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COMPARATIVE SEISMIC RESPONSE OF STIFFENED RCC FRAMES LOCATED IN UTTARAKHAND

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ABSTRACT

Considering the past earthquakes in India, the regions of Chamoli, Uttarkashi, Rudraprayag and numerous other areas in Uttarakhand have been repeatedly jolted by earthquakes. This study compares the seismic response of Reinforced Concrete frames incorporated with diverse steel bracings systems exposed to the ground motions of Chamoli earthquake. The structural response of Moment Resisting frames (MRs), V-Braced frames (VBs), Inverted V-Braced frames (IVBs) and X-Braced frames (XBs) are analyzed for storey heights of 4, 8, 12 and 16. The responses of each frame in terms of base shear, displacement, plastic hinge formation are studied by pushover analysis. The time based roof displacement, global damage index, over-strength factor, design factor are studied using time-history analysis. Etabs 2016 software is utilized for carrying over both non-linear pushover and dynamic time-history analysis. Comparative analysis shows enhancement in structural response of RCC frames as expected.

Key words: Seismic performance, Pushover analysis, Time-history analysis

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1. INTRODUCTION

On 29th March of 1999 one of the most devastating earthquake occurred in the Indian state of Uttar Pradesh (now in Uttarakhand) called as Chamoli earthquake taking over more than 50,000 houses. The structure has to bear lateral earthquake forces in addition to its own gravity loads when they are constructed over seismic active zones. Stiffness of the buildings are much concentrated in case of high rise buildings. Bracings were commonly used for increasing the stiffness of the building. Braced

frames behave well in case of high rise structures than Moment Resisting Frames (MRs) since MRs provide ductility through yielding thus lagging in stiffness concerns. There are two major classifications of bracings, eccentric and concentric bracings each having specific characteristics and design requirements. Several bracing systems are adopted among the structural engineers that includes diagonal, X, V, Inverted V, Chevron bracings etc. [1-5]. Roeder and Popov [6] suggested eccentric bracing systems, combining the features of both MRs and concentric braced frames. Shear links are provided in eccentric braced frames to dissipate the seismic energy. They form the integral part of the beams. Due to the issues on replacement of such shear keys they are mostly avoided. Ochoa [7] recommended knee bracing system which uses ductile fuse element to disperse the seismic energy through flexural yielding. Balendra et al. [8-10] suggested some alternations in knee bracing systems. The performance of chevron braces can be improved by designing them as strong beam weak bracing system. This design results in outstanding hysteretic response [11]. Tremblay et al. [12] analysed diagonal braced and X braced system under cyclic loading. Yang et al. [13] analysed the zipper braced frames for achieving good seismic performance. The zipper bracings redistribute the loads in the structure by triggering the buckling in all other storeys excluding the top storey [14]. Nouri et al.

[15] studied the constraints of concentric braced frames and suggested zipper bracings to diminish the vertical unbalanced force. Inelastic modelling have three main classifications: continuum finite element analysis, physical theory models and phenomenological. Finite element subdivides each braces into number of elements whose properties and materials are defined. Physical theory model approach was explored by D'Aniello et al. [16] in which the hysteretic behaviour of bracings are analysed by connecting the modelled bracing with plastic hinges. Force based elements with distributed or concentrated inelasticity and fibre discretization of the cross section were used for implementing physical theory models [17]. Plastic local buckling, low cycle fatigue effects were not taken into account in physical theory models. The time taken for analysing concentrated plasticity elements is much lower than distributed plasticity. Here analysis have been accomplished by concentrated plasticity model. Phenomenological models are based on simplified hysteretic rules that implies the relationship between the observed axial force and axial displacement. Continuum finite element provides the most accurate response of the bracings. Lignos and Krawinker [18] utilized the experimental data for calibrating the deterioration parameters of phenomenological models and for evolving the geometric and material property relationship of the model. Problems associated with design of high rise buildings prone to seismic excitations were addressed by some researchers [19-21]. Here the nonlinear static pushover and dynamic time history has been used to compare the performance of various bracing systems. The plastic hinge formation and its effects on the dissipation of energy and thereby increased stiffness has been studied in detail.

