Seismic Performance of RC Frame With Steel Bracings

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***Abstract* - Steel bracing is a highly efficient and economical method of resisting horizontal forces in a RC frame structure. Bracing has been used to stabilize laterally the tallest building structures. In the present study, the seismic performance of the steel inverted V and V braced frame structures are investigated. Static nonlinear analysis has been conducted to evaluate the effect of distributing the bracings in different spans with different number of storeys and influence of different cross sections of the braces. From the results it was found that, the brace configuration and height of the building has great influence on the load carrying capacity, inter storey drift, ductility, column forces and energy absorption capacity of the structures. The tube section has better performance in comparison to double angle and I sections.**

Keywords: steel bracing, RC frames, seismic performance, static nonlinear analysis

I. INTRODUCTION

In order to make multi-storey structures stronger and stiffer, which are more susceptible to earthquake, the cross sections of the member increases from top to bottom of building this makes the structure uneconomical owing to safety of structure. Therefore, it is necessary to provide special mechanism and/or mechanisms that to improve lateral stability of the structure. One of the main strengthening approaches is installing new structural element, steel braces to upgrade the seismic performance of structures. In recent years, there have been several studies on use of steel braces in RC buildings. Braced frames buildings were designed only for gravity loading. The gravity loads consists of dead load and live load. When calculating the dead load, the weight of structural members and masonry walls were included. The live loads on the floor are 4 kN/m^2 and the wall load on the beam is 17.5 kN/m. Also, the base of columns at the ground floor was assumed to be fixed. The geometric properties and material properties are follows:

Bay length : 4 m
Floor height : 3.5 m

develop their confrontation to lateral forces by the bracing action of diagonal members. Fully braced frames are more rigid. From saving view point arbitrarily braced ones have least forces induced in the structure and at the same time produce maximum displacement within prescribed limits. In the current study, load carrying capacity, interstorey drift, ductility, column forces, time period and energy absorption capacity of braced structure were compared based on the results obtained through static nonlinear analysis.

In this paper, the inverted V and V braced frames with different configurations were used to assess the performance of steel braced frame structures. Even though several authors have assessed performance of inverted V and V braced frame structures with different configurations, but there is little information about some parameters like column forces, energy absorption capacity and time period, it is still needed to develop the effective and economic configurations.

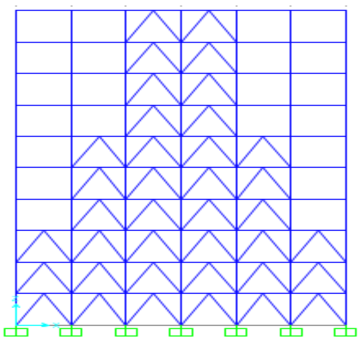
II. DESCRIPTION OF THE BUILDING

In this study, 6 bay 10 storey building have been used for investigating the effect of distribution of bracings in different spans and 6 bay 10, 12 and 14 storey buildings have been used for evaluating the height effect of building on performance. All RC

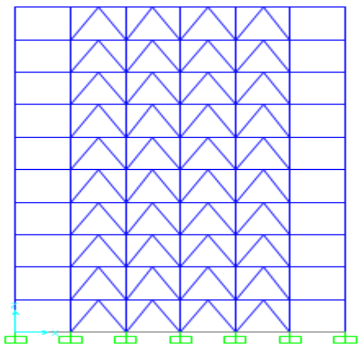
Beam sizes : 300X450 mm, 300X500 mm, 350X600 mm
Column sizes : 350X350 mm, 400X400 mm, 500X500 mm, 600X600 mm, 750X750 mm
Grade of concrete: M25
Grade of steel: Fe415

I. STRUCTURAL MODELLING AND ANALYSIS

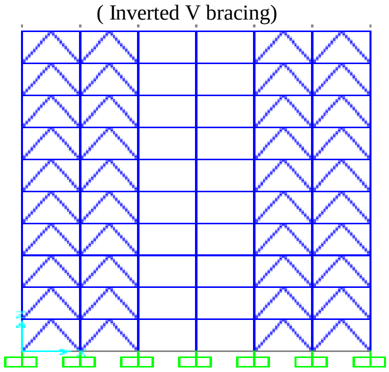
The frames have been modeled and analyzed using software SAP 2000 software. Beams and column



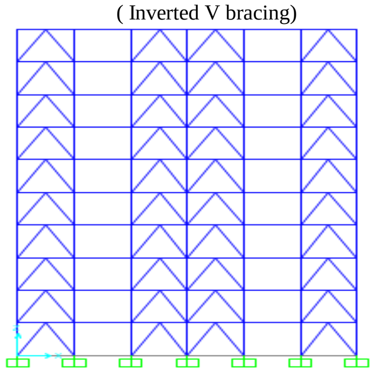
CONFIGURATION 1
(Inverted V bracing)



CONFIGURATION 2
(Inverted V bracing)



CONFIGURATION 3
(Inverted V bracing)

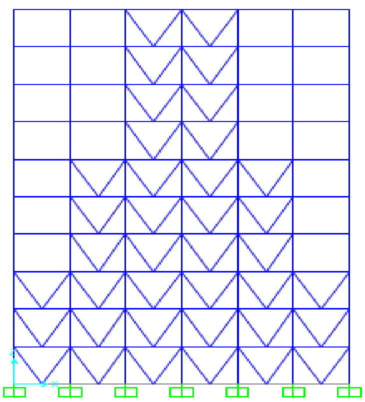


CONFIGURATION 4
(Inverted V bracing)

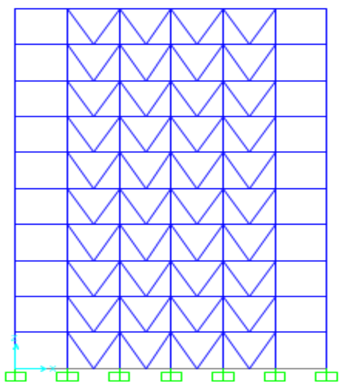
Fig 1: Different configurations of inverted V bracing systems

are modelled as frame elements with centreline dimensions. Supports at the base are assumed to be fixed. A pushover analysis is conducted to evaluate the performance of the building with acceleration as the load pattern. Two types of nonlinearity have been considered in modeling i.e. geometric nonlinearity and material non linearity. Geometric nonlinearity is provided in the form of P-Δ effects of loading. Material nonlinearity is provided in the form of plastic hinges in the frame elements. In the analysis M3 pushover hinges are assigned at both ends of beam elements (at locations of plastic hinge formations). PMM pushover hinges are assigned to columns at both ends. Steel bracing members (double angle back to back) are modeled as truss member. Inverted V and V bracing systems have been considered. Four different configurations were selected such that by keeping total weight of the frame structure same for both inverted V and V braced frames as shown in Fig 1and 2.The bracings of double angle section, I section and tube sections of sizes are 80X80X8, ISLB 150 and 122X61X5.4 respectively are used. The connection between steel brace and frame have been made rigid by providing end length offset with rigid zone factor 1, i.e. the entire connected zone has been made rigid.

