Mega bracing system with RC multistory based on plate-frame method by sap2000

Saja Sahib Ali[1*], *Mazin* A. Ahmed[1] and *Adel* A. Zahra[1]

[1]Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq.

Abstract. This study investigates the optimal arrangement of steel braces for a 15-story reinforced concrete building. The analysis is based on a 0.1 mm plate model at the exterior face of the building, which is subjected to nonlinear time history analysis of Elcentro ground motion earthquake. The study focuses on the internal forces path induced by seismic loads and aims to identify the most preferable results for different configurations of steel bracing using sap2000 software. By selecting the moment that led to the maximum internal drift, the study determined the maximum load concentrations. The results indicate that model 4 and 6 produced the optimal results, with a significant increase of 32% and 37% in base shear, as well as a notable improvement of 60.64% and 60.5% in roof displacement, respectively.

1 Introduction

Structures in areas of high seismic risk may be susceptible to severe damage in a large earthquake. [1]**.** The catastrophic seismic events have urged the need for effective retrofitting techniques for the non-seismically designed structures built in the seismic active zone. [2]**.** Steel bracing is used to enhance the seismic strength of reinforced concrete frames or multistory building, a wide research activity developed since 80's and the need to construct a multistory building for the increasing population worldwide. Steel bracing provides a similar advantage to shear walls by enhancing the structural integrity, rigidity, and ability to withstand deformation of the structure. The braces are commonly constructed inside existing bays of the building and they contribute to the lateral resistance of the structure through the axial force developing in their inclined members. The diagonals are pinned to steel plates that are anchored at the corners of each concrete bay with epoxy resins, whereas at the ground level special footing configurations for each brace are provided.

Steel bracing, by providing strength and stiffness, generally decreases the seismic demand on existing members, similarly to reinforced concrete shear walls (though usually to a lesser extent to the latter). The level of strength and stiffness increase can be tuned relatively easily by the choice of the number and the size of the braces, and it is easy to avoid large irregularities in elevation. Bracing is an ideal solution for the strengthening of soft ground story, where the steel braces are applied only at the lower building level.

*Corresponding author: pgs.saja.sahib@uobasrah.edu.iq

The additional weight on the building is negligible, but bracing have the capacity for adaptation to existing openings. Furthermore, it is a 'cleaner' construction method, because the braces are directly fitted to the concrete frame without the introduction of concrete and the creation of dust in the building. For larger buildings, steel bracing can be easily combined with dampers, in order to reduce the seismic demand.

Rahimi and Maheri [3] investigated retrofit RC frames of 4,8 and 12 story frames with peak ground acceleration (PGA) of 0.3 braced at the center bay of the frames vertically with tube bracing section with a variable dimension arranged from least cross section to largest and subjected to 20 earthquakes, they concluded that the best reduction in the inter story drift was the 8 story frames and performed less favorable, As the height of the frame rises, the bracing system's ability to enhance global reactions usually decreases.

Erdem and Karal [4] studied the performance of three, five and eight story existing RC building for span length of 21 m in x direction and 14.5 m in y direction as figure below strengthen with channel section CHS 219.1x8mm analyzed with nonlinear push over analysis with SAP2000, and explored that when damage ratios of the 3-story existing RC building is investigated, it is seen that there are no beams and columns in the collapse prevention (CP) performance level for both directions. However, the same strengthening procedures are also applied to the 3 story to obtain the changes in damage ratios of the structural members. After performing the analysis for the strengthened building, it is seen that all beams provide immediate occupancy (IO) performance level. In addition, while number of the columns in the LS level has decreased, the columns in the IO level have increased according to both seismic codes (Turkish and ASCE). With the importance of bracing scheme also considering the distributed area of bracing sections as **Abou-Elfath and Ghobarah [5]** that have investigated a low-rise building RC rehabilitated using concentric steel bracing, with different schemes for bracing, the building was of three story designed according to (ACI318-63) of concrete strength 21 Mpa, Fy is 300 Mpa.

L.L is (2.4 kN/m2) and snow load of 1.6 (kN/m2) supposing the building was located in Vancougher. The exterior columns of (300*300) mm.

