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Linear and Nonlinear Dynamic Analysis of Reinforced Concrete Building with V Shape Steel Bracing

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Abstract - In this study, the RC-MRCBFs were used with V braced frame. The core objective of this examination is to understand the earthquake behavior of the RC-MRCBFs in steel V braced frames. Response spectrum analysis (RSA) is used to understand the seismic performance of the steel braced and un-braced RC frames. Total 12 steel braced RC frames and 12 un-braced frames for all 4 story, 8story, 12 stories and 16 stories are studied and observed the seismic parameter such as fundamental time period (FTP), top story displacements, inter-story drift, base shear and story stiffness of the structures. After studying the parametric study of the 4 to 16 story buildings with a linear and nonlinear analysis tool it was observed that to get the effective braced frame with expected failure mechanism, ductility, the columns should be designed such that, they resist at least 50% base shear contributions. It is observed that using the steel V bracing in the low rise to mid-rise buildings, improves the seismic behaviors of the structures. The steel bracing reduces the maximum top story displacements, drift and time period of the building and increases the seismic base shear demand, stiffness of the structures. The result shows that as increasing the base shear contribution in the columns, the drift and displacement of the story increases and base shear decreases.

Key Words: Response Spectrum Analysis, displacement, Maximum storey drift, Storey shear, Storey stiffness, braced frame, RC buildings.

1. INTRODUCTION

Construction of RC structure with a shear wall and steel structure with steel bracing are the common practices in India. Moment resisting frame (MRF), SW and steel braced frames are used to resist the earthquake load and wind load and hence increased the seismic performance of the structure. It seemed that the earthquake load damaged the buildings even the collapsed the buildings. It is because if the buildings do not resist the lateral seismic force, the buildings collapse. For improving the lateral load capacity of the buildings in generally designers used the shear wall in the RC structure [1], [2]. This study, mainly concern about concerned with the concentrically braced moment-resistant RC frame. In concentrically braced frame V- Shape steel braced is used in the new construction RC frame to understand the linear and nonlinear performance of the structures with the different shear values provided in the columns with different heights.

In the previous research Godínez and Tena, 2010 and 2016 [3], [4]; Godínez et al., 2012 [5], they were focused on pushover and dynamic analysis of RC/MRCBFs using the chevron SB and applied MFDC-04 codes. Eskandari R. et al. (2017) investigated the diagonal steel bracing in concrete frame structure and analysis based on the Iranian Seismic Design Code. K. Du, et al (2020) investigated the inverted V, diagonal, V and observed the effect of forward directivity (FD) and fling-step (FS) on the RC structure having buckling-restrained braces (BRBs). E. A. Godínez and A. Tena (2019) [6] studied about X steel bracing in MRCBFs by using MFDC-04. Except the K. Du, et al (2020) [7] other literature mainly focused on developing the guideline of the new design of RC braced frames.

The researcher designed the 4 to 16 story moment resisting frame with V-shaped bracing with some outcomes. The study of the performance of buildings is performed by using the linear and time history method.

2. LITERATURE REVIEW

Retrofitting technique is used in an existing building to improve seismic performance [8]–[11]. It is a cheap and effective method of strengthening the RC frame against the lateral loading commonly known as earthquake loading.The different experimental and numerical techniques are investigated in RC building with a various type of bracing commonly X- bracing, chevron and inverted chevron bracing and diagonal bracing [12]–[15]. Several researchers studied the retrofitting, strengthening, and also seismic rehabilitation of the RC structure with concentric bracing and the result suggested an improvement of seismic performance and ductility of the existing structure.

Nateghi (1995) [16] investigated a building that was originally designed as a five-story structure but later the owners decided to add three more stories. It was observed the seismic retrofitting with X-steel bracing was acceptable for the 8-story RC structure by the owners of the building. Tena-Colunga et al. (1996) [17] studied existing nine-story building which is located in Mexico City. The building was retrofitted by steel bracing. The study were focusing on the resonant response and along with pounding potential from the structural point of view. The retrofitted building was survived the 1985's Michoacán earthquake which indicated the effectiveness of the steel bracings in RC buildings.

Abou-E. and Ghobarah (2000) [18] studied the low/rise RC structure which was re-strengthen by using X bracing. The three-story building was observed its seismic performance by using different ground motion. It was suggested that the number of braced bay to be increased then the load on RC columns was reduced.

A new device known as a compression release device(have no compressive stress) in steel bracing was also used in retrofitting the RC structure. In 2006 Ghaffarzadeh and Maheri, (2006) [19]used compression release device (CAD) for steel bracing in the RC frame. It was observed that buckling failure of the compressive brace was highly reduced the ductility of the RC frame. Ghaffarzadeh and Maheri (2006) [20]performed both experimental and numerical investigation in a 2/5 scale RC frame with and without steel bracing. In this experiment they used the directly connected concentric internal steel bracing. The researchers applied the cyclic loading on the experimented and the results shows that adding steel bracings reduced the lateral drift easily. Energy dissipation at high drift level of the structure having bracing found higher than without a bracing.

