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# Seismic Behavior of Full Scale Concentrically Braced Steel Building Structure

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***Abstract: This paper presents the structural behaviour of full-scale six-story, 2 by 2 bay concentrically braced steel building under seismic loading In this we have modelled three three-dimensional models and five two-dimensional frames with same material and section properties and dimensions. The main object is to study participation of braces and moment resisting frames in carrying storey shear. Each model is analysed using ETABS software and different parameters such as base shear, storey forces, displacement, storey shear and storey stiffness were compared and percentage storey shear carried by braces and moment resisting frames is obtained for frames with different types of bracings. The response of the building with different bracing configuration at different locations is represented in tables and graphs which will help to understand the behaviour of the concentrically braced steel building under seismic loading more accurately.***

***Keywords: Steel structure, Concentrically braced frames, Moment resisting frames, Full-scale, K-brace, X- brace, Equivalent static load, Response spectrum.***

## I. INTRODUCTION

In all kinds of structural building system the main aim is to transfer the gravity load effectively and thus assure safety of the structure. Structure is subjected to lateral loads which can develop high stress which will cause sway of the structure and also vertical loads. Usually buildings are subjected to various loads i.e. Lateral load due to wind and earthquake and vertical loads due to gravity. The structure should be strong enough to resist all types of loads. The structures show large displacement especially in tall structures when it is subjected to lateral loads, to reduce this displacement moment resisting frames along with different types of lateral load resisting structural forms are used. Among all lateral load resisting structural systems braces and shear walls are the most commonly used lateral load resisting systems. The present work focuses on behavior of concentrically braced steel structure.

For resisting lateral loads different types of structural systems are available such as bracings, moment resisting frames, shear walls coupled shear wall etc. In this study behavior of steel moment resisting frames with concentric braces will be examined. In the structure braced frame system consists of truss members as bracing elements. These bracings are commonly used in structures, subjected to lateral loads. They resist lateral forces mainly with the brace members in compression or tension, also makes the structure laterally stiff which makes the bracing system highly efficient in resisting the lateral loads.

Since the lateral load on building is reversible braces are subjected to both tension as well as compression but usually they are designed for the more critical case of compression hence bracing systems are shorter in brace length, in case of double diagonal brace system braces are designed for both tension as well as for compression. The advantage of triangulated bracing type is that the girders shears and moments are independent of the lateral loading.

## II. LITERATURE REVIEW

Ching-Yi TSAI et al. (2010) in this paper three specimens of full scale two-story steel concentrically braced frames are tested, specimen is single bay with two-story X-brace configuration. The three models are differ by the brace types (hollow structural or wide-flange section) and the design criteria adopted for the connections of gusset plate. To study the responses of the specimen the nonlinear finite element method (FEM) program ABAQUS was used. It is observed that for the steel concentrically braced frame both the 2t-linear and 8t-elliptical designs of the gusset plate connection provide satisfactory ductility. It is found that about 90% of the lateral forces were carried by the braces and 10% is carried by the moment resisting frames, however when the buckling of braces occur the lateral forces resisted by the braces decreased [1]. Douglas A. Foutch (1989) the aim of this paper is to study the performance of the full-scale building. In this the building was designed for gravity loads which includes floor dead loads, live loads, cladding, and partition loads, for computing the design seismic loads the weight used did not include the cladding and also the live load, which is neglected for the seismic design. The objective of the test was to investigate the ductility, strength and failure mechanism of the EBF. Initially the two tests were planned. It is observed that during the initial inelastic test, about 80% of the total story shear is carried by the braces in each story, this reduced to about 55% for the first story during yielding and again increased to about 60% at the end of the test [2]. Hiroyuki Yamanouchi et al. (1989) the main aim of this paper is to study the seismic behavior of an inverted-V-braced structure having slenderness (L/r = 70-120) for braces. Experimental and analytical tests on the inverted-V-braced system is carried out and the results were discussed. On half-scale three storey steel frames with inverted-Vbraces static loading tests were carried out.

The total seismic behavior of the frame is mainly affected by the interaction between the brace and the moment resisting frame and post-buckling behavior of the brace these effects are discussed by using the experimental results on the half-sealed three-story models of the inverted-V-braced system.