2. REINFORCED CONCRETE MODEL

In this research 3 dimensional 4, 8, 12 and 16 storey braced and unbraced frames are taken under study and are incorporated with X Bracings (XBs), V Bracings (VBs), Inverted V Bracings (IVBs) and Moment Resisting frames (MRs). The 3D view of 8 storey frame incorporated with bracings at their exterior bays are shown in Fig 1. The stiffness of the buildings are increased by incorporating bracings and checks for their maximum roof displacement are carried out. As stated by Santa-Ana and Miranda

[22] the buildings were designed as per strong column weak beam concept. Here the plastic section modulus of column connecting each joint is greater than the beams. Table 1 shows the details of the section properties. Steel I sections are chosen in such a way that the total volume of all bracing sections are nearly same. The first three fundamental periods of vibrations for the corresponding modes for both braced and unbraced frames are portrayed in Table 2. Fundamental periods are higher in case of unbraced frames and lower for braced frames, signifying higher stiffness on provision of bracings.

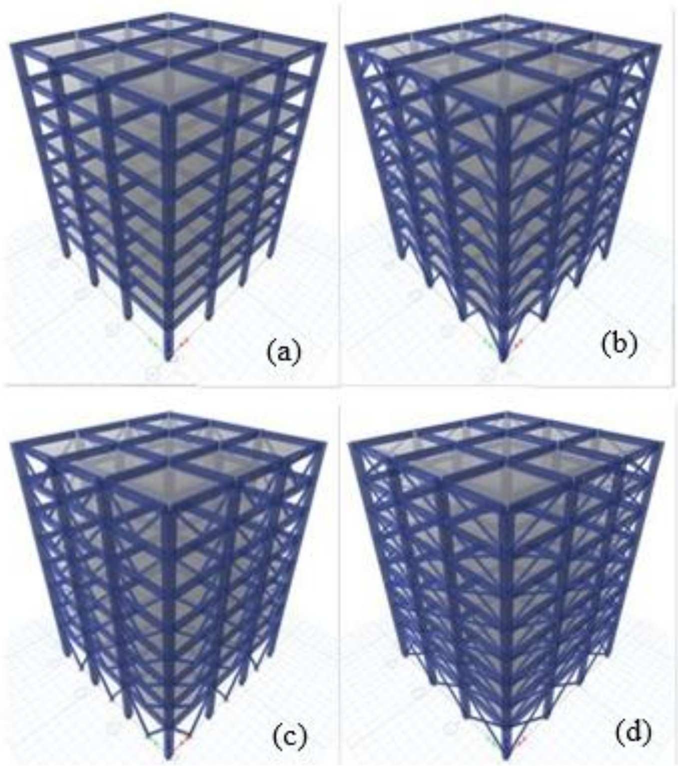


Figure 1 3D view of 8 storey (a) MR (b) IVB (c) VB (d) XB frames

3. NONLINEAR ANALYSIS

Structural frames are designed considering Importance factor as 1, Response reduction factor of 5, Seismic zone factor of 0.36, site type II and the structure is assumed to be located in seismic zone of V, Imposed load is taken as 3kN/m^2. Nonlinear analysis are carried out using ETABS 16 [23]. Displacement controlled lateral load is applied and default hinge properties are assigned as per FEMA 356 [24, 25]. Hinges are assigned at both the ends in case of beams and columns and at the mid-section of bracings [26]. Coupled hinges (PMM) are assigned for columns which yields based on the bi-axial bending moment and axial force. Axial hinges (P) are assigned for braces and beams are assigned with M3 moment hinges.

Table 1 Structural specifications

Concrete grade	M25
Nominal yield strength of steel	345MPa
Design Codes	IS 1893:2002, IS 800:2007, FEMA-356
Beam Dimension	550 mm x 350 mm
Column Dimension	750 mm x 450 mm
VBF & IVBF bracing	ISHB 200 x 200, tf = 9, tw = 6.1 mm
XBF bracing dimensions	ISHB 170 x 170, tf = 9, tw = 10.8 mm

