International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Seismic Response Assessment of Stiffened RCC Frames Located in Gujarat

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Abstract: Past earthquakes in India, China, Nepal and other nations convey that abundant medium to high rise structures suffered major damages, comprising of life and safety of the people. This research compares the seismic response of RCC frames incorporated with different steel bracing systems that are located in Gujarat. The structural performances of the different bracing systems are analyzed for storey heights of 8, 12 and 16 considering the earthquake data of Bhuj. Diverse Structural Configurations like X-Braced Frames (XBFs), V-Braced Frames (VBFs), Inverted V-Braced Frames (IVBFs) and Moment Resisting Frames (MRFs) were taken under study. Three bayed frames with steel braces incorporated in the exterior frames are taken under consideration. The structural responses of these frames in terms of base shear vs. displacement, hinge formation, storey displacements, global damage index, overstrength factor and design factor were studied through pushover analysis. The roof displacement vs. time parameter was evaluated using time-history analysis.

Keywords: Base Shear, Bracing systems, Pushover analysis, Roof displacement, Seismic performance, Stiffness, Structural response, Time-history analysis.

I. INTRODUCTION

The dominant earthquake that struck the Kutch area in Gujarat on 26 January 2001 has been the most destructive earthquake in the past five decades in India. Bhuj earthquake reached 7.7 in moment magnitude scale and an intensity of X-Extreme in Mercalli intensity scale. Nearly 20,023 people were killed 167,000 were injured and destroyed almost 400,000 structures. To avoid the huge impact, some measures have to be taken in reinforced concrete structures as they are the most preferred choices in case of residential buildings in India. Diverse bracing systems are currently used both in case of reinforced concrete and steel framed structures [1-5]. Eccentric and concentric bracings are the two major classifications of bracing systems which have a series of explicit design requirements and specific characteristics. During an earthquake phenomenon, in addition to the normal forces, the structures located in the seismic vulnerable zones are exposed to lateral seismic forces.

Manuscript published on January 30, 2020.
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In seismic analysis the two major parameters that defines the structural stability are the stiffness and the intensity of the earthquake. Stiffness, the human controllable parameter governs the design in case of high rise buildings. Commonly MRFs and diagonally braced frames used to resist the lateral seismic load. Without the provision of bracings, Moment Resisting Frames fails to

Satisfy the stiffness criteria [6]. Different bracing system are available for increasing the seismic resistance of the building. Some of the types of Concentric bracing systems include K type bracing, chevron bracing, V type bracing, X type bracing, diagonal bracing etc.[7] which are used for connecting the braces concentrically to the beam column joint. While looking out for bracing sections, rectangular hollow sections provide the maximum ductility [8]. A simple design procedure for zipper braced frames was suggested by Yang CS, Leon RT and DesRoches R mainly concentrating on the ductile behavior. The zipper bracing has the capacity to activate buckling by redistributing the loads in the structure [9,10]. In order to find the hysteretic behavior of steel braces under severe cyclic loading numerous analytical and experimental studies have been carried out. Those studies have provided considerable information on the effect of bracing on structural response. Inelastic modelling of bracing are broadly classified into three categories: physical theory models, phenomenological, continuum Finite Element Analysis. The phenomenological model approach signifies the relationship between the observed axial force and axial displacement based on simplified hysteretic rules. In case of finite element model, the bracings are longitudinally segmented into number of elements where the properties like material and geometry of each element are defined. Comparing all the three methodologies Finite element model gives the best approach in the simulation of behavior of braces [11]. D'Aniello M, GLM A, Portioli F and Landolfo R [12] emphasized that the vital parameter which characterize the performance of chevron braced frames by analyzing the relationship between ductility demand of bracing systems and the flexural stiffness of braced beam is the relative beam-to-brace stiffness. In this paper, the seismic performance of different braces like X-Braced Frames (XBF), Inverted V Braced Frames (IVBF), V Braced Frames (VBF) and unbraced like Moment Resisting Frames (MRF) are assessed. The structural response of the above frames are evaluated by exposing them to the simulated Bhuj Earthquake Ground motion. Bhuj earthquake is chosen to prove a high magnitude acceleration for the zone category 5 (The most susceptible areas prone to earthquake of higher magnitudes).

Non- linear static and dynamic analysis were performed by modelling 3D Reinforced Concrete frames of 8, 12 and 16 storey. The moment resisting frame take part in resisting the gravity load and partial seismic load, while the bracings take care of the seismic load.

