International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 2, Issue 2, pp: (24-34), Month: October 2014 - March 2015, Available at: www.researchpublish.com

A Comparative Study of Seismic Strengthening of RC Buildings by Steel Bracings and Concrete Shear walls

Yaseer Alashkar[1], Sohaib Nazar[2], Mohammad Ahmed[3]

[1] Associate Professor, College of Engineering, Zagazig University, Zagazig, Egypt
[2] Lecturer Colleges of Engineering, King Khalid University Abha, KSA
[3]Lecturer College of Engineering, King Khalid University, PhD Candidate Cairo University, Egypt

Abstract: **Shear wall and Steel bracing systems are most widely used in medium to high rise buildings to provide stiffness, strength and energy dissipation required to resist lateral load imposed by earthquakes and wind. In the past shear wall and steel bracing have been proved as most feasible solution for seismic retrofitting or strengthening of buildings. The newly adopted performance evaluation methodology and capacity design principles are examples of these important advancements in seismic engineering. Many existing RC buildings need to retrofit to overcome weaknesses to resist seismic loads. Therefore, there is an essential need to upgrade the seismic performance of existing RC buildings so that they can meet the requirements of the new performance-based seismic design techniques.**

In this paper, seismic performance of RC building rehabilitated with shear wall and concentrated steel bracing. An earthquake load is calculated and applied on nine stories building located in zone III. A comparison has been made between the effectiveness of different types of steel bracings with concrete shear wall at different locations of the building. The performance of the building is evaluated in terms of story drifts, lateral displacements, bending moments and base shear.

Keywords: **Retrofit, Seismic Strengthening, Steel bracings, Shear walls.**

I. INTRODUCTION

In the past thirty years moderate to severe earthquakes have occurred in world at intervals of 5 to 10 years caused severe damages and suffering to humans by collapsing the structure, tsunamis, floods, landslides in loose slopes and liquefaction of sandy soils. Socio-economic losses have been increased significantly in the world due to establishment of new cities in earthquake prone areas. However, these developments in construction have not been followed by guidelines of seismic codes in the past. Existing RC buildings designed without considering seismic criteria and ductile detailing may undergo severe damage during earthquake ground motion. The effect of horizontal forces due to wind loads, earthquake loads and blast loads etc. are attaining increasing importance. Strengthening of buildings have been proved as more economical and viable immediate shelter solution rather than replacement of buildings [1].

Reinforced concrete shear walls have been used as most effective solution to provide resistance and stiffening to the buildings against the lateral loads imposed by the earthquakes and wind. Moreover these walls also provide sufficient ductility and lateral control drift in order to minimize the strong lateral load effect especially during earthquake. The use steel bracing is also an effective solution for retrofitting and strengthening of seismically inadequate reinforced concrete frame structure [5, 6, 7]. It is highly efficient and economical method to increase the lateral resistant capacity of the building by increasing its lateral stiffness [8].

In the present study, an existing eight story RC frame structure building has been analyzed, retrofitted with concrete shear wall and steel bracing provided at the boundary and core of the building. SAP2000 (V.14.2) has been used [2]. A comparison has been made for the concrete shear wall and steel bracing in terms of base shear, lateral displacement, bending moments, story drifts.

II. SEISMIC RETROFITTING TECHNIQUES

Seismic retrofitting is done for a variety of reasons; the most common is to provide existing structures more resistance to ensure safety of the structure. In the past, various conventional and non conventional retrofitting techniques have been used with different combinations of strength and ductility enhancement at member and system levels. A feasible solution is always considered as the optimal combination of cost, downtime, disturbance, technical applicability and social impact. Seismic retrofitting for a structure is generally carried out globally or at member level [1,4].

2.1. Structure level or Global Retrofit Methods

In Structure level or global retrofit methods two approaches are used for structure level retrofitting.

i) Conventional methods based on increasing the seismic resistance of existing structure.

ii) Nonconventional methods based on reduction of seismic demands.

In conventional retrofitting techniques adverse effects of design or construction are eliminated to enhance the seismic resistance of existing structures. These techniques include the options like addition of shear wall, infill walls or steel braces. In case of non conventional methods, seismic base isolation and addition of supplemented device techniques are the most popular [1,9].

2.2. Member level or Local Retrofit Methods

In the member level or local retrofit the strength of the seismically deficient members is upgraded. This approach is more cost effective as compared to the structure level retrofit. It includes the addition of concrete, steel or fiber reinforced polymer (FRP) jackets for use in confining reinforced concrete columns, beams, joints and foundations. Various retrofitting techniques are shown below in Fig.1.

