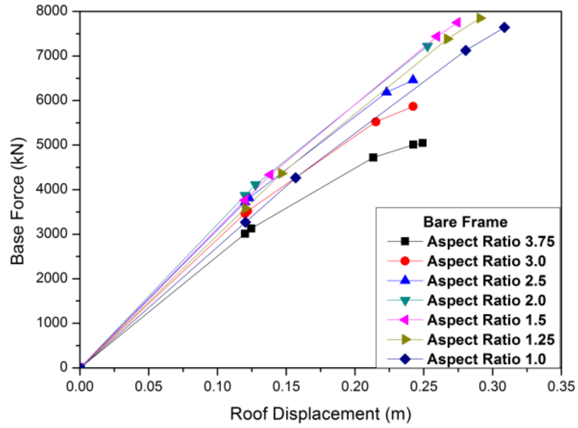

Fig. 3. Pushover curves for 2-bay bare frame structure with Type 1 section for different aspect ratios

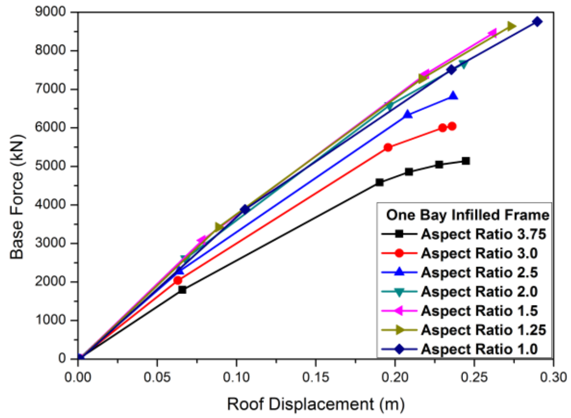

Fig. 4. Pushover curves for 2-bay one bay infilled frame structure with Type 1 section for different aspect ratios

According to Figures 3, 4 and 5, Steel Bare Frame, One bay infilled frame and two bay infilled frame with aspect ratio 1.0 is showing 34%, 41% and 46% better performance in terms of performance base force but weak in showing the ductile behaviour when compared to aspect ratio 3.75 respectively. It is also found in Figure 3 that for aspect ratio 1.25, performance base force has marginally increased when compared to aspect ratio 1.0 because of negligible variation in mass.

From Figures 6, 7 and 8 we can observe that frame with aspect ratio 1.0 is showing 92%, 90% and 87% better performance in terms of performance base force but weak in ductile behaviour than the aspect ratio 3.75 respectively. It is also observed that as aspect ratio decreased from 3.75 to 1.0 the performance base force increased considerably.

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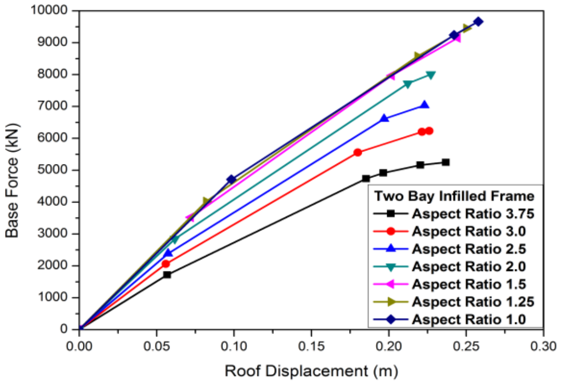

Fig. 5. Pushover curves for 2-bay two bay infilled frame structure with Type 1 section for different aspect ratios

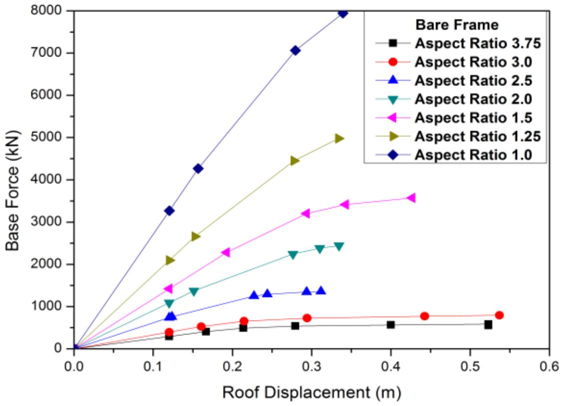

Fig. 6. Pushover curves for 2-bay bare frame structure with Type 2 section for different aspect ratios

