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Performance Assessment of Retrofitted RC Frames with Different Patterns of Steel Bracing

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Abstract

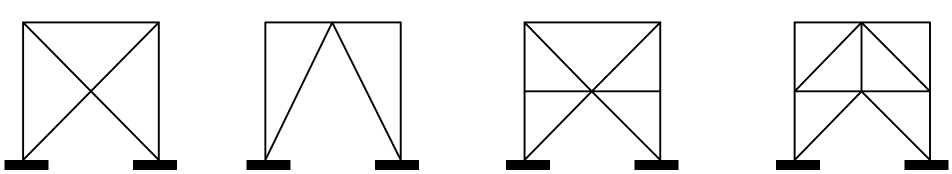
In recent years, many Reinforced Concrete (RC) buildings in Bangladesh are being retrofitted using different types of steel bracing system. However, there is a lacking of guideline or design philosophy to obtain the most efficient retrofitting system. Hence, efficient steel bracing patterns for different frames is required to be investigated. In this study the performance assessment of different bracing systems are compared in a seismically vulnerable RC building to find out the efficient bracing. Nonlinear static pushover analysis is carried out to assess the structural performance on different bracing systems in RC buildings. Different steel bracing pattern is used such as inverted V-braced frames, X-braced frames, ZX braced frames and Zipper braced frames. The effects of another parameter influencing the performance which is the lateral load patterns are also investigated.

Keywords: *Retrofitting, Pushover analysis, Steel bracing, Seismically Vulnerable, Bracing Pattern.*

1 Introduction

Bangladesh has experienced eight small magnitude on Richter scale earthquakes in last one year (https://earthquaketrack.com/p/bangladesh/biggest). An earthquake of even medium magnitude on Richter scale can produce a mass damage without any previous notice in major cities of the country, particularly in Dhaka (Sarraz, et. al.,2015). A great number of existing buildings in Bangladesh, especially in Dhaka city are designed without seismic design criteria and detailing rules (Sadat et. al. ,2010). To overcome the risk caused by seismic disaster, the structures are required to be retrofitted. Among the retrofitting techniques, steel bracing is one of the most efficient solutions (Navya and Agarwal, 2016). The better performance of steel braced RC frames depends on appropriate bracing patterns (Yu, X., Ji, T. and Zheng, T.,2015).

Badoux and Jirsa (1990) investigated analytically and conceptually steel braced RC frames and concluded that steel bracing is very suitable for exterior retrofitting scheme. Abou-Elfath and Ghobarah (2000) performed analysis for a three-storied building and concluded special arrangement for X bracing pattern only. Safarizki et al. (2013) performed pushover analysis to evaluate 5- storied building’s global capacity using X bracing pattern only. Kadid and Yahiaoui (2011) investigated the performance of RC frames strengthened with different types of steel bracing. In recent years, many RC buildings in Bangladesh are being retrofitted using different types of bracing. However, there is a lacking of guideline or design philosophy to obtain the most efficient retrofitting system. In this study, an attempt is made to assess the performance of different braced systems within a specific building. The attempt has been made to assess the performance of different bracing systems under application of different invariant lateral load patterns in a nonlinear static pushover analysis by using four structural configurations: X-braced, inverted V braced, ZX braced, and Zipper braced are shown in Figure 1.



(a) X- braced (b) Inverted V braced (c) ZX braced (d) Zipper braced

Figure 1.Structural configuration of different bracing systems.

2 Modeling of example RCC building

An existing RCC 6th storied factory building at Chittagong is considered which has 4x4 bay of approximately 6.95m to the horizontal direction and 5.94m in the vertical direction as shown in plan of buildings in Figure 2. The building is seismically vulnerable and retrofitting of the building is proposed by X-bracing pattern system as shown in Figure 3. The bracing elements in Figure 3 are designed by the retrofitting designer of the particular building. T-type steel section is used for bracing as shown in Figure 4. To assess the performance of the different bracing patterns as depicted in Figure 1, a particular external frame is selected for analysis which is shown in plan of the building as well as in Figure 3. Table 1-6 Describe the details of material properties, static load cases, beam section, column sections and bracing elements. Figure 4 describe the section details of bracing elements.

