Dynamic and Nonlinear Static Analysis of RC Structures with Steel Bracing

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Abstract

This work examines the nonlinear seismic behaviours of both non-retrofitted and retrofitted four-story reinforced concrete frames. For retrofitting, steel V-shaped bracings are employed. To look at the seismic behaviour characteristics, nonlinear dynamic analyses and nonlinear pushover analyses are carried out using seven earthquakes. Both non-retrofitted and retrofitted RC frame constructions exhibit the base shear, the fundamental time period (FTP) of the structure, capacity curves, failure patterns, maximum displacements, and maximum drifts. The steel V-shaped bracings are engineered to withstand 50% of the total base shear applied to the structures. The steel bracings shorten the basic time periods and raise the constructions' base shear. The ductility and seismic base shear capacity of the existing structures are increased by the addition of steel bracing. It was also noted that the columns must resist at least 50% base shear in order to produce the anticipated failure pattern. The V bracings lessened the structures' displacement and drift. Effectively enhancing the seismic behaviours of the structures are the V-shaped steel bracings.

Keyword: Pushover analysis, time history analysis, maximum displacements, inter-story drifts

1. Introduction

Retrofitting technique is the process of making existing structures strong and has resisted earthquake loading. When the structures are designed only considering the gravity loads, changing the seismic design parameter in codes, modification and changing the use or purpose of the structure, may need the retrofitting techniques. Many such types of RC buildings performed badly during the earthquakes. Existing RC structures that are non-ductile are assumed hazardous during ground motions. Different retrofitting techniques have been used to improve the seismic behaviors of the moment-resisting RC buildings. Adding shear wall, columns jacketing, jacketing the beam-columns joints, and steel bracings are some examples of retrofitting methods in existing structures.

Steel bracings are used in many countries such as Mexico, Japan, etc. for the rehabilitation of RC structures. Steel bracings offer many advantages such as its self-weight is less than the shear wall, provide enough openings. Steel bracing is widely used for retrofitting purposes as well as in the new construction of RC buildings as a lateral load resisting systems. Many experimental and numerical experiments are performed in the RC frame where steel bracing is used for retrofitting purposes. The experimental study on the retrofitting purposes of the RC frames where steel bracing were used where result suggested that steel bracing significantly improves the stiffness and strength of the structures (Higashi, Y. et al. (1984); Maheri and Sahebi (1995); Maheri MR, et al. (2003); Massumi, A. (1997); Liu F et al.(2012)). Different types of braces are used in both existing and new construction, X, inverted V, diagonal, multi X, etc. are come usual configurations of bracing used in the buildings. Different elevation and plan shape buildings were studied with steel bracing in RC frames. In many designs of retrofitting in existing buildings, bracings are used with energy dissipation device, buckling restrained bracings(H. Abou-Elfath et al (2016); Khampanit A. et al.(2014); K. Du, et al. (2020);Saingam, P. et al (2020)). Using the low slenderness ratio to avoid the buckling in the steel bracing (Badoux M, Jirsa O. (1990)). To get the adequate failure mechanism(strong columns, weak beam, and weaker bracing), researchers suggested the columns were designed such that they resist atleast 50 % lateral base shear (Bush TD et al. (1991); H. Abou-Elfath et al (2016); E. A. Godínez-D., A. Tena-C. (2019)**;**E. A. Godínez-D.et al**.**(2012); Godínez-D., Tena (2010)). Paper concluded that to get the ductile behaviors in the buildings, it is important to provide the minimum 50% lateral forces, resisted by the columns. Abou-Elfath and Ghobarah (2000) studied the low rise concrete building and the X steel bracing was used for a retrofitting purpose. Both pushover analysis and time history analysis were used in different braced RC buildings to understand the seismic behaviors of each configuration. Ke Du et al. (2020); Eskandari R, et al. (2017) studied the nonlinear behaviors of the steel braced RC buildings by using the near-fault ground motions. Yu, J. et al. (2020) observed the progressive collapse and behaviors of RC buildings when the steel bracing was used as a retrofitting technique. Using the steel bracing in the RC buildings, it improves both stiffness and strength and reduced the inter-story drift, displacement of the structures. X steel bracing is a widely used bracing system as a retrofitting the system. A Rahimi, MR. Maheri (2018), (2020), researchers studied the 2D RC frame and steel X bracing in the structures and observed both positive and negative sides of the steel bracing and its behaviors. In this study, researchers selected the low rise to mid-rise 2D frame and nonlinear time history behaviors were observed. Hendramawat A Safarizki (2013); Mazza, F., Mazza (2019); Yu et al. (2020); also studied the performance of steel braced retrofitted existing RC frame. The pushover analysis helpsthe understand the seismic capacity of the structure which helps to know about the response modification factors, overstrength factor and ductility behaviors of the structures.