El-Sokkary, K. Galal (2009) [21]performed incremental dynamic analysis in low to medium-rise non-ductile RC frame using four rehabilitated technique, these were reinforced concrete shear wall, steel bracing, diagonal FRP strips and wrapping. Seismic performance parameterswere studied in the term of maximum inter story drift ratio, maximum story base shear/seismic weight ratio and energy dissipater capacity. Study observed that adding the RC wall increased the story shear and when the FRP wrapping used the PGA, and energy dissipation capacity increased. Amoury and Ghobarah (2005) [22] also studied the steel bracing and FRP technique in 9 and 18 story buildings. Study concluded that adding the FRP reduced the ductile failure modes and steel bracings effectively play main role in stiffness and decreased the interstory drift of frames. Kadid and Yahiaoui (2011) [23]presented the retrofitting technique in 3- and 6- story RC building. Different type of concentrically steel braced that was used such that X-, chevron braced, Z/X-, and Z (Zipper) braced. It was concluded that adding the bracing and increasing the dimensions of the section enhanced the building strength capacity. Study also suggested that using tube sections performs better than other section. Liu et al. (2012) [24]the experimental analysis of 1/2 scale RC frame of bare, steel braced& FRP retrofitting techniques were considered. The seismic performance in these three models has been studied and concluded that the FRP technique improves global performance, ductility, and energy dissipation capacity. Massumi and Absalan (2013) [25]studied the experimental and numerical analysis of the RC frame having steel bracing to observe the performance of the building. Result shows that for dual system, ultimate strength of frame increased by 18.34%. Faella et al. (2014) [26]studied steel bracing as a commonly used retrofitting technique to increase seismic performance. The concentric X-bracings was used and also compared with different alternative bracing patterns.

Hadad et al. (2017)[27] studied a three concrete braced, steel braced and infilled frames for resisting the lateral shear force. The experimental of these models were tested under cyclic loading. The result revealed that the lateral load resisting capacity increases by using any type of bracing as compared to the without braced frame. Sukrawa (2017) [28]studied the strengthening of the RC frame with steel bracing in low to medium-rise building. The 3, 5, 8, and 10 story RC frame building having chevron-A braced and X-bracing provided in the mid-bay were considered.Result suggested that chevronA-type bracing showed better behavior than using X- type bracing. Chevron 'A' shaped was stiffer as compared to x braced frames with ratio 1.07 and 1.05 for 8 and 10 story buildings respectively. Qiao et al. (2017) [29]studied the topology optimization used to derive bracing configuration. The results indicated that the stiffness and strength of the structures improved when the steel bracings used but it may be reduced the ductility when excessive brace volume was applied.

Effect of steel bracings in RC buildings under the seismic effect was considered by Babu et al.,(2017) [30] however detailed informations were obtained in Rahimi and Maheri's study in 2018 paper. Rahimi, Maheri (2018)[31] investigated the effect of steel bracing in RC structures. The study highlighted some positive effects such as shear capacity, reduction in displacement, improvement of structural seismic performances, and decreased drift. The seismic effects in the columns were considered when the x bracing used in the RC structures. It was concluded, a low-rise RC frame with steel x bracing was shown good results during seismic loading. The nonlinear and linear static analysis shows that applying the steel bracing in suitable manner shows the better results and get better design [32]–[34]. Formisano, et al. (2020)[35]discussed the seismic vulnerability of RC structures designed for the gravity load only. The models (bare frame, full infilled, and pilotis frame) were retrofitted with using of external steel bracing systems. It was concluded that the use of the X bracing system was more effective and also increased the safety factor of the building.

3: METHODOLOGY: ANALYSIS & METHODS

The bracings are designed first and fixed the base shear capacity in the bracings and then beam and columns are designed. Code provisions are considered, the ETABs has used for design the RC frame with steel bracings with different strength capacity.

3.1 Design requirement

Indian standard 1893: 2016 (part 1) provides the design criteria for the earthquake design of the building. The Indian code IS is used to design ductile RC-MRCBFs. For ductile designing not only is 1893 part 1:2016 but also IS13920:2016 is used for ductile designing and ductile detailing. Most of the codes for ductile designing of RC-MRCBFs seem to be incomplete. For example, code only provides beam-columns joint for ductile design but there are no detailed methods and references that how to design and detailing the columns, beams, and bracing joints to ensure the ductile behaviors of the building. Both IS 1893 and IS13920 codes do not provide an adequate guideline for design the ductile design of RC frames with concentric braced frame.