They investigated different distribution for steel bracings and assessed that the best improvement in lateral capacity about 70% was in tripling the braces with considering the that bracings have decreasing area distributed over height. **Ahiwail** 2023[6] reported that the best performance in the term of internal drift ratio (IDR) was the cross bracing as well inverted V.

2 DESCRIPTION OF THE MODEL

sap v24 [7] is used to design multistory RC building by the ACI318-19 Code [8] for live and dead loads as describe in Table 1 according to ASCE7-16 [9] This building is designed for gravity loads only for 15 story each story is 3m height except the base is 3.5 height, with columns and beams arranged in such a pattern that every five stories have the same section to reduce the number of sections used in the structure and to focus on the main concept for utilizing steel braces.

Table.1

No. of Floor	Live loads (Kn/m^2)	Super dead load (Kn/m^2)
15 (roof load)	1	2
(1-14)	5	2

 https://doi.org/10.1051/bioconf/20249700072

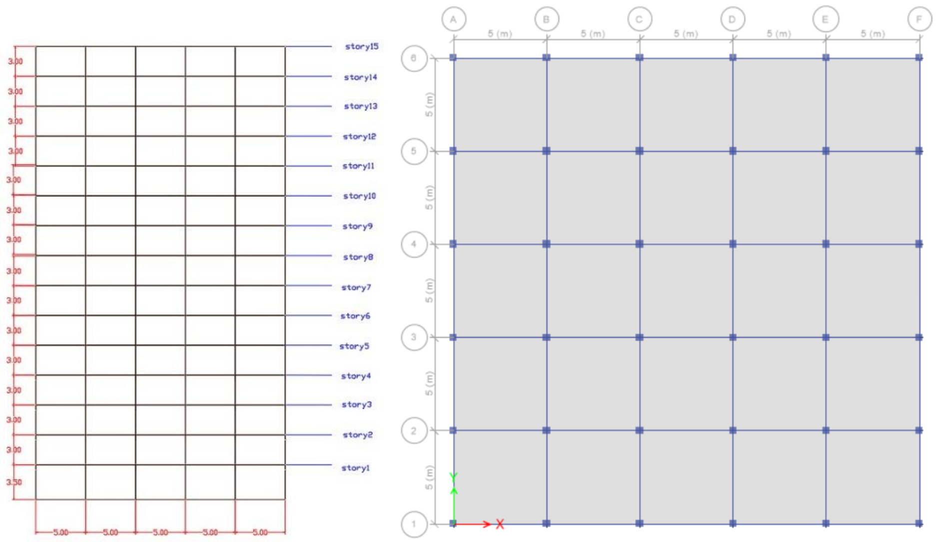

Fig.1. Elevation and plan view of building

Properties of RC building:

Table 2.

Property	**Value**	**Unit**
Unit weight	24	Kn/m³
Modulus of elasticity	248700.62	Mpa
Poisson ratio	0.2	……
Shear modulus	10362526	Mpa
Compressive strength fc	35	Mpa

Steel bracings properties:

Table 3.

Property	**Value**	**Unit**
Unit weight	77	Kn/m³
Modulus of elasticity	200000	Mpa
Poisson ratio	0.3	……
Shear modulus	76903069	Mpa
Fy	248	Mpa
Fu	399	
Fye	372	
Fue	440	

Members section

Columns for 1-5 stories	**Columns for 6-10 stories**	**Columns for 7-11stories**
600x600 mm	500x500mm	400x400mm
8Φ25	12Φ16	8Φ16
Beams for 1-8 story Beams for 9-11 story	600x400 mm 500x300 mm	4Φ16 top, bottom 6 Φ20 top3 Φ20 bottom 5 Φ20

3 Arrangement of steel bracings

This research focused on the best arrangement of bracing in the term of plastic hinge, roof displacement inter story drift and base shear.

Through arranging steel braces with the same sections at each pattern, it has been noticed that there was a different result, so it must select section for the same total weight of steel braces that the building need to by relying to the successful pattern in improving roof displacement, drift ratio and plastic hinges as Ayman et al[10], but in this method not all the patterns were successful in improving the resistance of earthquake, each pattern needed different sections but same weight as seen in table(4).

$$ƒ= \frac{W}{V} \ldots\ldots\ldots\ldots \quad (1)$$

Where:
ƒ: unit weight which is equal to 77
W: weight
V: volume which is the area * length of the braces

Table 4.