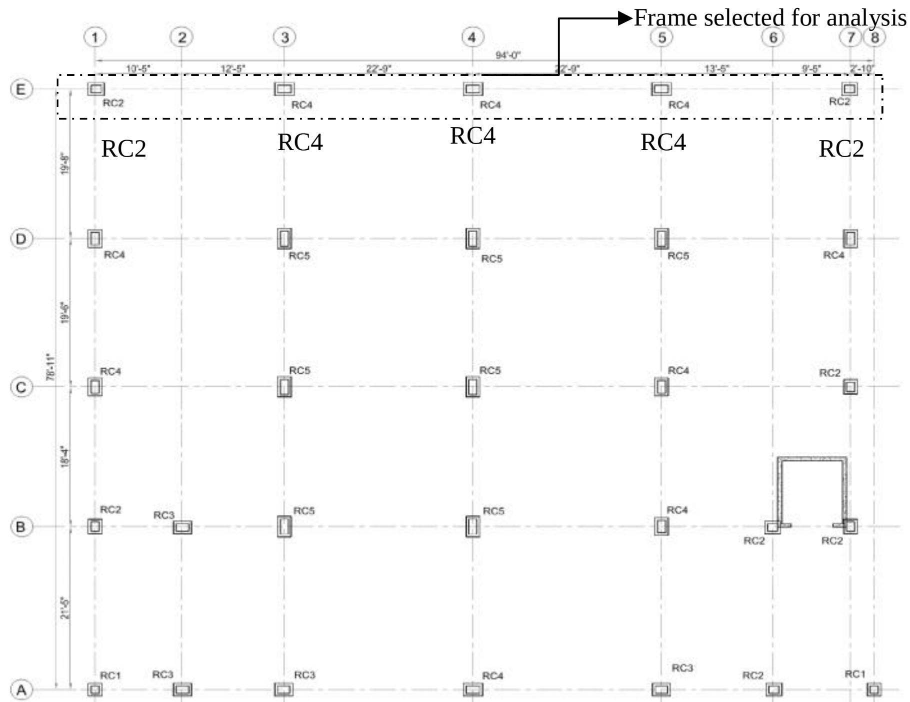


Figure 2. Plan of the example 6th storied factory building.

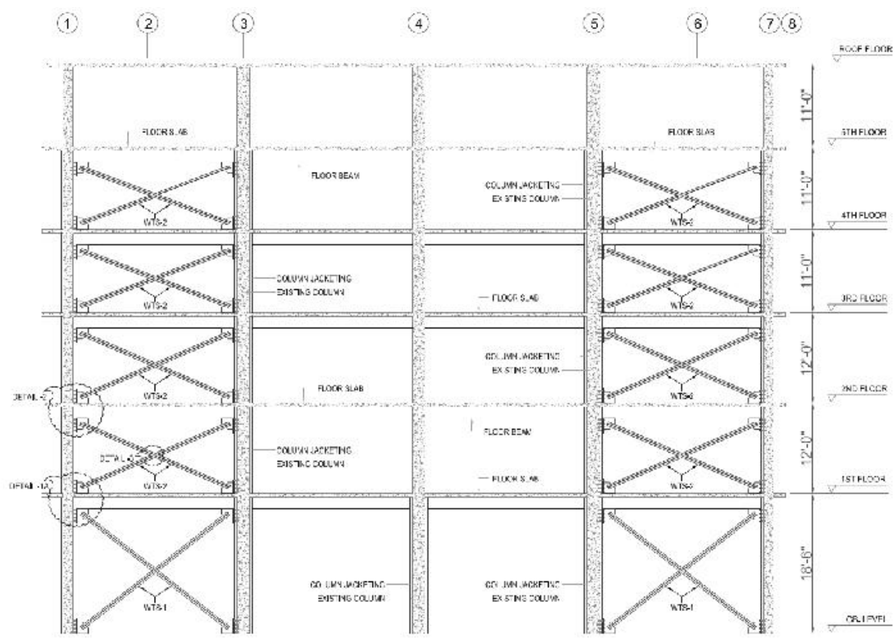


Figure 3. Retrofitted Section on Grid E

The sizes of beams and columns of the building with different bracing patterns are considered to be same. For performance assessment between the different bracing patterns, braces are added in each pattern in such a way that the total steel required is same for all the braces except for Zipper braced. The same brace sizes of X-braced (WTS-2) pattern are used in addition to zipper struts. Mass source is taken as dead load plus 25% live load.

