STUDY ON BEHAVIOUR OF HEXAGONAL BRACES IN IRREGULAR FRAMES AND BUILDINGS

SNIGDHA A.S.[1], BINI B.[2]

[1] *M.Tech Student, Dept. of Civil Engineering, Thejus Engineering College, Thrissur, Kerala*
[2]*Assistant Professor, Dept. of Civil Engineering, Thejus Engineering College, Thrissur, Kerala*

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Abstract - *During the earthquake motion, most of the damages in the structure is predominantly due to the structural weakness. The reason behind the weakness in the building is discontinuities in stiffness, strength, ductility, and the effects of these weaknesses are underscored by poor distribution of the reactive masses. Severe structural damage suffered by several modern buildings during recent earthquakes illustrates the significance of avoiding the discontinuities in lateral stiffness and lateral strength by using braces, shear walls, infill walls etc. It was observed from studies of the conventional bracing system that, the bracings help to improve stiffness but minimal ductility of the conventionally braced buildings leads to the failure of the structure due to the concentration of the damages. In recent years, many engineers have turned to the use of innovative earthquake resistant structural systems to increase the ductility without compromising the stiffness and strength. Recently, an innovative braced frame designated as hexa-braced frame for the improvement of the seismic response of conventional steel-braced frames was proposed. The objective of the proposed frame is to distribute the deformation demands along the height of the frame in order reduce the possibility of the soft-story mechanism and to improve the ductility of the structure, which is the most important concern in conventional steel braced frames particularly in the earthquake prone zones. Also the strong back system used also helps to improve the load carrying capacity and reduce the soft storey mechanisms.*

***Key Words*:** **Hexagonal braces, Irregular frames, Irregular buildings, Strongback system.**

1. INTRODUCTION

During the earthquake motion, damages in the structure are mainly due to weakness in the structure. These weaknesses are usually created by discontinuities in stiffness, strength, ductility, and the effects of these weaknesses are accentuated by poor distribution of reactive masses and the stresses on the structure. Severe structural damage suffered by buildings during recent earthquakes illustrates the significance of avoiding the discontinuities in lateral stiffness and strength. A typical example of the maleficent effects of these discontinuities can induce is seen in the buildings with a “soft storey”. Bracing, shear wall, wing walls, infill walls, jacketing are some of the methods used to avoid soft storey mechanisms. Commonly used bracing are cross bracing, V bracing, inverted V bracing. Due to the damage concentration in the conventionally braced frames, in recent years, many engineers have turned to the use of innovative earthquake resistant structural systems. One such is hexa-braced frame. The strong back along with the hexagonal braces help to improve the stiffness of the structure and also helps to reduce the soft storey and weak storey mechanisms.

1.1 OBJECTIVES

- To study the behaviour of hexagonal braces in irregular building frames (vertical irregularities).
- To study the behaviour of the strong back system along with hexagonal braces in the irregular frames.
- To study the behaviour of hexagonal braces in irregular building configuration (plan irregularities).

2. STUDY ON IRREGULAR FRAMES

A total of 3 irregular building frames, each having 3 models were modelled using the software Ansys workbench 16.1. The 2 models are of 8 and 12 stories. The rest of the models have 6 stories. Each model has without braced frame, with diagonal braced and with chevron braced models. All the models were of steel framed and the braces used were of hollow square sections. The sections used in beams and columns were of wide flange carbon steel sections.

A non-linear static analysis was done in ANSYS workbench 16.1 software for modelling of the building frames. The braced frames with ground storey having a height of 5.49 and rest of the floors having a height of 3.66 m each were used for objective. The hexagonal shaped braces consisting of inverted v shaped braces and v shaped braces are used in these models. The braced frames were modelled by using beam 188.