MODEL	stories	section	weight
X vertical	1	HSS 168.3x4.5	114.9639
	2-5	HSS 174.6x4.8	
	6-10	HSS 168.3x4.8	
	11-15	HSS 141.3x4.8	
V vertical	1-5	HSS 174.6x6.4	114.7449
	6-10	HSS 168.3x7.1	
	11-15	HSS 152.3x6.4	
X disributed	1	HSS 168.3x3.2	114.5175
	2,4,5,6,8,9,10	HSS 168.3x4.8	
	3	177.8X9.5	
	7	HSS 174.6x9.5	
	11	HSS 152.4x9.5	
	12-15	HSS 141.3x4.8	
V with I	1	HSS 168.3x4.5	114.9803
	2,3	HSS 190x12.7	
	4,5	HSS 177x9.5	
	6,7,10	HSS 174.6x9.5	
	8,9	HSS 177.8x12.7	
	11-13	HSS 151.4x9.5	
Mega X	1-5	HSS 177.8X9.5	
	6-10	HSS 174.6x9.5	
	11-15	HSS 152.4x9.5	114.7961
V as X	1	HSS174.6x6.4	114.0245
	2,5	HSS 168.3x4.8	
	3,4	HSS 174.6x6.4	
	6,9,10	HSS 168.3x4.8	
	7,8	HSS 168.3x7.1	
	11,12,15	HSS 141.3x6.6	
	13,14	HSS 141.3x4.8	

4 Method of work

As figure (5,6) of the first and second models by trial arrangements, it has been noticed that that there plastic formations at beams and column, this is due to the load concentrations in one direction for the fifteen floors.

This study involved modelling a thin plate with a thickness of 0.1 mm to cover the face of a building. The plate was subjected to a nonlinear time history analysis using Elcentro earthquake array #7. The maximum internal forces on the plate were determined at the moment of the maximum drift ratio, which occurred at 10.25 seconds into the earthquake. Based on the seismic loads and their distribution as seen in figure(3) , multiple schemes were considered to reduce roof displacement, inter-story drift, and plastic defor Each plan required distinct components to improve the seismic resilience of the reinforced concrete building, while maintaining the same weight as the way proposed by Aymen et al. [10].

The plate frame approach determined that the load path resulting from seismic loads led to a roof displacement of greatest magnitude at an inclination of near 45° figure (2 and 3).

It can be observed that an inclined arrangement is the most suitable approach for bracings to provide superior load dissipation throughout the building.