12 RC of V braced buildings were designed by using the Indian standards code. For seismic design IS 1896 part1, reinforced concrete design IS156, IS800 for steel design, ductile design guideline IS13920:2016, IS 4923:1997, were used to achieve required seismic behavior. The regular RC/MRCBFs using V-SB were designed for the soft soil's condition, using response reduction factor R=4.5. Where the diagram is corresponding to a 5% damping ratio. The building models are four-story, eight-story, twelve-story, and sixteen-story regular RC-MRCBFs having 7m spans in each X and Y direction and 3.2 m story height. Outer RC frames consist of steel bracing which is used to resist earthquake loads. The plan and elevation view is given in fig1. RC-MRCBFs are designed using various lateral force ratios between the MR system and the braced system. Live load is 5kN/m^2 (business and office building), LL at roof level is2 KN/m^2 and Finishing dead load = 2.5 KN/m^2 is assumed.

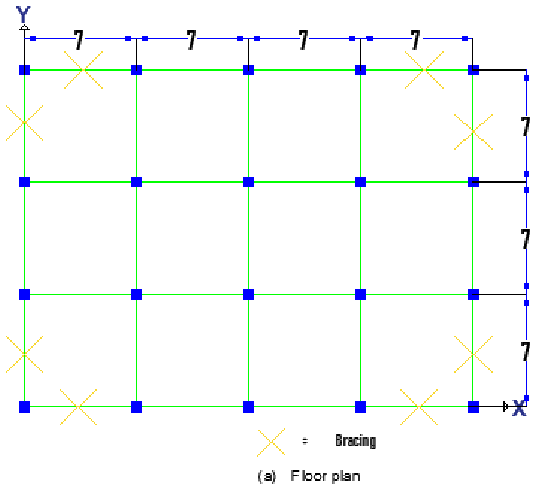

Figure 1 Floor plan and elevation view in dual systems (all units are in m)

3.2 Buildings and its characteristics

The different story height buildings are designed in the ETABs finite element software. The columns, beams and bracing are modeled in the software and designed by using the equivalent static and response spectrum method. The slabs are considered rigid diagram, base are restricted in x, y and z-direction. Load case are defined for RSA in both x and y direction as a U1 and U2 respectively. The design was based on the Indian standard and all drift and torsional are checked according to the code. The figure 2 and 3 shows the models designed in software.

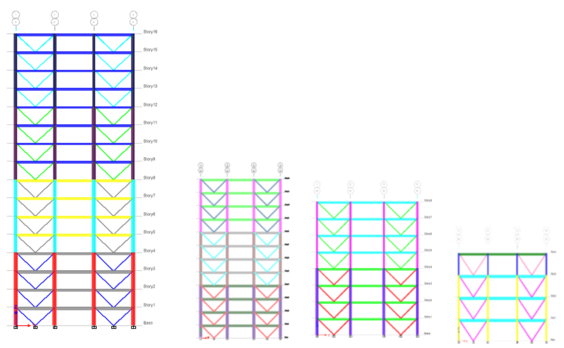

Figure 2 Elevation view of 4 to 16 storey building

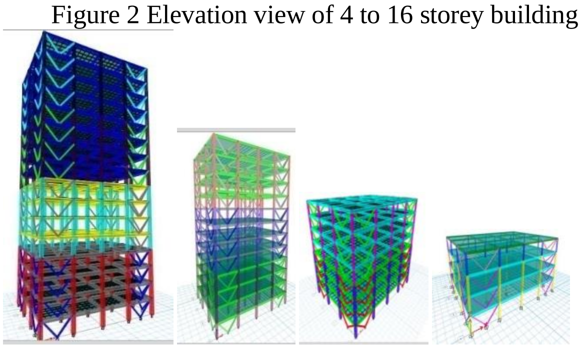

Figure 3 3D view of 4 to 16 storey building

3.3 Nonlinear dynamic analysis

Nonlinear THA is performed in the ETABS software program. To understand the actual nonlinear behaviors of the structure, a nonlinear THA is done. Linear and nonlinear two typesof dynamic analysis methods are present in the software. In the dynamic analysis, the real ground motions are applied in the structure, and response is observed. The real ground motionis also known as time history data are introduced in the ETABs software. This method gives the real behavior of the buildings during earthquakes. Different peak ground acceleration is used to understand the behaviors and to study the maximum top story displacement, ISD, base shear of the structure. Different PGA level gives different seismic behaviors.

3.4 Ground motions

The ground motions data are downloaded by the PEER center. The 7-ground motions are usedin the thesis in which the data are different magnitude range from 6.9 to 7.9 magnitude with their station name. Table 1 shows the seven earthquake ground motions with their name, magnitude, station name, and date of record.

Table 1 List of earthquake motion used in the study

No.	Earthquake name	Year	Station	Magnitude	Name Rjb	Km
EQ1	Landers	1992	Anaheim - WBall Rd	7.28	strike-slip	144.9
EQ2	Loma Prieta	1989	BRAN	6.93	"Reverse Oblique"	3.85
EQ3	Caldiran_ Turkey	1976	Maku	7.21	"strike slip"	50.78
EQ4	Denali_ Alaska	2002	Carlo (temp)	7.9	"strike slip"	49.94
EQ5	Chi-Chi_ Taiwan	1999	CHY065	7.62	"Reverse Oblique"	82.78
EQ6	Imperial Valley-02	1940	El Centro Array#9	6.95	"strike slip"	6.09
EQ7	Darfield_ NewZealand	2010	Kaiapoi North School	7	"strike-slip"	30.53

4: RESULTS AND DISCUSSION

4.1 Response spectrum analysis

This analysis study concern ablaut the fundamental time, base shear and other parameter for 4 to 16 storey buildings.