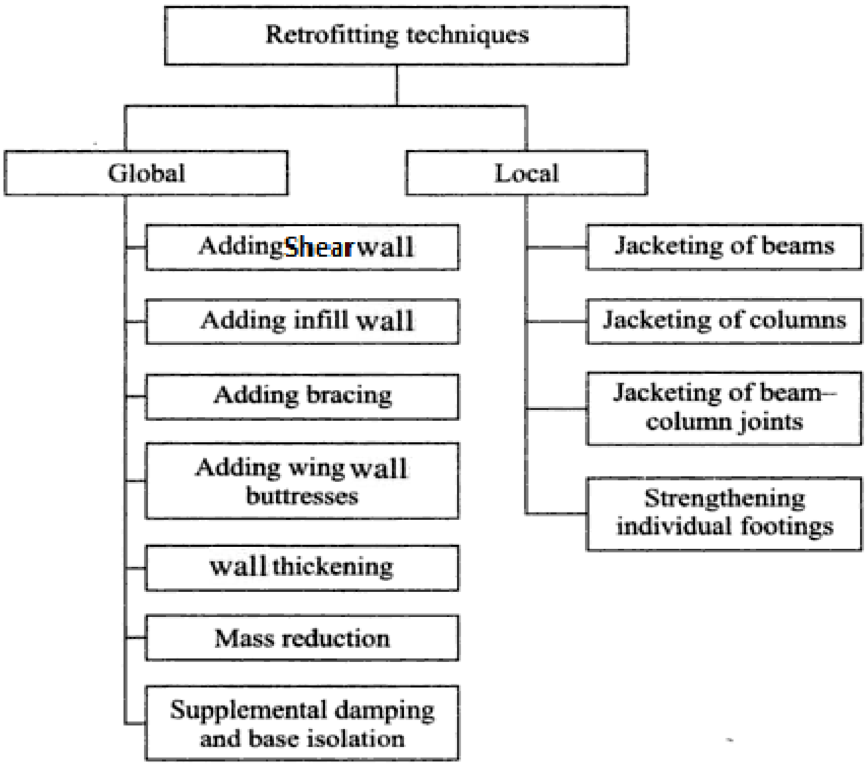

Fig.1: Global and Local Retrofitting techniques [1]

III. STRENGTHENING WITH SHEAR WALL

The addition of new reinforced concrete shear wall is most common practice to enhance the seismic resistance of existing building. This method has been proved more effective in controlling global drifts and structural damages in frame structures. The added elements can be either cast in place or pre cast elements. The optimal location of new elements should be considered while placing, which may align to the full height of building to minimize torsion. In this paper, results have been compared for frame structure coupled with shear wall at the boundary and exterior faces of building [1].

IV. STRENGTHENING WITH STEEL BRACING

Steel bracing is highly efficient and economic method to increase the resistance of existing structure against later forces. Bracing improves the performance of frame structure by increasing its lateral stiffness, ductility and capacity. Through braces load can be transferred out of frame to braces bypassing the weak columns while increasing strength.

Poor confinement of columns, week column beam joint, and inappropriate detailing of steel reinforcements are major factors for non-ductile behavior of frame structure. In the presence of these deficiencies, addition of steel bracing has been proved a viable and economic solution to enhance the seismic performance of the system. Moreover this technique of strengthening accommodates more openings and offer minimal self weight to the structure [3]. In this paper, results have been compared for a structure retrofitted with concentric X-bracing and eccentric V-bracing at the core and exterior face.

V. DESCRIPTION OF THE BUILDING

A ten-story residential building with plan and elevations as shown in Figures 2 and 3 is considered for study. The building is composed of moment resisting RC frame with solid slab, 140mm thickness, situated in zone 3. The structure members are made of in-situ reinforced concrete .The overall plan of building is rectangular with dimensions 20x16m as shown in Fig.2. Height of the building is 30.2 m. Story height for ground floor is 3.2m and rest of nine floors is 3m. All columns size is 600 x 300mm and beams size is 500×300 mm. The 3D model of the building is developed in SAP2000 [2] as shown in Fig.3. Beams and columns have been modeled as frame elements while in-plane rigidity of the slab is simulated using rigid diaphragm action. The columns are assumed to be fixed at the base. The building is analyzed as Equivalent Static Analysis by UBC-1997. The seismic load according to the code has been estimated and the building is analyzed for combined effect of gravity and seismic loads as shown in Table.1, considering all the design load combinations specified in code. Analysis results are considered for retrofitting at core and exterior face of the building.