To study the hysteretic lateral shear force versus inter-story drift relation of the structural system, hysteresis model for the inverted-V-braced systems is proposed based on post-buckling behavior of the braces. In the braced frame during test it is observed that column and beams are stable against lateral and local buckling and about 80% of lateral shear force is carried by braces in elastic range of deflection, which is then reduced to about 50% in the post-buckling range [3].

Douglas A. Foutch et al. (1989) in this paper seismic tests were carried out on a full-scale six-story, 2 by 2 bay steel building with concentric-K braces. At the Laboratory of the Building Research Institute of the Japanese Ministry of Construction steel building was constructed and the seismic tests are carried as a six-degree-of-freedom pseudo dynamic system.

Using several combinations of damping levels and input ground motion a linear and nonlinear analyses is carried out on the concentric braced building.

A connection panel zone failed during the moderate test resulting in the reduction in stiffness and strength of the structure. Before and after each major test of the research program vibration tests were performed on the structure, which will help in determining the damping of the structure and the frequencies or periods of the first several modes.

After the final test it is observed that initially about 80% of the total shear is carried by the braces and about 20% by the moment resisting frames, in later stages in the tests the braces are severely buckled and about 60% of the lateral load is carried by the moment resisting frames [4].

## III. OBJECTIVE AND METHODOLOGY

### *A. Objectives*

To study the seismic behavior of concentrically braced steel structure and compare the seismic parameters such as base shear, displacement etc. for steel frame with different bracing configuration at different locations. The main objective of study is to determine the percentage of story shear carried by seismic resistance braces and by moment resisting frames.

### *B. Methodology*

1) Modelling of steel structure using E-tabs software for the frames with different types of bracing configuration.
2) A linear response spectrum analysis is to be carried out as per Indian standard code (IS 1893:2002 part1).
3) Comparison of the seismic parameters such as base shear, displacement etc. for steel frame with different bracing configuration at different locations.
4) Study of % of storey shear carried by different type bracings and by moment resisting frames. 5. The overall behavior of a full-scale braced steel structure.

### *C. Modelling and Details of Structure*

It is a six-storey structure with a general floor plan and typical elevation. It is 15 m square plan with two bays of 7.5 m in each direction and storey height of 4.5m for storey 1 and 3.4m for the remaining storeys is considered. It measures about 21.5 m from the floor to the top of the roof girders. The structure consist of three frames (1, 2 and 3) parallel to the loading direction and three frames (A, B and C) perpendicular to the direction of loading.

*1) Material Properties*: It includes different properties such as grade, modulus of elasticity, poisons ratio, density etc. for different materials and also section properties for columns, girder, braces etc.

TABLE IMaterial Properties

| Concrete Properties | |
|---|---|
| Grade of concrete | M20 |
| Modulus of elasticity | 25000MPa |
| Density of concrete | 25 $kN/m^3$ |
| Poisson's ratio | 0.2 |
| Masonry Properties | |
| Density of brick wall including plaster | 20 $kN/m^3$ |
| Poisson's ratio | 0.2 |
| Steel Properties | |
| Mass per unit volume | 7850 $kg/m^3$ |
| Modulus of elasticity | 200000 Mpa |
| Poisson's ratio | 0.3 |

TABLE 2 Column Schedule

| Storey | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| 6-5 | ISMB450 | ISWB300 | ISWB300 | ISWB300 | ISMB400 |
| 4-3 | ISWB500 | ISWB450 | ISHB300 1 | ISMB500 | ISMB550 |
| 2 | ISMB600 | ISWB500 | ISMB450 | ISMB600 | ISWB600 2 |
| 1 | ISWB600 1 | ISWB600 1 | ISWB500 | ISWB600 2 | ISWB600 2 |

TABLE 3 Girder Schedule

| Storey | G1 | G2 | G3 | G4 |
|---|---|---|---|---|
| R-6F | ISMB300 | ISMB300 | ISMB350 | ISMB450 |
| 5F | ISMB300 | ISMB350 | ISMB350 | ISMB450 |
| 4F | ISMB350 | ISMB350 | ISMB350 | ISMB450 |
| 3F-2F | ISMB350 | ISMB400 | ISMB350 | ISMB450 |

TABLE 4 Miscellaneous Member Schedule

| Storey | Floor Beams | Braces |
|---|---|---|
| 6-5 | ISMB300 | ISB91.5X91.5X5.4 |
| 4 | ISMB300 | ISB125X125X6 |
| 3-2 | ISMB300 | ISB150X150X6 |
| 1 | ISMB300 | ISB150X150X12.5 |

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1) *Loading Details and Seismic Parameters:* Seismic parameters as per IS 1893-2002 and gravity load details are given in table no. 5 and 6 respectively.