The study is focused on the analysis of four-story RC frames with and without retrofitting. To know the nonlinear behaviors of RC frame building with steel bracings, the time history analysis and pushover analysis are performed. The study has main propose to develop the suitable process of applying V-bracings effectively. The columns of RC buildings are designed such thatthey resist nearly 50% base shear values. Many papers only focused on the study of X, inverted V and diagonal bracings in mid to high-rise buildings. This paper provided the basic nonlinear seismic behaviors of the RC frame with V shape bracings. The collapse behaviors and plastic hinges formation in both with and without a braced frame are performed in 4 story buildings.

2. Case study

To study the nonlinear behaviors of RC frame with and without concentric steel V shape steel bracing regular rectangular plan shape buildings as shown in fig1 is considered. The 4 story buildings are modeled in the ETABs 2018 finite element software. The buildings are designed according to the Indian standard codes. The two models have been analyzed one is without steel bracing and the second one is steel V-shaped braced RC frames. Where the steel V shape bracings are used for a retrofitting purpose. In the fig1 (a). Shows the plan shape of the RC frame structures and outer bays are provided V shape bracing (X in the fig shows the bays where bracing is provided). The moment resisting frames having 4 bays with 7m spans along with the x directions and along with the y directions the 3 bays with 7m span (shown in fig1).Each floor height is considered as 3.2m. The cross-section of the columns is 500mmX500mm for 1-3 stories and is reduced in the top story which is 400mmX400mm. The cross-section of the beam elements are 350mmX450mm (for 1 to 3 story) and for the top story, 300mmX350mm beams are provided. The V shape steel bracing used which is considered as a hollow square section to avoid the local buckling during the lateral forces. The cross-

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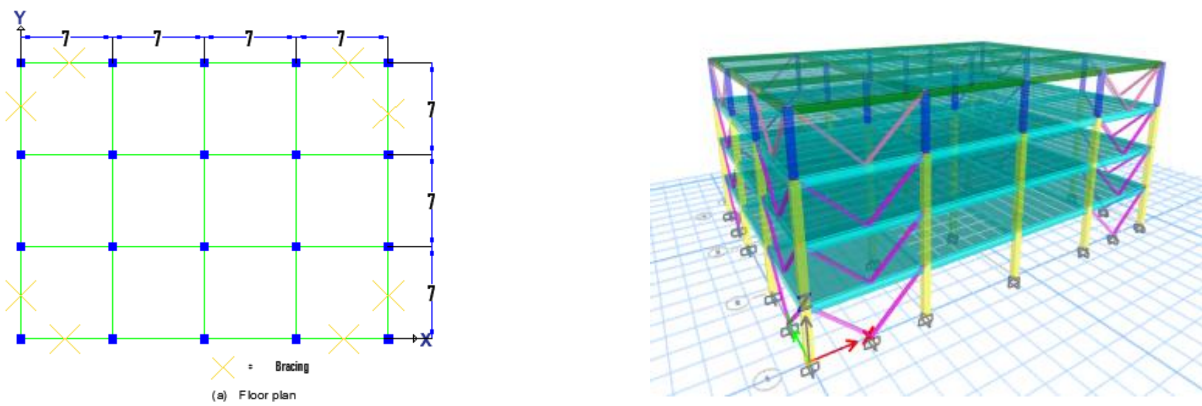
section of the bracings is 113.5mmX113.5 and the thickness of the bracing for 1 to 3 is 6mm and 4.5mm for the top story. The slab thickness is 120mm. the M25 grade of concrete is used for beams, columns and slabs. The grade of rebar used in RC members is considered as Fe-415. The yield stress of the steel bracings is 250 MPa.