Table 2 Fundamental period of vibrations(s) for first three modes

		Periods (s)		
Storey	**Bracing**	**1st**	**2nd**	**3rd**
4	MR	0.646	0.51	0.494
	XB	0.246	0.236	0.164
	VB	0.281	0.262	0.187
	IVB	0.276	0.258	0.187
8	MR	1.162	0.979	0.919
	XB	0.503	0.481	0.322
	VB	0.47	0.457	0.303
	IVB	0.49	0.469	0.322
12	MR	1.684	1.461	1.343
	XB	0.707	0.692	0.431
	VB	0.749	0.724	0.456
	IVB	0.727	0.705	0.456
16	MR	2.22	1.958	1.766
	XB	0.986	0.97	0.564
	VB	1.029	1.003	0.589
	IVB	0.997	0.974	0.589

4. PERFORMANCE EVALUATION

A total of 16 high rise 3D Reinforced Concrete buildings with and without bracings are analysed. The structure is analysed and the main outcomes of pushover analysis like base shear, displacement, plastic hinges are evaluated. Whereas global damage index, over-strength factor, design factor and time based roof displacement are assessed using time history analysis.

4.1. Capacity Curves

Global response of the structure can be evaluated by the main product of pushover analysis i.e. base shear versus displacement. Fig. 2 (a) – (d) shows the capacity curves of frames with and without braces. It can be observed that the MR shows bilinear property. The curve is initially linear and upon increase in lateral load, the inelastic deformation occurs in both columns and beams. While in braced frames elastic slope changes is primarily due to bracing followed by beams and then by columns. From this it is apparent that provision of bracings increases the structural stiffness of the frames.

4.2. Total Base shear

The Comparative base shear calculated from pushover analysis is shown in Fig. 3. From the graph it can be seen that the increment in base shear is primarily due to the provision of bracing, column and beams have much lesser influence. Type of bracing, number of storey, bracing section, self-weight of frames, site conditions etc. are some of key factors that contributes to the base shear. XB shows the maximum base shear in 4 storey while VB and IVB displays the maximum base hear in 8 and 12, 16 storeys respectively. The Comparative base shear calculated from pushover analysis is shown in Fig. 3. Overstrength factor V_u/V_1 (Fig. 4) is the ratio of maximum base shear to the base shear conforming to first nonlinear event. XB shows the higher overstrength factor thus having the least displacement. Higher the overstrength factor higher will be the rigidity and evidently lower displacement. Design factor

(V_1/V_d) (Fig. 5) is the ratio of base shear confirming to first nonlinear event and the design base shear. XB shows the least design factor value than other bracing systems.