II. DESCRIPTION OF MODELLED REINFORCED CONCRETE FRAMES

In this study a variety of braced and unbraced frames having a storey count of 8, 12 and 16 are taken under study and are braced with bracings like XBFs, IVBFs, VBFs along with MRF systems. The elevation of different storey taken under consideration has been shown in Fig. 1. To improve their stiffness different bracings stated above were used at the exterior bays of the building as shown in Fig. 2 and were checked for their maximum displacement. Here the concept of strong column weak beam theory has been utilized as stated by Santa-Ana PR and Miranda E [13].

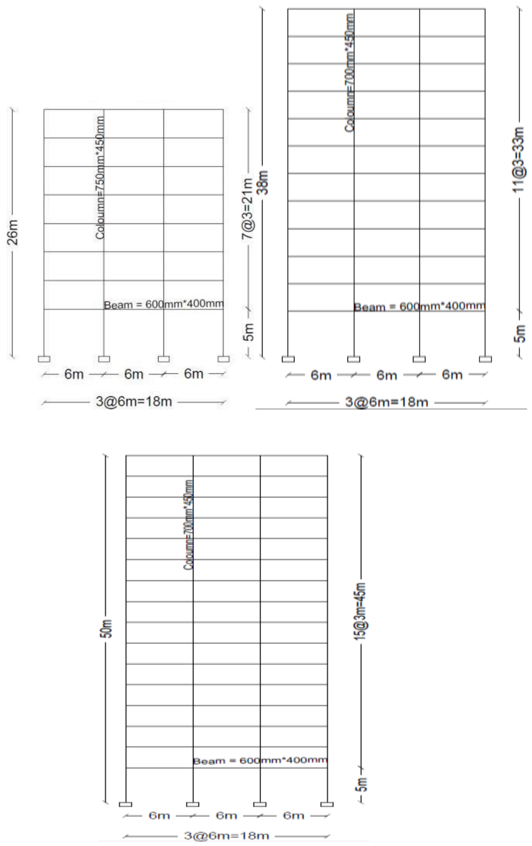
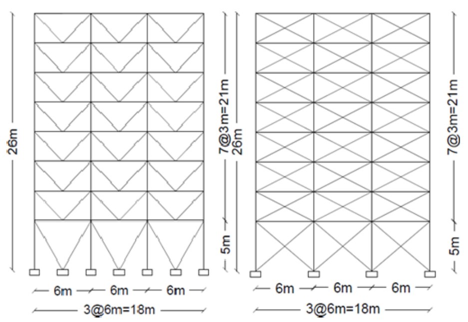


Fig. 1 Elevation of 8, 12 and 16 Storey MRFs



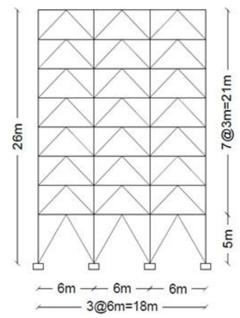


Fig. 2 Elevation of 8 storey (a) VBF, (b) XBF and (c) IVBF

Here the sum of plastic section modulus of beam connecting each connection is lower than that of the columns connecting the same connection. The details of the frames are furnished in Table 1. The rectangular hollow core steel sections were chosen in such a way that the total amount of steel is approximately same for all bracing systems. The fundamental period of vibrations for first three modes of unbraced and braced frames are given in Table 2. It can be observed that the fundamental periods were lower in case of braced frames, signifying that it has higher stiffness.

Table 1 Frame Specifications

Grade of Concrete	M30
Nominal yield strength of steel	345MPa
Design Codal Provisions	FEMA-356, ATC-40, IS 1893:2002 and IS 800:2007
Dimensions of beam	600 mm x 400mm

Table 2 Fundamental period of vibrations(s)

		Periods (s)		
Storey	**Bracing**	**1st**	**2nd**	**3rd**
8	MRF	1.052	0.878	0.831
	XBF	0.616	0.579	0.421
	VBF	0.61	0.568	0.41
	IVBF	0.601	0.56	0.41
12	MRF	1.512	1.293	1.197
	XBF	0.916	0.869	0.608
	VBF	0.893	0.844	0.58
	IVBF	0.877	0.829	0.58
16	MRF	1.988	1.728	1.563
	XBF	1.244	1.189	0.795
	VBF	1.206	1.15	0.75
	IVBF	1.182	1.129	0.75

III. NON-LINEAR ANALYSIS METHODOLOGY

Nonlinear static pushover analysis and nonlinear dynamic time history analysis were performed to assess the performance of the structural frames using ETABS v16 [22]. In the nonlinear static pushover analysis it is being considered that the structure is exposed to a displacement controlled horizontal load pattern in addition to self-weight or dead load of the structure which continuously increases through elastic and inelastic behavior until the structure fails upon reaching the ultimate load. The range of base shear may be represent by /the lateral loading which are induced by seismic excitations.

