International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Seismic Performance of Reinforced Concrete Frame with Steel Bracing System

Somil Khattar, K. Muthumani

Abstract*: The design of the 15 storey R.C building (seismic zone V) is made in accordance with IS 456:2000 using ETABS software. It is already reported that provision of concentric bracing throughout the building are reliable during seismic activity. Hence, this work is aimed to improve the performance of multi storey R.C. building by provision of eccentric steel bracing through analysis. Different types of bracing such as V bracing, Chevron bracing and Diagonal bracing are provided in concentric and eccentric manner. The effect of distribution of steel bracing throughout the height of the building is examined. It is found that the deflection in the building increases with increase in eccentricity. Moreover, V type bracing with 10 percentage eccentricity is found to be most reliable under seismic activity compared to other arrangements.

***Keywords*: Eccentric steel bracing, R.C. Building, Deflection, Seismic performance, ETABS**

I. INTRODUCTION

There are mainly two retrofitting approaches that are generally used to improve the seismic performance of the existing structures, before that are subjected to an earthquake. First one is to add new structural elements such as steel braces or structural wall; and other one is to provide concrete or steel jacketing to the deficient structural element. However, in first approach; shear walls are provided in R.C. structures and steel bracing is provided in steel structures. Now, in recent years, studies have been carried out to use steel bracing to retrofit R.C. structures; where most of the studies deal with provision of concentric steel bracing throughout the structure. However, in order to facilitate the use of eccentric bracing, further research needs to be done in this area. In Eccentrically Braced Frame (EBF), one end of the brace frame is connected to the nodal frame and other end is connected to the link beam.

Bracings are provided in the structure to resist wind and seismic forces. EBF have comparatively less stiffness than Concentrically Braced Frame (CBF), also they show more ductile behavior. Different types of bracing arrangement that are used are: V-type bracing, Chevron type bracing, K type bracing, Diagonal bracing, off centre bracing, X-braced frame, Knee type bracing, etc. Adil Emre Ozel and Esra Mete Guneyisi [1] studied the seismic reliability of a R.C. structure retrofitted using EBF.

Manuscript published on 30 September 2019
* Correspondence Author
Somil Khattar*, Structural Engineer, Vellore Institute of Technology, Chennai, India. Email: khattarsomil@gmail.com
K. Muthumani, Professor, Vellore Institute of Technology, Chennai, India. Email: muthumani.k@vit.ac.in

They examined the effectiveness of using different types of eccentric steel bracing with their varying distribution over the height of R.C. structure. Out of all the different arrangements, they found that provision of more number of braces at lower storey and by gradually decreasing the number till the top storey was the most reliable against seismic activity.

M.N.Chimeh and P.Homami [5] studied the seismic performance of steel structure by providing different type of bracing systems such as Chevron braced frame, X braced frame, Zipper column and EBF with long and short link beam. Their results showed that short linked EBF and Zipper columns give more ductility. Moreover, their results also concluded that as the storey height changes, the most effective arrangement based on their geometry also changes.

Salman Dalton hague [3] compared the seismic performance of R.C. structure with provision of CBF and EBF for 5, 7 and 9 storey structure and found that EBF are most efficient. And he concluded that the influence of load-deflection effect increases with increase in the height of the structure.

Nicka Keipour et al. [4] studied the seismic reliability of R.C. building retrofitted with steel knee braces. They tried different arrangements of steel knee bracing and found two of the most suitable arrangement for mid-rise R.C. building. Also, they concluded that knee type steel bracing system gives seismic reliability only for low-rise or mid-rise structures and it should not be used for high rise structure.

Homayoon Estekanchi et al. [2] investigated the seismic behavior of an off-center bracing system (OBS). Their results indicated that the load-deflection behavior of the structure follows a nonlinear stiffness-hardening pattern, which reflect the tensile failure of different bracings.

In this study, different arrangements of steel bracing are analyzed by varying the percentage of eccentricity and type of bracing. A particular arrangement of bracing throughout the height of the structure will be found, which is more effective to seismic response.

II. ANALYSIS METHOD

For this work, ETABS 2015 software is used. Codes and standards considered are as follows:

a) IS: 456 - 2000: Code of practice for plain and reinforced concrete, **b**) IS 875 – 1993: Code of Practice for Design Loads for Buildings and Structures (other than Earthquake) Part 1 - Dead Loads – Unit Weight of Building Material and Stored Materials, Part 2 - Imposed Loads, Part 5 - Special Loads and Load Combinations and **c**) IS 1893(Part 1):2016 - Criteria for Earthquake Resistant Structures.