TABLE 5 Seismic Parameters as per IS 1893-2002

| | |
|---|---|
| Zone (Z) | V (0.36) |
| Soil type | II (Medium) |
| Importance factor (I) | 1 |
| Response reduction factor (R) | 4 |
| Damping | 2% |

TABLE 5 Gravity Loads on the Structure

| Live load | |
|---|---|
| Floors | 3 kN/m$^2$ |
| Roof | 1.2 kN/m$^2$ |
| Dead load | |
| Self-weight of members | |
| Masonry wall load | 9 kN/m |
| Parapet wall load | 3 kN/m |

*D. Different Cases for Study*

*1)Model 1:* Building structure with three unbraced moment-resisting frames (Frames 1, 3 and B), a concentrically K brace (Frame 2 single bay) and X brace (Frame A and C) as shown in figure 1.

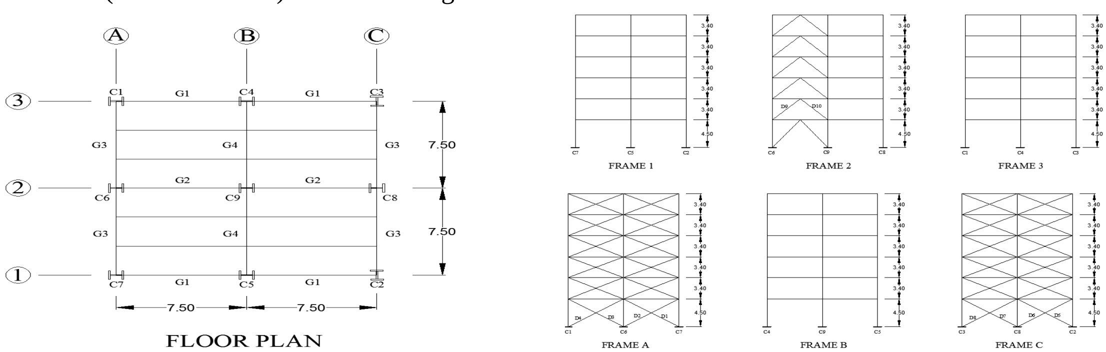


Fig. 1 Plan and frame details of model 1

2) *Model 2:* Building structure with three unbraced moment-resisting frames (Frames A, C and 2), a concentrically K brace (Frame 1 and 3 single bay) and X brace (Frame B) as shown in figure 2.

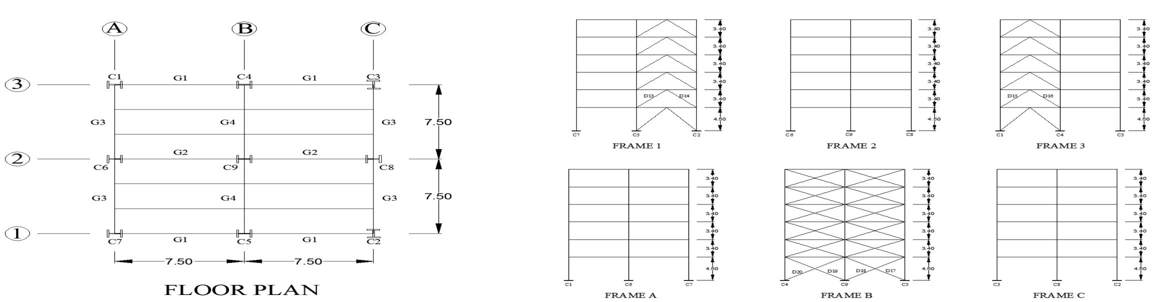


Fig. 2 Plan and frame details of model 2

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*3)* *Model 3:* Building structure with three unbraced moment-resisting frames (Frames 1, 3 and B), a concentrically K brace (Frame 2 for both bays) and X brace (Frame A and C) as shown in figure 3.