The structure must be capable of resisting specific target roof displacement for a specific seismic condition. Here it is considered that at the locations of plastic hinges in the frames, the nonlinear behavior occurs. This can be achieved by taking the nonlinearity into consideration by adopting plastic hinges with hysteretic relationships. The values are taken as per FEMA- 356 tables. These plastic hinges were provided at the midpoint of the braces, at both the ends for beams and columns [14]. Monotonic displacement controlled lateral loading was provided on the structures which were increased till the structure reaches its ultimate condition.

The maximum displacement reached by the structures were calculated and considered for evaluation.

IV.SEISMIC PERFORMANCE ASSESSMENT

A total of 12 three Dimensional RCC structures were taken under consideration. These structures were braced with different bracing types and their performances were compared among themselves and with the unbraced systems. The structural responses of the frames in terms of base shear vs. displacement, hinge formation, storey displacements, global damage index, overstrength factor and design factor were studied through pushover analysis. Time history analysis was utilized for assessing the roof displacement vs. time parameter.

V. BASE SHEAR VS DISPLACEMENT CAPACITY CURVES

The 3D structural frames were analyzed using nonlinear static pushover analysis. Displacement controlled pushover analysis has been performed where 0.4% of the height of the building is chosen as the target displacement as per FEMA-356 and ATC-40 [20] guidelines. These load displacement curves gives the structural behavior. Default hinge properties have been used for beams, columns and braces as per FEMA-356 [21]. The capacity curve obtained from base shear and displacement gives the global structural response. From the fig. 3(a) – (c) it can be observed that the capacity curve for MRFs is bilinear in nature. Initially the structure was observed to be in linear elastic stage and when there is further increase in seismic load the beams and columns shift to the inelastic deformation stage inducing slope change. However, in case of XBFs, VBFs and IVBFs the elastic slope changes was primarily due to yielding of braces, the yielding of columns and beams comes secondary. It is evident from Fig. 3(a) – (c) that provision of bracings increases the stiffness of the frames to a higher extent.

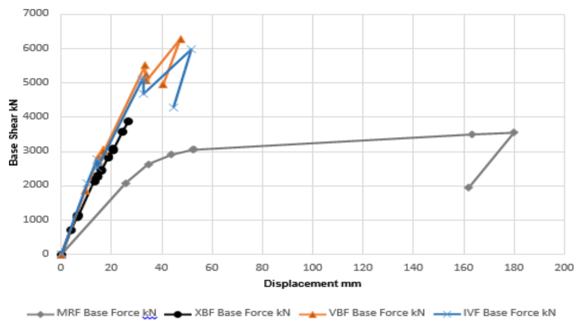


Fig. 3(a) Base shear vs. Displacement capacity curves of the braced and unbraced frames - 8 Storey

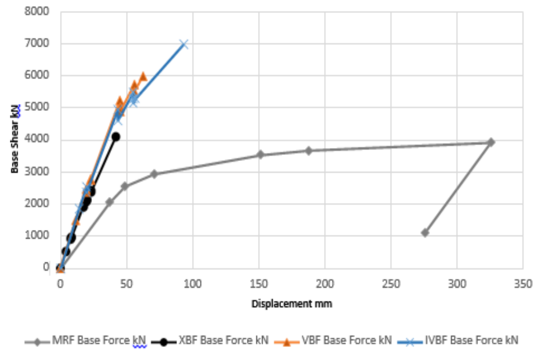


Fig. 3(b) Base shear vs. Displacement capacity curves of the braced and unbraced frames - 12 Storey

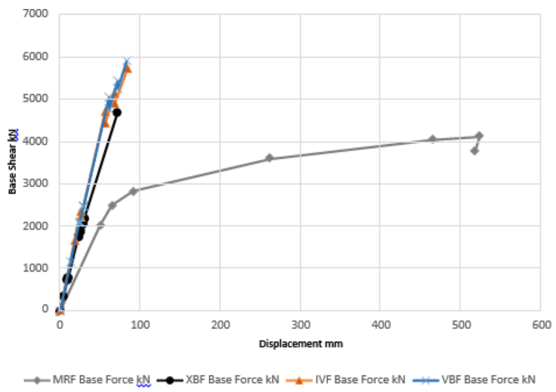


Fig. 3(c) Base shear vs. Displacement capacity curves of the braced and unbraced frames - 16 Storey