A. Input Data

The different parameters are considered like material property, components dimension, loading, and load combinations.

The building is of 15 storey. LL on the structure acting is 2 kN/m^2. Grade of concrete used is M30. All the columns are fixed at bottom.

Height of each storey is 3 m. There are 7 number of bay in x direction and 5 number of bay in y direction. Length of each bay is 5 m. The plan and elevation of the structure is shown in Fig. 1 and Fig. 2 respectively.

Material Properties – Properties of concrete are listed in Table I.

Table- I: Material Properties

Parameters	Values
Grade of Concrete	M30
Modulus of elasticity of concrete	273861 N/mm^2

Member Dimension – The dimension of the structural elements are given in Table II.

Table- II: Member Dimension

Parameters	Dimension
Size of Columns	– Up to 5th storey - 550 mm x 550 mm – From 5th -10th storey – 500 mm x 500 mm – From 10th -15th storey – 450 mm x 450 mm
Size of Beams	300 mm x 500 mm
Thickness of Slab	200 mm

Seismic Parameters – Earthquake zone is considered as Zone V. Building type is residential building, hence Importance factor is considered as 1. Ordinary Moment Resisting Frame is considered, (i.e. Response Reduction Factor, R = 3). Soil type is considered as Type II (i.e. Medium soil). However instead of Design Based Earthquake (DBE), the study considers Maximum Considered Earthquake (MCE).

Following load combinations are considered for the analysis:

1. 1.2 (DL + LL + EQX)
2. 1.2 (DL + LL - EQX)
3. 1.2 (DL + LL + EQY)
4. 1.2 (DL + LL - EQY)
5. 1.5 (DL + LL)
6. 1.5 (DL + EQX)
7. 1.5 (DL - EQX)
8. 1.5 (DL + EQY)
9. 1.5 (DL - EQY)

Out of all the above mentioned load combinations, combination number 1, 3, 6 and 8 are governing.

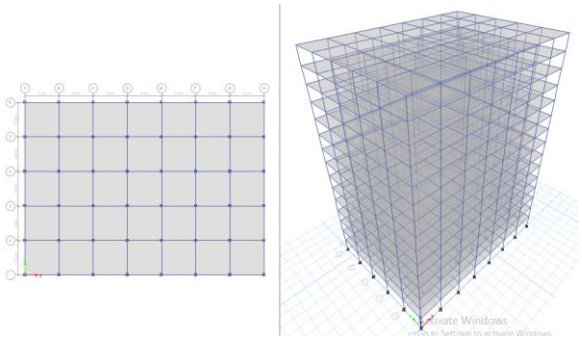

Fig. 1. Plan of G+15 storey building

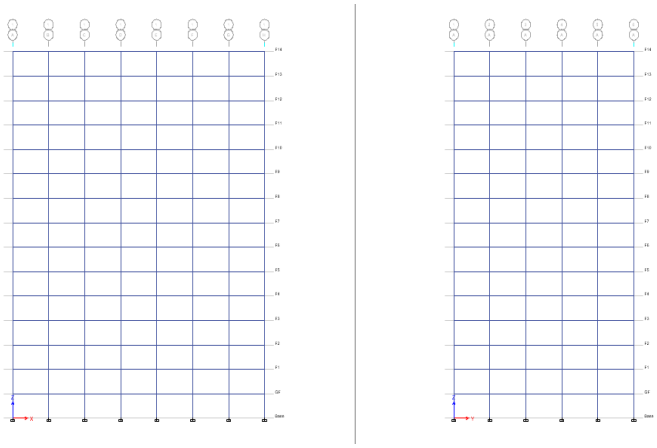

Fig. 2. Elevation of G+15 storey building

III. CONCENTRIC BRACED FRAME

For this work, three types of CBF are designed, i.e. V type bracing (Fig. 3), chevron bracing (Fig. 4) and D type bracing (Fig. 5). Full bracing is provided up to five storeys and with increase in height, bracings are reduced at every five storey interval. The models with all three arrangements are as shown below.

