Modelling of Bracing Systems for Seismic Behaviour of High Rise Steel Building

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Abstract: This study mainly emphasised on compare the seismic behaviour of high-rise steel building with different types of bracing systems. Non-linear static analysis were performed to observe the structural performance on high rise steel building of heights 10,15,20,25,30 and 35 storeys. For this study, four types bracing systems were used: V-Braced frames (VBF), Chevron Braced frames (CBF), X-Braced frames and Self-centring energy dissipating braced frames (SCEDBF). The performance of different types of bracing system has been evaluated by changing the parameters like height of building and different types of lateral load pattern. It has been observed that different braced frames performed well in terms of storey displacement, inter-storey drift ratio, base shear capacity and performance point when compared with moment resisting frame in high-rise steel buildings. It has been observed that VBF and CBF performed similar manner under seismic event and XBF and SCEDBF performed similar manner. It can be concluded that, based on obtained results, that the use of VBF, CBF, XBF and SCEDBF enhances the seismic performance of overall structure.

Keywords: Nonlinear analysis (pushover analysis), Bracing, Ductility, Moment resisting frame (MRF), Seismic behaviour.

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1. Introduction

In seismic prone zones, structures will undergo lateral load apart from gravity loads. The performance of structures mainly varies with parameters like intensity of earthquake and properties of the structures. It has been observed that seismic response of a steel structure varies from elastic to highly inelastic state during seismic activities. The steel structures should design in such a way that dissipation of energy will takes in large extent at the time of earthquake.

Steel structures have a vital role in civil engineering construction, especially for industrial buildings and tall buildings. It has been observed that steel frames without bracing performed poorly under past earthquakes. The seismic performance of steel structures with bracing could be increased by using different types of bracing systems. From the past experience engineers came to know that seismic performance of steel structures greatly depends on type of bracing, bracing configuration, height of building and type of lateral load pattern. Nowadays bracings have been used for retrofitting of buildings those are damaged during light and moderate earthquakes. There are different types of bracings are available such as X-bracing, V-bracing and Chevron bracing and self-centring energy dissipating bracing system. It has been observed that ductility is main concern about seismic design of steel buildings. Ductility is the property of material by which it can undergo deformation without compromising strength or at constant stress. The seismic performance of steel frames with and without bracings can be evaluated by using a technique known as non-linear static analysis (pushover analysis).

Anyway, nonlinear static (pushover) analysis has been developed into intensive tool throughout past decades because of its simplicity, ability and fruitfulness in seismic assessments of the existing buildings. This technique is a practice for estimating the structural capacity of the structures in post elastic range. It helps to understand the successive failure pattern of the structure and as a result, the weak part or damaged part can be replace or retrofit until it has to prevent from collapse.

In high-rise building stiffness is more significant rather than strength. The bracing provided on the structure will increase the stiffness but it will limit the ductility. Roeder suggested bracing system known as eccentric bracing, mixture of good features from moment resisting frames and concentric frames [1, 2]. In eccentric braced frame energy, dissipation is gained through by the introduction of shear link [3]. Because of earthquake, this shear link is damaged and it should be replaced with new one. Subsequently former bracing system has been dominated by a system called knee braced frame and in this system fuse element played important role in energy dissipation and it has been achieved through flexural yielding. Afterwards Balendra et al. [4-6] suggested some modification in knee braced frame. The seismic performance the steel structure enhanced by the introduction of chevron bracing which helps in reprieving fracture. This can be attained in chevron by the modification of floor beam and bracing as strong beam and weak bracing. This updated version of chevron brace frame lead to excellent hysteric response and meanwhile ductile braces leads to achieve excellent redistribution of damage throughout the building height [7]. Yang investigated about the seismic behaviour of the concentrically braced frame especially regarding diagonal brace and X-brace which subjected to cyclic loading and observed that those bracings given quiet satisfactory result. The zipper elements helps to buckle all stories except top one by ensuring distribution of load throughout the building and so there won't be any stress concentration[8-9]. Nouri et al. studied about drawbacks of concentrically braced systems and introduced one zipper braced system which helps distribute vertical unbalanced force in chevron bracing system [10]. It has been observed that each system has some advantages and disadvantages over the other.

In this study, we concentrated assess the seismic behaviour of high rise building because so many studies have been carried out in past regarding low-rise and medium rise buildings. Problems regarding with design of high-rise buildings those undergone to strong wind and earthquake of long duration have been considered by some researchers. A protracted analytical evaluation of high rise buildings with heights 10, 15, 20, 25, 30 and 35 has been carried out by non-linear static pushover analysis and also with use different types of bracing system.