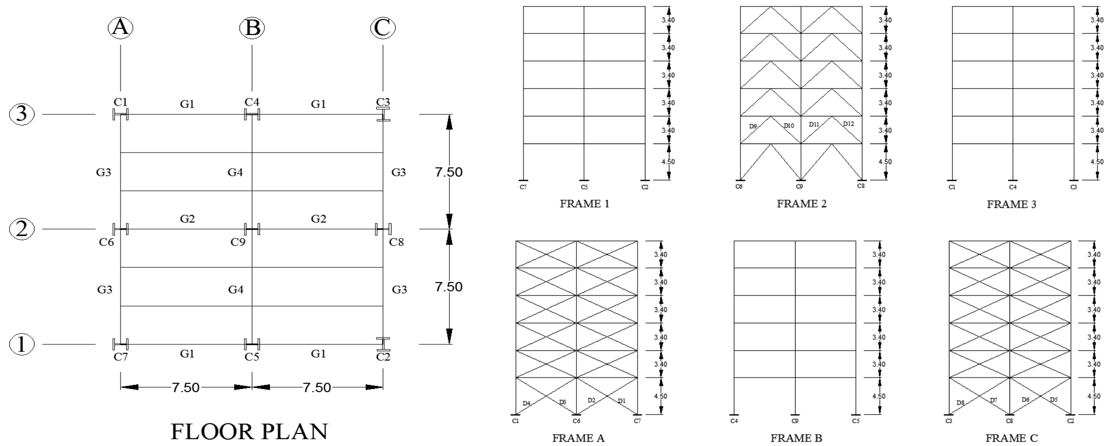


Fig. 3 Plan and frame details of model 3

## IV. RESULTS AND COMPARISION

### *A. Results and Comparison for Different Models*

In this project a six-storey steel structure with K and X braces is modelled in ETABS and its structural behavior is observed for various loads such as lateral loads, dead load and live loads as per Indian standards and different parameters such as base shear, storey forces, displacement, storey shear and storey stiffness were compared.

*1) Comparison of base shear*


Fig. 4 Comparision of Base shear

TABLE 6 Seismic Weight of the Structure (kN)

| Model 1 | Model 2 | Model 3 |
|---|---|---|
| 11948.56 | 12950.85 | 11618.16 |

The base shear for model 1 is nearly 16% and 10% of the total seismic weight of the structure along ‘X’ and ‘Y’ direction respectively. Similarly for model 2 is nearly 12% of the total seismic weight of the structure along ‘X’ and ‘Y’ direction and for model 3 is nearly 11% and 10% of the total seismic weight of the structure along ‘X’ and ‘Y’ direction respectively.

*2) Comparison of Storey Forces:*

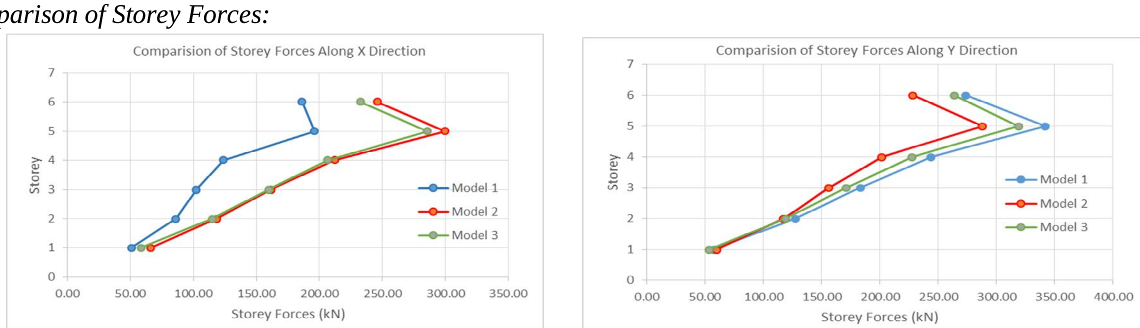


Fig. 5 Comparision of Storey Forces Along X and Y Direction

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Storey forces taken by model 1 and model 3 along Y direction is more than that along X direction, whereas storey forces taken by model 2 along X direction is more than that long Y direction, this is because gross area of braces is more along Y direction in model 1 and 3 and along X direction in model 2, resulting in increasing in the stiffness of structure along Y direction for model 1 and 3 and along X direction for model 2.

