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Retrofitting of a Seismically Deficient RCC Building by Steel Bracing System

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Consideration of seismic effect in structural design has become an important issue recently in Bangladesh as it lies ina seismically active region. With better understanding of seismic demand on structures and with recent experiences with large earthquakes, many residential buildings in our cities including Dhaka may become seismically deficient structures. Therefore, seismic retrofitting of these structures is utmost important. Application of Steel Bracing system is one of the efficient structural retrofitting strategies. The type and arrangement of bracing system are important for efficient performance of the structure under seismic load. This paper presents numerical analysis to assess the effects of using different type of bracing systems, and also efficient arrangement of bracing systems for a six storied structurally inadequate RC frames under seismic load. The structure is located at moderate seismic zone like Dhaka. Effects of using different type of steel sections for bracing members are also analyzed.

1. Introduction

Earthquake is a natural event of internal system of the earth. Earthquake in Bangladesh has been considered as a potential natural killer to human lives. The last major earthquake in Bangladesh was occurred in 1918 known as Srimangal Earthquake with a magnitude of 7.6. Many residential buildings in our cities including Dhaka are non-engineered, which is very risky even for a moderate earthquake. If a major earthquake shakes the capital and its periphery, most parts of the city might experience a trail of destruction. Due to unplanned urbanization and construction of buildings defying the building code, the issue is even more serious. Earthquakes cannot be prevented, but its damage can be reduced with suitable measures. Retrofitting is one of the most suitable measures to prevent structural collapse. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes (en.wikipedia.org).

Majority of buildings in our country are still designed for gravity loads only with nominal non seismic detailing provisions. In the past, building codes were less stringent compared to today's standards, thus it is a good idea to examine buildings constructed prior to 1994, as they were built prior to current structural code/requirements such as Uniform Building Code, UBC 1994. Numerous types of structures may benefit from a seismic retrofit, including various building structures bridges, dams, etc. In this paper existing building structure with moment resisting frames designed for gravity loads only or misconstruction are concerning.

As a first step towards the process of seismic retrofitting, the basic construction characteristics and earthquake resistivity of the existing building is determined. The performance objectives for rehabilitation are decided and the corresponding seismic hazard level is determined. FEMA 273 and New Zealand Draft Code (1996) clarify that the component is allowed to resist large deformation without collapse by improving the deformation capacity or ductility of the component.

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For example, placement of a jacket around a reinforced concrete column to improve its confinement which increases its ability to deform without degrading reinforcement splices (Asgor, 2013). Another way is to stiffen such structure at a global level (ATC 1996, Bush et. al. 1991). FEMA 273 and New Zealand Draft Code suggest the addition of new braced frames or shear walls within an existing structure for increasing the stiffness. While some existing structures have inadequate strength, which result into inelastic behavior at very low levels of earthquake forces and large inelastic deformation throughout the structure. By strengthening the structure, the threshold of lateral force at which the damage starts can be increased. A strengthening scheme consists of one or many strengthening techniques to remedystructural deficiency. Such schemes are specific to structural system and material type.

The paper focuses on theevaluation of seismic performance of existing six storied reinforced concrete building designed only for gravity load and also on the design of a seismic retrofitting scheme by steel bracing system. It presents about the type of bracing efficient for retrofitting of existing building and also the efficient arrangement of bracing.

1.1 Seismic loading in the context of Bangladesh National Building Code (BNBC)

As per BNBC 1993, the country is divided into three region ofdifferent possible earthquake ground acceleration ranging from 0.075 to 0.25g. The codedefines a simple static method for seismic analysis which is Equivalent Static Method. It also defines two methods for dynamic analysissuch as Response Spectrum Analysis and Time History Analysis.

Equivalent static load method is an assumption of linear mode shape for the first mode of the structure. Actually it is the calculation of base shear from an earthquake load and distribution of base shear along the height of the structure.Total design base shear is denoted by V in a given direction and V is calculated from the following relation

$$V = \frac{ZIC}{R} W \qquad (1)$$

The term of the right hand side of the Eq.1 consist of the parameter such as Zone coefficient, Z, Structure importance coefficient, I, and Response modification coefficient for structural system, R. The parameter can be determined from the Table 1, 2 and 3. Seismic dead weight, Wof a building includes permanent structural and nonstructural components such as column, beam, slab, floor finish, partition walls, fixed service equipment etc.

