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STUDY OF STEEL CONCENTRIC BRACED FRAME STRUCTURES UNDER SEISMIC LOADING FOR VARIOUS SEISMIC ZONES

Sain Mukul[1], Gupta Archana Bohra[2]

[1]*Master of Engineering (Civil - Specialization in Structure Engineering) Scholar M.B.M. Engineering College, J.N.V. University, Jodhpur, India*
[2]*Associate Professor, Dept. of Structural Engineering, M.B.M. Engineering College, J.N.V. University, Jodhpur, India*

Abstract - *Concentric braced frame is a type of structural system which is used to resist lateral forces (wind or seismic forces). In the recent few years, world has witnessed many severe seismic events. These events have challenged the bracing systems of steel structures and standard criteria being used in their design. Past earthquakes in United States and Japan show the nature and behavior of steel concentric braced frames during the calamity. Studies of moderate to severe earthquakes give us a good opportunity to study and adequately design these structures. In this study, Single braced, X-braced, V-braced and Chevron (Inverted V) braced frame structures have been compared with unbraced framed structure for various seismic zones for seismic behavior case study by using of software package ETABS. The ground is kept sloping at 10o. The study showed that Chevron bracing gives the maximum advantage in terms of reduced bending moment and reduced deflection for seismic loading as compared to other braced frames considered in the study.*

Keywords*- Steel concentric braced frame, sloping ground, Single bracing, X-bracing, V-bracing, Chevron bracing, seismic behavior, ETABS*

I. INTRODUCTION

In recent few decades steel structures play an important role in the field of construction industry. When we design, it is necessary to design a structure to perform well under seismic loads. Shear capacity of the structure can be improved by introducing steel bracings in the structural system. Bracings can increase the energy absorption of structures or decrease the demand forced by earthquake loads. The addition of bracings to the structures with amplified energy dissipation may safely resist forces and deformations triggered by vigorous ground waves. Concentrically braced frames are widely used all over the world to provide lateral strength and stiffness to low and mid-rise buildings to resist wind and earthquake forces. A braced frame is a structural system which is commonly used in structures subject to lateral loads. The addition of bracings to any structural frame increases the structure's stability, stiffness and strength against lateral loads such as wind load and seismic load. The members in a braced frame are many times made of structural steel which can work effectively both in tension and compression.

Concentrically braced frames are classified as either ordinary concentric braced frame or special concentric braced frame. Ordinary concentric braced frames (OCBF) do not have large scale requirements regarding members or connections and are frequently used in areas of low seismic risk zone. Special concentrically braced frames (SCBF) or eccentrically braced frames (EBF) are equipped with enhanced design requirements, and are frequently used in areas of high seismic risk.

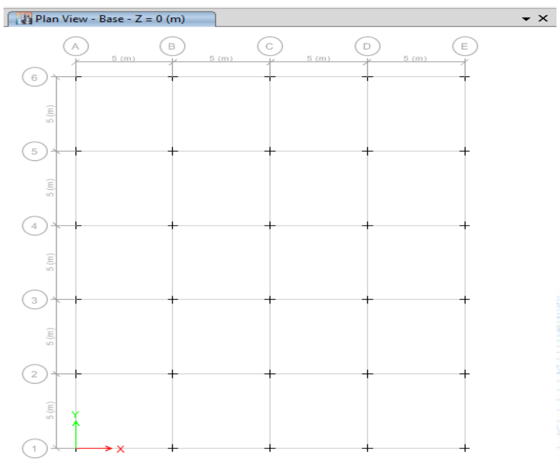
II. PAST REASERCHES

1. Tremblay R. (2000), studied nonlinear dynamic analyses which were performed on 2-, 4-, 8-, and 12-storey Chevron (inverted V) braced steel frames subjected to earthquake ground motions.
2. Fell B. V., Kanvinde A. (2004) studied about a methodology to predict ductile crack initiation in structural steel members. The underlying process of Ultra Low Cycle Fatigue (ULCF) is modeled through a micromechanics-based fracture criterion which combines material properties and stress-strain histories at individual material points, as opposed to using gross measures of strain. Experimental results from the first test are encouraging in that predictions of failure are fairly close to the real failure points in time and location.
3. Broderick B.M., Elghazouli A.Y. (2004) did an experimental study by which the response of hollow and filled cold-formed hollow steel bracing members to cyclic loading was investigated.
4. Miri M. et al (2009) studied on the effects of asymmetric bracing on steel structures under seismic Loads**.** He mentions that the structure is irregular because sometimes mass source and stiffness source are not coincident due to its architectural condition and structure appositeness.