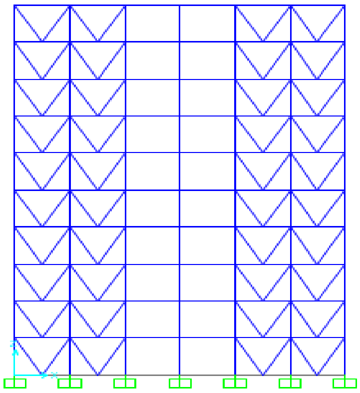
The building frame considered in this study is assumed to be located in Indian seismic zone V with medium soil conditions. The design peak ground acceleration (PGA) of this zone is specified as 0.36*g*.

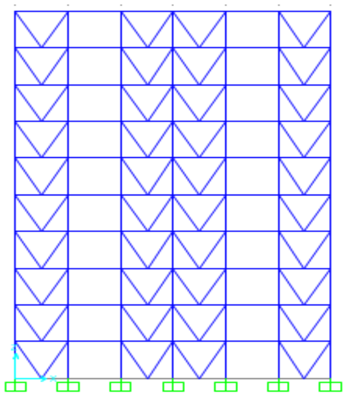


CONFIGURATION 1
(V bracing)



CONFIGURATION 2
(V bracing)





CONFIGURATION 3

CONFIGURATION 4

(V bracing)

(V bracing)

Fig 2:Different configurations of V bracing systems

II. RESULTS AND DISCUSSIONS

The selected frame models are analyzed using pushover analysis. The results obtained from these analyses are compared in terms of lateral strength and stiffness; inter storey drift, energy absorption, ductility, column forces and time period of the structures with different arrangement of braces, varying number of storeys and cross sections of bracings.

A. Load capacity and stiffness

Fig 3 to 6 shows the capacity curves for inverted V braced and V braced frames with different configurations and number of stories. The variation of base shear is studied for the frames with V and inverted V bracing having different number of storey and cross sections of braces. The strength defines the capacity of a member or an assembly of members to resist actions. The most obvious effect of bracings is increasing the ultimate strength of the system. Adding bracing itself will be accompanied with increased strength and stiffness, but according to research done, the type and structural configurations of the bracing system is very effective.

In fig 3 and 5, the relationship of base shear and displacement at the centroid of inertia for the inverted V and V braced frames are compared. All the curves show similar features. They are initially linear but start to deviate from linearity as the member undergoes inelastic actions. When the frames are pushed well into the inelastic range, the curves become linear again but with a smaller slope. The increase in lateral ultimate strength and stiffness for configuration 1 in both type of braced frame is considerable. On the other hand, lateral strength and stiffness increased with increased height of the structures. Furthermore, the influence of type of cross section of bracings on lateral strength and stiffness is compared as shown in fig 7 and 8. The lateral strength and stiffness is influenced by section properties. The cross sectional area of sections is kept constant for comparison, the tube section with inverted V braced frame performed better than other sections. The increase of ultimate strength by tube section is about 22.7 to 25.2 % compared to double angle and I sections respectively. Compared to the bare frame, for the ten stories building with the tube section, the capacity of V bracing and inverted V bracing systems is increased. This indicates that the capacity of RC frames can be greatly enhanced through the addition of steel braces especially with the inverted V bracing systems and that the number of stories determines which system performs better.

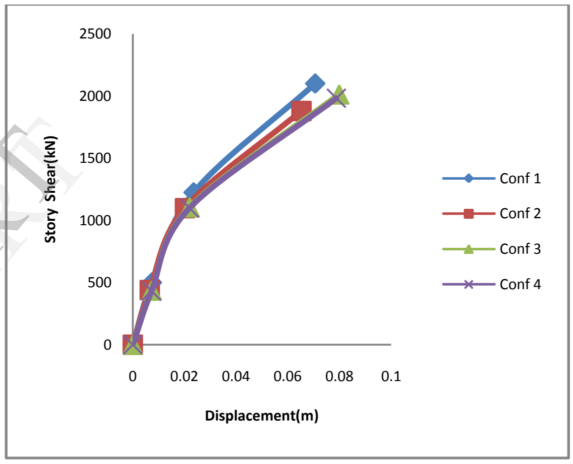


Fig.3. Pushover curve for inverted V bracing systems with different configurations

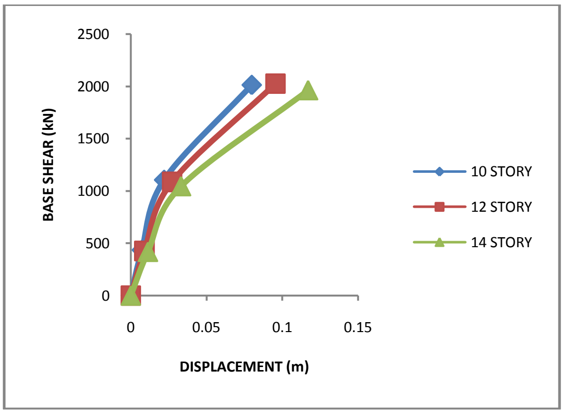


Fig.4. Pushover curve for inverted V bracing systems with different no. of stories