Table 1: Seismic Zone Coefficient

Zone	**Zone coefficient ,Z**	**Zone description**
1	0.075	Low seismic zone
2	0.15	Moderate seismic zone
3	0.25	High seismic zone

Source: BNBC 1993 Table 6.2.22

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Table 2: Structure importance coefficient,I

Structure importance	Occupancy type	Structure importance coefficient ,I
I	Essential facilities	1.25
II	Hazardous facilities	1.25
III	Special occupancy structures	1.00
IV	Standard occupancy structures	1.00
V	Low-risk structure	1.00

Source: BNBC 1993 Table 6.1.1 and 6.2.23

Table 3: Response modification coefficient for structural system, R

Basic structural	Lateral force resisting system	R
RC moment resistingframe	Special moment resisting frame	12
RC moment resistingframe	Intermediate moment resisting frame	8
RC moment resistingframe	Ordinary moment resisting frame	5

Source: BNBC 1993 Table 6.2.24

Numerical coefficient, C: This is the coefficient that point out the fundamental period of structure property of soil. C can be calculated by following relation

$$C = 1.25S\frac{W}{T^{\frac{2}{3}}} \qquad (2)$$

Where, S is the site coefficient depending on the characteristics of the soil. The value of S stipulated in table 6.2.25, BNBC 1993 and T is the fundamental period of the structure can be calculated by following empirical formula

$$T = C_t(h_n)^{3/4} \qquad (3)$$

Where, Ct = 0.03 for RC moment resisting frames and hn = Total height of the structure in feet.

Vertical distribution of lateral forces: In the absence of more rigorous procedure, the total lateral force, which is the base shear, V shall be distributed along the height of the structure in according with the equations (4), (5), (6)

$$V = F_t + \sum_{i=1}^{n} F_i \qquad (4)$$

Where, Fi = Lateral force applied at story level i and
Ft = Concentrated lateral force considered at the top of the building in addition to the force Fn. The concentrated force, Ft acting at the top of the building can be determined by following formulas

$$Ft = 0.07TV \leq 0.25V \quad \text{when } T > 0.7\ Second \qquad (5)$$

$$Ft = 0.0 \quad \text{when } T \leq 0.7\ \text{Second} \qquad (6)$$

The remaining portion of base shear (V- Ft), shall be distributed over the height of the building including level n, according to the following relation

$$F_X = \frac{(V-F_t)w_x h_x}{\sum_{i=1}^{n} w_i h_i} \qquad (7)$$

At each story level x, the force Fx shall be applied over the area of the building in the proportion to the mass distribution at that level.

Horizontal distribution of shear: The design storey shear Vx, in any storey x is the sum of the forces Fx and Ft above that storey. Vx shall be distributed to the various

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vertical elements of the lateral load resisting system in the proportion to their rigidities, considering the rigidity of the floor diaphragm.

2. Modeling and Analysis

A six storied RCC building having area of 2000 sft is considered in the present study. The building has aspect ratio of1.75. The framing system of the buildings is composed of RCC column and beam. RCC slab is considered monolithically casted with beams and act as rigid diaphragm among the frame structure. Figure 1 represent the framing system of the building including typical three dimensional finite element model. It also shows the length and width including number of bay sand length of span in each direction of the building.