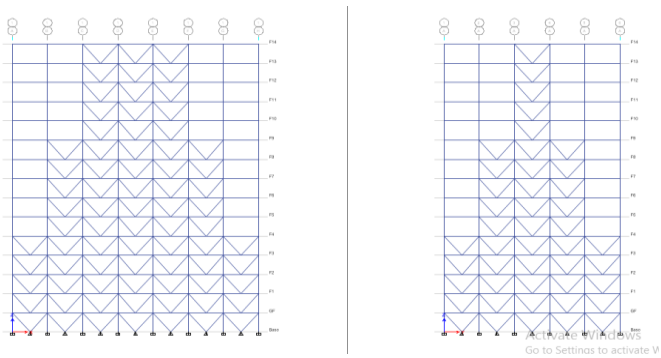

Fig. 3. Concentric V bracing

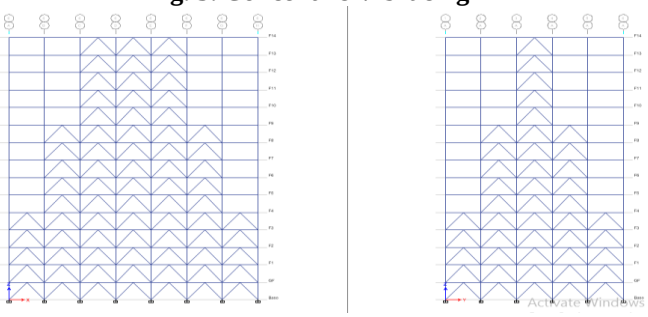

Fig. 4. Concentric Chevron bracing

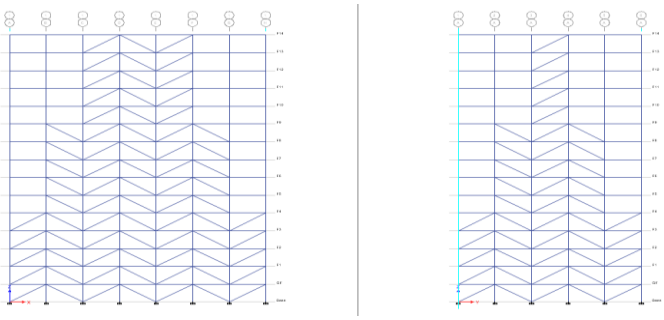

Fig. 5. Concentric D bracing

IV. ECCENTRICALLY BRACED FRAME

For this work, different types of EBF are designed, i.e. with V type bracing, chevron bracing and D type bracing. Similar to CBF, full bracing is provided up to five storey and with increase in height, bracings are reduced at every five storey interval.

V type bracing:

For V type bracing, three models are designed for an eccentricity of 10%, 20% and 30% (i.e. at 500 mm, 1000 mm and 1500 mm). Model for Eccentric V type bracing is as shown below (Fig. 6).

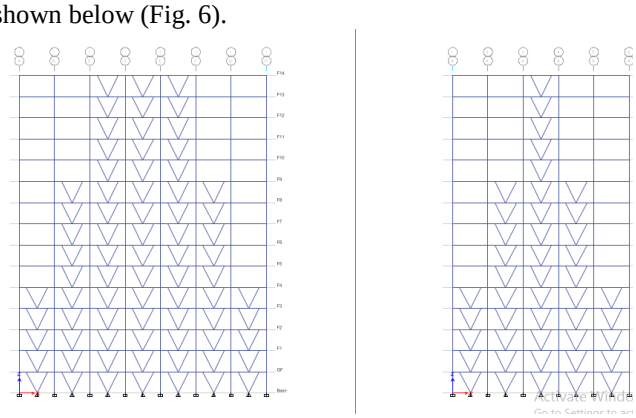

Fig. 6. V type bracing with 20% eccentricity

Chevron bracing:

For chevron bracing, two models are designed for an eccentricity of 10% and 20% from centre. Model for Chevron bracing is as shown below (Fig. 7).