Table 1. Material Properties

f'c	27.57 MPa (4000 psi)
fy	413.685 MPa (60000 psi)
All structural steel sections	275.79 MPa (40 Ksi)
All connection plates	A36 Grade

Table 2. Static Load Case

Load Name	**Load Type**	**Details**	**Value**
Dead	Dead Load	Slab self wt (152.4mm)	3.591 kN/m^2 (75psf)
		Floor Finish	1.436 kN/m^2 (30 psf)
		Partition Wall	1.436 kN/m^2 (30 psf)
		Wall	8.03 kN/m (0.55 k/ft)
Live	Live Load	On floor	3.02 kN/m^2 (63 psf)

Table 3. Beam Section

Story	**Beam**				**DL (kN/m)**	**LL (kN/m)**
	Dimension (mm)		Reinforcement (sq mm)			
	Depth	Width	Top	Bottom		
1-5	609.6	304.8	23.622	23.622	35.61	12.87
6	609.6	304.8	23.622	23.622	29.77	12.87

Table 4. Column Section

Story	**Column**	**Dimension (mm)**		**Number of Bars**		**Bar Area (sq mm)**
		X-dir	Y-dir	X-dir	Y-dir	
1-5	RC2	584.2	508	7	8	283.87
1-5	RC4	711.2	508	10	7	283.87
6	RC2	381	304.8	4	5	200
6	RC4	508	304.8	10	7	200

Table 5. Bracing element for X pattern

T- Section				
Name	**D(mm)**	**TW(mm)**	**BF(mm)**	**TF(mm)**
WTS-1	300	20	350	20
WTS-2	300	12	300	12

Table 6. Bracing element for inverted V, ZX and Zipper pattern

T- Section				
Name	**D(mm)**	**TW(mm)**	**BF(mm)**	**TF(mm)**
WTS-1	325	25	381.31	25
WTS-2	270	20	255.79	20

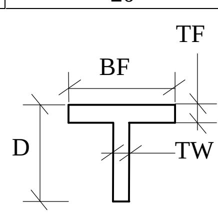


Figure 4. T -Section of Bracing Element

3 Nonlinear static pushover analysis

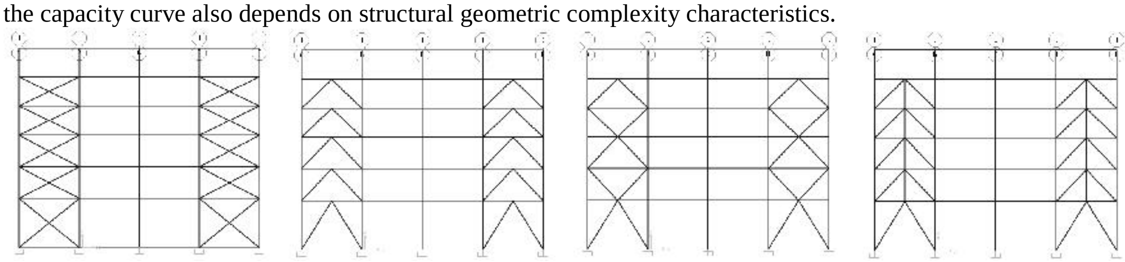
Nonlinear static pushover analysis is a very powerful feature offered in the nonlinear version of SAP2000 v15 (Computer and Structures, Inc., Berkeley) software. Nonlinear static analysis is performed on 2-D RC Frame using different lateral load patterns to determine the effects of the lateral load on the global structural behavior through load–displacement curve. In the pushover analysis method, force and displacement demands are estimated by FEMA-356 criteria are used for beams, columns and braces. Hinges are assigned at both the ends of each column, beam element and at mid-span of braces. For column, coupled (PMM) hinges, which yields based on the interaction of axial force and bi-axial bending moments at the hinge location, are used. P (axial) hinges are assigned for steel braces in tension/compression and M3 (moment) hinges are assigned for the beam elements. In this study, displacement controlled pushover analysis for all the example frames are carried out. The target displacement used for each frame is 4% of the total height of the frame (ATC-40). Default-hinge properties are available in some programs based on the FEMA-356 and ATC-40 guidelines. In SAP2000v15 uncoupled moment (M2 and M3), axial force (P) and shear force (V2 and V3) displacement relation can be defined according to FEMA-356. The different lateral load patterns used in this study are (a) Uniform lateral load pattern in which the lateral force at a storey is proportional to the mass of the storey. (b) Elastic first mode lateral load pattern. The first mode load pattern is related to the first displacement mode shape (Φ) of vibration. The lateral force of a storey is proportional to the product of the amplitude of the elastic first mode and mass at the storey.