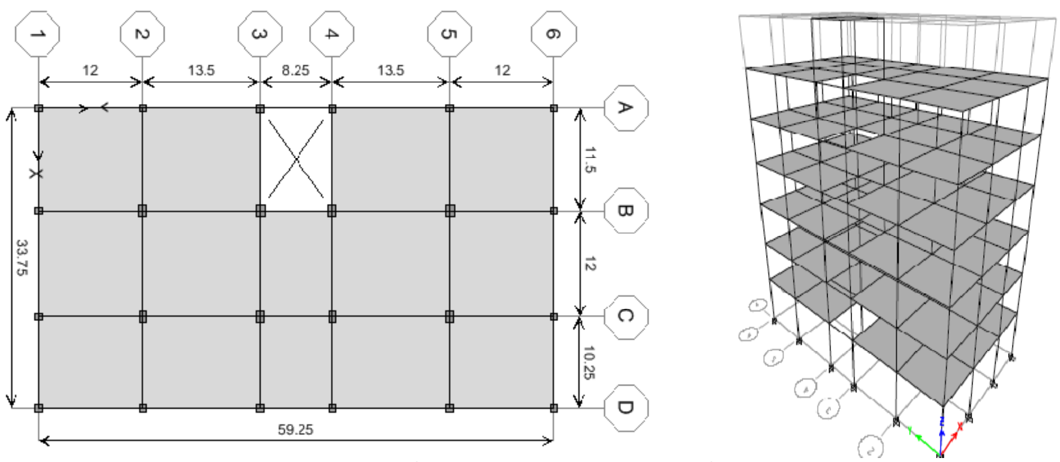

Figure 1: 3D finite element model of the building

Material properties are considered as concrete compressive strength = 3000 psi and yield strength of reinforcement= 60,000 psi. Slab thickness of 4.5 inch has been considered. Column size of 100 square inch with least lateral dimension of 10 inch is considered. The minimum depth of beam is 15 inch and width is 10 inch.

Dead load and Live Load: Floor Finish load of25 psf, and 165 lb/ft load on grade beam are considered other than self-weight of the structure. 250 psf uniformly distributed load on the stair roof slab and 200 lb/ft load on the stair roof beams have been assigned for roof top water reservoir including water. As per Bangladesh National Building Code (BNBC, 1993 part 6, 2.3) 40 psf uniformly distributed live load has been assigned.

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Seismic loads: Zone coefficient, Z **=** 0.15, Structure importance coefficient I = 1.0 and R = 8 are considered for seismic analysis.

The following Load Combinations are considered.

1. U = 1.4D (8)
2. U = 1.4D + 1.7L (9)
3. U = 1.05D + 1.275L + 1.4025E_x (10)
4. U = 1.05D + 1.275L - 1.4025E_x (11)
5. U = 1.05D + 1.275L + 1.4025E_y (12)
6. U = 1.05D + 1.275L - 1.4025E_y (13)
7. U = 0.9D + 1.43E_x (14)
8. U = 0.9D - 1.43E_x (15)
9. U = 0.9D + 1.43E_y(16)
10. U = 0.9D - 1.43 E_y (17)

After the analysis, it is found that the building is structurally deficient due to seismic lateral load as shown in Figure 2. Figure 2 shows the P-M-M interaction ratio of the columns of some frames of the structure to be greater than 1, which indicates that the column are under-designed. Table 4 shows the columns which are structurally deficient.