2. Modelling of high rise Steel Building (Sap 2000)

Modelling of high-rise steel buildings labels the structural arrangements of different braced buildings and loading condition. The different bracing systems like VBF,CBF, XBF and SCEDBF were introduced into MRF systems shown in Fig.1. Two bays of 6m and middle bay of 4m chosen for the analysis from the building plan shown in Fig 2. The cross sectional area of beams and columns for different bracing system kept constant as in the case of MRF. Bracings were introduced in such a manner that amount of steel consumed kept constant for all. The bracing was designed in a such way that amount of steel consumption minimum as possible. High rise 2-D steel buildings with different bracing configuration and of different heights which varies from 10 to 35 as a multiples of five are used for the investigation.

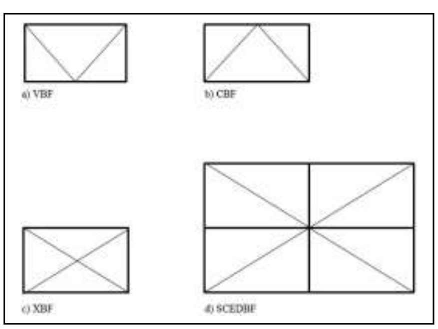
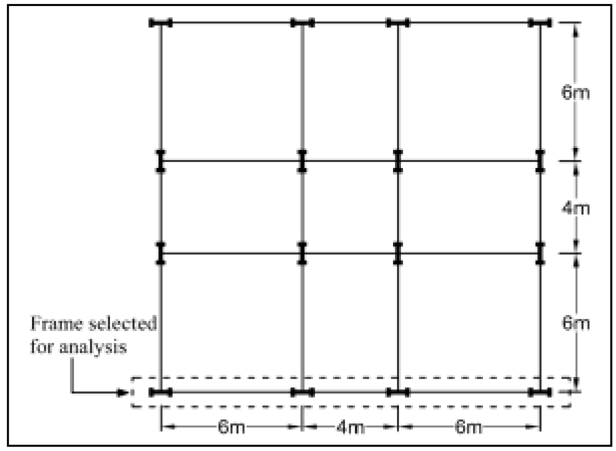


Figure 1. Structural configuration of different types of bracing system



2.1 Loadings consideration

First, Every buildings is designed using codes IS 1893 (Part-1):2002 and IS 800:2007[11-12]. Nominal yield strength of 345 MPa is assigned for beams and columns. Seismic parameters considered in this design are class-1 with subsoil type III and seismic region where structure located is V zone. The live load taken as 4 KN/m^2 and loadings at floor finishes assumed to be 2 KN/m^2 .

Figure 2. Plan of building

2.2 Non-linear static pushover analysis

Pushover analysis is carried out using SAP 2000[13] on high-rise 2D steel buildings by the use of different types of lateral load pattern to calculate the effects of lateral load on the structure through load-displacement curve. In the case of push over analysis force and displacement, parameters determine by initial applying of gravity load in the structures and lateral seismic load later on. Lateral seismic force will increased up to final collapse of the structure occurs.

In this study displacement controlled pushover analysis for all the structures has been carried out with target displacement of 4% of the total height of the building (ATC-40)[14]. Default hinge properties are available in some programs as per FEMA-356 [15] and ATC-40. These default hinge properties are used in this study. Hinges are assigned at both ends of each column and beam element and at mid span of brace element. For column, PMM hinges were used, P hinges are assigned for braces and M3 are assigned to beam. Lateral load patterns adopted for this analysis given below.

1) Codal lateral load pattern : Push 1

The codal load shape represents the forces acquired from the principal mode of vibration. The equation used for analysis given below.

$$V_B = A_h W \quad (1)$$

$$Q_i = \frac{V_B W_i h_i^2}{\sum W_i h_i^2} \quad (2)$$

Where,

V_B - design base shear as per IS 1893(Part-1):2002 [18]

h_i - height of floor i calculated from the base.

Q_i - lateral force at the floor level i.

W_i - seismic weight at the floor i.

2) Uniform lateral load pattern: Push 2.

In this lateral load pattern, lateral force at a storey is proportional to the mass of the storey.

$$F_i = \frac{m_i}{\sum m_i} \quad (3)$$

Where,

F_i - lateral force at the level of floor i

m_i - mass at the level of floor I in the building.