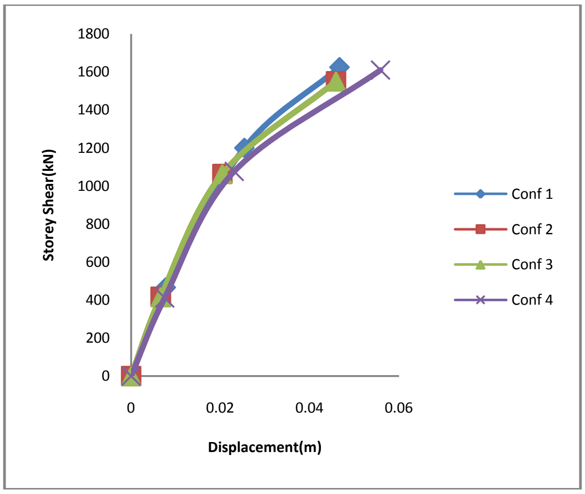


Fig.5. Pushover curve for V bracing systems with different configurations

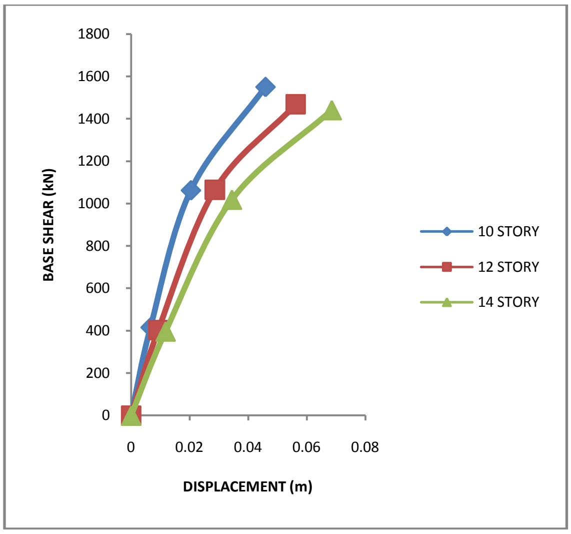


Fig.6. Pushover curve for inverted V bracing systems with different no. of stories

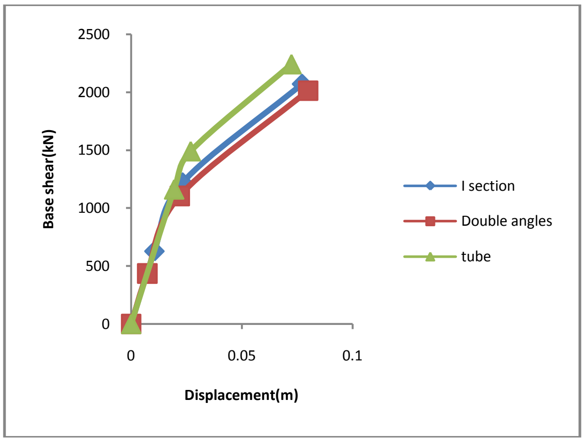


Fig.7. Pushover curve for inverted V bracing systems with different cross sections

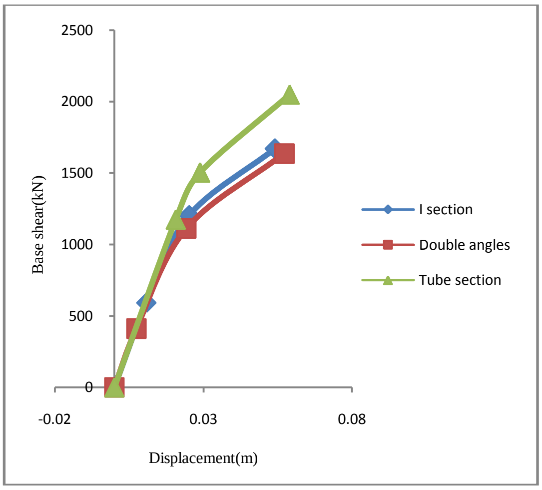


Fig.8. Pushover curve for V bracing systems with different cross sections

B. *Inter story drift*

The lateral deformability of structural systems is measured through the horizontal drift. The inter storey drift define the relative lateral displacements between two consecutive floors. The inter storey drifts are generally expressed as ratios δ/h of displacements. The interstorey drift causes distress in the structural elements, excessive cracking, loss of stiffness and consequent failure by soft storey. Bracing is the viable solution to reduce this large drift. A comparison of inter storey drift obtained for original and braced frames for four different configurations, number of storeys and cross sections of bracings are shown in Fig. 9 - 11.

The addition of steel bracings reduces maximum inter storey drift and distributed more uniformly along the height of structure particularly in storeys 4 to 8 as is in original frame by inverted V brace compared to V brace. The estimated values are 0.2-0.3% and 0.3% to 0.4% for inverted V and V braced frame. The configuration 2 of both type of bracing effectively limits the response and interstorey drifts in the building and provides an adequate safety against collapse by reducing the floor displacements. The result also shows that inter storey drift increase with increased height of frames (Fig 10 and 12).