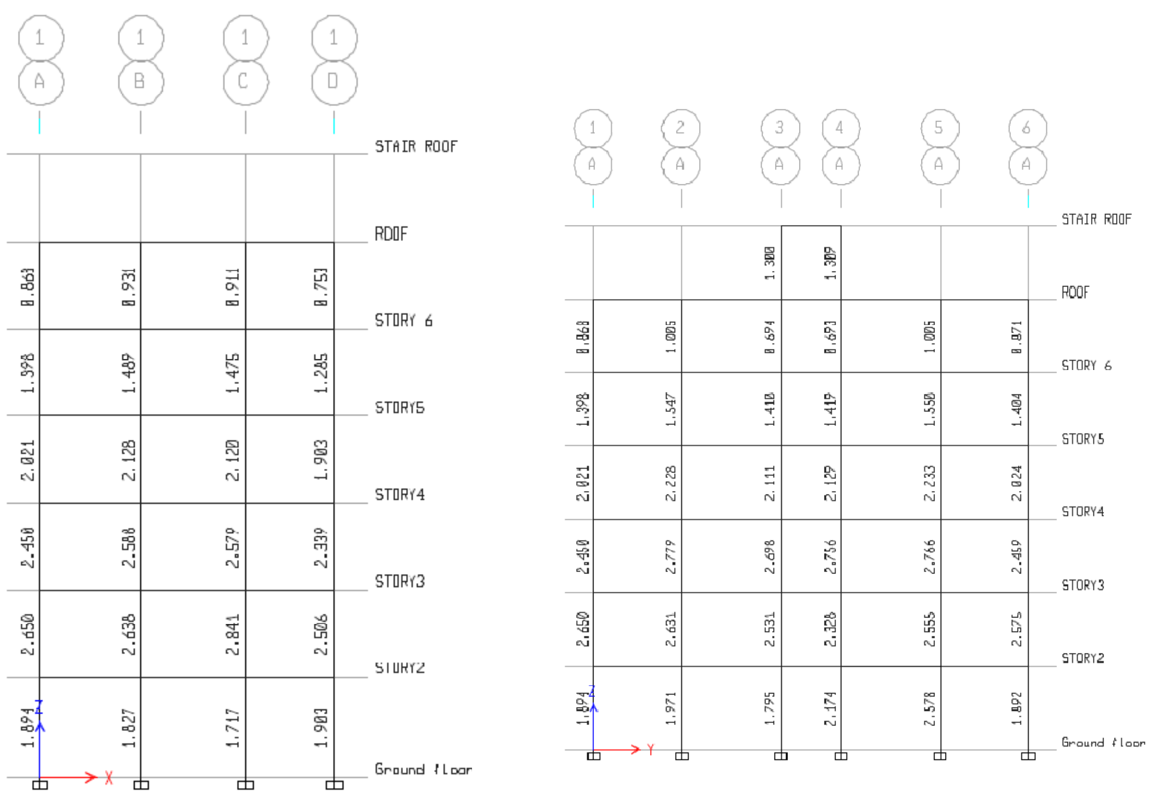

Figure 2: Column P-M-M ratio of frame 1-A-B-C-D and A-1-2-3-4-5-6

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Table 4: The seismic deficiency of columns of the building without any bracing

Column name	Grid location	Comments	Column name	Grid location	Comments
C24	A1	Unsafe from GB-5th storey	C22	C1	Unsafe from GB-6th storey
C17	A2	Unsafe from GB-6th storey	C19	C2	Unsafe from GB-5th storey
C16	A3	Unsafe from GB-5th storey	C14	C3	Unsafe from GB-5th storey
C9	A4	Unsafe from GB-5th storey	C11	C4	Unsafe from GB-5th storey
C8	A5	Unsafe from GB-6th storey	C6	C5	Unsafe from GB-5th storey
C1	A6	Unsafe from GB-5th storey	C3	C6	Unsafe from GB-6th storey
C23	B1	Unsafe from GB-6th storey	C21	D1	Unsafe from GB-5th storey
C18	B2	Unsafe from GB-6th storey	C20	D2	Unsafe from GB-5th storey
C15	B3	Unsafe from GB-6th storey	C13	D3	Unsafe from GB-5th storey
C10	B4	Unsafe from GB-6th storey	C12	D4	Unsafe from GB-5th storey
C7	B5	Unsafe from GB-6th storey	C5	D5	Unsafe from GB-5th storey
C2	B6	Unsafe from GB-6th storey	C4	D6	Unsafe from GB-5th storey

3. Modeling for Seismic Retrofitting with Steel Bracing

Bracing is a highly efficient and economical method to laterally stiffen the frame structures against earthquake loads. A braced bent consists of usual columns and girders whose primary purpose is to support the gravity loading, and diagonal bracing members that are connected so that total set of members forms a vertical cantilever truss to resist the horizontal forces. Bracing is efficient because the diagonals work in axial stress and therefore call for minimum member sizes in providing the stiffness and strength against horizontal shear.

Steel bracing is a very easy, economic acceptable retrofitting techniques (Ferraioli et. al. 2006, Ravikumar and Kalyanaraman 2005, Mahmoud 2005, Vishwanath, 2010). This process has been adopted in the building in this study. By using various type of steel bracing in ETABS, modeling for seismic retrofitting has been done. Following models are considered for the analysis and design for seismic retrofitting: X brace model, V brace model and Inverted V brace model. As regular arrangement of bracing Figure 3 represents various type of modeling of steel bracing for seismic retrofitting.