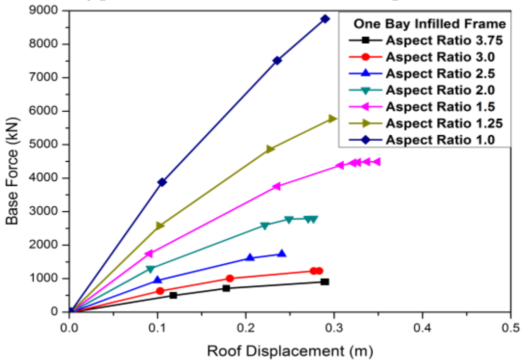

Fig. 7. Pushover curves for 2-bay one bay infilled frame structure with Type 2 section for different aspect ratios

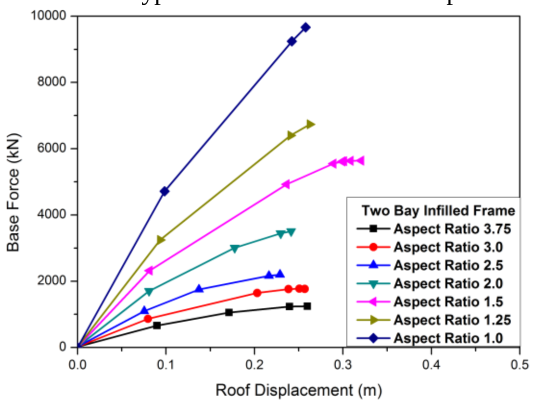

Fig. 8. Pushover curves for 2-bay two bay infilled frame structure with Type 2 section for different aspect ratios

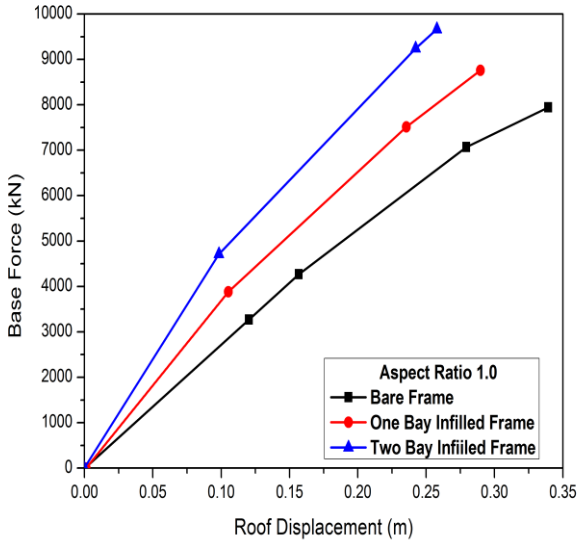

Fig. 9. Pushover curves for bare frame, one bay infilled frame and two bay infilled frame structures of Type 1 section for aspect ratios 1.0

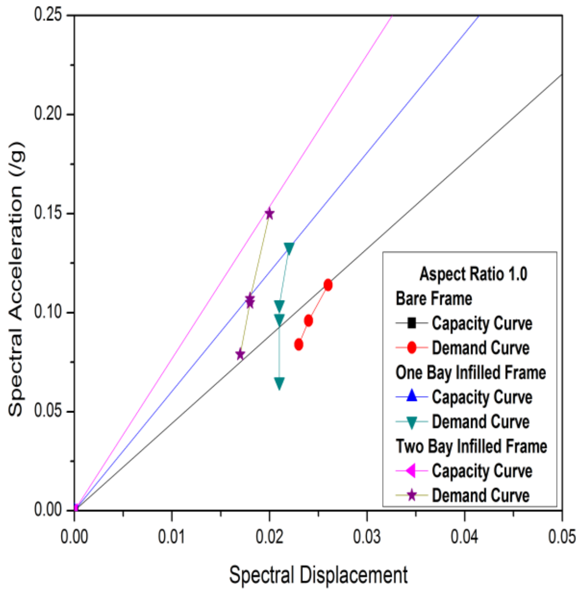

Fig. 10. Capacity and Demand spectrum curve for bare frame, one bay infilled frame and two bay infilled frame structures of Type 1 section for aspect ratios 1.0