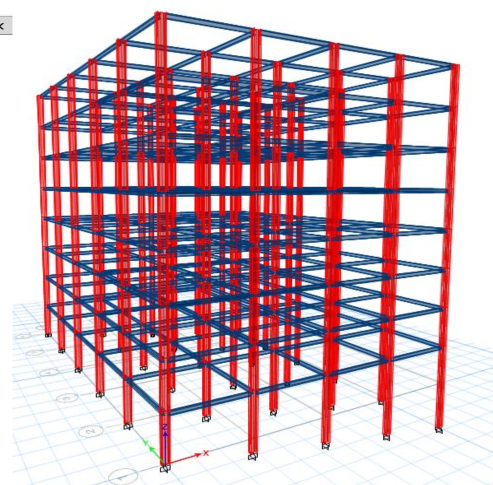
5. G.Brandonisio et al (2012) made some modifications to the design procedure in modern European seismic code, for improving the ductile cross concentric bracing frame.
6. Zalka K.A. (2014) studied the deflection of asymmetric wall-frame buildings under horizontal load. He presented a new analytical procedure for the determination of the maximum deflection of asymmetrical multi-story buildings braced by frameworks, shear walls and cores.
7. Salawdeh S., Goggins J. (2016) studied the direct displacement based design (DDBD) procedure for single-storey concentrically braced frames (CBFs).

III. PROBLEM FORMULATION

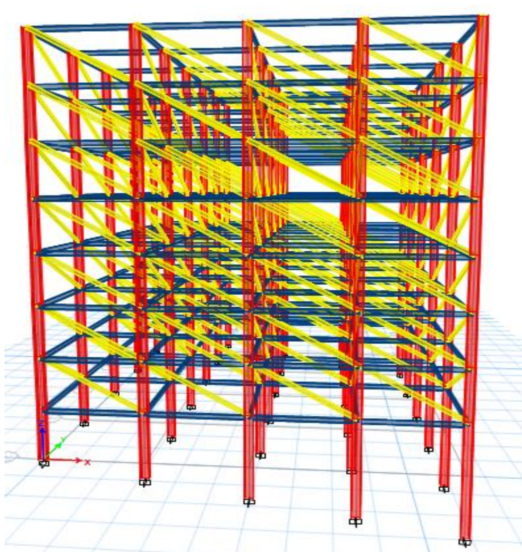
An un-braced building having eight-storeys has been considered for the study of maximum bending moment, maximum shear force, and maximum deflection for seismic zones II to V. the two lateral directions are taken as X and Y directions and the vertical direction is the Z direction in the study. In X-direction we have considered 4 panels while in Y-direction we have considered 5 panels. The length and width of each panel in both directions are taken as 5 meters. The height of each storey is taken as 3 meters. This building is situated on a ground sloping at 10 degree in X direction. A hard soil stratum is taken for the study. This model is considered as frame-1 which we can call as standard or reference frame building. Single braced frame, X-braced frame, V-braced frame, and Chevron braced frames are considered as frame-2, frame-3, frame-4, and frame-5 respectively for the study.