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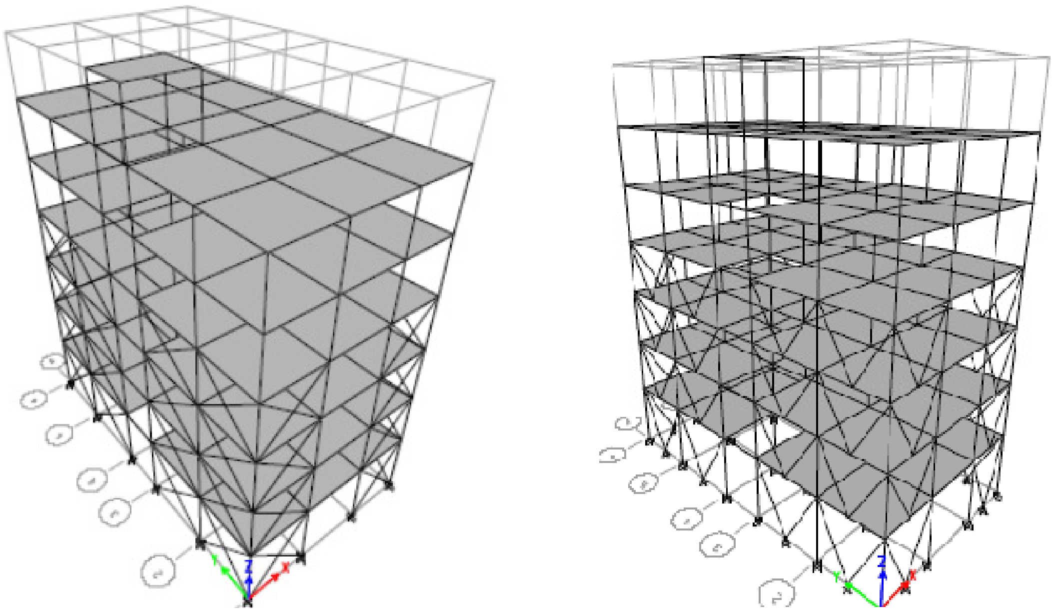
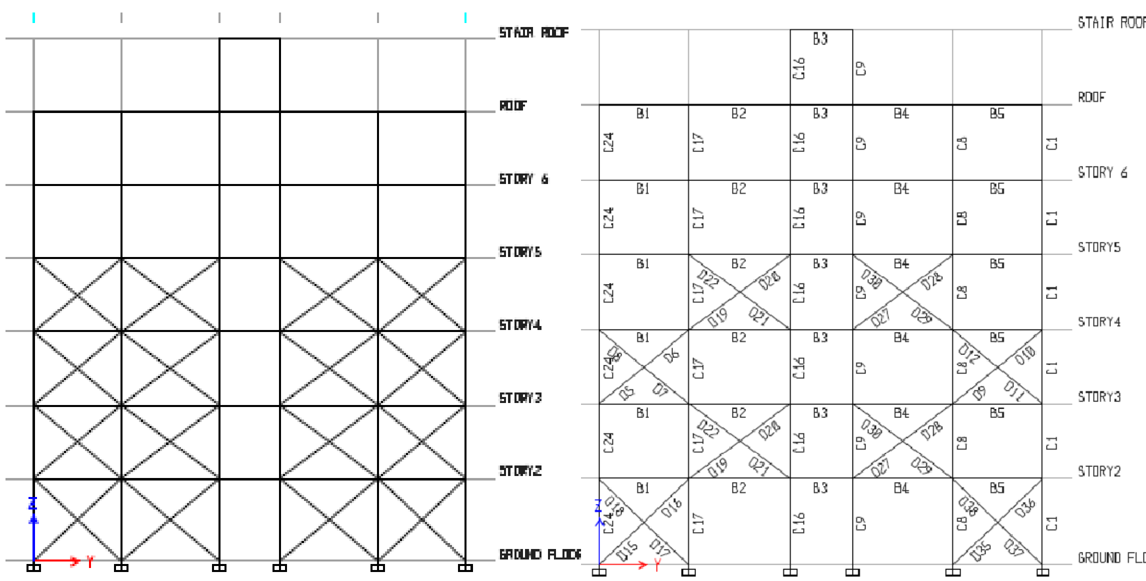


Figure 3: 3D modelling of the building with X type and V type bracing



(a) Regular arrangement (b) Arrangement-1

Figure 4: Elevation of building with X bracing type

Figure 4. 5 and 6 represent the difference between different types of modeling of steel bracing for seismic retrofitting with regular arrangement and Arrangement 1.