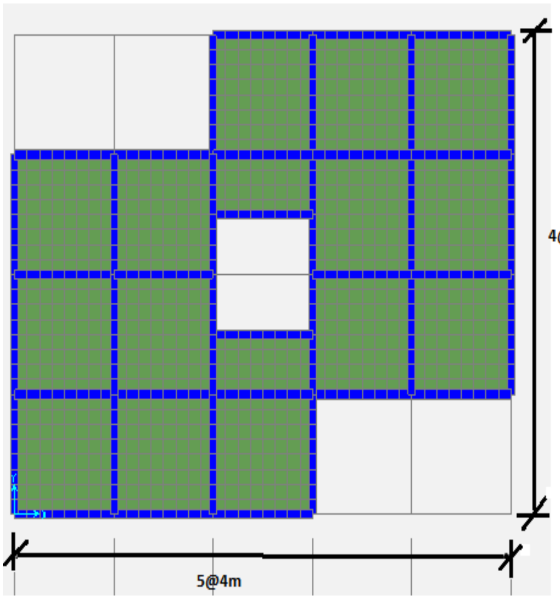

Fig.2: Plan of the building

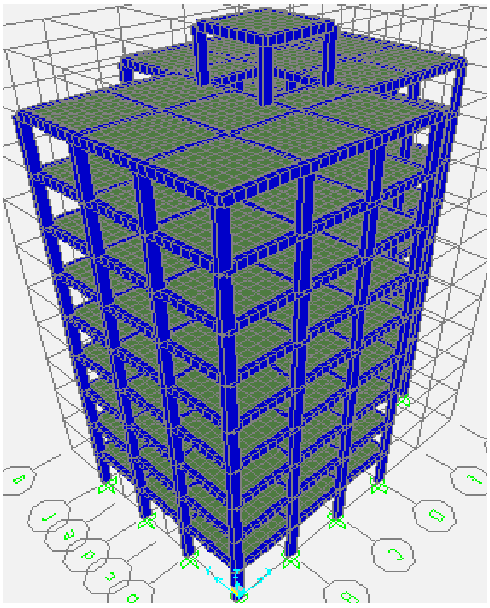

Fig.3: 3-D View of building

VI. EQUIVALENT STATIC ANALYSIS BY UBC-1997

The total design base shear along any principal direction can be calculated by following equation.

$$V = \frac{Cv\,I}{R\,T}.W \tag{1}$$

The total base shear need not to be exceed the following

$$V = \frac{2.5\,Ca\,I}{R}.\,W \tag{2}$$

The total base shear shall not be less than the following

$$V = 0.11\ I\ C_a\ W \tag{3}$$

The approximate fundamental period (T), in seconds, is determined from the following equation:

$$T = C_t\,.\,h_n^{3/4} \tag{4}$$

Whereas:

C_a and C_v are acceleration and velocity based seismic co-efficients respectively.

C_t = 0.035 (0.0853) for steel moment-resisting frames.

C_t = 0.030 (0.0731) for reinforced concrete moment-resisting frames and eccentrically braced frames.

C_t = 0.020 (0.0488) for all other buildings.

The base shear shall be distributed over the height of the structure, including Level *n*, according to the following formula:

$$Fx = \frac{(V-Ft)\ wx\,.hx}{\sum_{i=1}^{n} wi.hi} \tag{5}$$

Whereas:

$F_t = 0.07\ T\ V < 0.25\ V$; when $T \le 0.7$ sec.

VII. LOAD COMBINATIONS AS PER UBC-1997

According to UBC-1997, following combinations must be used when analysis and design is done by using Load and Resistance Factor Design (Strength Design) [10].

1.4D (i)

1.2D + 1.6L + 0.5 (L_r) (ii)

1.2D + 1.6 (L_r) + (f_1L) (iii)

1.2D + f_1L + 0.5 (L_r) (iv)

1.2D + 1.0E + (f_1L) (v)

0.9D ± (1.0E) (vi)

Whereas:

$E = \rho E_h + E_v$ (vii)

$E = \rho E_h + 0.5CaID$ (viii)

$1.0 \le \rho \le 1.5$

f_1 = 1.0 for floors in places of public assembly, for live loads in excess of 100 psf (4.9 kN/m2), and for garage live load.

f_1 = 0.5 for other live loads.

f_2 = 0.7 for roof configurations (such as saw tooth) that do not shed snow off the structure.

f_2 = 0.2 for other roof configurations.

Table I: Gravity Loads on building

Dead Loads	
Water proofing	2.5KN/m^2
Super Imposed load on roof	1 KN/m^2
Floor Finish	1 KN/m^2
Partitions	3KN/m^2
Live Loads	
On roof	1 KN/m^2
On floors	3 KN/m^2

VIII. RESULTS AND DISCUSSION

The frame structure building has been analyzed with shear wall, V-bracing and X-bracing at core and boundary as shown in Figure 4 to Figure 9. Results have been compared in terms of displacement, inter story drift, bending moments and shear forces in columns and beams in X and Y direction respectively.