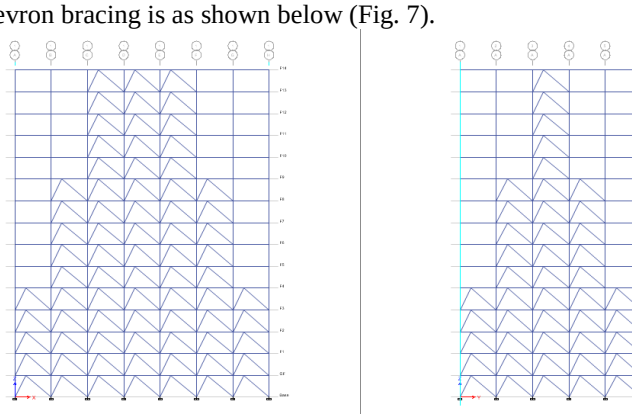

Fig. 7. Chevron bracing with 20% eccentricity

D type bracing:

For D type bracing, two models are designed for an eccentricity of 10%, 20% and 30% (i.e. at 500 mm, 1000 mm and 1500 mm). Model for Eccentric type D bracing is as shown below (Fig. 8).

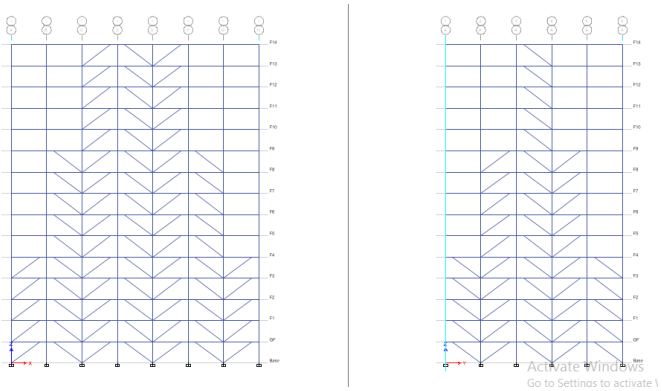

Fig. 8. Eccentric D type bracing

V. RESULTS AND DISCUSSIONS

According to IS 1893:2016 Cl 7.11.1.1, maximum allowable deflection in the structure is equal to 0.004 times the height of the structure. Height of the structure in this case is 45 m. Hence, maximum allowable deflection in the structure is 0.004 x 45 m = 180 mm. Arrangement and number of bracing remains same for all the modeling cases (as shown in figure above).

The deflection is checked for all the 13 load combination mentioned above. Following are the results of the maximum deflection in the building for the governing load combination, when no bracings are provided.

Table-III: Deflection of Unbraced frame

Sr. No.	Load combinations	Deflection (mm)
1	1.2 (DL + LL + EQX)	207.8
2	1.2 (DL + LL + EQY)	222.1
3	1.5 (DL + EQX)	258.6
4	1.5 (DL + EQY)	276.1

Results show that the deflection in the structure due to mentioned load combination exceeds the allowable deflection limit i.e. 180 mm. Purpose of providing bracing is to reduce the deflection in the building.

Three different types of concentric bracing are provided in the structure: V type, Chevron type and D type bracing. The results of maximum deflection for the same are shown below in Table IV.

Table-IV: Deflection of CBF system

Sr. No.	Load combinations	Deflection (mm)		
		V type	Chevron type	D type
1	1.2 (DL + LL + EQX)	120.5	118.3	134.7
2	1.2 (DL + LL + EQY)	160.6	156.2	168.8
3	1.5 (DL + EQX)	149.6	147	160.3
4	1.5 (DL + EQY)	199.5	194.2	209.8

Results for concentric bracing show that the deflection at top storey exceeds in all three arrangement for the load combination 1.5(DL + EQY). Hence, concentric bracing is also not sufficient.

To further reduce the top storey deflection, eccentric braced frame is designed with different types of bracing. Models are designed with varying eccentricity and different arrangement of EBF (V type, Chevron type and D type) to check the deflection of structure, and axial force and bending moment for the load carrying member.

The results for V type EBF system with varying eccentricity is shown in Table V.

Table-V: Deflection for V type EBF system

Sr. No.	Load combinations	Deflection (mm)		
		10% (500 mm)	**20%** (1000 mm)	**30%** (1500 mm)
1	1.2 (DL + LL + EQX)	38.1	48.4	150.5
2	1.2 (DL + LL + EQY)	60.8	70.2	183.6
3	1.5 (DL + EQX)	47.3	59.4	194.6
4	1.5 (DL + EQY)	74.6	86.4	228.5

The above result shows that the deflection increases with increase in eccentricity. For 10% and 20% eccentricity, deflection for all the load combinations is within the allowable limits and for 30% eccentricity the deflection value exceeds the allowable deflection limit of structure.

The deflection for chevron type bracing with eccentricity is shown below in Table VI.