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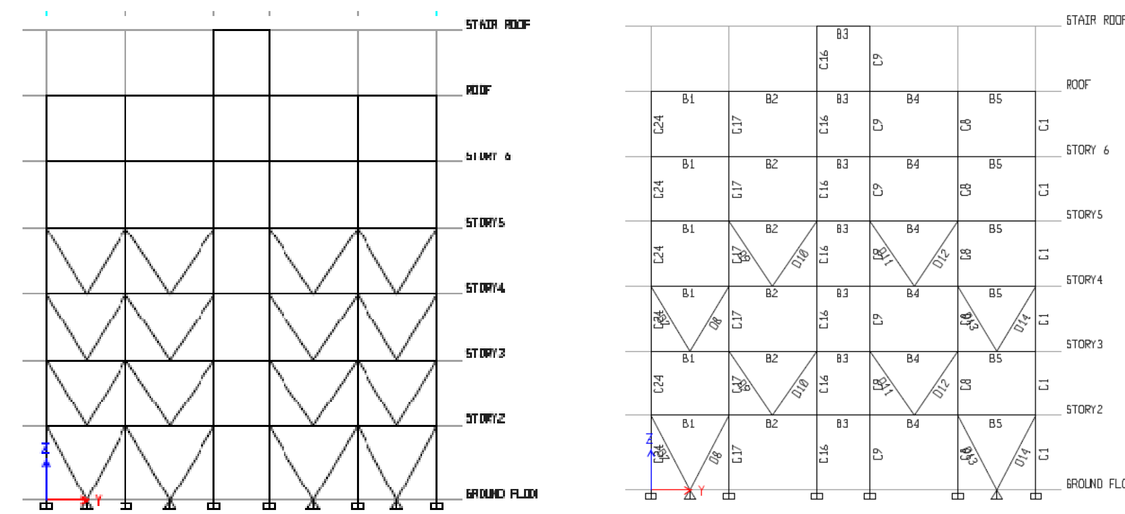
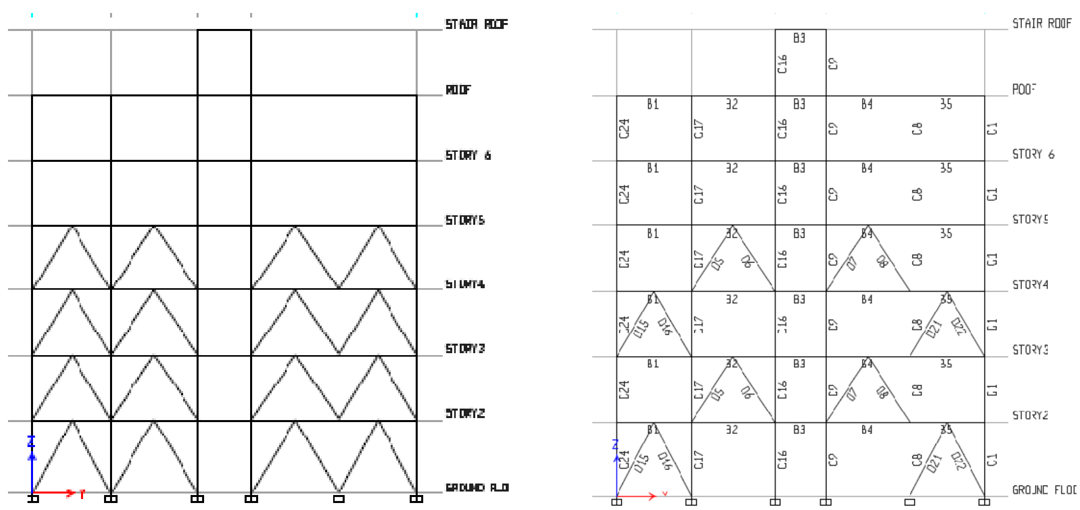


(a) Regular arrangement (b) Arrangement-1

Figure 5.Elevation of building with regular arrangement and Arrangement-1for V bracing



(a) Regular arrangement (b) Arrangement-1

Figure 6.Elevation of with regular arrangement and Arrangement-1for inverted V bracing

After applying the bracing system as explained above, the analysis is performed again for the retrofitted structure for different type of bracing system also the arrangement until the design of the structure becomes satisfactory. Figure 7 shows the column P-M-M interaction ratio for the retrofitted structure for the various arrangements. Similarly, for other type of bracing system the retrofitted structure is found safe for both for regular arrangement and Arrangement-1.