4 Results and Discussion

In this study, nonlinear static pushover analysis is performed using the calculated lateral load patterns on example RC building. P-Delta effect is not considered for each load combination used in this study.

FEMA 356 suggested using at least two load pattern / lateral load distribution to have upper limit capacity and lower limit capacity for a specific structure. Uniform load pattern provides the maximum capacity curves (Oguz, 2005). Where BNBC 2015 suggested to use elastic first mode load pattern / lateral load distribution which provides the lower limit capacity curve.

The results obtained from pushover analysis of the steel braced retrofitted RC buildings are presented and discussed in this heading. Figure 5 represents the different bracing models. The capacity curves using the models (Figure 5) are shown in Figure 6-7, revels that the shape of capacity curve directly depends on lateral load patterns. Figure 6 also shows that, for this particular building when uniform load pattern is used, the capacities of ZX- bracing, Zipper and Inverted V bracing are nearly same. ZX bracing and Zipper bracing showed approximately 25% greater capacity. In the case of (see Figure 7) Elastic first mode load pattern all the bracing pattern showing approximately same capacity, this is due to the geometric complexity of the structure, because the capacity curve also depends on structural geometric complexity characteristics.



(a) X- bracing (b) Inverted V bracing (c) ZX bracing (d) Zipper bracing

Figure 5. Bracing models

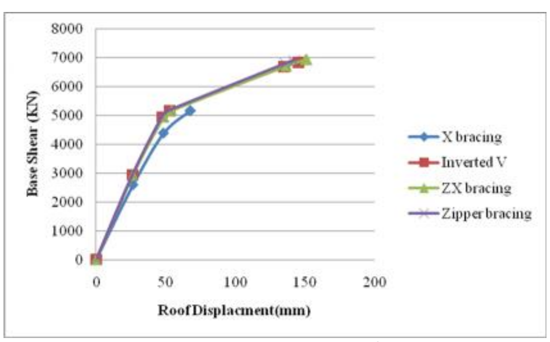


Figure 6. Capacity Curves using Unifrom load pattern

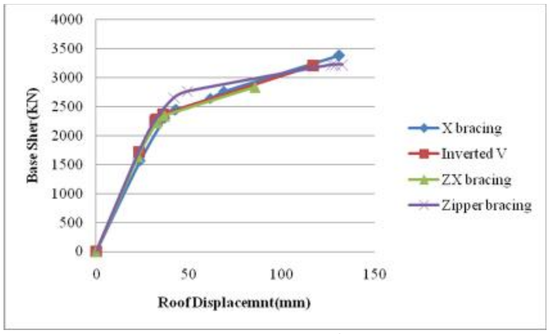
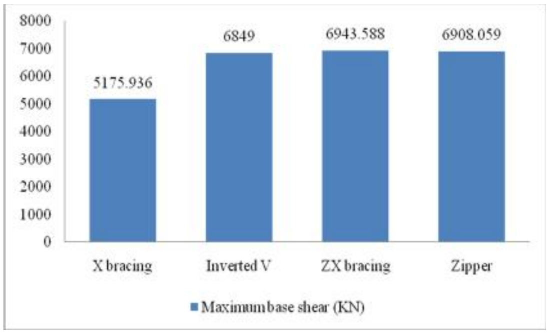