Fundamental time period (FTP)

The fundamental time of the 12 braced and 12 un-braced frames has been calculated by using the software and shown in fig. 4. The graph (fig. 4) shows the FTP of the un-braced RC frame is relatively higher than the steel V-braced RC frame. In the model 4X25 without bracing have observed 0.957 sec and when the steel bracing is used it is reduced by 0.425 sec which is almost 44% reduced from the un-braced time period. When the base contribution increased (in X50 and X75) the 58% and 76% time period was reduced from the un-braced time period observed. The time period value increased as the height of the structures increases. However the FTP of the buildings without bracing, the time period decreased as increased for X25, X50 and X75 models.

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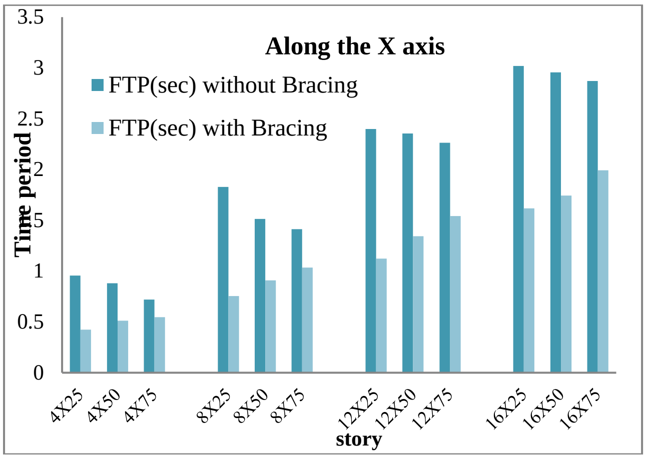

Fig. 4 FTP of the braced and un-braced RC Frame (along the X direction).

Story displacements and Inter-story drift (ISD)

Overall it is observed the providing the steel V bracing in the RC frame reduced both inter-story drift, and maximum top story displacements shown in the table 2 - 4 for all 8, 12 and 16 story buildings. The maximum top story displacement is evaluated as 25.5 in without braced frame and 7.1 in when the steel braced frame is used in the 4 stories along the X direction when the columns resist 25X base shear. When comparing the maximum displacement for 4, 8, 12 and 16 story RC buildings with and without steel bracing frame is shown in table 2 - 4. The steel bracing reduced both drift and displacement of the structure when the V-shaped steel bracing is used. When the percentage of the base shear contribution increased, the maximum displacement and drift also increased. The fig.5 shows that the base shear contribution in the columns increased and the ISD also increased. As increased the height of the structure the ISD also increased and similar observations are made along with the y directions.

Table 2. Maximum Displacement and maximum stiffness of the 8 story buildings.

Story	Seismic parameter	lateral load contributions					
		Along X axis			Along Y axis		
		8X25	8X50	8X75	8Y25	8Y50	8Y75
8 Story Structure	Max. Displacement without Bracing	47.7	38.9	37.1	48.4	39.8	38.1
	Max. Displacement with Bracing	23.4	25.1	27.8	23.3	25.3	28.2
	Disp. With bracing/ without bracing (%)	49	65	75	48	63	74
	Max. stiffness without bracing (KN/m)	450129	600764.8	806089.8	438284	583697	783329
	Max. stiffness with bracing (KN/m)	2198583	1394415	1276011	2198138	1382613	1257501
	Without bracing /with bracing (%)	20	43	63	20	42	62

Table 3. Maximum Displacement and maximum stiffness of the 12 story buildings.

Story	Seismic parameter	lateral load contributions					
		Along X axis			Along Y axis		
		12X25	12X50	12X75	12Y25	12Y50	12Y75
12 Story Structure	Max. Displacement without Bracing	63.6	60.8	58.4	63.0	62.0	59.6
	Max. Displacement with Bracing	35.9	39.4	43.4	35.6	39.5	43.7
	Disp. With bracing/ without bracing (%)	56	65	74	56	64	73
	Max. stiffness without bracing (KN/m)	691121.4	741230.6	968710.8	670898	719416	941030
	Max. stiffness with bracing (KN/m)	3422154	1928260	1634618	3427382	1915969	1613982

Without bracing /with bracing (%)	20	38	59	20	38	58

Table 4. Maximum Displacement and maximum stiffness of the 16 story buildings.