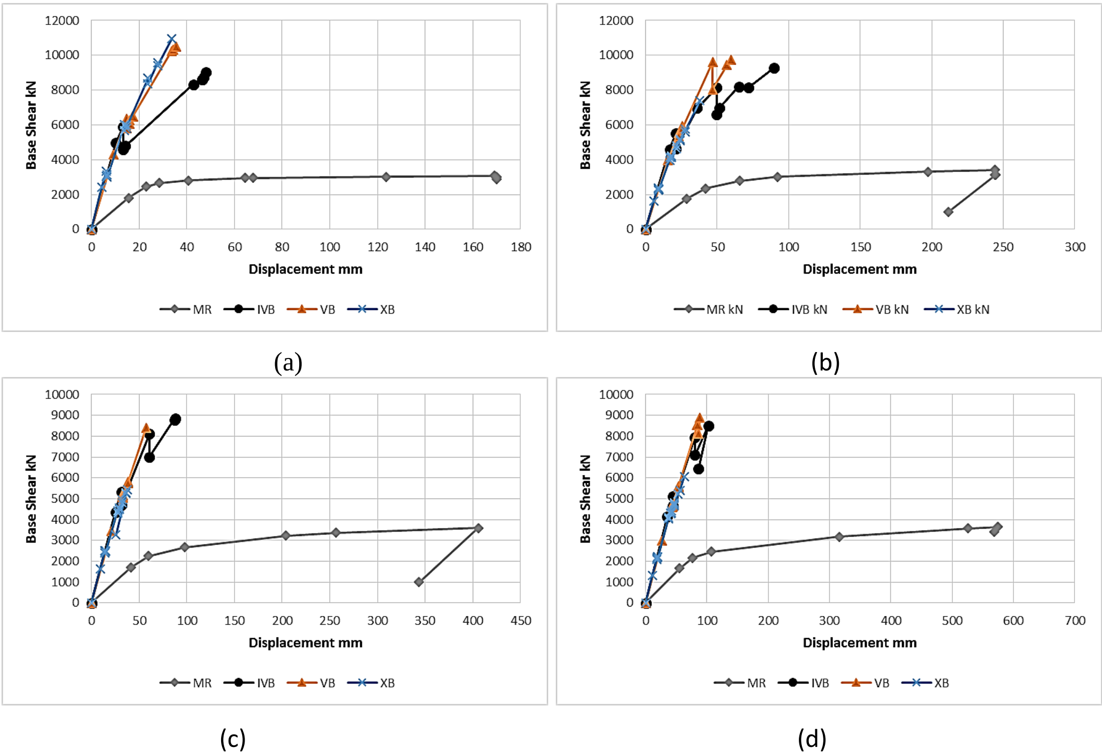


Figure 2 Capacity curves of braced and unbraced frames for (a) 4 (b) 8 (c) 12 (d) 16 Storey

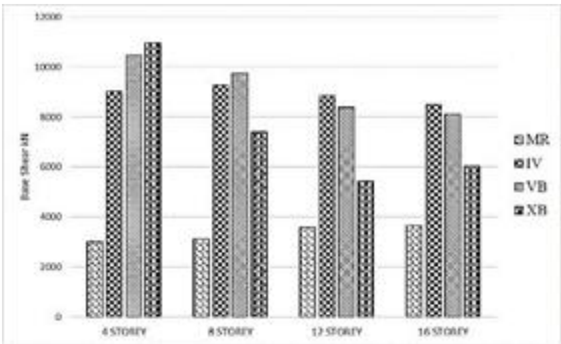
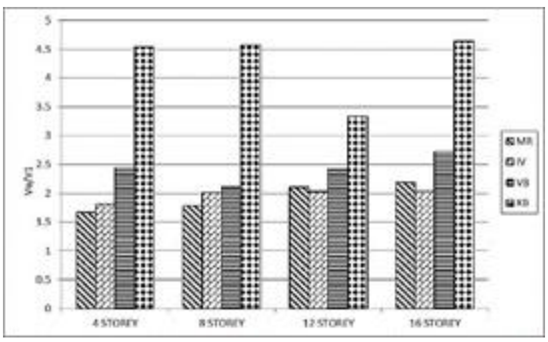


Figure 3 Total Base Shear variation



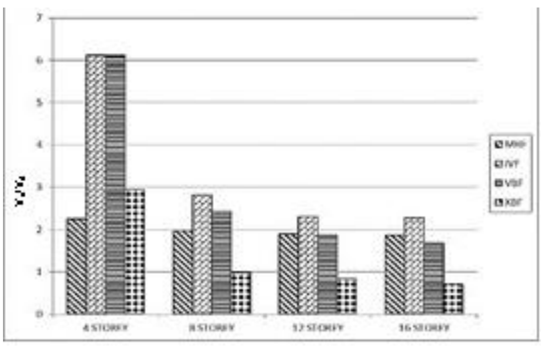


Figure 4 Overstrength factor (V_u/V_1)   **Figure 5** Design factor (V_1/V_d)

4.3. Plastic Hinges formation in frames

Failure modes of the frames and their weak points can be assessed from the plastic hinge formation. Those points are to be taken special care and attention during both design and maintenance stages. Inelastic deformation of the structural elements can be assessed from the formation of plastic hinges. The plastic hinges forms primarily in the braces, followed by beams and then by columns. From Fig. 6 it is evident that plastic hinge formation in column and beams are very much less in case of braced frames and their sequential formation has been tabulated in Table 3. The formation of plastic hinges in columns leads to higher probability of residual drift and also paves the way for column axial shortening, which leads to adverse effects in frames. Column has less deflection capacity than beams, so yielding of column through the formation of hinges can be a hint to the designers to concentrate on those columns to avoid column axial shortening. The number of hinges increases with the storey heights.