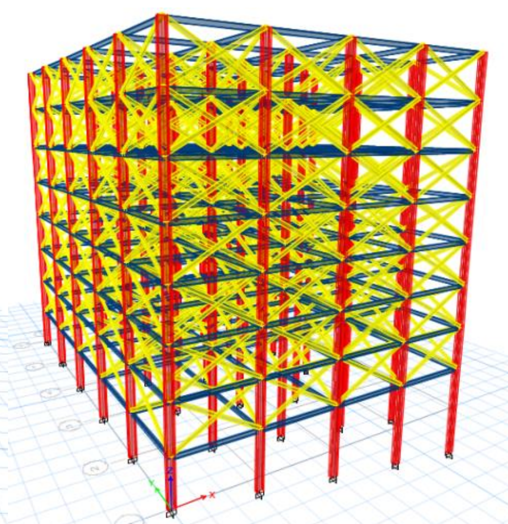
Plan view



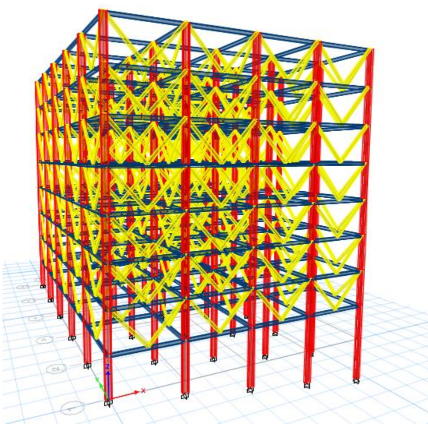
Frame-1 Un-braced frame



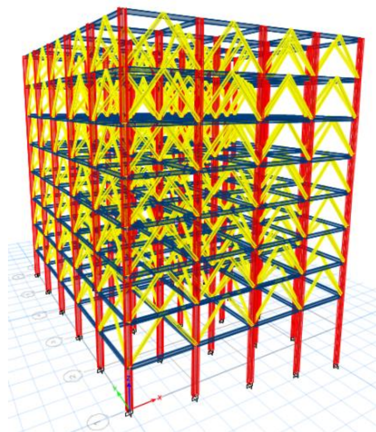
Frame-2 Single braced frame



Frame-3 X-braced frame



Frame-4 V-braced frame



Frame-5 Chevron (Inverted V) braced frame

Figure-1 Frames 1 to5

The following frame sections have been considered (taken from SP-6):

Table-III.I Frame sections

TABLE: Frame Sections									
Name	Material	Shape	Sections	d	b	tf	tw	bf	tf
				mm	mm	mm	mm	mm	mm
BEAM	Fe250-1	Steel I/Wide Flange	ISMB 250	250	125	12.5	6.9	125	12.5
BRACING	Fe250-2	Steel I/Wide Flange	ISMB 200	200	100	10.8	5.7	100	10.8
COLUMN	Fe250	Steel I/Wide Flange	ISHB 400	400	250	12.7	10.6	250	12.7

Fe250, Fe250-1, Fe250-2 are all same mild steel with yield stress 250 N/mm^2. The difference in names has been taken only for ease in modeling in the software.

Seismic load definitions:-
Seismic load is as per IS: 1893 (Part 1) - 2002. Following are the parameters:-
Zone factor- For each model/frame four different zone factors has been taken.
Zone II – 0.10, for Zone III– 0.16, for Zone IV– 0.24, for Zone V- 0.36.
Steel concentric braced frame structures have been considered.
Type I Hard soil has been taken. Response reduction factor- 4, Importance factor 1
The following loading combinations have been taken for the study:-
1. DEAD LOAD
2. EQ+X – Earthquake load acting in the positive X direction,
3. EQ+Y - Earthquake load acting in the positive Y direction,
4.1.5 D.L. + 1.5 EQ+X
5.1.5 D.L. - 1.5 EQ+X
6.1.5 D.L. + 1.5 EQ+Y
7.1.5 D.L. - 1.5 EQ+Y

In the present study, frame-2, frame-3, frame-4, and frame-5 are compared with frame-1 for all seismic zones. In the observation part, the parameters namely maximum bending moment, maximum shear force and maximum deflection have been studied.

IV. OBSERVATIONS AND DISCUSSIONS

Table-IV.1 Percentage reduction/increase in bending moment zone wise (Negative sign shows increase)

S. No.	Frame	Percentage Reduction/Increase in Max. Bending Moment for Critical Load Combination							
		ZONE 2		ZONE 3		ZONE 4		ZONE 5	
		X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.
1	Single Braced Frame	1.64	-59.97	19.89	-58.11	35.15	-55.73	48.87	-52.35
2	X- Braced Frame	38.19	-3.04	50.30	-1.80	60.49	-0.22	69.65	2.01
3	V - Braced Frame	33.02	-11.14	46.05	-9.68	57.01	-7.82	66.87	-5.19
4	Inv V- Braced Frame	81.83	70.89	85.05	71.25	87.76	71.71	90.20	72.35

Table-IV.2 Percentage increase in shear force zone wise

S. No.	Frame	Percentage Increase in Max. Shear Force for Critical Load Combination							
		ZONE 2		ZONE 3		ZONE 4		ZONE 5	
		X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.
1	Single Braced Frame	38.08	107.50	36.27	100.80	35.24	96.27	34.55	92.82
2	X- Braced Frame	80.56	196.56	77.77	187.41	76.18	181.23	75.11	176.51
3	V - Braced Frame	46.90	72.01	47.14	77.47	47.28	81.20	47.37	84.04
4	Inv V- Braced Frame	49.19	99.16	48.05	95.69	47.40	93.35	46.96	91.58