The frame details:

The height of ground floor = 5.49m

The height of each floor = 3.66m

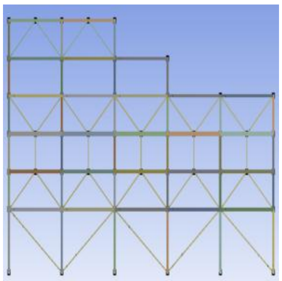
Inverted v braces = HSS 5X5X1/4

The models mainly include carbon steel frames and the hollow square steel sections and were modelled by beam 188 element. The steel sections were of carbon steel sections and the young’s modulus, E of steel is 200,000MPa. The yield strength of steel , fy =420 MPa , the density of the steel is taken as 7850 kg/m3, the coefficient of the thermal expansion is 1.2x10-5 1/C. The poisons ratio is taken as 0.3.The table 1 shows the sections used for the frames.

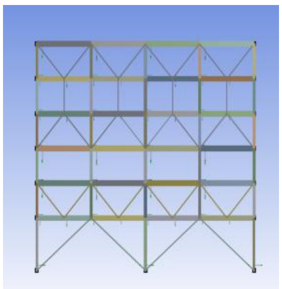
Table -1: Sections

Members	Sections
Top beams	W24x94
Bottom beams	W24x104
Outer columns bottom	W14x109
Outer columns top	W14x90
Inner columns bottom	W4x176
Inner columns top	W14x 145

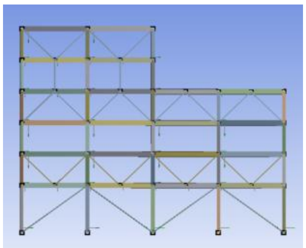
The geometry of the models are shown below in FIG-1.



a. Model 1



b. Model 2

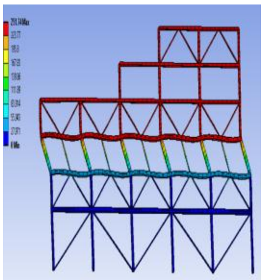


c. Model 3

Fig-1: Geometry

The bottom columns in the underground sections were restrained against all degree of freedoms. Fixed supports were provided in the bottom columns. The displacement controlled load was applied to frame. The maximum base shear and the deformation is noted.

The FIG-2 shows the deformation of the models.



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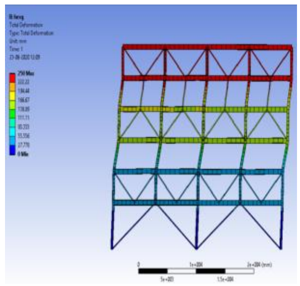
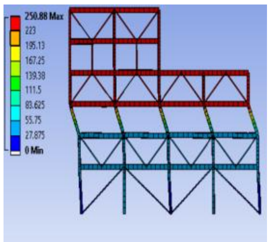


b. Model 2



c. Model 3

Fig-2: Deformations

The chart-1 shows the displacement v/s base shear for the models.

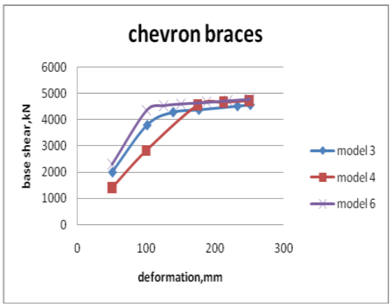
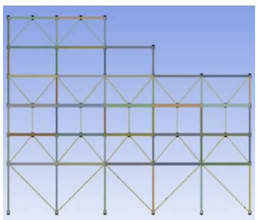


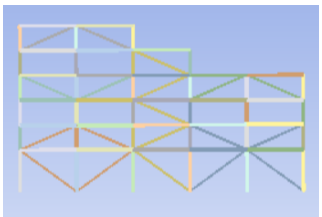
Chart -1: Displacement v/s base shear

3. STUDY ON STRONGBACK SYSTEM ALONG WITH HEXAGONAL BRACES

A total of 4 frames ,one without braces, 2 irregular building frames with braces(one diagonal and one chevron bracing types) and one frame having strong back system were modelled using the software Ansys workbench 16.1. The figure 3 shows the geometry of the models.



a. Model 1



b. Model 2

Fig-3: Geometry

The different frames modelled were of 6 storied with same heights & area. The material properties and the loading is same as that of first objective.

The chart-2 shows the displacement v/s base shear for the models.