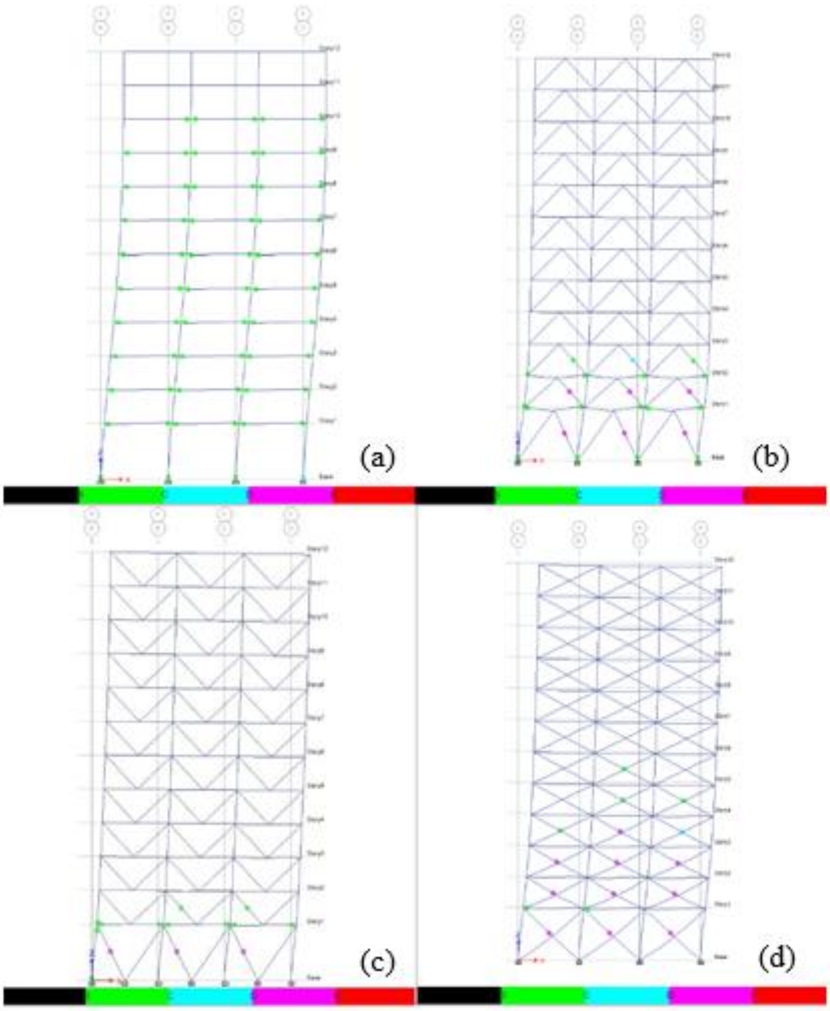


Figure 6 Plastic hinge formation in 12 storey frame with and without bracings

4.4. Global Damage Index

Maximum displacement (D) of the structural frame to the total storey height of the structure (H) is termed as Global Damage Index (GDI). Time history analysis has been performed using Chamoli earthquake ground motion to compare the performance of braced and unbraced frames. Fig. 7 shows the Global Damage Index (GDI) of 4, 8, 12 and 16 storey MF, XB, VB and IVB frames. From the figure it can be seen that XB shows the least GDI percentage which can be directly correlated with its stiffness to resist the lateral forces.

4.5. Storey Displacement

The story displacement corresponding to various storey heights, braced and unbraced frames induced by the Chamoli earthquake are analysed. In Fig. 8 it can be observed that the maximum displacement is shown by MR when compared with other braced frames. The ductile nature of MR leads to the maximum deformation while the stiffened braced frames shows comparatively less displacement. Among the braced frames XB shows the least displacement.