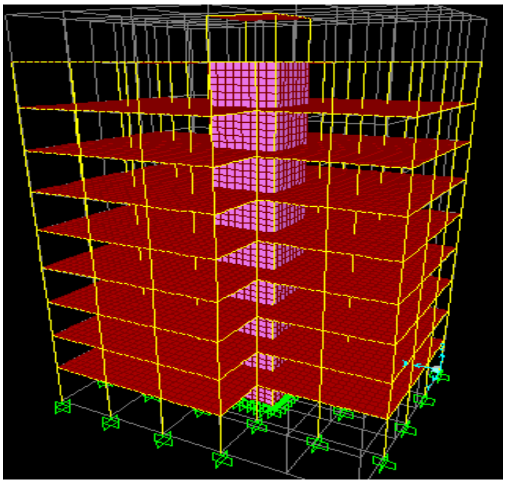

Fig.4: Building with Shear Wall at core

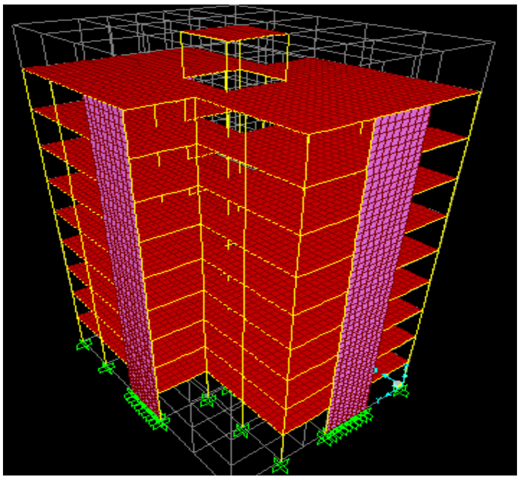

Fig.5: Building with Shear Wall at boundary

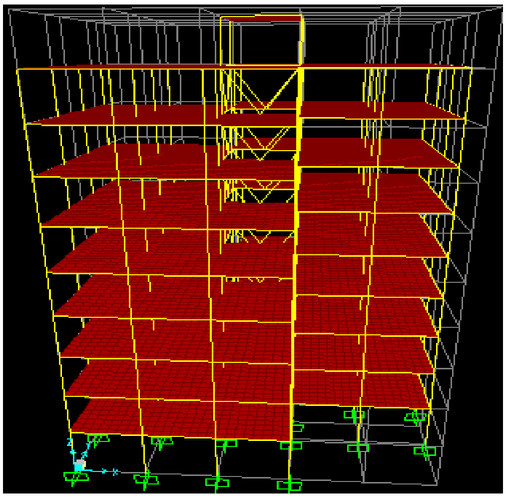

Fig.6: Building With V-bracing at core

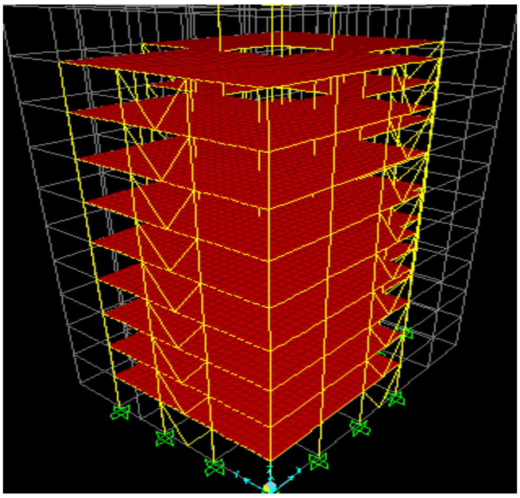

Fig.7: Building with V-bracing at boundary

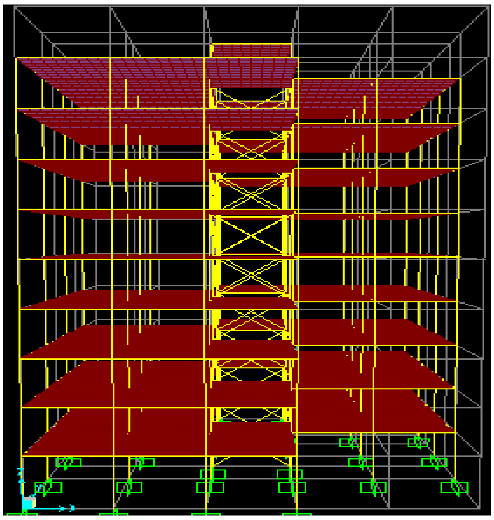

Fig.8: Building with X-bracing at core

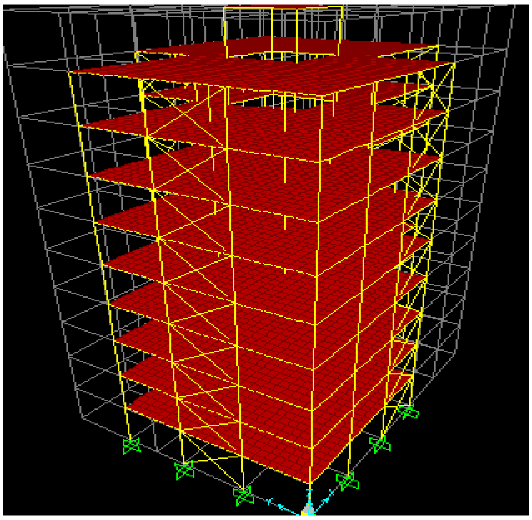

Fig.9: Building with X-bracing at boundary

8.1 Base Shear

The building is analyzed to calculate the base shear for shear wall and bracings at the core and boundary. Addition of new elements to the building increases its dead load which increases the base shear. However value of base shear increases more with shear walls as compared to building coupled with bracings as shown in Figure 10.