*3) Comparison of Storey Shear*

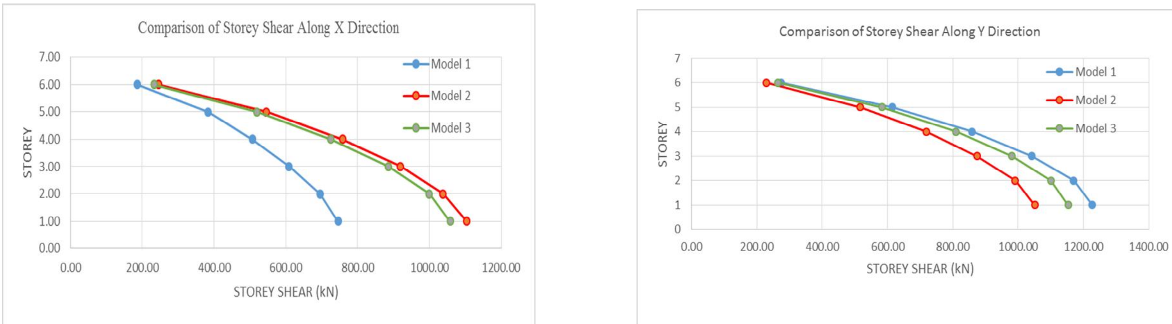


Fig. 6 Comparision of Storey Shear Along X and Y Direction

Storey shear for model 1 and model 3 along Y direction is more than that along X direction, whereas storey shear taken by model 2 along X direction is more than that long Y direction, this is because gross area of braces is more along Y direction in model 1 and 3 and along X direction in model 2, resulting in increasing in the stiffness of structure along Y direction for model 1 and 3 and along X direction for model 2.

*4) Comparison of Storey Displacement:*

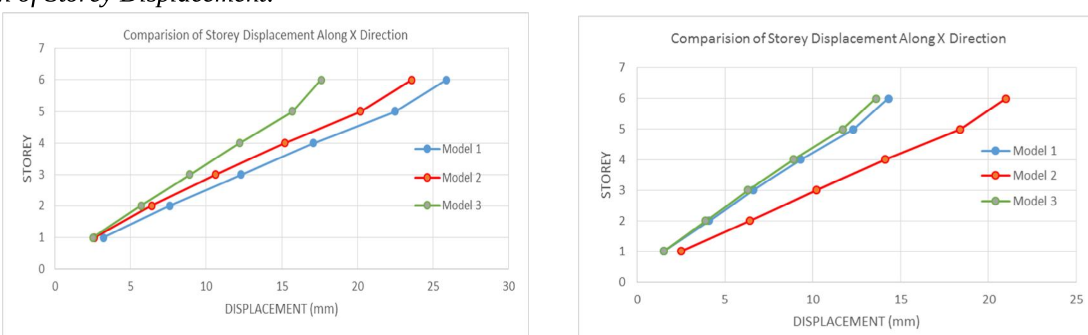


Fig. 7 Comparision of Storey Displacement Along X and Y Direction

The storey displacement for the model 3 is less compare to that in model 1 and 2 along both X and Y direction this is because of the stiffness of model 3 is more than the model 1 and 2 along both direction. Storey displacements for all the three models along X direction is more than that along Y direction, this is because gross area of braces is more along Y direction resulting in increasing in the stiffness of structure along Y direction.