Table 3 Plastic hinge formation

No. of Storey	Frame type	Storey height up to which Hinges are formed		
		Bracings	Beams	Columns
4	MR	-	4	1
	XB	4	2	1
	VB	2	1	2
	IVB	2	1	2
8	MR	-	8	1
	XB	6	2	1
	VB	3	2	1
	IVB	3	2	1
12	MR	-	10	1
	XB	6	1	0
	VB	2	1	2
	IVB	3	2	3
16	MR	-	14	1
	XB	9	1	0
	VB	2	2	2
	IVB	3	3	3

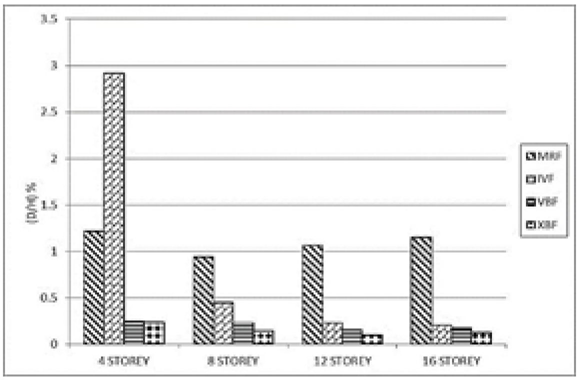


Figure 7 Global Damage Index (D/H) %

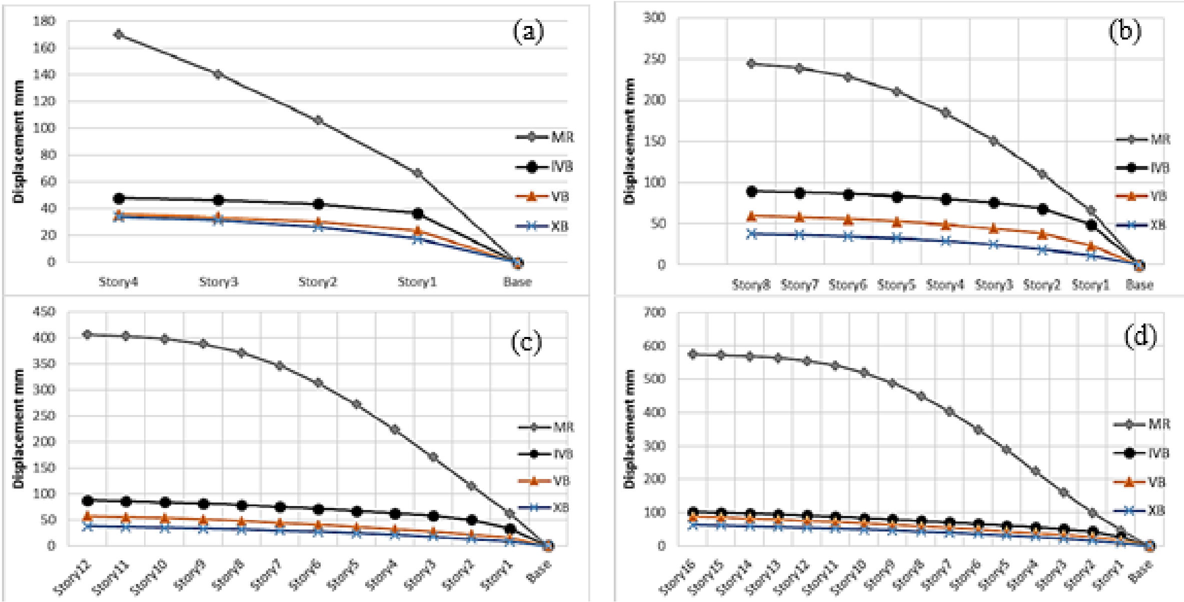


Figure 8 Storey displacement of MR, IVB, VB and XB for (a) 4 (b) 8 (c) 12 (d) 16 Storey

5. TIME HISTORY VS. ROOF DISPLACEMENT

Chamoli earthquake ground motion data is utilized for carrying over the time history analysis. Fig. 9 projects the time bound roof displacements of MR, IVB, VB and XB frames for different storey heights. From the roof displacement it is evident that bracing would be the best choice for counteracting larger displacement. In the 16 storey frame the roof displacement (D) of MR is 574.17mm, whereas in IVB it is 102.26mm, in VB D is 85.89mm and in XB D is 63.06mm.