TOTAL BASE SHEAR

Target displaced push over analysis was calculated for MRF, XBFs, VBFs and IVBFs. It can be observed that the base shear results for MRF is less than the rest of the frames. The base shear increment is predominantly due to the provision of braces and the column has minimal influence. Bracing type, number of storey, dead weight of frames, bracing section, site conditions are some of the prime contributors of the base shear. Maximum base shear has been displayed by the VBF in case of 8 storey while IVB Frames shows the maximum in 12 and 16 storey (Fig. 4.). Overstrength variation (V_u/V_1) is depicted in the Fig. 5. Overstrength factor is the ratio of maximum base shear to the base shear corresponding to the first nonlinear event. Higher overstrength factor induces higher rigidity and lower displacements. The Fig. 6. depicts the design factor variation V_1/V_d. Design factor is the ratio of base shear corresponding to the first nonlinear event and the design base shear [15,16].

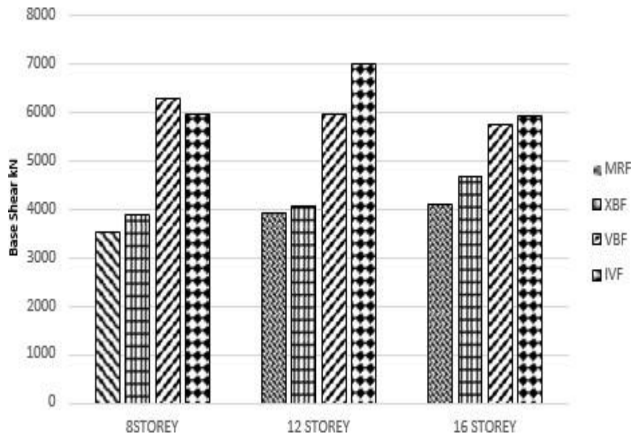


Fig. 4 Total Base Shear variation for MRF, XBF, VBF and IVBF

PLASTIC HINGES IN FRAMES

Pushover analysis gives the failure modes and weak points location that would occur in the structure in case of seismic events. The parts of the structure that need special care and attention can be predicted from these plastic hinge formation.

From the plastic hinges formation the inelastic deformation of different structural elements can be observed. In case of braced frames the sequence of formation of plastic hinges is first in braces then in beams and at last in columns while in unbraced frames it is in beams followed by columns. Column hinges form at the bottom most storey in all types of braced and unbraced frames and in some cases may also form at the other levels.

Fig. 5 Vu/V1 variation of MRF, XBF, VBF and IVBF

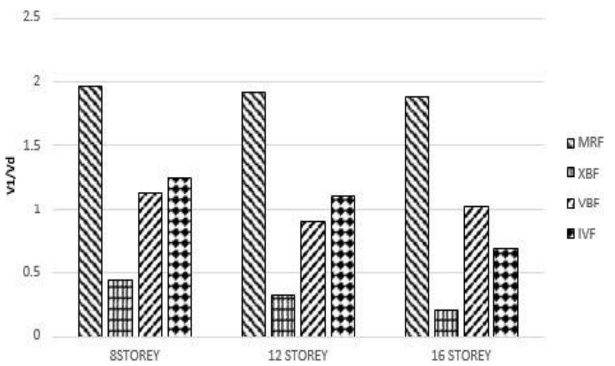
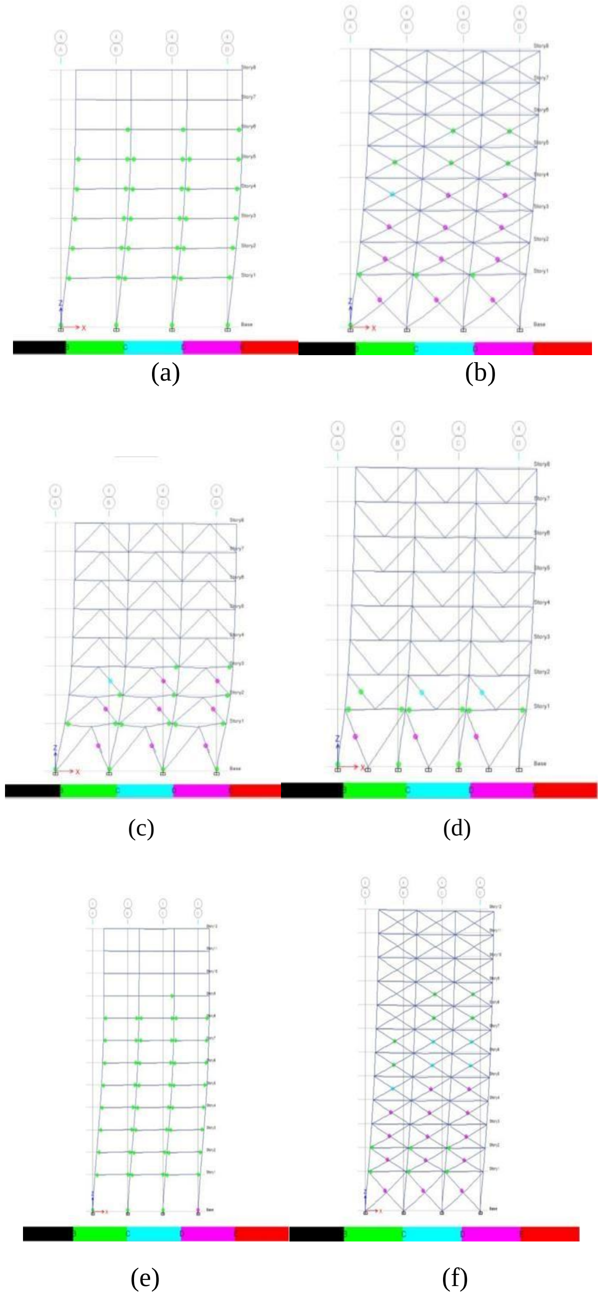