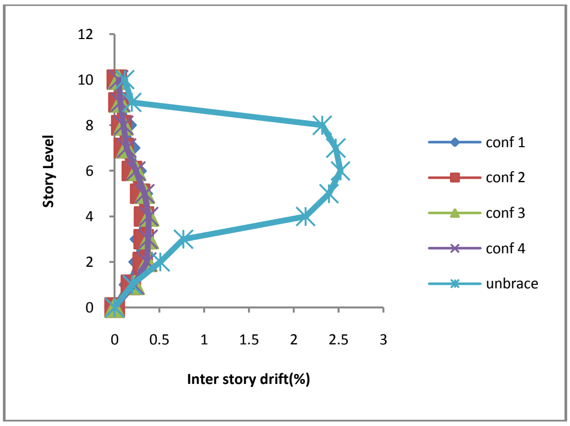


Fig.9.Inter story drifts for inverted V bracing systems

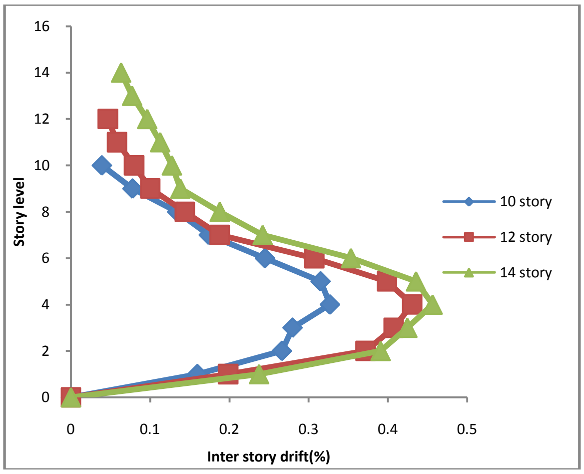


Fig.10. Inter-story drift for inverted V brace with different no. of stories

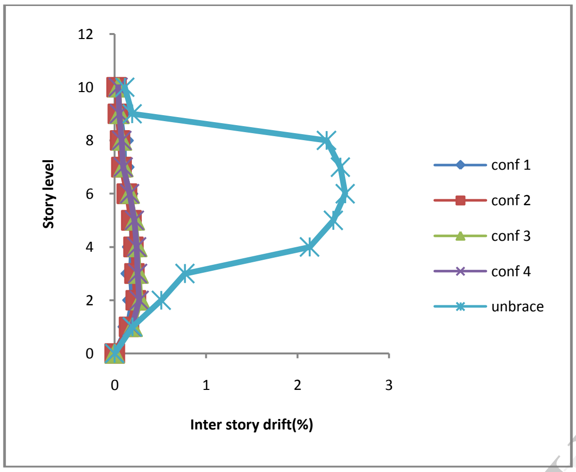


Fig.11.Inter story drifts for inverted V bracing systems

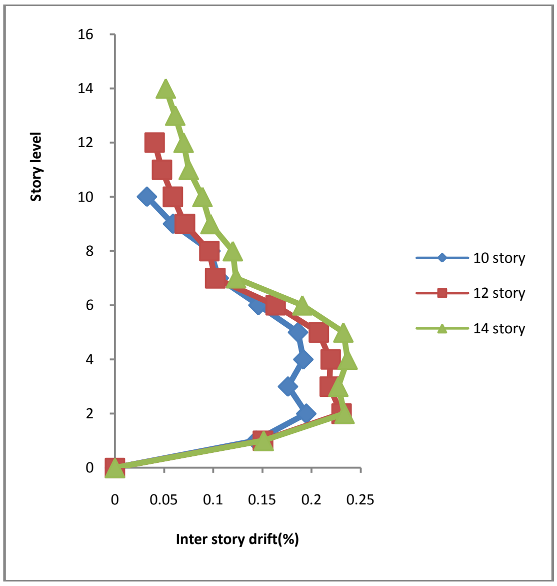


Fig.12. Inter-story drift for inverted V brace with different no. of stories

C. *Energy absorption capacity*

Ability of a structure to dissipate the ground motion energy is an accurate measure for its expected seismic performance. In this study, the energy absorbed by the braced frame is calculated as the area enclosed by the load-displacement curve. The load displacement relationship is obtained through nonlinear static analysis. The variation of energy absorbed by the braced frame is studied with four configurations, number of storeys and cross sections of bracings.

Fig 13 shows a plot of the energy absorbed by the different configurations of bracings. It is observed that, the energy absorbed by the inverted V braced frame with configuration 3 and 4 is much higher than that by the other configurations. This is mainly due to the high post yield stiffness and ductility of frames. The variation of energy absorbed with number of storeys is presented in Fig 4. It is observed that, for given braced frames, the energy absorbed values increased with increase in number of storey which is found different for inverted V and V braced frames. The 14 storey inverted V brace frame has 17.9-53.43% and 42.49-75.46 % higher energy absorption than the 10 and 12 storey of inverted V and V braced frames. Comparison of total energy absorbed by the inverted V and V braced systems with Double angle section, I section and Tube sections is shown in Fig 15. The braced frame with tube sections absorbed more energy than the other sections. The energy absorbed by the inverted V and V braced frames ranges from 93 to 144 and 46 to 78 respectively. For comparison, the inverted V braced frames absorbed 43 to 49% more energy than V braced frames.

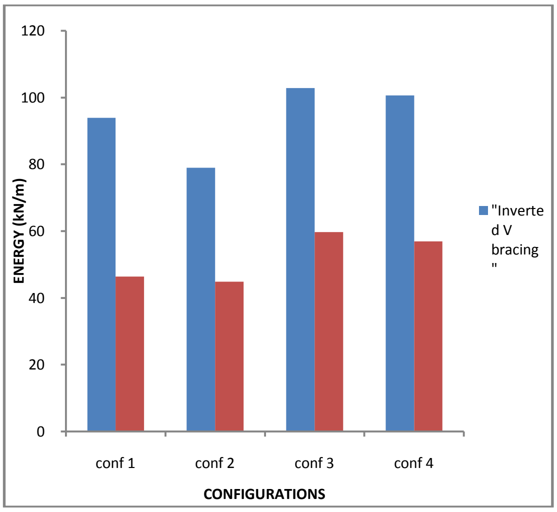


Fig.13. Energy absorbed by the inverted V and V bracing systems with different configurations

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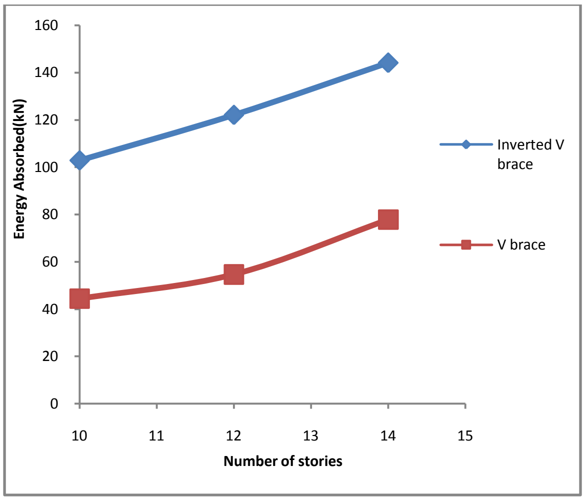

Fig.14. Energy absorbed by the inverted V and V bracing systems with different no of stories