From Figure 9, it is found that as masonry infill effect is considered to the structure maximum base force increased considerably for all types of aspect ratios considered.

It is also found that two bay infilled frame is showing higher performance base force than other types of frame structures considered in the study.

From Figure 10, it can be observed that as masonry infill effect is considered to the structures the performance point increases considerably, where performance point is the intersection between the capacity curve and demand curve.

This represents the performance of the building.

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Table 3. Base shear and roof displacement at performance point for Type 1 section

Aspect Ratio	Type 1 Section Performance Point(V(kN),d(mm))		
	Bare Frame	*One Bay Infilled Frame*	*Two Bay Infilled Frame*
1.00	(936.69, 35)	(1099.22, 31)	(1247.73 , 26)
1.25	(881.28, 30)	(1011.27, 27)	(1134.34 , 21)
1.50	(829.40, 27)	(935.31, 24)	(1038.34 , 21)
2.00	(735.60, 23)	(807.86, 21)	(843.78, 18)
2.50	(651.09, 21)	(677.84, 19)	(676.95, 16)
3.00	(569.07, 20)	(566.28, 18)	(564.54, 15)
3.75	(457.63, 18)	(455.06, 17)	(452.88, 15)

Table 4. Base shear and roof displacement at performance point for Type 2 section

Aspect Ratio	Type 2 Section Performance Point(V(kN),d(mm))		
	Bare Frame	**One Bay Infilled Frame**	**Two Bay Infilled Frame**
1.00	(936.69, 35)	(1099.22, 31)	(1247.73, 26)
1.25	(657.23, 38)	(800.48, 33)	(931.09, 26)
1.50	(488.39, 41)	(632.03, 34)	(760.53, 26)
2.00	(372.16, 41)	(472.05, 35)	(566.64, 26)
2.50	(266.19, 43)	(335.88, 37)	(408.04, 27)
3.00	(175.48, 53)	(245.67, 42)	(318.88, 28)
3.75	(135.23, 55)	(181.30, 45)	(232.60, 30)

From the Tables 3 and 4, bare frame, one bay infilled frame and two bay infilled frame with aspect ratio 1.0 is showing 51%, 59% and 64% increase in base shear at performance point than the aspect ratio 3.75 for Type 1 section whereas it is showing 86%, 84% and 81% increase in base shear at performance point for Type 2 section respectively. It is also observed that performance displacement in Table 3 is reduced considerably from aspect ratio 1.0 to 3.75, whereas increased in case of Type 2 section given in Table 4. From both the tables it is found that as masonry infill effect is considered to the structure the base shear at performance point increased and displacement is reduced considerably.

V. CONCLUSIONS

The following are the observations drawn from the present analysis.

1) Steel bare frame, one bay infilled frame and two bay infilled frame with aspect ratio 1.0 showed better performance base force and show weak ductile behaviour than other aspect ratios considered.
2) The performance point with aspect ratio 1.0 for the bare frame, one bay infilled frame and two bay infilled frame with Type 1 section is increased by 51%, 59% and 64% respectively in comparison with the aspect ratio 3.75.
3) The performance point with aspect ratio 1.0 for the bare frame, one bay infilled frame and two bay infilled frame with Type 2 section is increased by 86%, 84% and 81% respectively in comparison with the aspect ratio 3.75.
4) As masonry infill effect is considered to the structure the base shear increased and roof displacement reduced for all aspect ratios considered.
5) From the analysis it is found that the presence of infill stiffness contributes significantly to the performance of the structure compared to bare frame.

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