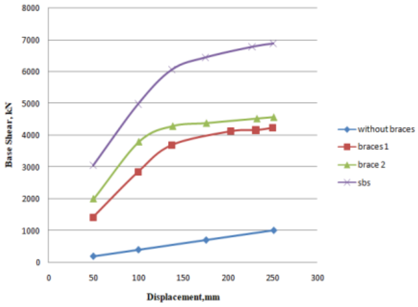


Chart -2: Displacement v/s base shear

The table 2 below shows the ductility of the frames, where ductility is determined by the ductility factor.

Table 2- Ductility

Model	Yield Displacement , mm	Ultimate displacement, mm	Ductility
SBS	137.93	251.4	1.822
Chevron	100.37	250.61	2.49
Diagonal	101.32	251.71	2.48

4. STUDY ON IRREGULAR BUILDINGS

A total of 4 buildings were modelled i.e. 1 irregular building without braces, 2 with V and Inverted V braces and 1 building with hexagonal braces using the software Ansys workbench 16.1for the study of different braces in L shaped building. In the second study the 2 different irregular buildings i.e. L and T shaped building of same area and same height is investigated for unbraced and hexagonal braces. The 15 storied irregular buildings were modelled. All the models were of steel framed and the braces used were of hollow square sections. The sections used in beams and columns were of wide flange carbon steel sections. The figure 4 shows the plan of the buildings.

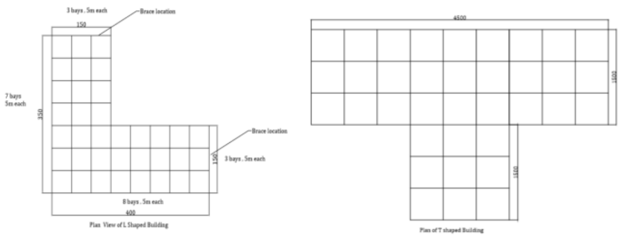


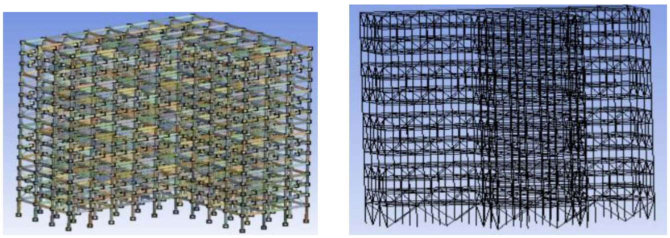
Fig-4: Plan of L & T Shaped Buildings

The table 3 gives the sections used for the buildings.

Table 3- Sections

Members	Sections
Columns	W14x176
Beams	W24x104
Brace	HSS 5X5X1/4

The FE models used for the objective are shown below.



a. L Shaped Buildng b. T Shaped Building

Fig-5: FE Models

The material properties and the loading conditions are same same as that of first objective

4.1 STUDY ON L SHAPED BUILDING HAVING DIFFERENT BRACES

From the study, it was found that the building with hexagonal braces behaves effectively than the building with other braces. The building resistance to the lateral load can be easily studied from this study.

The displacement and the corresponding base shear for different models are shown in the chart 3.

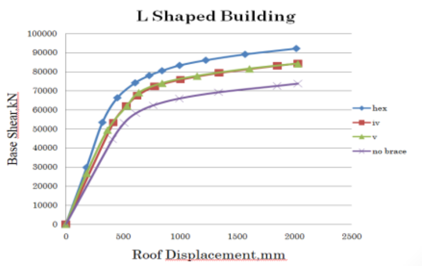


Chart -3: Displacement v/s base shear

The table 4 below shows the ductility of the frames, where ductility is determined by the ductility factor.

Table 4- Ductility

Frame	Yield displacement, mm	Ultimate displacement, mm	Ductility
Hexagonal	450.71	2014.2	4.5
Inverted v	531.25	2031.4	3.8
v	535.01	2029	3.8

The stiffness is determined from the base shear v/s displacement curve.