Fig. 6 V_1/V_d variation of MRF, XBF, VBF and IVBF

This leads to the probability of high residual drifts and also leads to column axial shortening, the main cause of adverse effects in frames. Since column is a compression member it has less deflection capacity than the beams. Column yielding through the formation of hinges can be considered as a warning sign for the designers. So those column areas can be concentrated and thus it can pave a way for the avoidance of column axial shortening. Sequential formation of hinges in bracings, beams and columns in different storey levels are portrayed in Table 3. From the Fig. 7. It is evident that the number of hinge formation in the storey increases with the storey height. It can also be seen that the XBF shows higher amount of hinge formation at bracings in 8 and 12 storey thereby reducing the number of hinge formation at the beams whereas the VBF shows comparatively less hinges formation at both bracings and beams in all storey.



Retrieval Number: E5799018520/2020©BEIESP
DOI:10.35940/ijrte.E5799.018520
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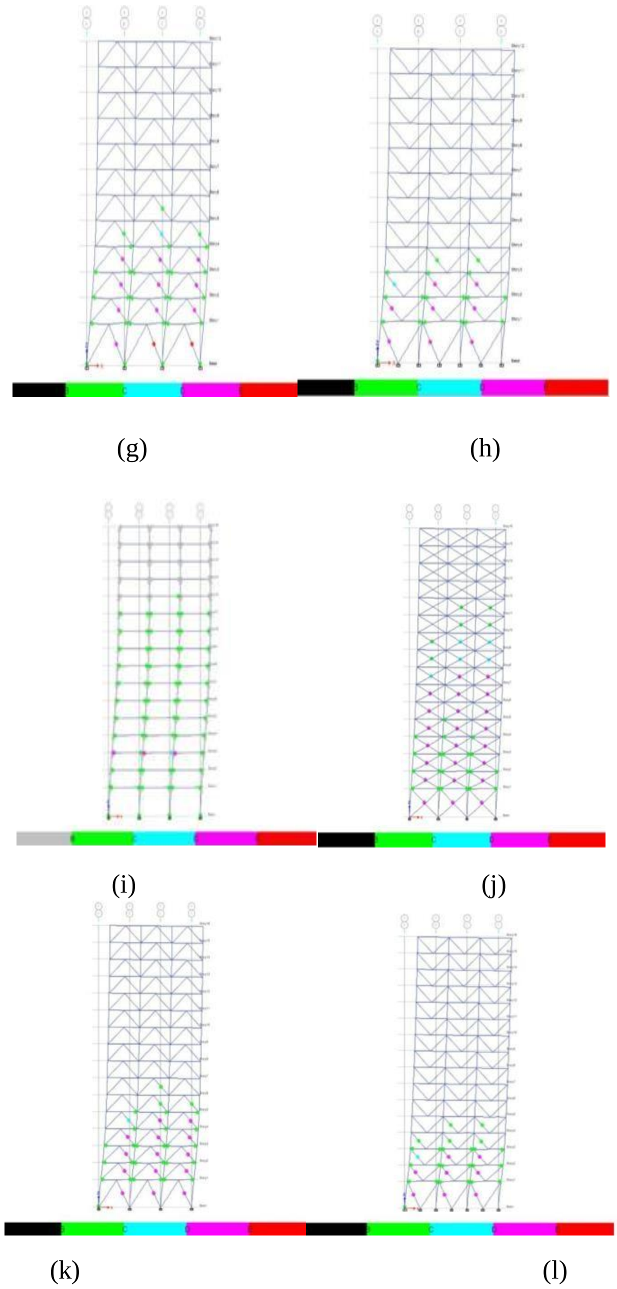