Maximum storey displacement for various types of bracing and arrangement are shown in Table5 and Figure 8. Maximum displacement is found minimum for X-type bracing with arrangement -1 compared to the V type bracing & Inverted V type bracing with regular arrangement & arrangement -1. Therefore, X type bracing with arrangement-1 is more efficient.

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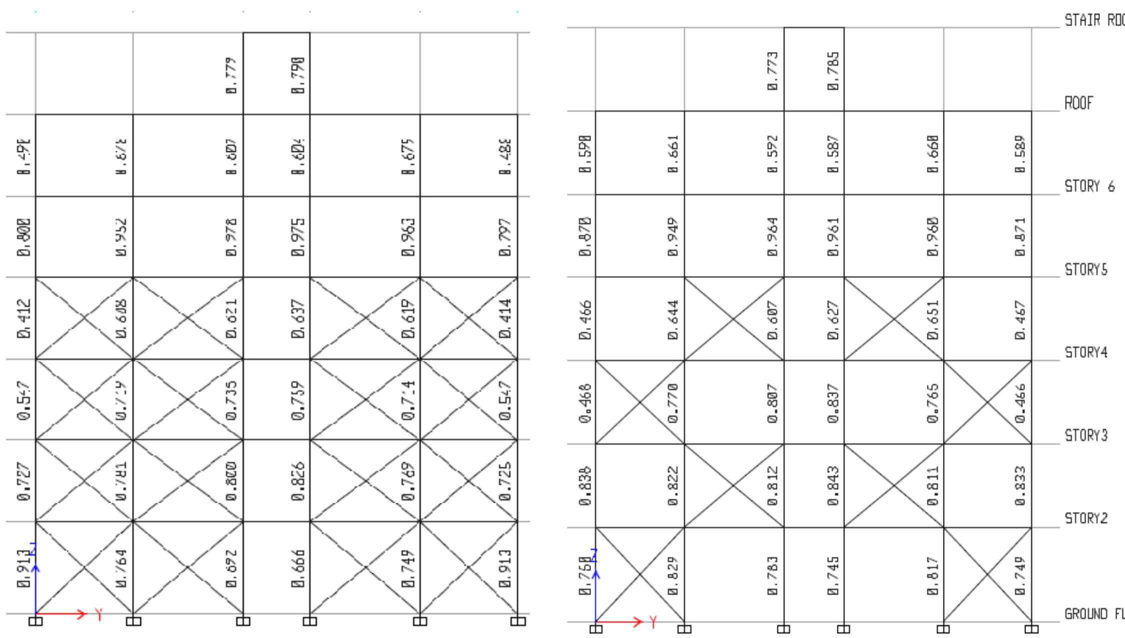

(a) Regular arrangement (b) Arrangement-1

Figure 7.Column P-M-M ratio for X bracing of frame 1-A-B-C-D for regular arrangement and Arrangement-1

Table 5: Maximum storey displacement for various type of bracing

Maximum storey displacement (in)		
Without bracing	2.101558	
Types of bracings	Regular arrangement	Arrangement 1
X type bracing	0.865773	0.760787
V type bracing	0.994068	0.899518
Inverted V bracing	0.889866	0.856996

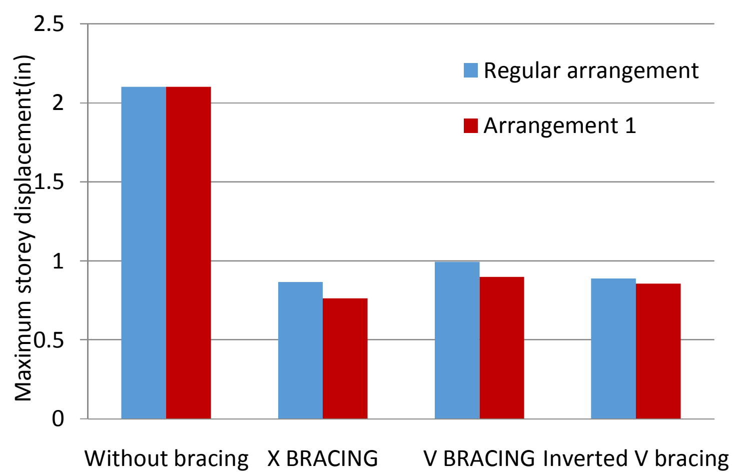

Figure 8: Maximum storey displacement vs types of bracings

Bracings change the stiffness of the moment resisting frames. Hence, it has a significant effect on the shear force and bending moment of columns as they take most of the lateral loading acting as a truss member. They can take only tension or compression. Here, the values of shear force, bending moment and axial force of the corner columns at the 1st bay is observed and discussed.