Table 5- stiffness

Model	Base Shear , (kN)	Displacement , mm	Stiffness (angle, degree)
Hexagonal	7936	20.42	89
Inverted V	1936	103.15	76
V	1936	103.15	76

4.2 STUDY ON DIFFERENT IRREGULAR BUILDINGS WITH AND WITHOUT HEXAGONAL BRACES

The displacement and the corresponding base shear for different models are shown in the chart 4.

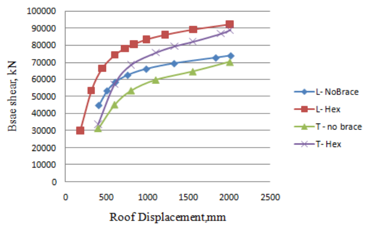


Chart -4: Displacement v/s base shear

5. RESULTS AND DISCUSSIONS

Finite element analysis of hexagonal braced frames and buildings was done using Ansys workbench 16.1. The behaviour of the frames and buildings with the hexagonal braces were studied and were compared with no braced and conventional braced models and the study was completed.

5.1 STUDY ON IRREGULAR FRAMES

Chevron bracings showed more stability when compared with other models. Chevron braces showed almost 8 % increase in the strength when compared to the diagonal type braced frames.

Building frames with chevron braces having same height and same area showed almost same base shear values. This is because the v and inverted brace reduce the buckling capacity of compression brace so that it is less than the tension yield capacity of tension brace and resisting the bending of the horizontal members.

5.2 STUDY ON STRONGBACK SYSTEM ALONG WITH HEXAGONAL BRACES

SBS when compared with chevron braced frame the base shear is increased by 34 %. The increase in the base shear means that the lateral resistance of the structure is increased. This increase in the shear value is mainly due to the presence of the strong back system in the frames, which ultimately increases the stiffness in structure.

Ductility is more for chevron and diagonal braced frame by 28 % than SBS system.

The ductility is low for SBS system compared with other braced frame as the structure is stiffer compared with the other structures, the frame incorporating the SBS showed low ductility compared with the other structures.

5.3 STUDY ON IRREGULAR BUILDINGS

From the displacement v/s base shear curve, it was found that the shear is higher for the buildings having hexagonal braces than other type of braces. The base shear of the building having hexagonal braced building is 9 % more than the inverted and v shaped braced building. Which means the strength is high for the hexagonal braced building frames.

From the ductility factor values for the L shaped buildings given in the table 6.4, it was clear that the ductility of the hexagonal braced frames is increased by 15.5 % than other braced frames. The hexagonal braces mainly incorporate the V shaped and inverted v shaped braces, so that during the lateral loads before the buckling of the compression member, the load is transferred to the tension members thus ensuring the ductility of the structure.

The increase in the angle for the hexagonal braced building indicates the at the stiffness is high for the hexagonal braced building. The stiffness is increased by 15 % and this increase in the stiffness is mainly due to decrease in the buckling of the compression member of the braces when compared to the other models.

6. CONCLUSIONS

The hexagonal braces in the frames and buildings showed improvement in the base shear, stiffness and ductility. The study of hexagonal braces in building frames ad buildings can be concluded in the following ways:

- Hexagonal braces showed improvement in load carrying capacity of steel structures compared with the base model due to the distribution of the load rather than concentration of damages in the floors.
- Chevron braces in the vertical irregular frames showed almost 8 % increase in the base shear when compared to the diagonal type braced frames. And 9 % increase in the base shear for building with plan irregularities.

Therefore hexagonal bracings improve the base shear of the steel structure due to the distribution of the stress in the bracing system.

- For same height, showed almost same performance but depending upon the irregularity, different frames showed different yield points in the members.
- The chevron braced frame showed improvement in the ductility because the hexagonal braced frames incorporates V shaped and inverted V shaped braces, so that during the lateral loads before the buckling of the compression member, the load is transferred to the tension members thus ensuring the ductility of the structure.
- SBS showed improvement in lateral resistance because of stiffness in the shape. Strong back system showed an increase in the ultimate load capacity.
- The SBS model showed decrease in the ductility because of the stiffness of the structure.
- The uniform storey drift in the SBS structure helps to reduce the soft storey behaviour.

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