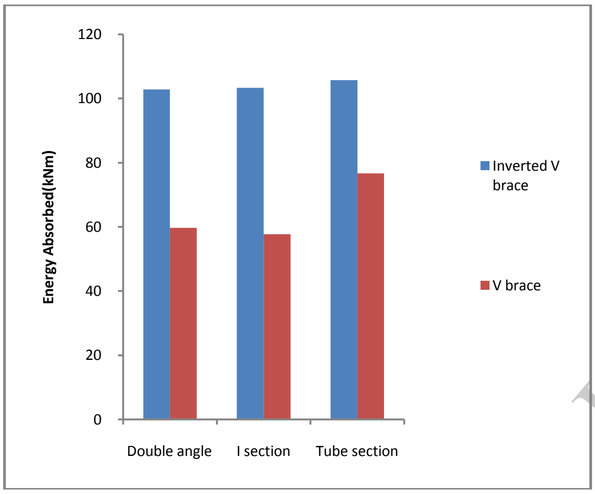

Fig.15. Energy absorbed by the inverted V and V bracing systems with different cross sections of bracings

D. Ductility

Ductility is defined as the ability of the material, component, connection or structure to undergo inelastic deformations with acceptable stiffness and strength reduction. Most structures are designed to behave inelastically under strong earthquake for reasons of economy. The response amplitudes of earthquake induced vibrations are dependent on the level of energy dissipation of structures, which is a function of their ability to absorb and dissipate energy by ductile deformations. The ductility of the frame are obtained by the following analytical expression of displacement ductility

$$\mu = {}^{\Delta_u}\!/_{\Delta_y} \tag{1}$$

Where Δ_u and Δ_y are displacements at ultimate and yield points respectively.

Fig 16 to 18 indicates the effect of distribution of bracings in different spans, number of storeys and cross section of bracings on the ductility of the structure. For 10 and 12 storey structures, the inverted V bracing with double angle section results in higher ductility and with the increase of building height the ductility is decreased. The ductility of configuration 3 and 4 are significantly higher than the values of configuration 1 and 2. Further more, the ductility exhibited by double angle section considerably exceeded the ductility of I section and tube section. The tube section yield significantly less ductility which is about 13 to 36% than double angle section. The lower modulus of rigidity of double angle section is the main cause to yield higher ductility since deformation is maximum causing a high capacity of dissipation of energy. For I section and tube sections the ductility is generally small since the modulus of rigidity of the structure is large implying a small capacity of dissipation of energy.

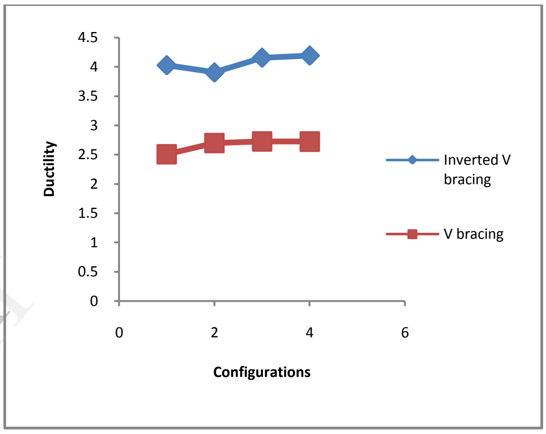

Fig.16. Ductility for inverted V and V braced frames with different configuration

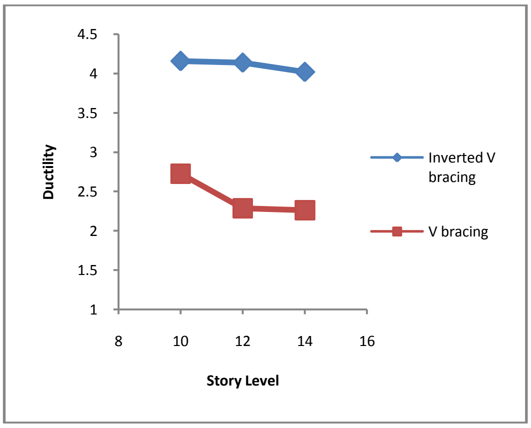

Fig.17. Ductility for inverted V and V braced frames with different number of storeys

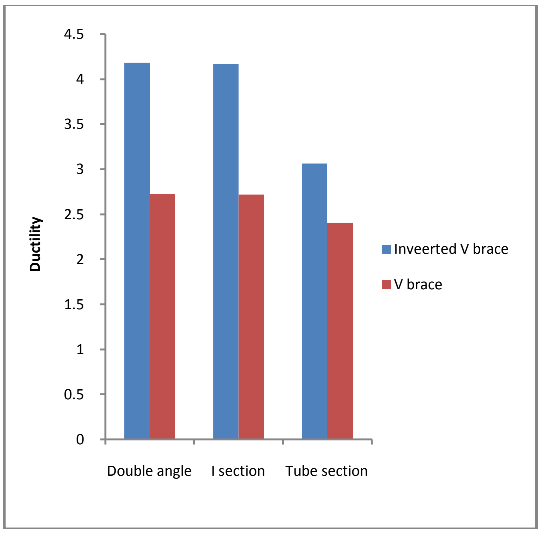

Fig.18. Ductility for inverted V and V braced frame with different type of cross sections

E. *Column forces and moments*

The axial forces and bending moments without bracing, for dead load, live load and for seismic analysis is presented in Fig 19. The results are compared with that of building frames with inverted V and V bracings for different configuration and cross sections of bracings. It is seen that the maximum axial forces are increased for buildings with bracings compared to that of the buildings without bracings. Further, while bracings decrease the bending moments and shear forces in columns to which they are connected since the reinforced concrete columns are strong in compression it may not cause a problem in steel braced reinforced concrete frames, but the tensile forces are developed opposite compressive force columns these columns are need to be prevented from the tensile failures. The columns connected to inverted V bracings have larger forces and bending moments than those columns connected to V bracings. This means that the energy absorbed by the inverted V bracings is more than V bracings and this absorbed energy transferred to the columns as axial forces and moments.