The live load is considered as 5KN/m^2 for each floor except the top floor where 2KN/m^2 load is considered. For all floor extra super imposed dead load is considered as 2.5KN/m^2. For seismic design, the live load is considered 25% for less than 3KN/m^2 and 50% for greater than 3KN/m^2 load and dead load is taken as 100%. For the seismic design, the soil is considered as soft soil and the importance factor which is 1. The seismic zone factor is 0.36 and the damping ratio of the buildings is 5% is taken. The response reduction factor of the studied buildings is taken as 4.5.



b)

Fig.1 Four-story buildings a) plan of the structure where X represents the place where used V shape steel bracing (units are in m), b) 3D view of steel braced buildings.

3. Methodology

The ETABs finite element software is used for the analysis and design of RC frames with and without bracings. The capacity design methodology is used for design the V shape steel braced RC frame (E. A. Godínez-D., A. Tena-C. (2019)**;**E. A. Godínez-D.et al**.**(2012); Godínez-D., Tena (2010)). The design sections are fixed by using the linear dynamic analysis. In the design, the columns are designed such that, the columns resist the 50% base shear and remaining resisted by the V bracings. Researchers suggested that to get the excepted failure pattern and to get ductile behaviors, the columns designed to contribute the atleast 50% base shear (E. A. Godínez-D., A. Tena-C. (2019)**;**E. A. Godínez-D.et al**.**(2012); Godínez-D., Tena (2010)). In this design the bracing is designed as weakest members and columns are strongest members. In this system, the bracings are designed as a retrofitting purpose for improving the strength of the existing buildings. The bracings joints are pin joint is assumed and p-Δ effect also considered. To study the nonlinear seismic behaviors, the nonlinear dynamic analysis and pushover analysis are used in the 4 story buildings.

4. Results and discussions

The design of 4 story RC buildings with and without steel bracings is done and where the columns resist 50% base shear. The seismic demands of the buildings and the FTP of the building are interdependent. The result shows that the FTP of the structures decreases after using the V shape steel bracings. The FTP of the existing buildings is 0.881 sec and after the retrofitting by using the steel V shape bracing it is 0.512 sec along the x-axis. The design base shear value of the buildings increased when the steel bracings are used. The design base shear of the without bracing structure is 1676 KN and when the steel bracing is used it becomes 2215KN along the y axis. The similar results obtained along the y axis.

a) Nonlinear pushover analysis

The nonlinear pushover analysis was conducted to study the strength, failure mechanisms and stiffness of the 4 story buildings. The capacity curve obtained forms pushover analysis which is the graph plotted by base shear and displacement of the structures. The comparative study is done between the with steel bracing and without steel bracings. Hence the main reasons of study of the pushover analysis in the models is to know the lateral strength, failure mechanism and pattern of damage up to the collapse levels.