Table-IV.3 Percentage reduction in deflection zone wise

S. No.	Frame	Percentage Reduction in Max. Deflection for Critical Load Combination							
		ZONE 2		ZONE 3		ZONE 4		ZONE 5	
		X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.	X Dir.	Y Dir.
1	Single Braced Frame	77.18	75.12	78.24	77.34	78.82	78.58	79.21	79.40
2	X- Braced Frame	76.39	80.42	78.42	80.60	79.58	80.71	80.35	80.78
3	V - Braced Frame	78.13	81.75	79.79	82.05	80.73	82.21	81.36	82.33
4	Inv V- Braced Frame	79.22	82.75	80.80	82.88	81.70	82.94	82.30	82.98

1. VARIATION OF BENDING MOMENT

The values of maximum bending moment for each type of frame are increasing when we calculate from zone II to zone V. The maximum value of bending moment in any frame is obtained in the top most column at the end of the frame when earthquake load is applied in the X direction. The actual maximum values for some frames (inverted V frame, X braced frame) are obtained at the base since there the frame is unbraced. This has been neglected in comparison to obtain a clear picture of the advantage/disadvantage of providing bracings in the frames. There we neglect the bottom most frame where bracings are not provided. The maximum bending moment values reduce when braced frames are provided. When earthquake load is applied in the other lateral direction, due to slope of ground in perpendicular direction, the behavior of the frame changes to a great extent and maximum bending moment locations change for each frame.

(A) The bending moments for the frames 1 to 5 for seismic zone II for critical load combination in X-direction, we find that it is reduced by 1.64% for single braced which is the minimum reduction. The maximum reduction is for Chevron braced frame which is 81.83%. For critical load combination in Y-direction, the bending moment increases by 59.97% for single braced, 3.04% for X-braced, 11.14% for V-braced while bending moment reduced by 70.89% in Chevron braced frame. When the lateral load is applied in this direction, the frame is subjected to twisting in addition to bending, due to slope of ground in the perpendicular direction. That is why the bending moment nature has changed at a particular location for the various frames.

(B) For seismic zone III, the bending moments for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 19.89% for single braced which is the minimum reduction and the maximum reduction is for Chevron braced frame which is 85.05%. For critical load combination in Y-direction, the bending moment increases by 58.11% for single braced frame, 1.80% for X-braced frame, 9.68% for V-braced frame while bending moment is reduced by 70.89% in Chevron braced frame.

(C) For seismic zone IV, the bending moments for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 35.15% for single braced which is the minimum reduction, 60.49% for X-braced frame, 57.01% for V-braced frame. The maximum reduction is for Chevron braced frame which is 85.05%. For critical load combination in Y-direction, the bending moment increases by 55.73% for single braced frame, 0.22% for X-braced frame, 7.82% for V-braced frame while bending moment is reduced by 71.71% in Chevron braced frame.

(D) For seismic zone V, the bending moments for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 48.87% for single braced which is the minimum reduction, 69.65% for X-braced frame, 66.87% for V-braced frame. The maximum reduction is found by the Chevron braced frame which is 90.20%. For critical load combination in Y-direction, the bending moment increases by 52.35% for single braced frame, 5.19% for V-braced frame while bending moment is reduced by 2.01% for X-braced frame and 72.35% for Chevron braced frame.

2. VARIATION OF SHEAR FORCE

The values of maximum shear force for each type of frame are increasing when we calculate from zone II to zone V. The maximum value of shear force in any frame is obtained in the column at the location where the bracing starts from the bottom of frame.

(A) For seismic zone II, the shear force for the frames 1 to 5 for critical load combination in X-direction, we find that the shear force is increased by 38.08% for single braced frame which is the minimum increase. The maximum increase is for X - braced frame which is 80.56%. While for critical load combination in Y-direction, it is increased by 72.01% for V-braced which is the minimum increase. The maximum increase is for X -braced frame which is 196.56%. We also found that shear force increase by 107.50% for single braced frame and 99.16% for Chevron braced frame.

(B) For seismic zone III, the shear force for the frames 1 to 5 for critical load combination in X-direction, it is increased by 36.27%, 77.77%, 47.14% and 48.05% respectively for single braced, X-braced, V-braced and Chevron braced frame. While for critical load combination in Y-direction, it is increased by 100.8%, 187.41%, 77.47% and 95.69% respectively for single braced, X-braced, V-braced and Chevron braced frame.