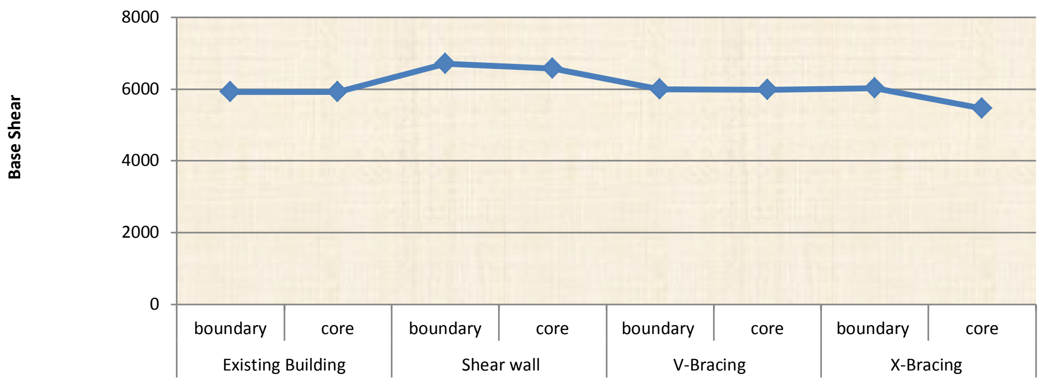

Fig.10: Base Shear

8.2 Lateral Displacement

The lateral displacement has been calculated for both X and Y-directions, for effects of earthquake in both directions. The building coupled with shear wall shows less displacement than steel bracing whether it's provided in core or boundary of structure. However, building coupled with V-bracing shows more displacement as compared to X-bracing when provided at boundary, while there is sufficient variation with bracings at core as shown in Figure 11 and Figure 12.

8.3 Story Drift

Drift is generally defined as lateral displacement of one story relative to story below. Drift control is necessary to limit damage to interior partitions, elevator and stair enclosures, glass, and cladding systems. Drift, $\Delta_x = \delta_x - \delta_{x-1}$ is calculated with the provisions of UBC-97 for long(X) and short (Y) directions as shown in Table II, Fig.13 and Fig.14. Building with shear walls show significant decrease in inter story drift in both directions as compared to steel bracings. However, shear walls at core shows least inter-story drift.

8.4 Bending Moment

Bending moment has been checked for corner frame in both X and Y direction. The selected beams and columns in corner frame are shown in Figure 13 to Figure 16.

Table II: UBC Provisions

UBC
(Max. inelastic disp.) $\delta_x = 0.7\ R\ \delta_{xe}$
$\Delta_a = 0.020 h_{sx}$ (T $\geq$ 0.7 Sec)
Where h_{sx} is height below level x.