Fig. 7 Plastic hinge formation for braced and unbraced frames at (a) 8 Storey MRF (b) 8 Storey XBF (c) 8 Storey IVBF (d) 8 Storey VBF (e) 12 Storey MRF (f) 12 Storey XBF (g) 12 Storey IVBF (h) 12 Storey VBF (i) 16 Storey MRF (j) 16 Storey XBF (k) 16 Storey IVBF (l) 16 Storey VBF

Table 3 Formation of plastic hinges in braced and unbraced frames

Storey	*Type of Frame*	*y numbers up to which the Hinges are formed*		
		Bracing	*Beam*	*Column*
8	*MRF*	*-*	*6*	*1*
	XBF	*6*	*1*	*1*
	VBF	*2*	*1*	*1*
	IVBF	*3*	*3*	*1*
12	*MRF*	*-*	*9*	*1*
	XBF	*9*	*2*	*0*
	VBF	*4*	*3*	*1*
	IVBF	*6*	*4*	*1*
16	*MRF*	*-*	*12*	*1*
	XBF	*12*	*5*	*0*
	VBF	*5*	*3*	*1*
	IVBF	*7*	*5*	*1*

GLOBAL DAMAGE INDEX (GDI)

GDI is defined as the ratio of horizontal roof displacement (D) to the total height of the framed structure (H). Bhuj earthquake ground motion data is taken under study for performing time history analysis to relate the GDI of braced and unbraced frames. Fig. 8. shows the GDI of 8, 12 and 16 storey MRF, XBF, VBF and IVBF. It can be found that the XBF gives the least GDI while comparing with other types of frames which reflects its stiffness capacity to resist the lateral loads thereby decreasing the extent of displacement of the structure.

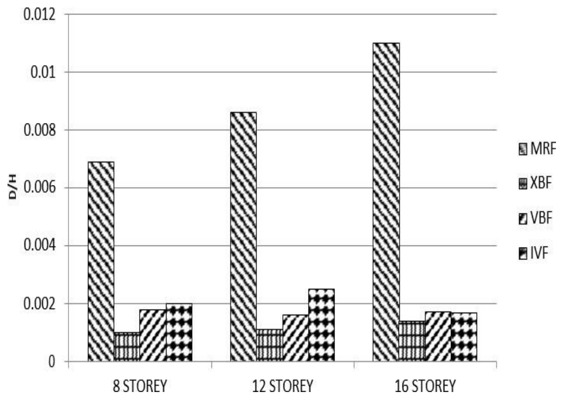
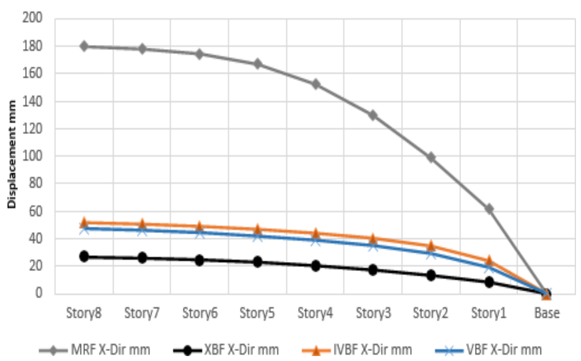


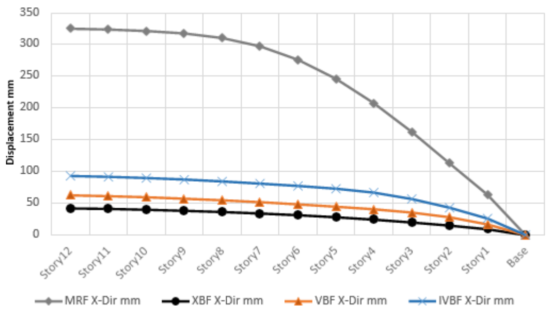
Fig. 8 Variation in Global Damage Index (D/H)

STOREY DISPLACEMENT

Displacement of storey corresponding to various frame heights are analyzed using time history analysis incorporating Bhuj earthquake data. Storey displacement conforming to different storey height frames exposed to Bhuj earthquake ground motion are illustrated in Fig. 9. It can be observed that MRF shows higher degree of displacement when compared with other bracing systems because of its ductile nature whereas the XBF shows the least displacement in comparison with other systems.