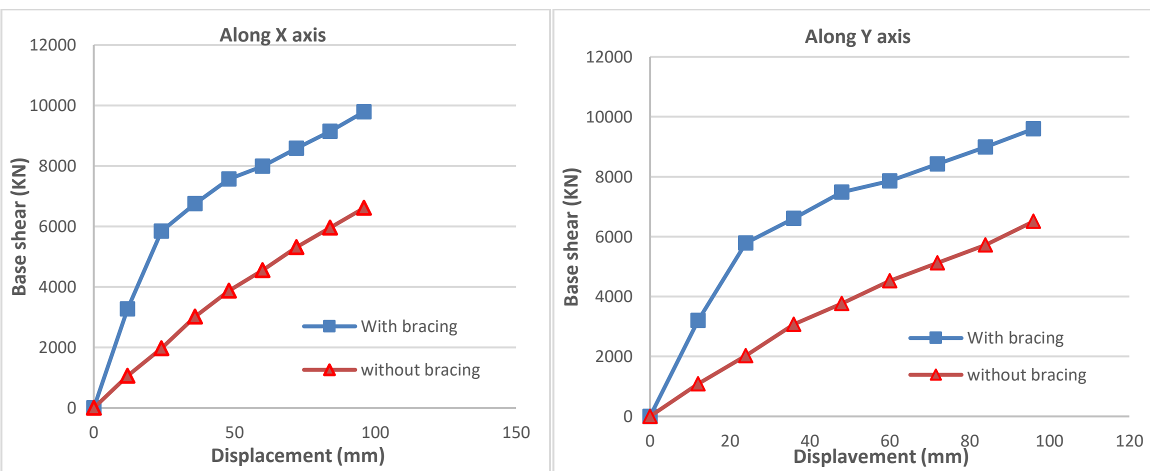


Fig. 2 Capacity curves for 4 story structures, a) along the x axis, b) along the y axis.

Figure 2 represents the capacity curves of the 4 story structures. The fig. 2. Shows the capacity curve of both braced and unbraced frame structures along the x and y-axis and shows the using the steel bracing, significantly increasing the strength of the structure. It is observed that the moment-resisting frame (without bracing) have less strength capacity than the braced frames. Retrofitting the existing structure by using the V bracings increases the strength of the structure. The increasing the lateral load the formation of plastic hinges in the bracings also increases. It is noticed that the formation of the first hinge is seen in the bracings. The right-hand bracings are failed due to the compressive loading hence know as compressive braces and left-hand side hinges are formed due to the tension forces. Adding the steel bracings helps to reduce the damage in main structural members such as beams and columns. The expected failure pattern is observed, where the first failure is observed in the bracing, then beam and at last columns. The columns is the strong members, which is good seismic behavior. Adding the steel bracing in the existing structure improves the structural ductility of the structures. The observation of the capacity curve (Fig2) shows the drift at the yielding level also decreases. After using the steel bracing in the existing moment-resisting frame structures it reduces the drift at yielding, which is 0.0024. It is less than the code based limiting drift for service level 0.004. However, using the steel bracing in the existing structures improve the energy absorption capacity.

b) Nonlinear time history analysis

The low rise buildings with and without steel braced RC frames are analyses by using the 7 selected ground motion to observe the nonlinear behaviors. The 7 different earthquake records are selected according to the American standard (ASCE), they contain a wide range of magnitudes and durations. All earthquakes are scaled acceding to the codel provisions. Table 1 shows the 7 different earthquake data which is taken fromthe peer earthquake database and the maximum earthquake have a magnitude of 7.9 and minimum magnitude is 6.93. The maximum displacement and drift of the existing and retrofitted structures are observed under each 7 ground motions.

Table1 Seven earthquake ground motions

Design name	Ground motion	Date	Station Name	Magnitude	Mechanism	Rjb (km)
GM1	Landers	1992	Anaheim - W Ball Rd	7.28	strike slip	144.9
GM2	Loma Prieta	1989	BRAN	6.93	Reverse Oblique	3.85
GM3	Caldiran_ Turkey	1976	Maku	7.21	strike slip	50.78
GM4	Denali_ Alaska	2002	Carlo (temp)	7.9	strike slip	49.94
GM5	Chi-Chi_ Taiwan	1999	CHY065	7.62	Reverse Oblique	82.78
GM6	Imperial Valley-02	1940	El Centro Array #9	6.95	strike slip	6.09
GM7	Darfield_ New Zealand	2010	Kaiapoi North School	7	strike slip	30.53