(C) For seismic zone IV, the shear force for the frames 1 to 5 for critical load combination in X-direction, it is increased by 35.24%, 47.28%, 47.4% and 76.18% respectively for single braced, V-braced, Chevron braced frame and X-braced frame. While for critical load combination in Y-direction, it is increased by 81.20% for V-braced frame which is minimum while shear force is increased by 181.23% for X-braced which is maximum.

(D) For seismic zone V, the shear force for the frames 1 to 5 for critical load combination in X-direction, it is increased by 34.55%, 75.11%, 47.37% and 46.96% respectively for single braced, X-braced, V-braced and Chevron braced frame. While for critical load combination in Y-direction, it is increased by 84.04% for V-braced frame which is minimum value while shear force is increased by 176.51% for X-braced which is maximum value.

3. VARIATION OF DEFLECTION

The values of maximum lateral deflection for each type of frame are increasing when we calculate from zone II to zone V. The maximum value of deflection in any frame is obtained in the top most end joint of the frame. These values reduce when braced frames are provided.

(A) For seismic zone 2^{nd}, the deflection for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 76.39% for X-braced which is the minimum reduction. The maximum reduction is for Chevron braced frame which is 79.22%. In Y-direction, deflection reduced by 75.12% for single braced frame which is the minimum reduction. The maximum reduction is for Chevron braced frame which is 82.75%.

(B) For seismic zone 3^{rd}, the deflection for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 78.24% for single braced which is the minimum reduction. The maximum reduction is for Chevron braced frame which is 80.80%. We also find that the deflection in X-braced frame and V-braced frame are reduced by 78.42% and 79.79%

respectively. In Y-direction, it is reduced by 77.34% for single braced which is the minimum reduction. The maximum reduction is for Chevron braced frame which is 82.88%. We also find that the deflection in X-braced frame and V-braced frame are reduced by 80.6% and 82.05% respectively.

(C) For seismic zone 4^{th}, the deflection for the frames 1 to 5 for critical load combination in X-direction, we find that the deflection reduces by 78.82%, 78.42% and 79.79% for single braced frame, X-braced frame and V-braced frame respectively. The maximum reduction is for Chevron braced frame which is 80.80%. In Y-direction, the deflection reduces by 78.58%, 80.71% and 82.21% for single braced, X-braced frame and V-braced frame respectively. The maximum reduction is for Chevron braced frame that is 82.94%.

(D) For seismic zone 5^{th}, the deflection for the frames 1 to 5 for critical load combination in X-direction, it is reduced by 79.21% for single braced, 80.35% for X-braced, 81.36% for V-braced and 82.3% for Chevron braced frame. In Y-direction, we find that the deflection reduces by 79.40% for single braced, 80.78% for X-braced, 82.33% for V-braced and 82.98% for Chevron braced frame.

V. CONCLUSIONS

[1] There is a reduction in bending moment when braced frames are provided in place of unbraced frame for earthquake loading in X direction where ground is sloping. [2] The inverted V braced frame (Chevron braced frame) provides maximum reduction in bending moment for earthquake in X direction while single braced frame provides the minimum reduction in bending moment. [3] The values of maximum shear force for each type of frame are increasing when we calculate from zone II to zone V. [4] The percentage increase in the values of maximum shear force when braced frames are taken in place of unbraced frame reduces when we calculate from zone II to zone V (five) except for V braced frame where the percentage increase is increasing with the increase in zone but the increase is very small. [5] The X braced frame has maximum percentage increase in shear force for earthquake in X direction while single braced frame provides the lowest increase in shear force. Then V frame has the second highest values of percentage increase in maximum shear force as compared to unbraced frame. Inverted V frame has the third highest values of percentage increase in maximum shear force as compared to unbraced frame. [6] The inverted V frame provides maximum reduction in deflection for earthquake in X direction while single braced frame provides the minimum reduction in deflection. However the difference in percentage reduction in maximum deflection between single braced and inverted V braced frame is only 2-3% (2.04% for zone II, 2.56% for zone III, 2.88% for zone IV and 3.09% for zone V). [7] The Chevron braced frame provides maximum advantage when we consider earthquake forces as compared to an unbraced frame. [8] Single braced frame is more economical as compared to Chevron braced frame. It also provides considerable advantage as compared to unbraced frame when we consider earthquake forces, as far as deflection is concerned but the reduction in bending moment is less. [9] The changes in variation trend of bending moment and increase of shear force when earthquake force is applied in Y direction are due to the twisting of frame owing to slope of ground in perpendicular direction (X direction), which needs further study with varying slopes to get a better understanding of the behavior of braced frames for such a case.

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