(a)



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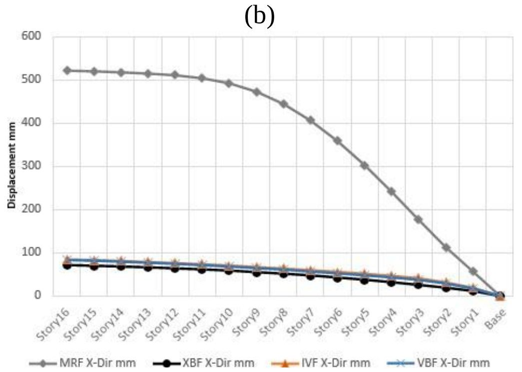
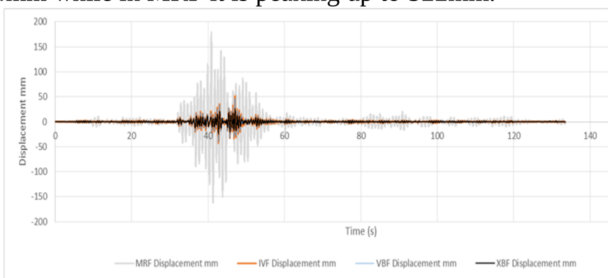


(c)

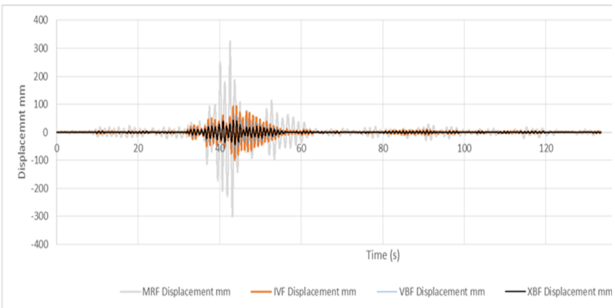
Fig. 9 Storey displacement of MRF, XBF, VBF and IVBF for (a) 8 Storey (b) 12 Storey (c) 16 Storey

VI.TIME HISTORYVS ROOF DISPLACEMENT

The time history analysis is carried over by feeding the Bhuj earthquake ground motion data. Fig.10. projects the relation between displacement and time for the braced and unbraced frames subjected to Bhuj earthquake ground motion. Braces prove to be the best option to counteract against the larger displacement. For instance considering the 16 storey frames the maximum roof displacement (D) of XBF is 71mm, VBF is 83mm, IVBF is 84mm while in MRF it is peaking up to 522mm.



(a)



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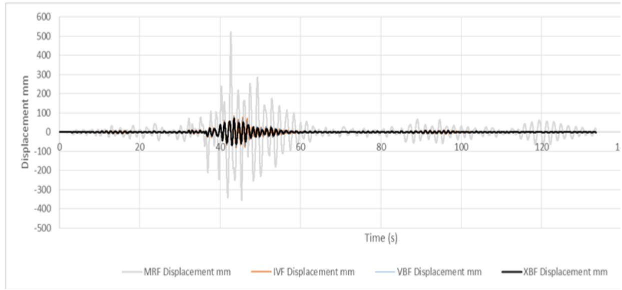

(c)

VII. RESULTS AND CONCLUSIONS

In this research an attempt has been made to evaluate the seismic performance of frames incorporated with diverse bracings namely XBF, VBF and IVBF which are compared with that of MRF systems. 8, 12 and 16 storey frames are analyzed and from the results the following conclusions are drawn:

- The fundamental natural periods for the unbraced MRFs are very much high than that of the braced frames. Thus frames with higher natural periods corresponds to lower stiffness.
- The average reduction in displacement and the percentage increase in base shear, both with reference to MRF has been projected in Table 4. From the table it can be seen that the XBF shows the crowning reduction in displacement and least increment in base shear.