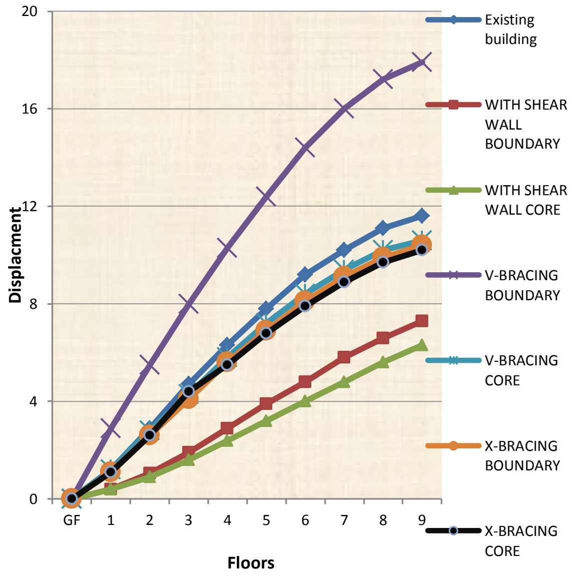

Fig.11: Lateral displacement in X-direction

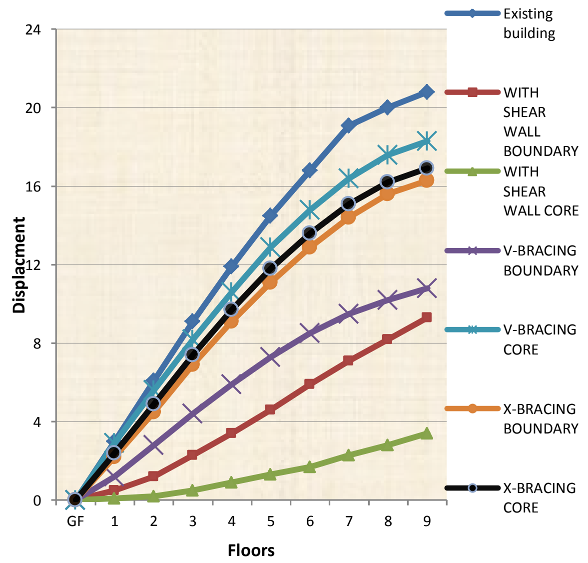

Fig.12: Lateral displacement in Y-direction

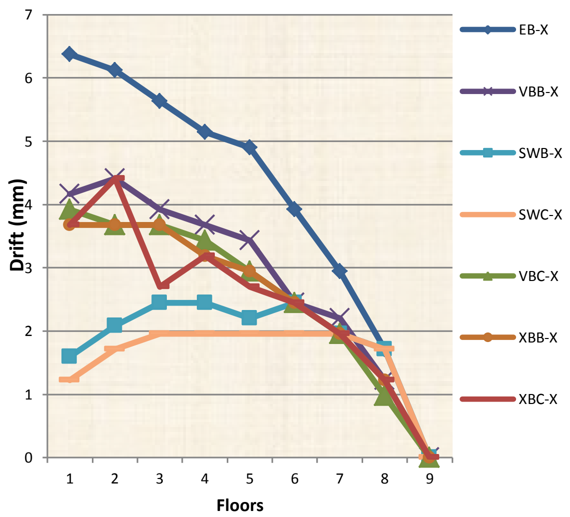

Fig.13: Inter Story drift in X-direction

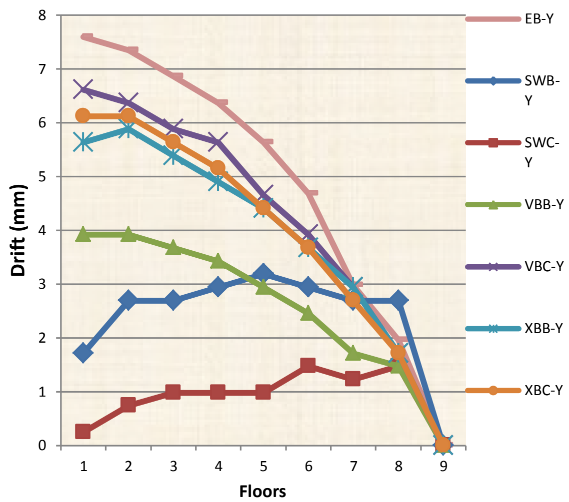

Fig.14: Inter Story drift in Y-direction

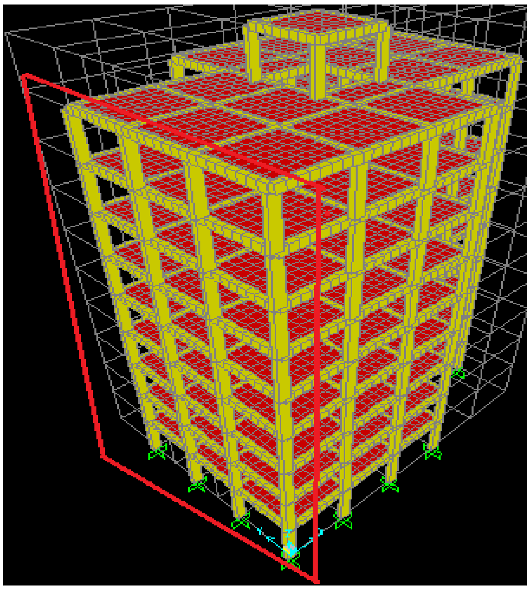

Fig.13: Selected frame in Y-direction

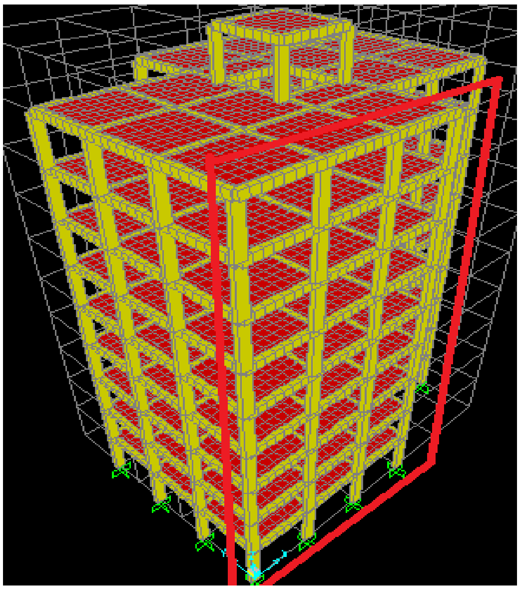

Fig.14. Selected frame in X-direction

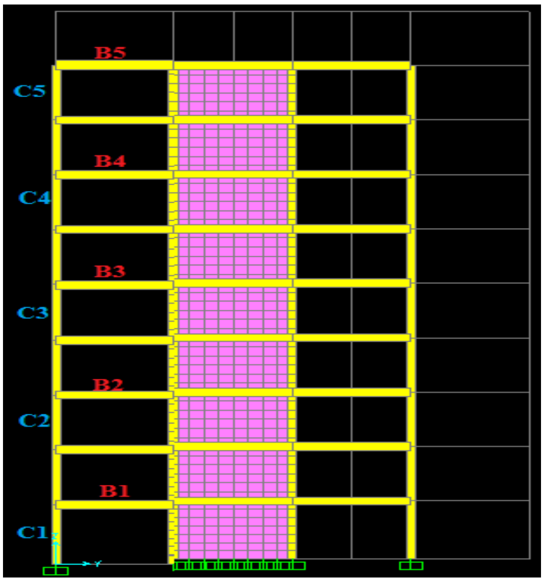

Fig.15: Selected beams and column in Y-direction

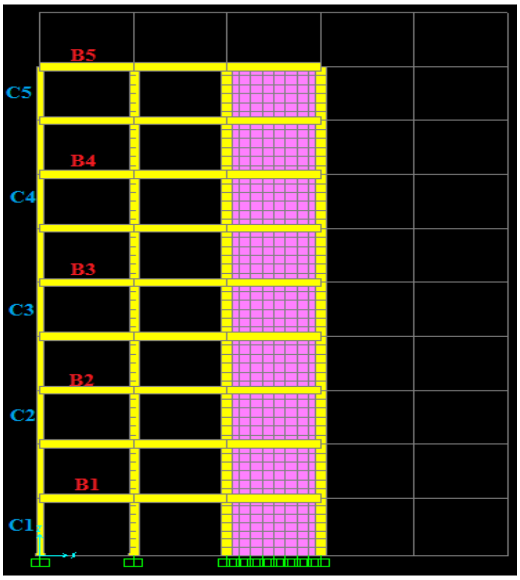

Fig.16: Selected beams and column in X-direction

The results are compared for the building retrofitted with shear wall and bracings. Bending moment in corner frame of the building coupled with shear wall is sufficiently reduced as compared with bracings. The concentric or X-bracing increases the lateral stiffness of the frame which, increasing the natural frequency and decreasing the lateral drift. However, increase in the stiffness may attract a larger inertia force due to earthquake. Furthermore, while the bracings decrease the bending moments and shear forces in columns, they may increase the axial compression in the columns to which they are connected. Since reinforced concrete columns are stronger in compression, it may not pose a problem to retrofit building using concentric steel bracings.