Fig 22 to 24 illustrates the axial forces and moments in bottom storey columns for different cross section of bracings. The axial forces in columns are increased but moments have decreased. The tube section braced frame has axial forces 10.98 to 16.70% and 8.3 to 11.91 % higher than double angle and I section braced frames in both inverted V and V braced frames. Compared to Tube section the double angle and I section decrease the moments by 4 to 22.19% and 5.23 to 21.48% respectively. The cross sectional area and shape of the cross section of bracings increases the axial and shear capacities, while flexural moment of inertia influence the flexural capacity. The area of all the sections is same but shapes are different, hence tube section has high axial capacity than the other sections. These axial forces from the brace transfer to the columns and hence axial forces are increased in columns.

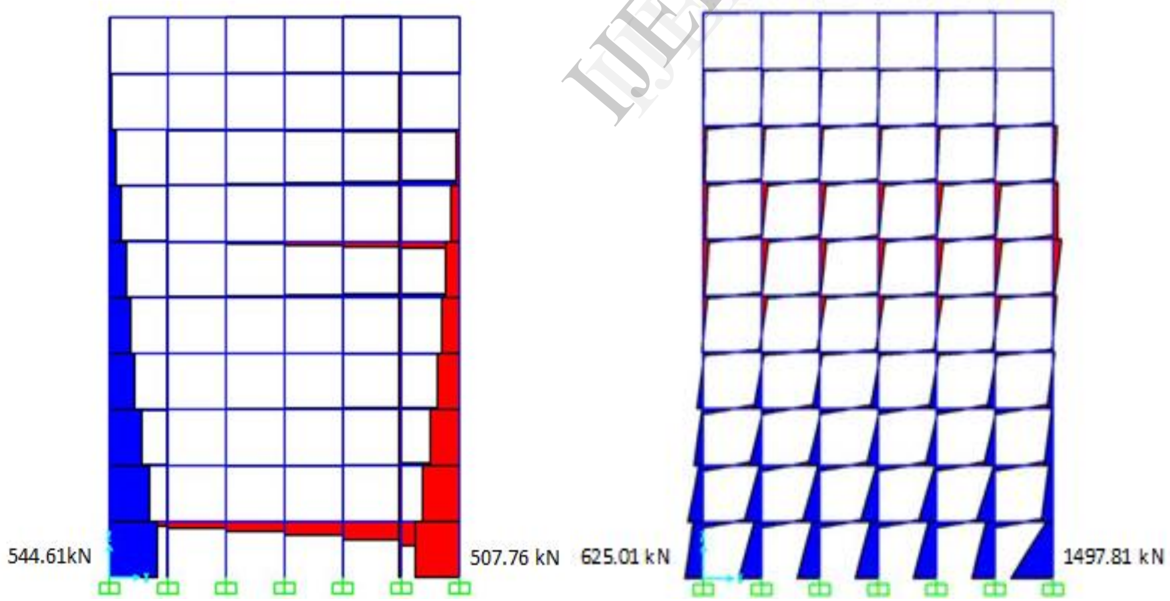

Fig.19. Column axial forces and moments in unbraced frame

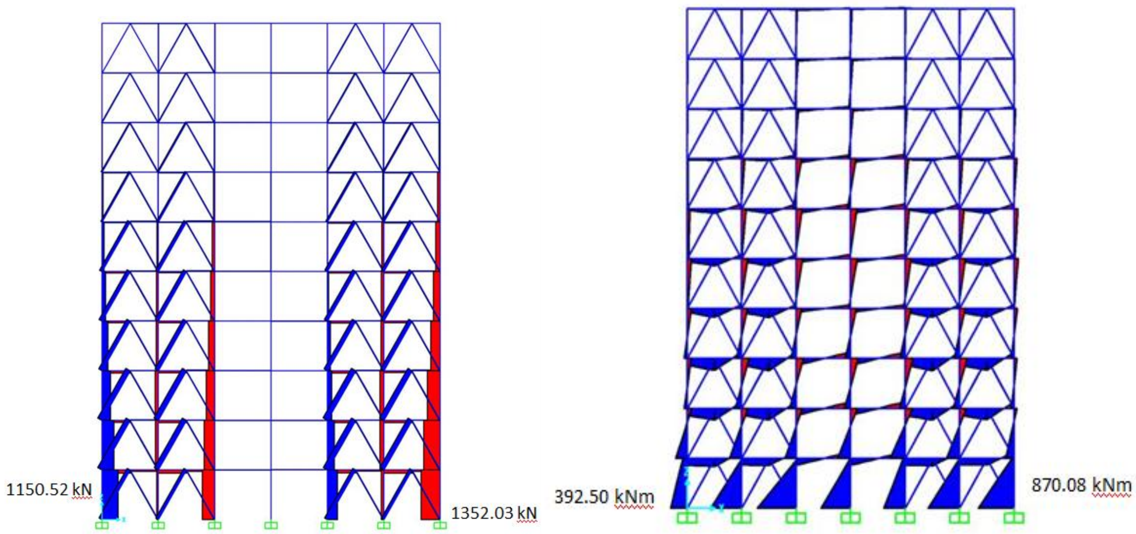

Fig.20. Column axial forces and moments in inverted V braced frame

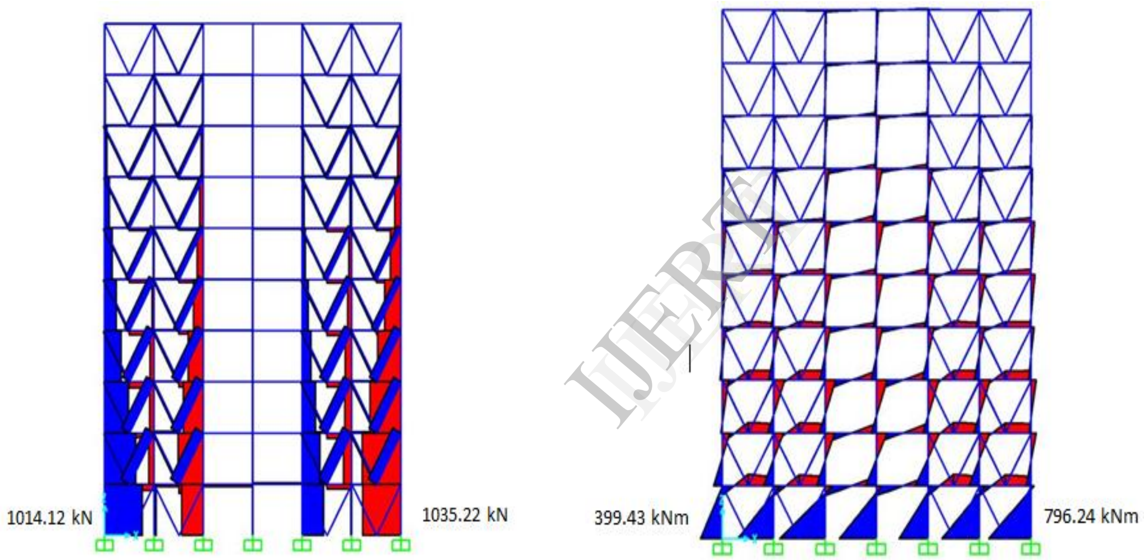

Fig.21. Column axial forces and moments in V braced frame

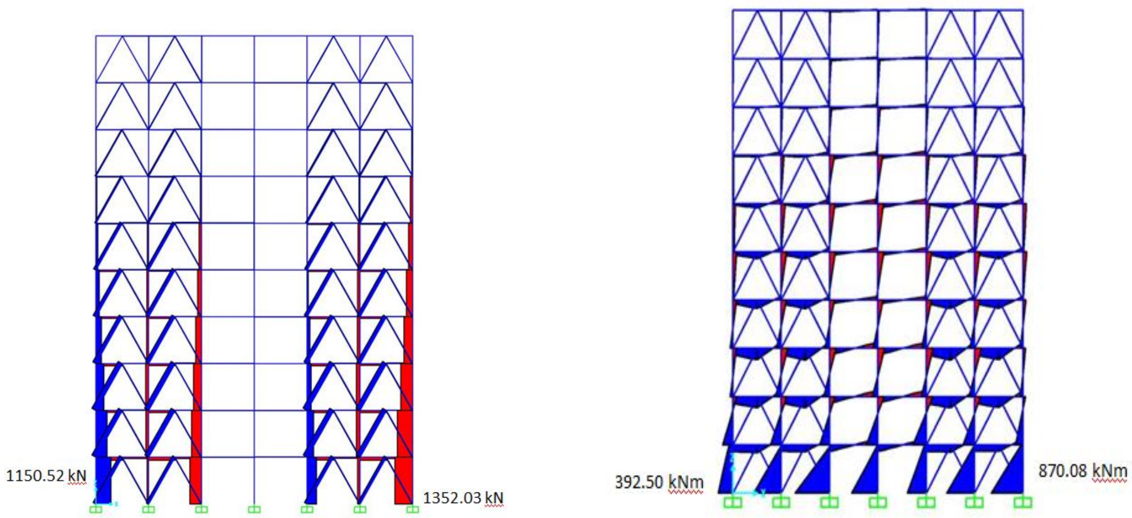

Fig.22. Column axial forces and moments in inverted V braced frame with double angle section

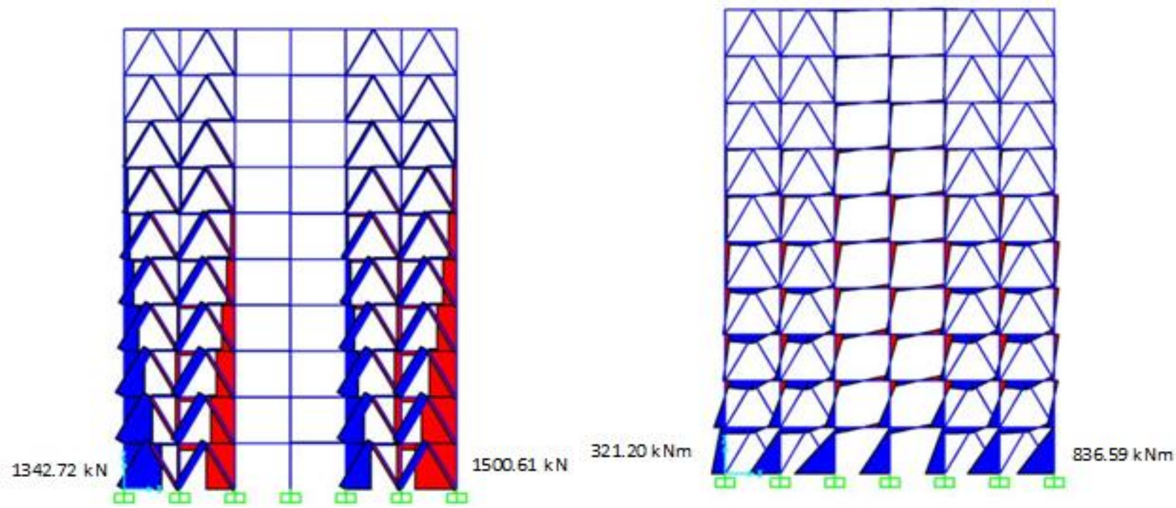

Fig.23. Column axial forces and moments in inverted V braced frame with tube section