Table- VI: Deflection for Chevron type EBF system

Sr. No.	Load combinations	Deflection (mm)	
		10%	**20%**
1	1.2 (DL + LL + EQX)	119	121.4
2	1.2 (DL + LL + EQY)	156.7	158.4
3	1.5 (DL + EQX)	148	150.8
4	1.5 (DL + EQY)	194.6	197.1

Results show that the deflection value exceeds for the load combination 1.5(DL + EQY). Also, the deflection exceeds the value of deflection then concentric chevron type. Hence more number of braces should be provided in Y direction to reduce the deflection.

Three models are designed for D type bracing with varying eccentricity. The results of deflection are shown below in Table VII.

Table- VII: Deflection for D type EBF system

Sr. No.	Load combinations	Deflection (mm)		
		10% (500 mm)	**20%** (1000 mm)	**30%** (1500 mm)
1	1.2 (DL + LL + EQX)	133	136.9	145.6
2	1.2 (DL + LL + EQY)	167	169.3	175.4
3	1.5 (DL + EQX)	165.3	170.1	181
4	1.5 (DL + EQY)	207.6	210.6	218.2

Results show that deflection exceeds the allowable limit for the load combination 1.5(DL + EQY). Hence similar to chevron type, more number of braces should be provided in Y direction to limit the deflection within allowable limits.

VI. AXIAL LOAD AND MOMENT CARRYING CAPACITY

Axial stress in a member shall not exceed 40% of f_{ck} under seismic loading as per Cl. 7.1, IS 13920:2016. Hence the allowable axial stress is 12 N/mm2. For analysis, one interior and one exterior column are selected at the ground storey which experience the maximum axial load. The columns selected are as shown below in Fig. 9.

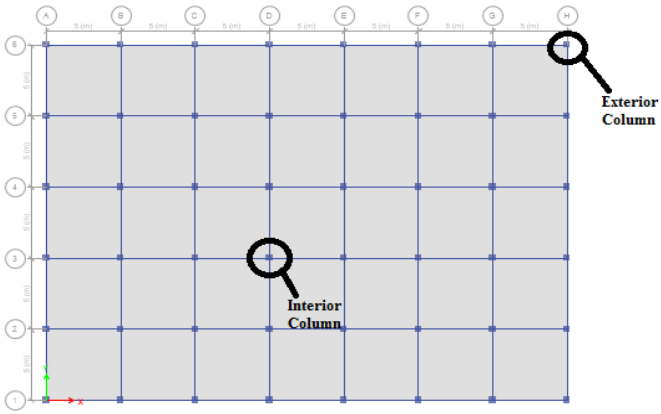

Fig. 9. Position of interior and exterior column

The axial load and moment carrying capacity for exterior column are as shown below in Table VIII.

Table- VIII: Moment capacity of exterior column

ARRANGEMENT	AXIAL COMPRESSIVE LOAD (kN)	MOMENT (kN.m)
Unbraced	5746.11	773.5
V bracing (10%)	5977	423.43
V bracing (20%)	5776	434.08
V bracing (30%)	6647.33	689.19
Chevron (10%)	9490.76	198.45
Chevron (20%)	9330.64	215.15
D bracing (10%)	8712.5	575.76
D bracing (20%)	8431.48	566.15
D bracing (30%)	7896.36	209.96

(Number in bracket indicates percentage of eccentricity)

From the results, it is found that axial load in the model with bracing is more than that compared to unbraced model. Bending moment is significantly very less in the models with bracing compared to that of unbraced model. Moreover, it is found that axial stress for all the arrangement exceeds the allowable limit for exterior column.

The axial load and moment carrying capacity for interior column are as shown below in Table IX.

Table- IX: Moment capacity of interior column

ARRANGEMENT	AXIAL COMPRESSIVE LOAD (kN)	MOMENT (kN.m)
Unbraced	7939.13	770.36

V bracing (10%)	7946.06	254.03
V bracing (20%)	7944.59	285.9
V bracing (30%)	7935.35	651.25
Chevron (10%)	7936.68	222.32
Chevron (20%)	7936.32	228.46
D bracing (10%)	7939.35	546
D bracing (20%)	7939.26	561.9
D bracing (30%)	7939.2	597.5

(Number in bracket indicates percentage of eccentricity)

Similar to interior column, axial stress for exterior column also exceeds the allowable stress. Hence the section is to be redesigned.