Eccentric bracing or V-bracing reduces the lateral stiffness of the system. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame. However, vertical component of the bracing forces causes lateral concentrated load on the beams at the point of connection of the eccentric bracings.

Table III: Bending moments in beams and columns in Y-direction

Beam/Column no.	Existing building	WITH SHEAR WALL		V-BRACING		X-BRACING	
		BOUNDARY	CORE	BOUNDARY	CORE	BOUNDARY	CORE
B1	365.7	101.1	18.3	306.1	306.4	280.1	252.8
B2	310.1	203.4	12.6	281.9	251.5	271.5	207.4
B3	234	230.2	8.1	230.4	187.4	227.6	158.8
B4	128.3	214.3	9.1	146.3	99.7	150	80.3
B5	12.1	128.4	5.9	40.5	27	27.2	21.8
C1	371.3	71.6	59.1	377.4	327.2	306.5	274.7
C2	185.3	81.6	58.6	162.2	156.4	153.1	131.7
C3	136.1	85.1	60.1	123.1	116	118.7	98.2
C4	73	72.9	50.7	71.1	63.2	70.8	53.4
C5	40.5	56.7	36.5	40.6	41.2	40.2	40.7

Table IV: Shear force in beams and columns in Y-direction

Beam/Column no.	Existing building	WITH SHEAR WALL		V-BRACING		X-BRACING	
		BOUNDARY	CORE	BOUNDARY	CORE	BOUNDARY	CORE
B1	211.3	105.2	40.7	200.4	184.7	178.1	160.7
B2	184.2	163.1	39.6	191.2	158	177.6	138.2
B3	147.5	178.1	43.2	166.4	126.8	157	111.9
B4	98.2	169.4	46.9	126.3	85.6	120.1	77.4
B5	45.4	131.2	46.6	81.7	52.4	75.9	42.4
C1	176.6	28.9	24	184	156.2	146	130.8
C2	125	49.2	34.8	108.7	105.2	102.1	88.2
C3	96.2	55.9	39	86.4	81.7	83	69
C4	57.2	49.9	34.3	54.5	49.2	53.8	41.5
C5	2.4	42.7	28.1	6.1	1.25	9	1.7