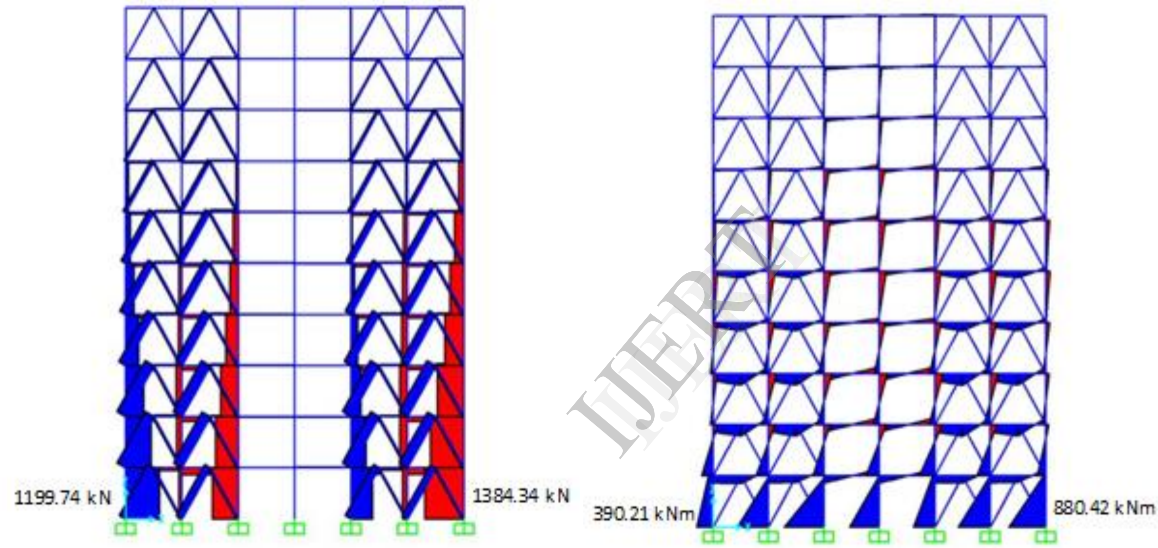

Fig.24. Column axial forces and moments in inverted V braced frame with I section.

F. Time period

The time period T is an inherent property of a building. Any alterations made to the structure will change its time period. The value of time period depends on the stiffness and mass of the structure; lesser is the stiffness, longer the time period and, more the mass, the longer is the time period. In general, taller structure is more flexible and has larger mass and therefore have longer time period. It is possible to have structure and ground to have the same time period and there is a high probability for the structure to approach a state of resonance. The periods of original and braced structures are obtained through nonlinear static analysis. The variation of time period for inverted V and V braced frames are studied with different configurations, number of storeys and cross section of bracings.

The variation of time period for inverted V and V braced frames with different configurations are presented Fig 25. It is seen that, the configuration 1 has lower time period than the other configurations, this is because the stiffness of the configuration 1 is much more than other configuration. The lower time period makes the building to vibrate for shorter period and the lesser is the damage. The time period of inverted V braced frames and V braced frames are less than the unbraced frames, this decrease is about 34.91 to 48.59% for inverted V brace and 28.59 to 37.435 for V braced frames. Further, fig 26 the time period increases with increase in number of storeys, because as the number of storeys increases the stiffness decreases, if stiffness decreases the time period increases. Fig 27 shows the variation of time period for different types of cross sections of bracings. The inverted V braced frame with tube section exhibit lower time periods than the double section and I section.

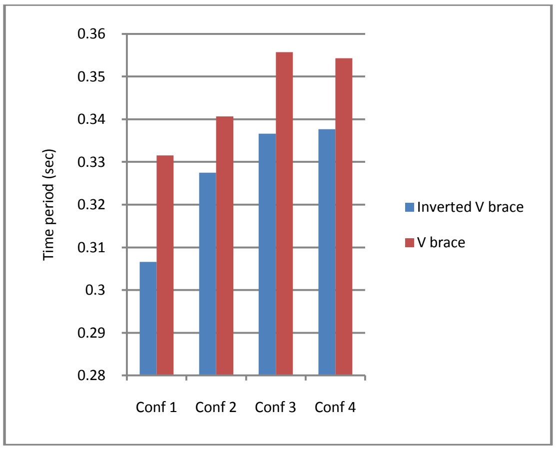

Fig.25. Time period for inverted V and V braced frames with different configurations

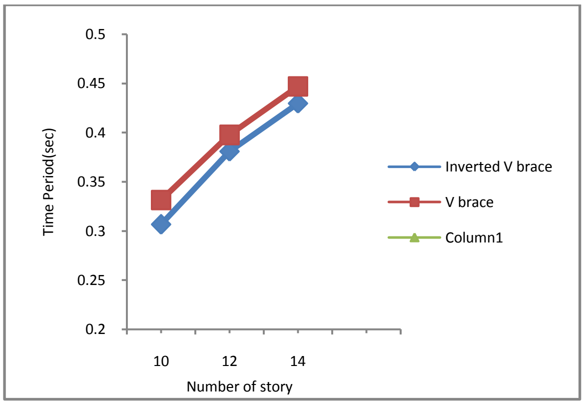

Fig.26. Time period for inverted V and V braced frames with different number of storeys

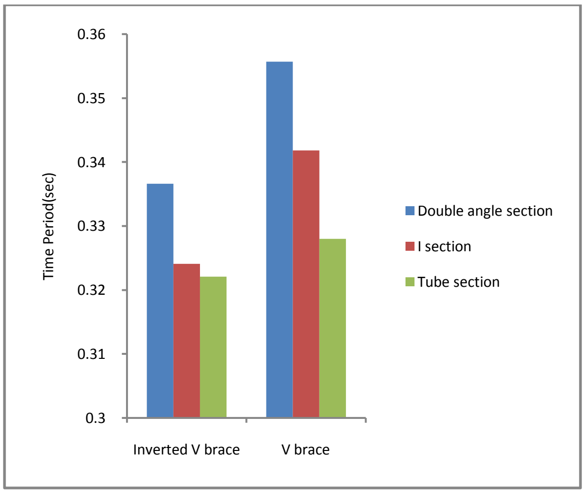

Fig.27. Time period for inverted V and V braced frames with different cross sections of bracings

III. CONCLUSIONS

The following conclusions are drawn from the results

1. The estimated inter storey drift values ranges between 0.3 to 0.4% for inverted V bracing while 0.2 to 0.3% and 0.5 to 2.5 % for unbraced frame.
2. The energy absorbed by inverted V bracing system is 43 to 49 %, which is more than the V bracing systems.
3. Steel bracings reduce flexure and shear demands on beams and columns and transfer the lateral loads through axial load mechanism.
4. The section type is seen to have a global influence on stiffness and ductility capacities of buildings and the performance of the type of the bracing system.
5. The performance of the tube section braced frame is better than the double angle section and I section.
6. Considering the range of ductility capacities shown by different systems discussed, it is found that the bracing arrangement in inverted V and V bracing, configuration 1& configuration 2 respectively are found to be performing better compared to that of others.
7. The performance of the inverted V braced frame is better as compared to that of the V braced frame.

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