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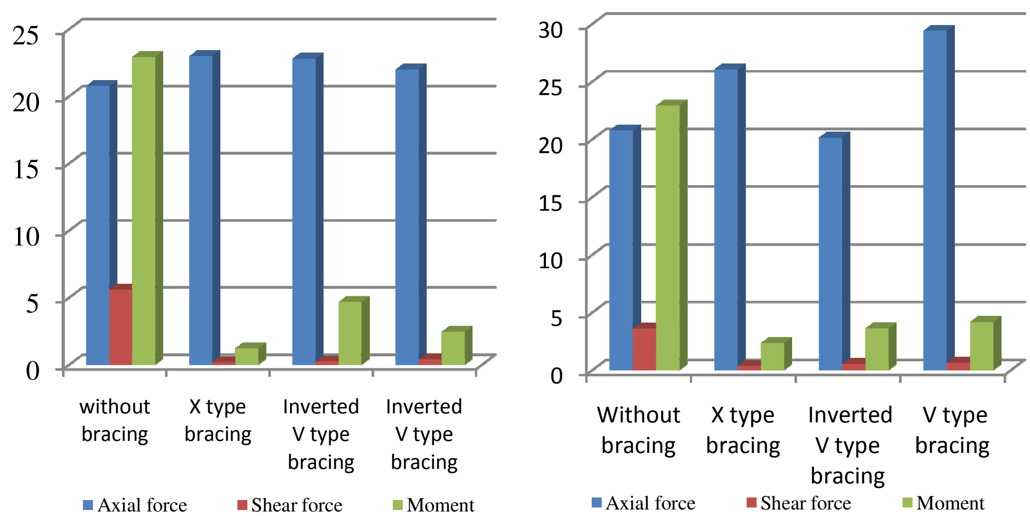
Figure 9 shows the axial force, shear force and moment of a particular column with different types of bracings with different arrangement. In all the bracing type, the shear force and moment are reduced in the retrofitted structure as compared to the structure without bracing. Further, for both the arrangement, it is observed that due to bracing shear force and bending moment in columns tend to decrease. Figure 9shows that reduction of shear force and bending moments is maximum for X bracing as compared to V bracing, Inverted V bracing and frame without bracing. Therefore, X type bracing is found more efficient in the present analysis for regular arrangement and Arrangement-1. Figure 9 also represent an increase in axial force of column due to application of bracing frame without bracing.



(a) Regular arrangement (b) Arrangement-1

Figure 9: Force diagram of a corner column A1 (Regular Arrangement and Arrangement 1)

Considering Squire Hollow Section (SHS) the percentage reduction in steel is achieved by Arrangement-1 compared to the regular arrangement for different pattern of bracing is shown in Table 6. Table 6 represents that Arrangement-1 is economical than regular arrangement in terms of reduction of steel required in bracing system.

Table 6: Minimum steel required for different types of bracings with different Arrangement

Type of bracing	Steel Required(ft)		% reduction of steel
	Regular arrangement	Arrangement-1	
X type bracing	1010	897	11.19
V type bracing	765	675	11.77
Inverted **V** bracing	765	675	11.77

4. Conclusion

The following conclusions have been drawn based on the results obtained from the

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- The concept of using steel bracing is one of the advantageous concepts which can be used to strengthen or retrofit the existing structures.
- Arrangement-1 is more economical compared to the regular arrangement.
- X type bracing reduces maximum storey displacement compared to the Vtype &Inverted V type bracing.
- X type bracing reduces shear and bending moment and increases axial force of the column.
- V type and Inverted V type bracings result in more reduction in steel as compared to the X type of bracing.

Present study has been done for single aspect ratio of the building with different size. Further study can be done considering other more aspects ratios of the buildings with various sizes. This study has been done considering moderate seismic zone and 6 storied buildings. Future study can be done for high rise buildings with severe seismic zone. In present study the seismic design of structure is linear static but it can be more advanced non-linear pushover analysis for future study.

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