ISD is one of the significant parameters to understand the seismic behaviors of the buildings. The ISD help to predicting structural damage. The fig3 shows the inter-story drift of the 7 ground motions for retrofitted buildings. It is noticed that applying the bracings reduced the inter-story drift. The maximum ISD is 0.000923 recorded along the x-axis for Caldiran_ Turkey ground motions. However the without steel bracings the ISD is 0.00228 for landers ground motions. In fig 4 the average ISD for braced and unbraced frames are plotted. This fig.3 shows that applying the steel bracing reduced the inter-story drift effectively. The 60% reduction in ISD is recorded from ISD for unbraced frames along the x-axis. Similar observations are noticed along the y-axis. the maximum ISD is recorded at the mid-story of the structures. the steel v bracing improves the seismic performance of the 4 story structures.

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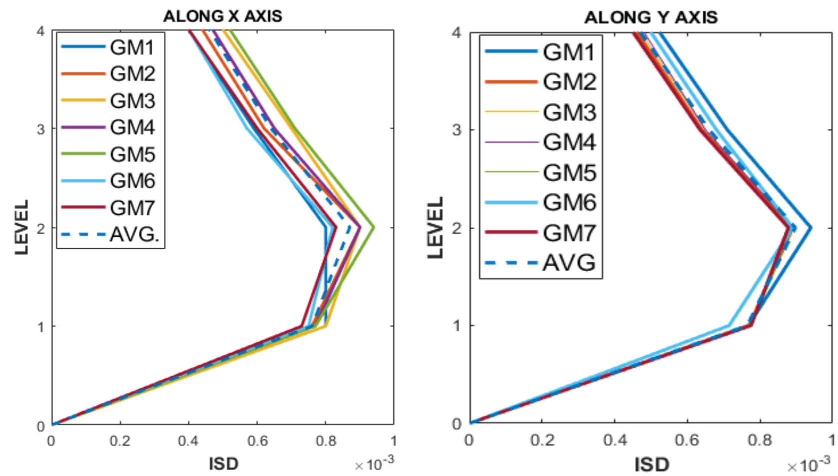

Fig.3 Inter story drift (ISD) of four-story with steel bracing (retrofitted) building in both direction

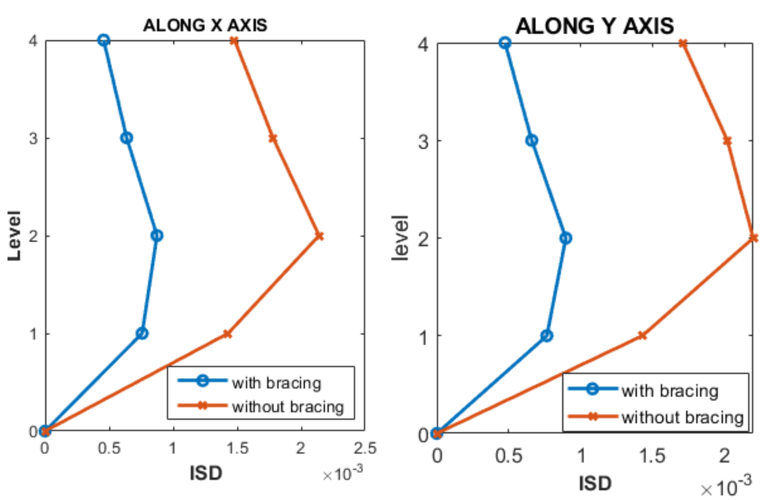

Fig.4 Average ISD for with and without bracing frame in both direction

The maximum lateral displacements one of theparameters to study the damage level of the buildings. Introducing the v bracings reduces the global top displacement of the structures. Fig 5 and 6 shows the comparative study between the retrofitted and non-retrofitted bracings.The maximum top story displacements of each seven ground motions are given in fig 5. The maximum displacements recorded for retrofitted structures is 9.3mm and for non-retrofitted, the displacement is 23mm recorded along the x-axis. It means that the 60% reduction in global displacement is recorded along the x-axis. Similar behaviorsare also observed in y directions. Fig6 shows the reduction of maximum average displacements when the steel bracing is used in the existing structures. Overall the results suggested that applying the V-shape steel bracings in the existing RC buildings, improves the seismic behaviors and effectively reduces the maximum displacement and drifts.