Table 4 Base shear and displacement variations

Type of Frame	Average reduction in displacement (%)	Average increase in base shear (%)
XBF	86.13	9.21
VBF	79.59	56.39
IVBF	75.44	63.56

- The analyzed results of time history offers the same result as that of pushover analysis. It reveals that the braced frames show lower displacement and much less Global Damage Index in comparison with the unbraced frames.
- The hinge formation in beams are higher in case of MRFs while in other braced frames the hinge formation in beams are much lesser due to the redistribution of hinges to the bracings. In braced frames the hinge formation follows a sequential order starting from bracings then on beams followed by the columns. In case of MRFs the hinge forms in the order from beams followed by columns. Thus provision of bracings reduces the susceptibility of failure of beams and columns due to lateral loading.
- Seismic performance comparison of bracings shows that the XBF performs well with much lower displacement. Also while considering the base shear capacity of bracings and the formation of plastic hinges XBF holds higher priority than the rest of the frames when prone to seismic events like Bhuj.

REFERENCES

1. Dia Eddin Nassania, Ali Khalid Husseinb, Abbas Haraj Mohammed. Comparative Response assessment of steel frames with diff erent Bracing systems under seismic effect. Structures. 2017 August 17; 11: 229–242.
2. Kiran Kamath, Sachin Hirannaiah, Jose Camilo Karl Barbosa Noronha. An analytical study on performance of a diagrid structure using nonlinear static pushover analysis. Recent Trends in Engineering and Material Sciences. 2016 September 20; 8: 90-92.
3. G Navya, Pankaj Agarwal Dhanaraj. Seismic Retrofitting of Structures by Steel Bracings. 12th International Conference on Vibration Problems, ICOVP. 2016 May 25; 144: 1364 – 1372.
4. Hendramawat A Safarizki, S.A. Kristiawan and A. Basuki. Evaluation of the Use of Steel Bracing to Improve Seismic Performance of Reinforced Concrete Building. The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering, ICRMCE. 2013 April 18; 54: 447 – 456.
5. Shen J, Wen R, Akbas B, Doran B, Uckan E. Seismic demand on brace-intersected beams in two- story X-braced frames. Engineering Structures. 2014 August 6; 76: 295–312.
6. Balendra T, Sam MT, Liaw CY. Diagonal brace with ductile knee anchor for aseismic steel Frame. Earthquake Engineering Structural Dynamics. 1990 August 10; 19(6): 847–858.
7. Dhanaraj M. Patil, Keshav K. Sangle. Seismic behaviour of different bracing systems in high rise 2-D steel buildings. Structures. 2015 August 3; 3: 282-305.
8. Tremblay R, Archambault MH, Filiatrault A. Seismic response of concentrically braced steel frames made with rectangular hollow bracing members. Journal of Structural Engineering ASCE. 2003 December; 129(12): 1626– 1636.
9. Yang CS, Leon RT, DesRoches R. Design and behavior of zipper braced frames. Engineering Structures. 2008 April 15; 30(4): 1092–1100.
10. Yang CS, Leon RT, DesRoches R. Pushover response of a braced frame with suspended zipper struts. Journal of Structural Engineering ASCE. 2008 October 10; 134(10): 1619–1626.
11. Dicleli M, Calik E. Physical theory hysteretic model for steel braces. Journal of Structural Engineering ASCE. 2008 July 15; 134(7): 1215–1228.
12. D'Aniello M, GLM A, Portioli F, Landolfo R. Modelling aspects of the seismic response of steel concentric braced frames. Steel and Composite Structures. 2013 January 15; 15(5): 539–566.
13. Santa-Ana PR and Miranda E. Strength reduction factors for multidegree-of-freedom systems. 12th World Conference on Earthquake Engineering; Auckland, New Zealand, 2000 January 10; 1:1-8
14. Guneyisi EM, Muhyaddin GF. Comparative response assessment of different frames with diagonal bracings under lateral loading. Arabian Journal for Science and Engineering. 2014 March 14; 39(5):3545–58.
15. Maheri MR, Akbari R. Seismic behaviour factor, R, for steel X-braced and knee braced RC buildings. Engineering Structures. 2003 July 5; 25(12): 1505–1513.
16. Haamidh A and Lakshmivarsha C. Comparative Seismic Response of Stiffened RCC Frames Located in Uttarakhand. International Journal of Civil Engineering and Technology. 2019 February 10; 10(02): 2240–2249
17. ATC-40. Seismic evaluation and retrofit of concrete buildings. Applied Technical Council; California. 1996
18. FEMA 356. (Federal Emergency Management Agency) Pre-standard and commentary for the Seismic rehabilitation of building. Washington DC. 2000
19. ETABS Computers and Structures Inc., Berkeley. 2016

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