3. Results and Discussions

TABLE I. FUNDAMENTAL TIME PERIOD AS PER IS 1893(PART-1):2002

Number of stories in the building	10	15	20	25	30	35
Time (s)	.6750	1.0125	1.3500	1.6875	2.0250	2.3625

TABLE II. FUNDAMENTAL TIME PERIOD(S) OF VIBRATION OBTAINED THROUGH MODAL ANALYSIS

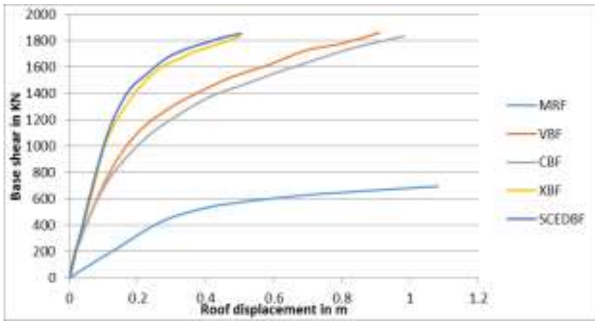
Number of stories	MRF	VBF	CBF	XBF	SCEDBF
10	0.47	0.1580	0.1551	0.1625	0.1640
15	0.7392	0.2708	0.2572	0.2784	0.2770
20	1.0187	0.4149	0.3940	0.4215	0.4203
25	1.31	0.5930	0.5648	0.5981	0.5971
30	1.6205	0.8068	0.7713	0.8098	0.8093
35	1.947	1.0569	1.0141	1.0577	1.0579

TABLE III. BASE SHEAR AND ROOF DISPLACEMENT OBTAINED FROM PUSH 1

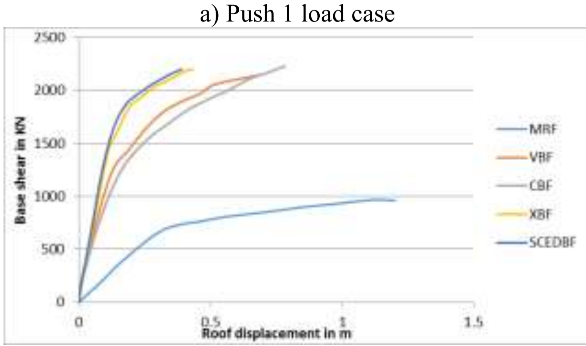
No. of stories	Type of bracing	Base shear(KN)	Roof displacement(m)
10	MRF	720	1.2
	VBF	1852	0.92
	CBF	1829	0.98
	XBF	1830	0.50
	SCEDBF	1854	0.51
15	MRF	614	1.8
	VBF	1362	0.63
	CBF	1343	0.70
	XBF	1465	0.38
	SCEDBF	1583	0.44
20	MRF	550	2.4
	VBF	1088	0.57
	CBF	1163	0.60
	XBF	1200	0.42
	SCEDBF	1247	0.41
25	MRF	500	3
	VBF	870	0.56
	CBF	916	0.66
	XBF	946	0.49
	SCEDBF	960	0.48
30	MRF	462	3.6
	VBF	710	0.65
	CBF	741	0.70
	XBF	750	0.57
	SCEDBF	750	0.56
35	MRF	430	3.69
	VBF	707	0.97
	CBF	630	0.80
	XBF	610	0.67
	SCEDBF	610	0.66

TABLE IV. BASE SHEAR AND ROOF DISPLACEMENT OBTAINED FROM PUSH 2

No. of stories	Type of bracing	Base shear(KN)	Roof displacement(m)
10	MRF	970	1.2
	VBF	2200	0.62
	CBF	2150	0.79
	XBF	2200	0.43
	SCEDBF	2200	0.40
15	MRF	840	1.8
	VBF	1708	0.52
	CBF	1861	0.61
	XBF	1830	0.35
	SCEDBF	1932	0.38
20	MRF	730	2.4
	VBF	1408	0.50
	CBF	1390	0.56
	XBF	1630	0.45
	SCEDBF	1720	0.48
25	MRF	647	3
	VBF	1175	0.53
	CBF	1320	0.60
	XBF	1300	0.45
	SCEDBF	1400	0.48
30	MRF	580	3.09
	VBF	1000	0.59
	CBF	1055	0.68
	XBF	1110	0.55
	SCEDBF	1114	0.54
35	MRF	530	3.49
	VBF	840	0.66
	CBF	890	0.74
	XBF	900	0.63
	SCEDBF	900	0.61