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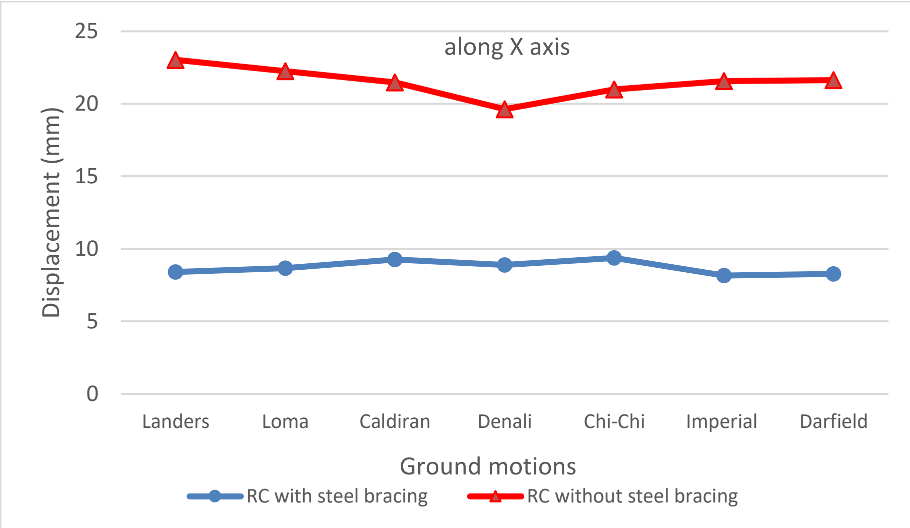

Fig.5 Maximum displacement of the selected ground motions along with the x directions

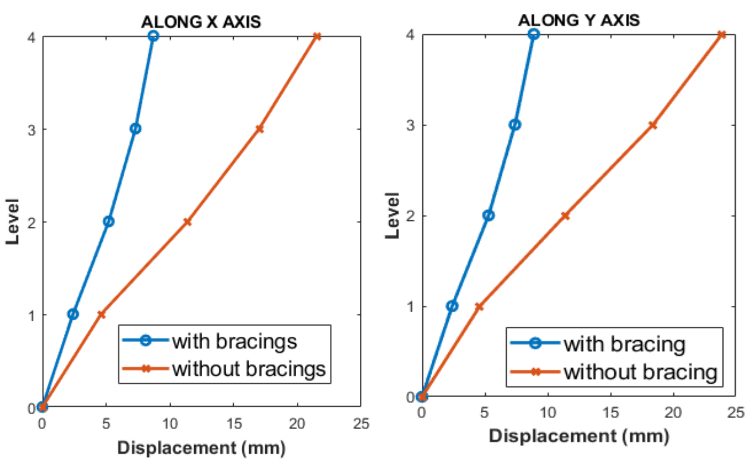

Fig.6 Average displacements of the with and without steel bracings

5. Conclusions

The study of the effect of steel bracing in RC buildings is observed. By using the nonlinear static and dynamic analysis, the performance of the 4story buildings is studied and the following conclusions are made;

i. The steel V shape bracings reduced the fundamental time period and increase the base shear of the structures.
ii. When the bracings are designed such that they resist the 50% base shear, it increased the strength of the structures as compared to non-retrofitted frames. The excepted failure mechanism is also

observed in these conditions. Where the columns are stronger members and bracings its weakest members. The steel bracings also improve the ductility and stiffness of the retrofitted frame.

iii. The V bracings reduced the maximum displacement and inter-story drift of the structures effectively.

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