From the results, it is found that V bracing with 10% eccentricity is ideal against seismic activity as the deflection of the building is well within the limits; and axial load and moment carrying capacity are also less compared to other arrangements. Hence, it is to be checked that reinforcement required for V bracing with 10% eccentricity is within the limits.

VII. REINFORCEMENT REQUIRED

For unbraced building, it is found that percentage of steel required is 7.5%. To find reinforcement required for V bracing with 10% eccentricity, maximum axial load out of both the two cases (i.e. interior column and exterior column) is considered. Hence for interior column,

Pu = 7946.06 kN

Mu = 254.03 kN.m

$$\frac{P_u}{f_{ck}.b.D} = \frac{7946.06 \times 10^6}{30 \times 550 \times 550} = 0.876$$

$$\frac{M_u}{f_{ck}.b.D^2.} = \frac{254.03 \times 10^6}{30 \times 550 \times 550^2} = 0.050$$

Using above values from Chart 44, SP-16; it is found that percentage of steel required is 5.1%. But according to IS 456:2000 - Cl. 26.5.3.1 (a), maximum allowable percentage of steel in column is 4%. Hence, this arrangement of V bracing is not satisfactory.

VIII. SOLUTION

As the amount of reinforcement required exceeds the allowable limit, there are two possible solutions: To increase the cross section of the column at bottom storey or to increase the grade of concrete.

Case I: To increase the size of column

Due to increase in size of column, axial stress in the column decreases. Let the column size be taken as,

- Up to 5th storey - 650 mm x 650 mm
- From 5th -10th storey – 500 mm x 500 mm
- From 10th -15th storey – 450 mm x 450 mm

With the above mentioned dimension of column, percentage of steel required for V bracing with 10% eccentricity is 2.4%. The required reinforcement is within the allowable limits according to IS 456(2000) - Cl. 26.5.3.1 (a). And the maximum deflection in the building is 69.1 mm, which is within the allowable limits (i.e. 180 mm).

Case II: To increase the grade of concrete

By increasing the grade of concrete to M40, it is found that the percentage of reinforcement required for V bracing with 10% eccentricity is 3.6%. The required reinforcement is within the allowable limits according to IS 456(2000) - Cl. 26.5.3.1 (a). Also maximum deflection in the building is 67.3 mm, which is within the allowable limit (i.e. 180 mm).

IX. CONCLUSION

This paper presents the performance of RC building with steel bracing under seismic loading. Different types of bracing such as V type bracing, chevron bracing and diagonal bracing are used for analysis. On comparing between results of CBF and EBF, it is found that deflection in EBF is comparatively less than that of CBF for 10% eccentricity. Also, it is found that with increase in eccentricity, deflection also increases. With increase in eccentricity from 10% to 20% for V type bracing, deflection increases by 15.81%. And with increase in eccentricity from 10% to 30%, deflection increases by 206.3%.

The deflection for Unbraced, CBF and EBF system with various load combinations is shown in Fig. 10. From results, it is found that for V type bracing with 10% eccentricity, deflection decreases by 81.66% compared to unbraced frame and it decreases by 68.38% compared to CBF.

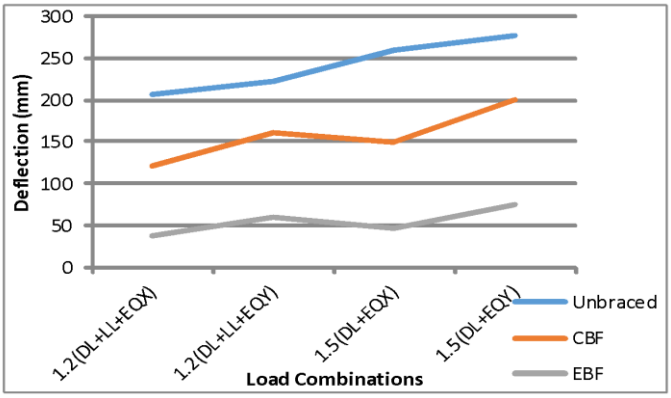

Fig. 10.Load Combination V/s Deflection

The deflection for different types of EBF system is shown in Fig.11. From that we can conclude that the V bracing is efficient then Chevron bracing and Diagonal bracing.