*5) Comparison of Storey Stiffness*

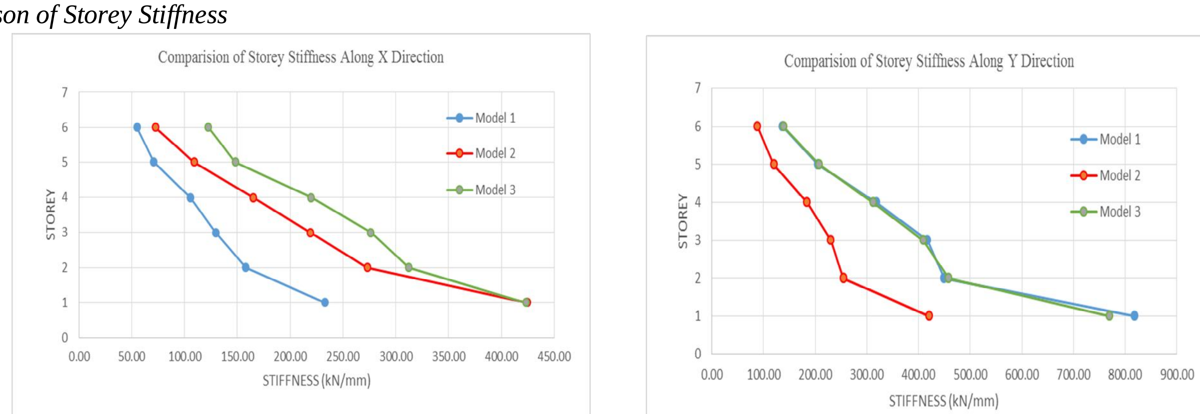


Fig. 8 Comparision of Storey Stiffness Along X and Y Direction

It is observed that for model 1 has stiffness 66% less along X direction compare to that along Y direction, model 2 has almost same stiffness along both X and Y direction and model 3 has stiffness 30% less along X direction compare to that along Y direction. While looking on the stiffness in both direction model 3 gives greater stiffness compared to model 1 and 2.

*B. Results and Comparison for Different Frames*

In this study the frame consist of different types of braces such as K-braces and X-braces parallel to the loading direction. Material properties and section properties are taken same as described in table no. 1 for material properties and 2, 3 and 4 for column, girder and braces respectively. In this some lateral forces are applied at each storey percentage storey shear carried by braces and moment resisting frames is obtained for frames with different types of bracings. Following are the different types of frames considered for study.