Story	Seismic parameter	lateral load contributions					
		Along X-axis			Along Y-axis		
		16X25	16X50	16X75	16Y25	16Y50	16Y75
16 Story Structure	Max. Displacement without Bracing	76.8	76.2	74.3	79.6	78.7	76.4
	Max. Displacement with Bracing	48.0	50.5	53.9	47.6	50.6	54.7
	Disp. With bracing/without bracing (%)	62	66	73	60	64	72
	Max. stiffness without bracing (KN/m)	896062.6	1015791	1413407	867771	983952	1371252
	Max. stiffness with bracing (KN/m)	4004476	2594199	2333121	4005284	2577334	2302751
	Without bracing /with bracing (%)	22	39	61	22	38	60

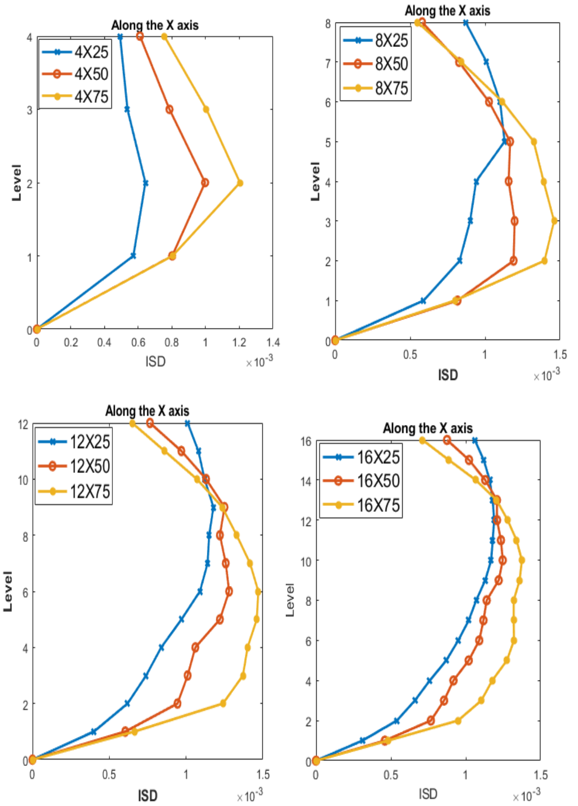

Figure 5. ISD of the 4,8,12 and 16 stories with steel V braced RC frame).

Base shear and maximum story stiffness

Adding the V steel bracing with different capacity in the RC frames, increased the base shear and story stiffness of the structures. Base shear is the maximum lateral force that occurs because of the seismic force at the base of the structures. Along with the X directions, the base shear values are calculated for each 24 (12 braced and 12 un-braced frames) model as shown in fig. 6. The lateral shear capacity of the structures is increased as an increased base shear contribution in the bracing increases. In the 4 stories braced frame, it is observed that 30%, 24% and 7% increment in the 4X25, 4X50 and 4X75 models respectively. In the eight-story model, nearly 59%, 40% and 26% base shear value increased when the steel bracing used in the 8X25, 8X50, 8X75 models respectively. When the V-shaped steel bracing used in the 12 and 16 story building, it increased base shear 54%, 43%, 31% in 12 stories, 48%, 41%, 30% in 16 stories for X25, X50, X75 shear force contribution models respectively.

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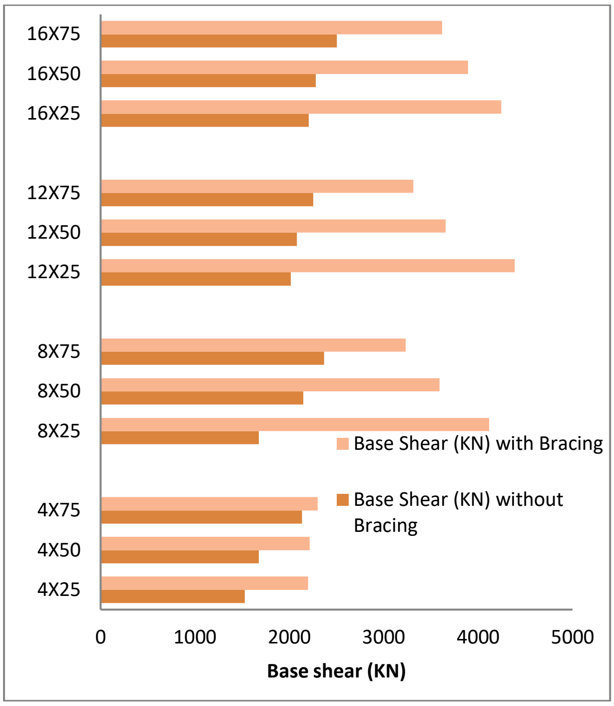


Figure 6. Design base shear in 4, 8, 12, and 16 stories with and without steel braced RC frame (along X direction)