Figure 7. Capacity Curves Elastic first mode load pattern

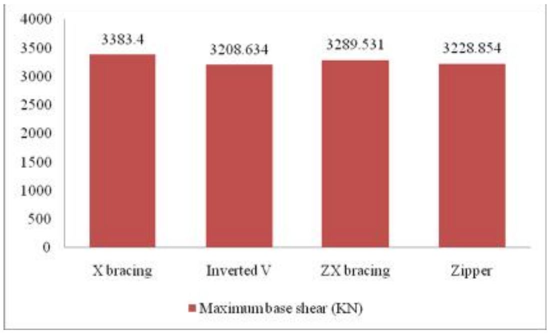
Table 7 describes the maximum capacity for two lateral load patterns in which for uniform load pattern compared to X bracing system inverted V, ZX and Zipper bracing system exibit 24.42%, 25.45% ,25.07% respectively greater capacity. In the case of Elastic first mode, capacity curves are nearly similar in which compared to X barcing system inverted V, ZX and Zipper bracing system show respectively 5.16%, 2.7% and 4.5% lower capacity. The differnces in maximum base shear for different lateral load cases are depicted in Figure 8.

Table 7. Maximum Base Shear for Different bracing

Pattern	Load case	Maximum Base Shear (kN)	Load case	Maximum Base Shear (kN)	Average Capacity (kN)
X	Uniform	5175.936	Elastic first mode	3383.4	4279.668
Inverted V	Uniform	6849	Elastic first mode	3208.634	5028.817
ZX	Uniform	6943.588	Elastic first mode	3289.531	5116.595
Zipper	Uniform	6908.059	Elastic first mode	3228.854	5068.4565



(a) Uniform lateral load pattern



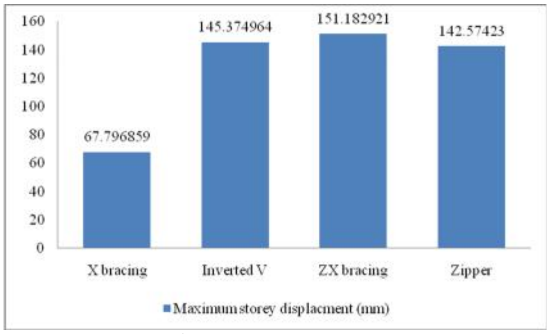
(b) Elastic first mode lateral load pattern

Figure 8. Bar diagram for Maximum base shear

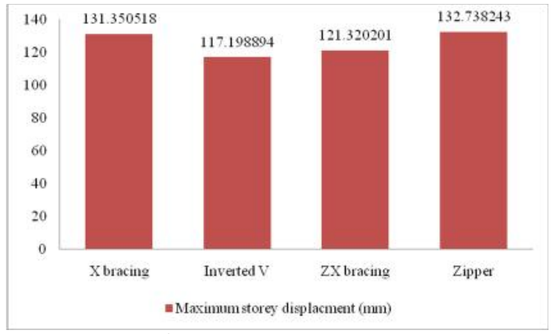
Table 8 and Figure 9 represent that, ZX bracing system shows the maximum roof displacement for uniform lateral load pattern compared to the other bracing system. On the other hand Zipper- bracing system shows the maximum roof displacement for elastic first mode lateral load pattern compared to the rest of the bracing system. Hence ZX and Zipper bracing systems are more ductile compared to other bracing systems. So it can be concluded that ZX and Zipper bracing system are more efficient in terms of maximum roof displacement.

Table 8. Roof displacement

Pattern	Load case	Maximum roof displacement (mm)	Load case	Maximum roof displacement (mm)
X	Uniform	67.80	Elastic first mode	131.35
Inverted V	Uniform	145.37	Elastic first mode	117.20
ZX	Uniform	151.18	Elastic first mode	121.32
Zipper	Uniform	142.57	Elastic first mode	132.73



(a) Uniform lateral load pattern



(b) Elastic first mode lateral load pattern

Figure 9. Bar diagram for Maximum roof displacement

5 Conclusion

In this paper, a numerical study is conducted to an existing RC building which is already retrofitted with X-pattern braced system. Performance of different bracing patterns to this building is assessed using pushover analysis. The performances are compared based on the capacity curve and maximum storey displacement of the building. The results obtained indicate that, ZX and the Zipper bracing systems are found to be the most efficient.

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