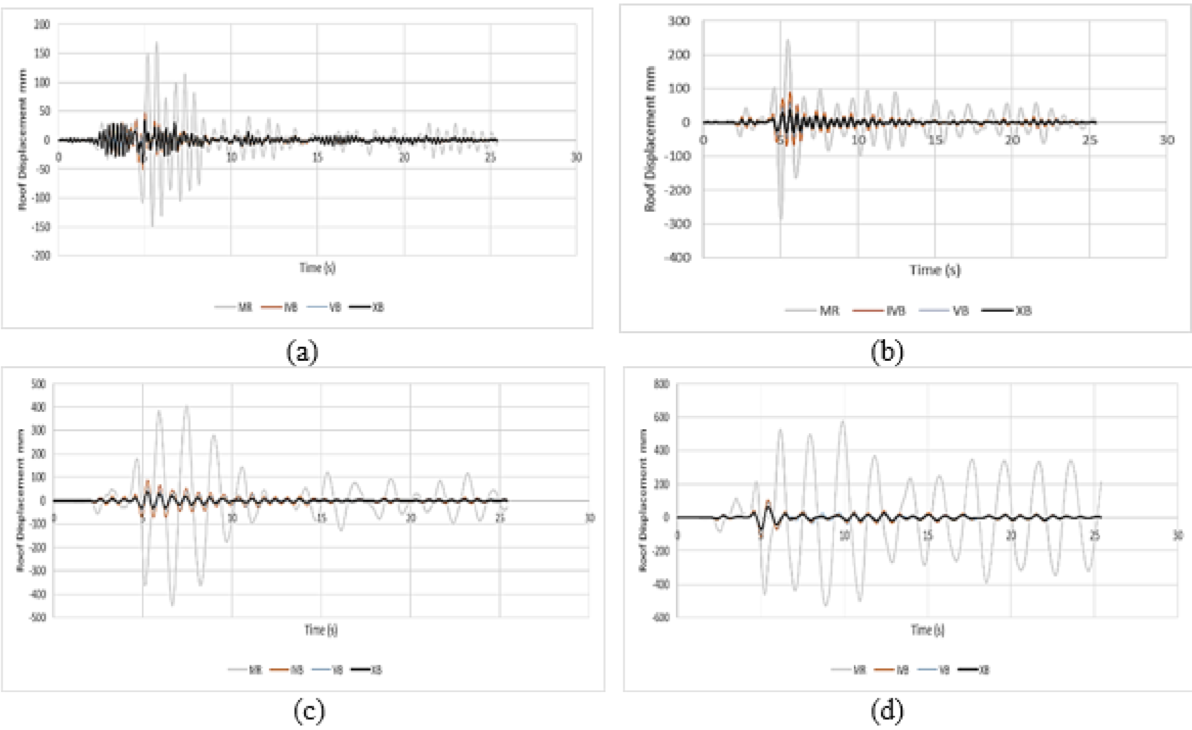


Figure 9 Roof displacement time history response of braced and unbraced frames for (a) 4 storey (b) 8 storey (c) 12 storey (d) 16 storey

6. CONCLUSION

In this paper an attempt has been made to assess the seismic response of unbraced MR frames and the braced XB, VB and IVB frames. 4, 8, 12 and 16 storey framed structures are modelled and analysed from which some of the following conclusions can be drawn.

- The fundamental natural periods of braced frames are very well less than that of the unbraced MR frames. Thus lower natural periods corresponds to higher stiffness.
- In comparison with MR frames the average percentage reduction in displacement in case of XB is 86.11%, VB is 81.38% and IVB is 73.91%. Whereas the increase in base shear in case of XB, VB and IVB are 1.34, 1.81 and 1.73 times that of MRs respectively.
- The braced frame shows much lesser displacement and correspondingly much lesser GDI in comparison with MR frames.
- The hinges are redistributed to the bracings and thus the number of hinge formation in beams and columns are much lower in braced frames. The hinges follow a sequential order starting primarily from
- Bracings followed by beams and then by columns while in unbraced structures the hinge forms primarily in beams followed by columns. Thus bracing reduces the vulnerability of failure of beams and columns to a greater extent.
- The number of hinges formed in MRs are much higher while comparing with that of the braced frames denoting higher amount of failure points.

Here XBs have the minimum displacement while comparing with that of the other braced frames but considering the maximum base shear and hinge formation aspects VBs holds the priority for the frequent earthquake prone zones of Uttarakhand.

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