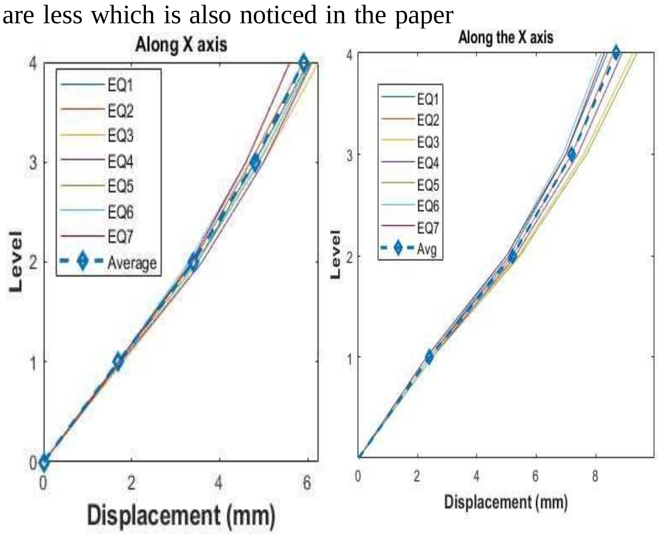
4.2 Nonlinear time history analysis

To understand the seismic behaviors of each 4, 8, 12, and 16 story models, nonlinear THA is performed in the ETABs software. The THA helps to know the actual performance of the buildings during ground motion (earthquake effect). In this analysis, the 7 ground motion data are used (EQ1 to EQ7) shown in table 1.

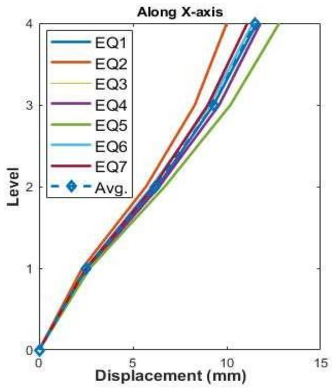
Maximum displacements

The maximum lateral displacements for 4 to 12 story buildings reported in different subjected seven earthquake records are shown in figure 7 and 9 and summarized in. It is noticed that the maximum displacement is observed in EQ3 along X-axis and EQ5 along Y-axis for VF25X4 and VF25Y4 respectively. For models VF50X4 and VF25Y4, the maximum displacements are observed in the EQ5 and EQ1 respectively. In the models VF75X4 and VF75Y4, the maximum displacements were noticed in the models EQ3 and EQ2 respectively. The average displacements for 4 story buildings are 6mm, 8.7mm, 11.5mm for VF25, VF50 and VF75 respectively along the X-axis. As the base shear contributions in the columns increases, the maximum displacements also increase. The standard deviations are 0.23, 0.48and 0.84 for VF25, VF50 and VF75 respectively observed in 4 story buildings along X-axis. A similar observation is made along Y-axis. The standard deviation shows that the uniformity of the obtained data and variation of the data. The maximum displacements observed EQ1 and EQ6 for VF25X8 and VF25Y8 respectively. For 50% base shear contributed models, the EQ4 and EQ1 shows maximum displacements along X and Y axis respectively for 8 story. EQ6 and EQ7 show the maximum displacement along the X and Y axis respectively for VF75 models. The average displacements are 22.2mm 25.3mm and 28.2mm for VF25X8, VF50X8 and VF75X8 respectively, observed in 8 story buildings along X-axis. The standard deviations are reported in 8 story buildings are 2, 3, and 2 for VF25, VF50 and VF75 models respectively along with X directions. However, the average displacement for 12 story observed as 35.2mm, 37mm and 42.2mm along with standard deviations 2, 3, and 3 for VF25, VF50 and VF75 respectively.

The maximum top story displacements is noticed in the 16 story buildings shows in figure 9. It is observed that the maximum displacement is observed in EQ3 and EQ5 in the VF25 models along with the X and Y directions respectively. In the models VF50, the maximum displacements is observed in EQ4 in X direction and EQ7 in Y directions. In the last, EQ1 and EQ7 ground motions shows the maximum displacement along the X and Y-axisin the model VF75. The overall observations shows that the displacements are increased as increasing the heightof the structures. When the base shear contributions in the columns increased, the displacements of the buildings also increase effectively. It is noticed that when the base shear contributions in the columns increase, the standard deviations also increase. However, overall the standard deviations of each 4-16 story buildings are less which is also noticed in the paper



(a) VF25X4 (b) VF50X4



(c) VF75X4

Figure 7. Maximum displacements in 7 earthquake motions for four story along Xdirections.

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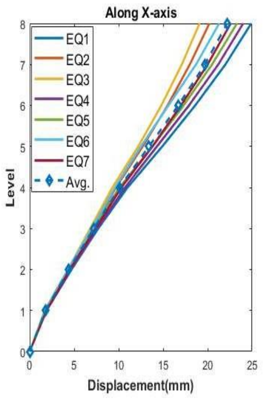
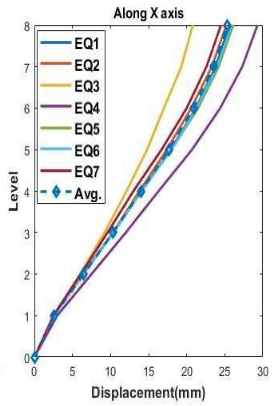
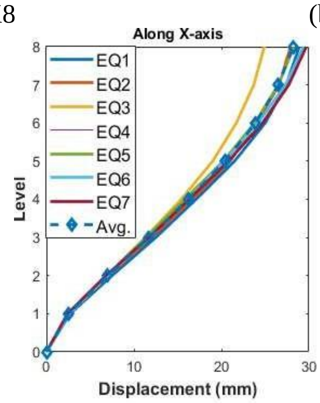