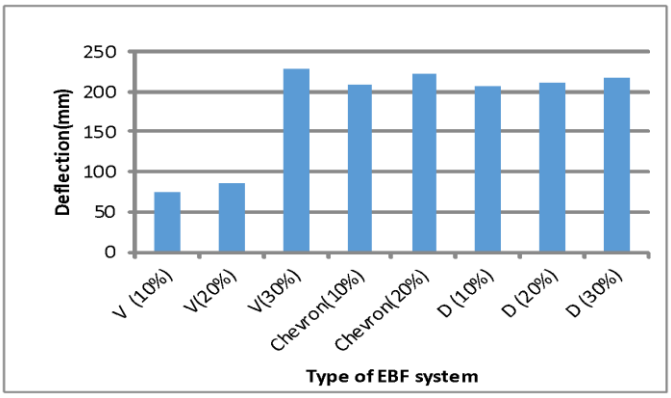

Fig. 11.Deflection for different types of EBF

Moment carrying capacity of interior column is found very less for EBF compared to unbraced building. Also, moment carrying capacity is found to increase with increase in eccentricity. Hence to find the suitable arrangement of bracing, all the aspects must be considered.

Out of all the different arrangements with EBF, only V bracing with 10% eccentricity and 20% eccentricity are found to have their deflection within allowable limits. Also for these two arrangements, axial load and moment carrying capacity are found very less compared to other arrangement.

Hence, V type bracing with eccentricity up to 20% are reliable under seismic condition.

REFERENCES

1. Adil Emre Ozel and Esra mete Guneyisi, "Effects of eccentic steel bracing system on seismic fragility curves of mid-rise RC building," Structural Safety 33, 2011, pp. 82-95.
2. Homayoon Estekanchi, Ahmad Soltani and Abolhassan Vafai, "Seismic behaviour of stell frames with off-center bracing system" 13th world conference on earthquake engineering, Vancouver, 2004, paper No. 1787.
3. Samuel Dalton Hague, "Ecentrically braced steel frames as a seismic force resisting system," unpublished.
4. Nicka Keipour, Elyar Zafarkhah and Masood Mofid, "Effect of height of buildings and arrangement of braces on RC buildings retrofitted with steel knee braces based on incremental dynamic analysis(IDA)," 15 WCEE, Lisboa 2012, pp. 1-10.
5. M.N. Chimeh and P. Homami, "Efficiency of bracing system for seismic rehabitation of steel structures", 15 WCEE, Lisboa 2012, pp. 1-8.
6. Moghaddam H.A. and Estekanchi H.E., "Seismic behaviour of off-centre bracing systems", J. Construct Steel Research, Vol.51, 1999, pp. 177-196.
7. Balendra T, Lam K.Y., Liaw C.Y. and Lee S L. "Behavior of Eccentrically Braced Frame by Pseudo- Dynamic Test," ASCE, Vol. 11: 3, 1987, pp. 673-688.
8. IS 456 (2000) : Plain And Reinforced Concrete – Code Of Practice, Bureau of Indian Standards, New Delhi, July, 2000.
9. IS 13920 (2016) : Ductile Detailing Of Reinforced Concrete Structures Subjected To Seismic Forces – Code Of Practice, Bureau of Indian Standards, New Delhi, July, 2016.
10. SP 16 (1980) : Design Aids For Reinforced Concrete To Is 456(1978), Bureau of Indian Standards, New Delhi, March, 1999.
11. IS 1893 (Part 1) : 2016 – Criteria For Earthquake Resistant Design Of Structures, Bureau of Indian Standards, New Delhi, June 2002.
12. C.V.R. Murty, " Earthquake Behaviour of Buildings", unpublished

AUTHORS PROFILE

Somil Khattar has completed his Masters in Structural Engineering from Vellore Institute of Technology, Chennai, India. He holds interest in performance-based building design and designing high-rise building. He is a member of GICEA (Gujarat Institute of Civil Engineers & Architects) and ICE (Institute of Engineers India). Currently he is practicing structural engineering at one of the leading consultants firm of India.

Dr. Muthumani K. has completed his Master and Ph.D from Indian Institute of Technolgy, Madras (India). He has served as Chief Scientist at Structural Engineering Research Centre, Chennai. He headed a research team which carried out projects in performance based earthquake resistant design. He established Advanced Seismic Testing and Research Laboratory at Structural Engineering Research Centre. Ha has experience of more than 35 years in the field of Structural Engineering and is currently serving as the professor at Vellore Institute of Technology, Chennai, India.