Table V: Bending moments in beams and columns in X-direction

Beam/Column no.	Existing building	WITH SHEAR WALL		V-BRACING		X-BRACING	
		BOUNDARY	CORE	BOUNDARY	CORE	BOUNDARY	CORE
B1	310.6	87.5	80.2	296.1	272.7	255.2	233.1
B2	280.1	125	106.3	246.6	240.9	233.1	207.1
B3	211.8	132	107.7	188.2	184.4	184	160.2
B4	121.2	116.6	95.5	105.4	108.6	116.5	96.2
B5	21.8	46.8	50.9	36.1	22.6	25.7	22.4
C1	371.3	71.5	59.1	377.4	327.2	306.5	274.7
C2	185.3	81.6	58.6	162.2	156.4	153.1	131.7
C3	136.1	85.1	60.1	123.1	116	118.7	98.2
C4	72.9	72.9	50.7	71.1	63.2	70.8	53.4
C5	31	56.7	36.5	31.5	32.1	31.3	31.7

Table.VI: Shear force in beams and columns in X-direction

Beam/Column no.	Existing building	WITH SHEAR WALL		V-BRACING		X-BRACING	
		BOUNDARY	CORE	BOUNDARY	CORE	BOUNDARY	CORE
B1	193.5	74	68.7	183.1	172.5	163.9	151.1
B2	176.1	96	83	158.1	155	151.4	136.9
B3	139	99.7	83.9	128.8	124.2	125.6	111.2
B4	90.3	91.7	77.1	88.9	83.4	88.9	76.6
B5	40.7	59.9	56.6	43.2	40.8	44.7	40.4
C1	176.6	28.9	24	184	156.2	146	130.7
C2	125	49.2	34.8	108.7	105.2	102.1	88.2
C3	96.2	55.9	39	86.4	81.7	83	69
C4	57.2	49.9	34.3	54.5	49.2	53.8	41.5
C5	24	42.7	28.1	24	24.4	23.8	24.1

IX. CONCLUSIONS

Existing RC buildings designed without considering seismic criteria and ductile detailing may undergo severe damage during earthquake ground motion. The need for retrofitting or strengthening of earthquake damaged or earthquake vulnerable buildings has been tremendously increased after the devastating earthquake in the past years. Generally structural level retrofitting is applied when the entire lateral load resisting system of the structure deemed to be deficient. Following conclusions can be drawn from this study.

- The addition of new concrete shear wall is more oftenly practiced technique which has prove to be effective for controlling global lateral drifts and reducing damages in frame structures.
- Shear walls reduces significant amount of lateral displacement, bending moment and shear forces in frame members as compared to other techniques of retrofitting.
- Optimal location of shear walls in frame system is critically important to reduce the lateral forces.
- Shear walls located at the core of building shows better performance than at the boundary of building.
- Steel bracing is one of advantageous and economic technique to enhance the seismic performance or strengthen the structure.
- The increment in dead load due to addition of steel bracings is significantly less than the other strengthening techniques.
- The V-type bracings show some additional flexural moment in columns and beams due to concentric load at the point where they are attached.
- The X-bracing system shows the minimum moment as compared to other types of bracings.

REFERENCES

[1] Pankaj A., Manish S.,(2006): Earthquake Resistant Design of Structures, ISBN-81-203-2892-2. Prentice Hall of India (pvt). PP-534-540.

[2] Computers and Structures. SAP2000: Three Dimensional Static and Dynamic Finite Element Analysis and Design of Structures, Computers and Structures Inc., Berkeley, California, U.S.A. 2001.

[3] Viswanath K.G , Prakash K.B., Anant Desai,(2010): Seismic Analysis of Steel Braced Reinforced Concrete Frames, International Journal of Civil and Structural Engineering, Volume 1, No 1.

[4] UBC-1997: Structural Design Requirements, Vol. 2: International Conference of Building Officials, California, USA, 1997.

[5] Alashker, Y., El-Tawil, S. and Sadek, F. (2010). "Progressive collapse resistance of steel-concrete composite floors," Journal of Structural Engineering, Vol. 136, No. 10, October 1, p1187-1196.

[6] Alashker, Y., El-Tawil, S. and Honghao, Li, (2011). "Approximations in progressive collapse modeling" Accepted for publication, Journal of Structural Engineering, ASCE, Vol. 137, No. 9, September 1, p914-924.

[7] Khandelwal, K. and S. El-Tawil (2011). "Pushdown Resistance as a Measure of Robustness in Progressive Collapse Analysis." Engineering Structures, Vol. 33(9), pg 2653-2661.

[8] Khandelwal, K., El-Tawil. S., and Sadek, F. (2009). "Progressive Collapse Analysis of Seismically Designed Steel Braced Frames." Journal of Constructional Steel Research, Vol. 65, No. 3, pg 699-708.

[9] M., Mouzzoum et. al "Seismic Damage Prediction of Reinforced Concrete Buildings Using Pushover Analysis' International Journal Of Computational Engineering Research (ijceronline.com) Vol. 3 Issue2013.

[10] Nazar S., (2014): A Comparative Study of Seismic Provisions Provided in UBC-97 and Saudi Building Code, World Academy of Science, Engineering and Technology, International Journal of Civil Science and Engineering Vol:10 No:3, 2014.