(a) VF25X8

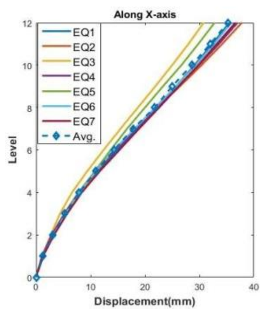


(b) VF50X8

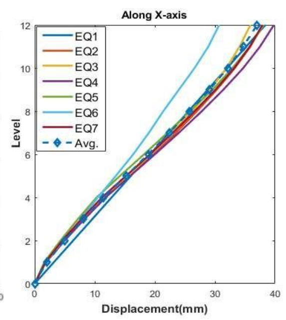


(c) VF75X8

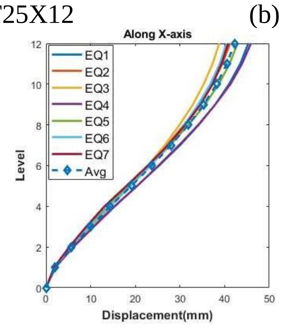
Figure 8. Maximum displacement in 7 earthquake motions for 8 story along Xdirections.



(a) VF25X12



(b) VF50X12

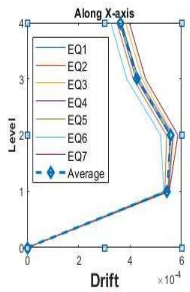


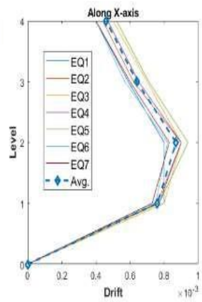
(c) VF75X12

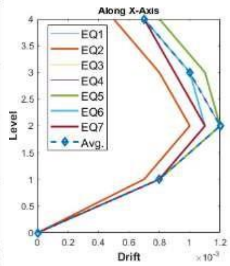
Figure 9 Maximum displacement in 7 earthquake motions for 12 story along Xdirections.

Inter-story drift (ISD)

Inter story drift is the one of another important seismic parameters to observed the structural performances. It helps to examine structural damage and shows more reliability in predicting the structural damage as compared to the lateral displacements. In the figure 10-14 shows that as increases the base shear contribution in the columns, the inter-story drift also increases effectively. It suggested that when the strength of columns increases and the strength of bracing decreases, the drift of the structures seem higher. It is also noticed that the maximum ISD of the structures is less than 0.002. In the different ground motions, the ISD obtained in the acceptable ranges. However, the drift of the structures is highly less than the Indian code limit of 0.004. However, some international codes suggested that for braced RC frame, the drift limit is limited to 0.002. The steel V bracings effectively reduced the drift of the structures in different strength levels in bracing or columns. The model VF25 reduced the maximum amount of drift and displacements, it is due to the heavy section of the lateral load resisting system that is bracings, but these models show unsuitable failure pattern. So it is important to considered the atleast 50% base shear contribution in the columns, for design of RC-MRCBF for V shaped bracings in new constructions of buildings.

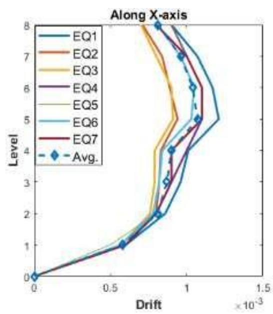


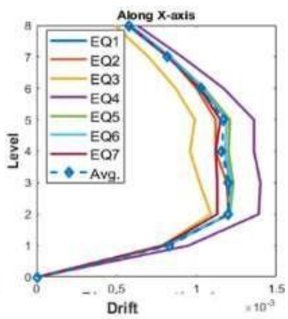




(a) VF25X4 (b) VF50X4 (c) VF75X4

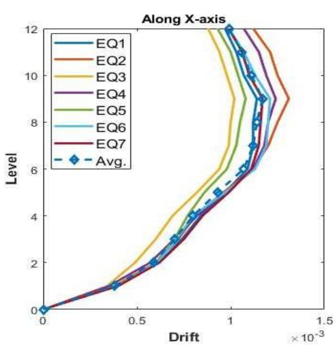
Figure 10. Inter-story drift in 7 earthquake motions for 4 story along with X directions.

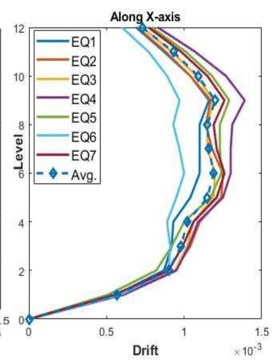




(a) VF25X8 (b) VF50X8

Figure 11. Inter-story drift in 7 earthquake motions for 8 story along with X directions.