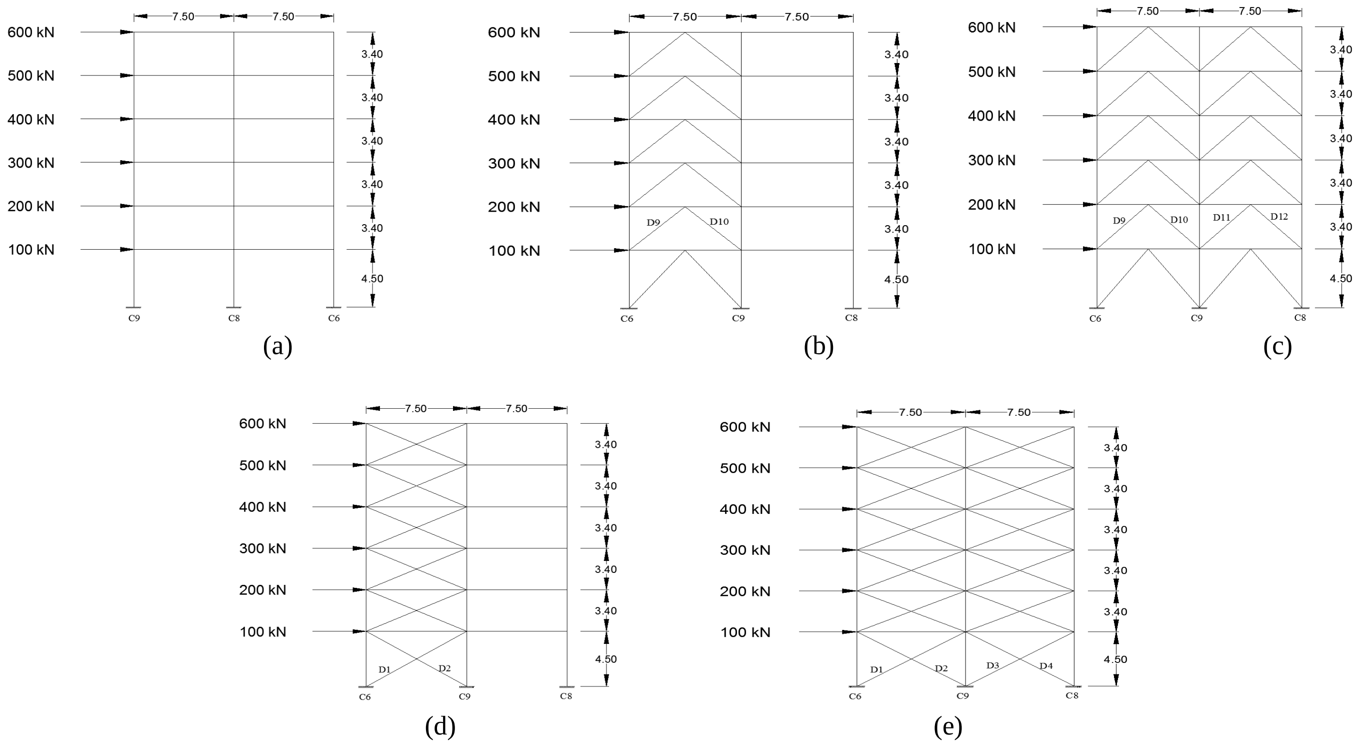


Fig. 9 (a) Details of Frame 1, (b) Details of frame 2, (c) Details of frame 3, (d) Details of frame 4 and (e) Details of frame 5

TABLE 9 % Storey Shear Carried by MRF and Braces in Different Types of Frames

| % Storey Shear Carried by | | Frame 1 | | Frame 2 | | Frame 3 | | Frame 4 | | Frame 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MRF | Braces | MRF | Braces | MRF | Braces | MRF | Braces | MRF | Braces |
| Storey | Load Case | | | | | | | | | | |
| 6 | Lateral Load | 100 | 0 | 8 | 92 | 2 | 98 | 10 | 90 | 2 | 98 |
| 5 | Lateral Load | 100 | 0 | 9 | 91 | 4 | 96 | 10 | 90 | 4 | 96 |
| 4 | Lateral Load | 100 | 0 | 8 | 92 | 3 | 97 | 9 | 91 | 3 | 97 |
| 3 | Lateral Load | 100 | 0 | 5 | 95 | 2 | 98 | 7 | 93 | 2 | 98 |
| 2 | Lateral Load | 100 | 0 | 12 | 88 | 6 | 94 | 15 | 85 | 7 | 93 |
| 1 | Lateral Load | 100 | 0 | 8 | 92 | 5 | 95 | 8 | 92 | 3 | 97 |

Since there is no lateral load resisting braces in the frame 1 it is seen that the entire storey shear is carried by the moment resisting frames whereas in frame 2 it is seen that almost 92% of storey shear is carried by K-braces and remaining 8% is by moment resisting frames. In frame 3 it is seen that almost 97% of storey shear is carried by K-braces and remaining 3% is by moment resisting frames. In frame 4 it is seen that almost 90% of storey shear is carried by X-braces and remaining 10% is by moment resisting frames and in frame 5 it is seen that almost 96% of storey shear is carried by X-braces and remaining 4% is by moment resisting frames.

## V. CONCLUSION

*A. From the results and comparison following points were concluded.*

1) Providing braces in to the structure resulting in increase in the lateral stiffness of the structure, which in turn reduces the lateral displacement of the structure.
2) Without lateral load resisting braces, the structure would have little stiffness and strength and might not survive major earthquakes.
3) Under lateral loading braces act as axially loaded members and they are more effective in carrying a lateral forces then moment resisting frames.
4) The moment resisting frames are designed to independently resist at least 25 percent of the seismic base shear.
5) From this study it is observed that the suitable location for K-brace is in the central frame as shown in frame 2 of model 3.
6) From this study it is observed that K-brace is more effective in carrying storey shear compared to X-brace.
7) Lateral load resisting braces carry about 90% of total storey shear before yielding.
8) Moment resisting frames with lateral load resisting braces is the most effective and commonly used lateral load resisting system.

## VI. SCOPE FOR FUTURE STUDY

*A.* Seismic behavior of eccentrically braced steel structure can be studied.
*B.* Seismic response of irregular structure can be studied with concentric and eccentric braces.
*C.* Same study can be done with different bracing configurations and with different sections.
*D.* Nonlinear behavior lateral load resisting braces cane be studied.
*E.* Same study can be done to check the variation of percentage storey shear carried by braces and by moment resisting frames before and after buckling of lateral load resisting braces.

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