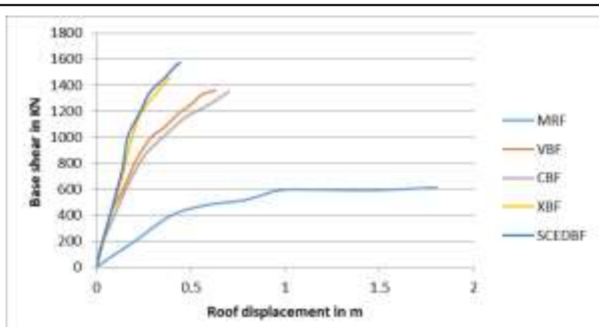


a) Push 1 load case

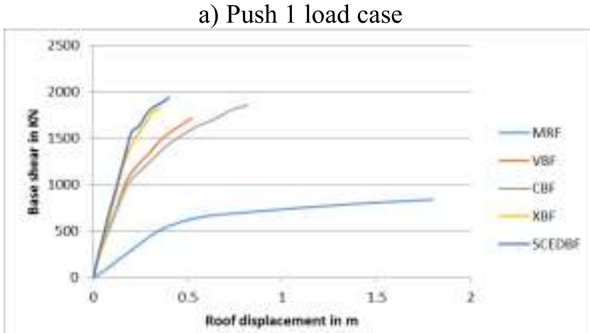


b) Push 2 load case

Figure 3. Capacity curves of 10-storey building

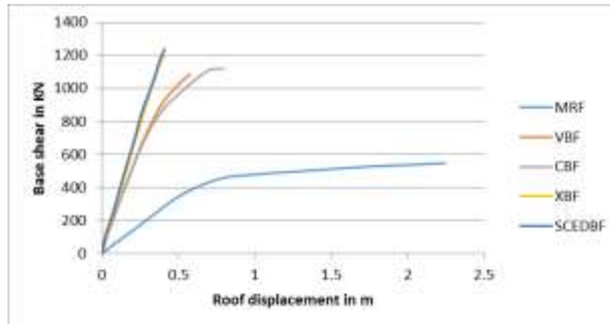


a) Push 1 load case

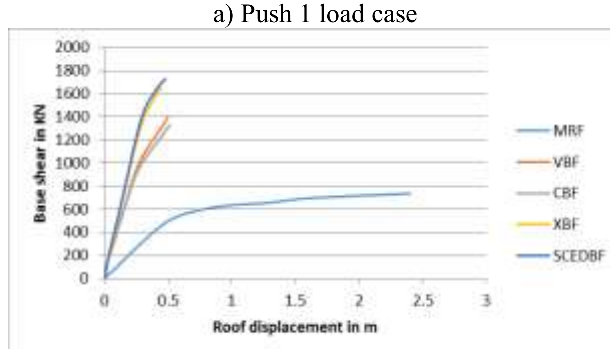


b) Push 2 load case

Figure 4. Capacity curves of 15-storey building

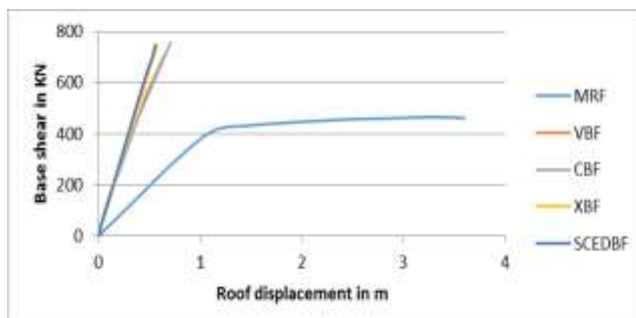


a) Push 1 load case

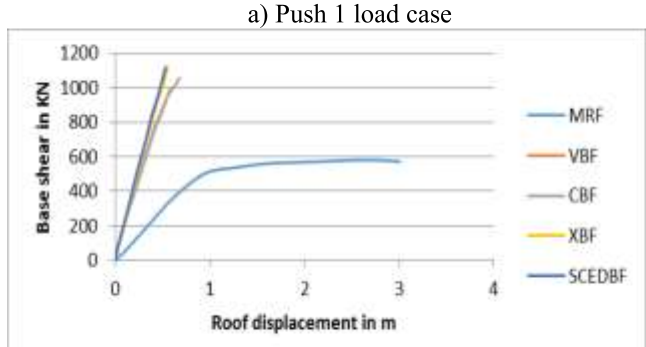


b) Push 2 load case

Figure 5. Capacity curves of 20-storey building

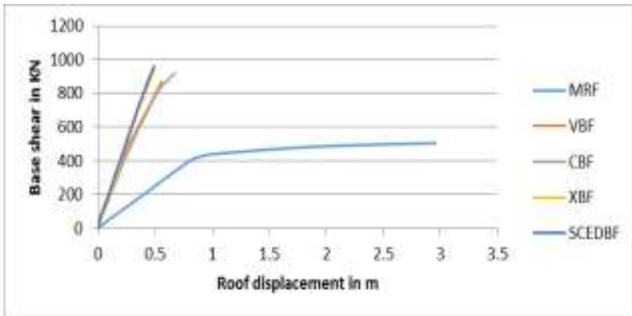


a) Push 1 load case

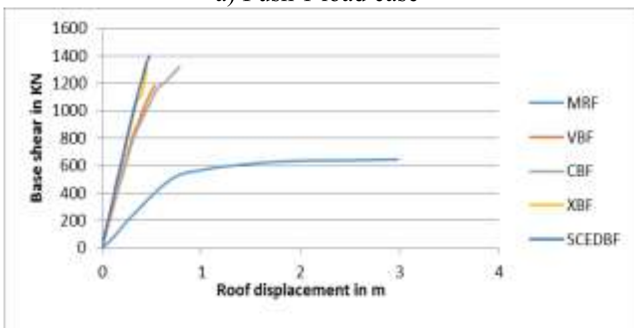


b) Push 2 load case

Figure 6. Capacity curves of 25-storey building

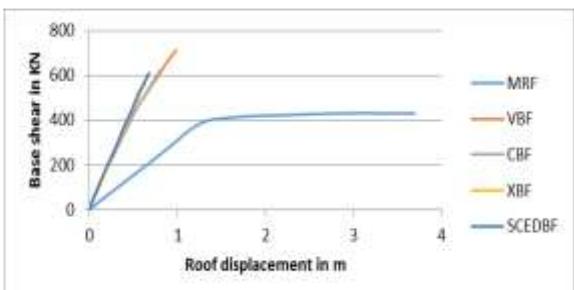


a) Push 1 load case

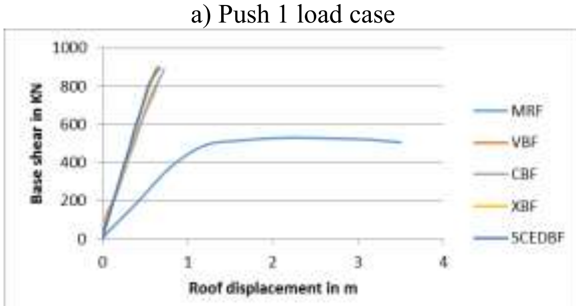


a) Push 2 load case

Figure 7. Capacity curves of 30-storey building



a) Push 1 load case



b) Push 2 load case

Figure 8. Capacity curves of 35-storey building

4. Conclusion

In the investigation an effort is made to evaluate the seismic response parameters of the building with or without different bracing system and for this study building with different bracing systems were studied for various storeys. The performance of bracing systems compared in an extensive manner. So that we will get a clear idea about the bracing system which has huge role in dissipation of energy that producing under the earthquake. Seismic performance analysis has been carried out by non-linear pushover analysis. The conclusion of this study briefly given below.

- In high-rise building design mainly focused on strength and stiffness aspects, so according to these aspects suitable bracings can easily introduce to MRF. MRF buildings have been subjected to higher roof displacement as compared to MRF with bracing systems. It is showing the vulnerability of MRF building under seismic event.
- Seismic response like shear capacity and roof displacement of VBF and CBF is nearly similar manner. In addition to that, XBF and SCEDBF performed almost similar manner in terms of shear capacity and displacement.
- It has been observed that in MRF more beams subjected to plastic hinge formation as compare to other braced building. In addition to that, sequence of failure due to plastic hinge formation start first at the brace, then at the beam and then at the column, while in MRF plastic hinge form first at the beam then at the column.
- Seismic behaviour of the building hugely influenced by the height of building and type of lateral load pattern.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.