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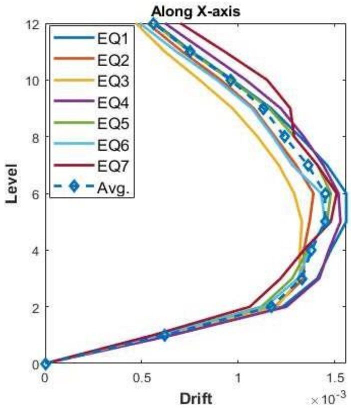
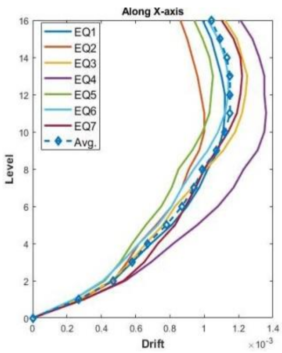
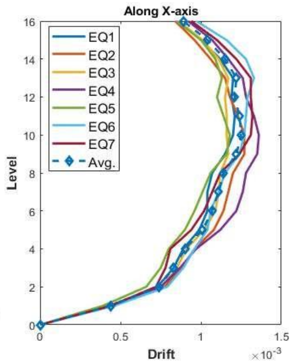
(a) VF25X12 (b) VF50X12



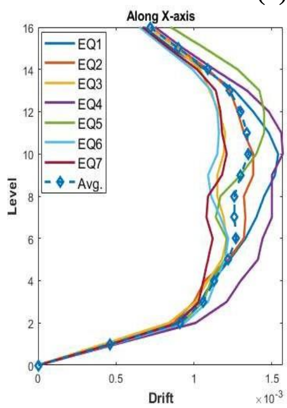
(c) VF75X12

Figure 12. Inter-story drift in 7 earthquake motions for 12 story along with Xdirections.



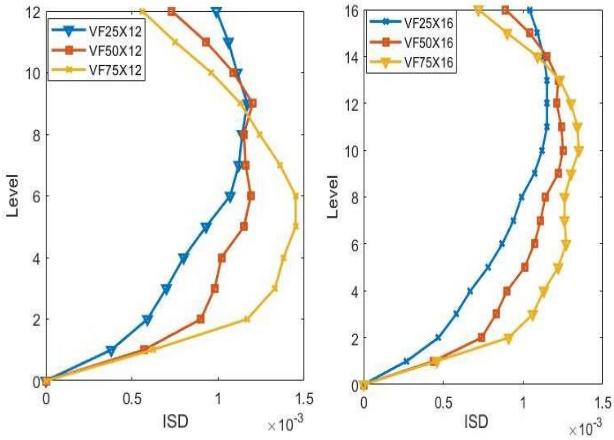


(a) VF25X16 (b) VF50X16



(c) VF75X16

Figure 13. Inter-story drift in 7 earthquake motions for 16 story along with X directions.



a) b)

Figure 14. Comparative study between 25%, 50 % and 75% base shear contributed bythe columns along X-axis, a) 12 story and b) 16 story structures.

5: CONCLUSIONS AND SUMMARY

The study of the effect of V-shaped steel bracing in the RC frame was discussed in the result sections. After studying the behaviors of the RC frame with and without steel bracing based on story displacement, story shear, ISD, time period and base shear of the 4 to 16 story buildings, the following conclusions may be discussed:

a. The application of the steel bracing with different lateral force contributions, it reduced the fundamental time period in all 4 to 16 story buildings.
b. As increased base shear capacity in the columns, the time period of the models increased. The story height and time period of the structure are directly proportional to each other.
c. In the braced frames, the maximum top story displacements are reduced. When the height of the structure increased, the top story displacement also increased. The bases shear contribution in the columns increased, the top story displacement also increased. Similar behaviors are observed in the inter-story drifts.
d. As the increase in height and base hear contribution in the bracing, it increases the base shear and story stiffness of the structures.
e. Overall the steel bracing used in the RC frame improves the seismic capacity and reduces the inter-story and displacements of the structures. The base shear contributions in the columns (25%, 50% and 75%) increased, its seismic behaviors also changed. In the 25% base shear contributions in the columns, these models are more likely assumed that steel is the first line of defense whereas in 75% base shear contribution assumed as concrete columns are the first line of defense.
f. After applying the time history analysis, it is observed that as increasing the height and base shear contribution in the columns, the displacements, inter-story drift of the structures also increase.
g. The maximum inter-story drift of the buildings under all ground motions it is obtained less than 0.002 which is less than the code provided values 0.004 (Indian standard code).

h. As increasing the strength of columns that is when base shear contributions of the columns increased, the capacity of the structures is decreased. However, the when columns resist less than 25% base shear, the steel bracings is the main line of defense, which means, the structures do not shows expected failure mechanism and non-ductile behaviors.
i. Providing the steel V bracings in RC frames improves the seismic performances of the structures effectively. It improves the stiffness, strength and ductility of the structures if a suitable design methodology is used.

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