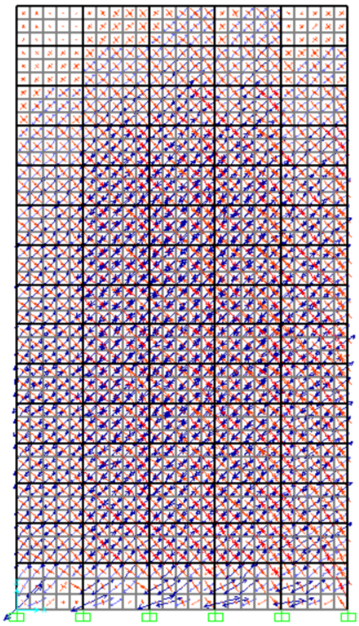

Fig.2. Internal forces

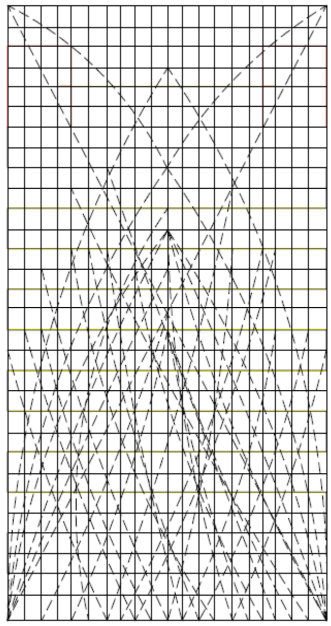

Fig.3. load path for the bracings

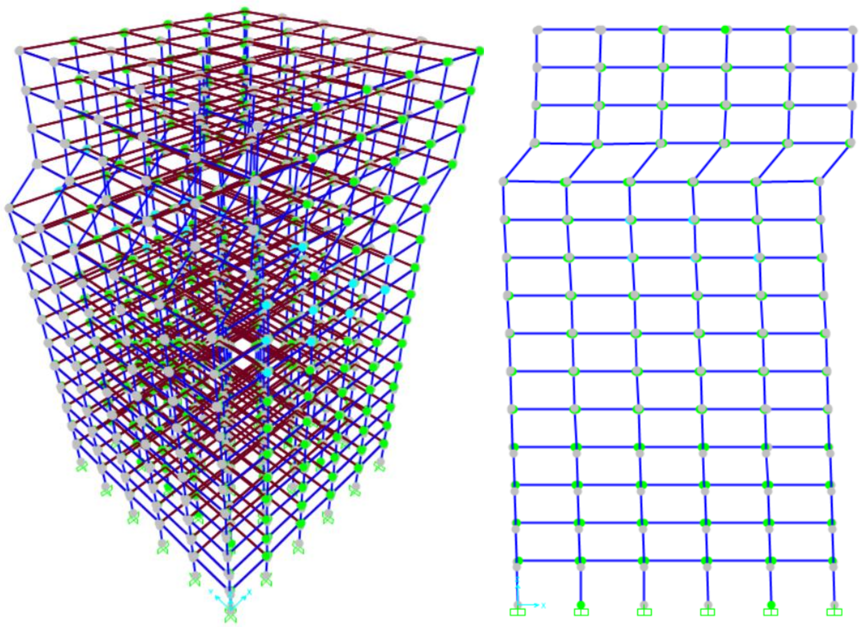

Fig.4. Model 1 : Bare building subjected to Elcentro

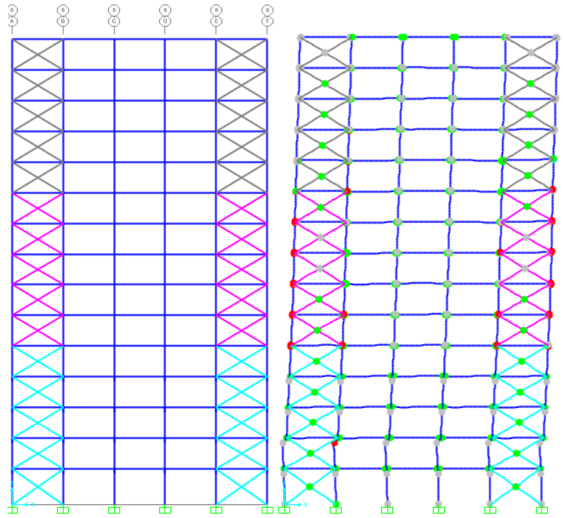

Fig .5. Model 2 vertical x

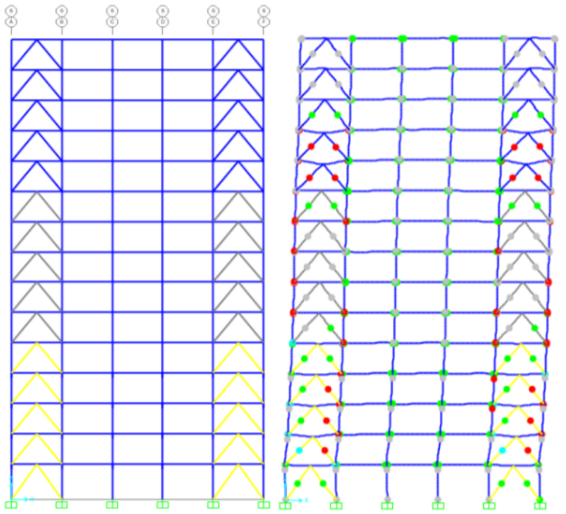

Fig .6.model 3: vertical v

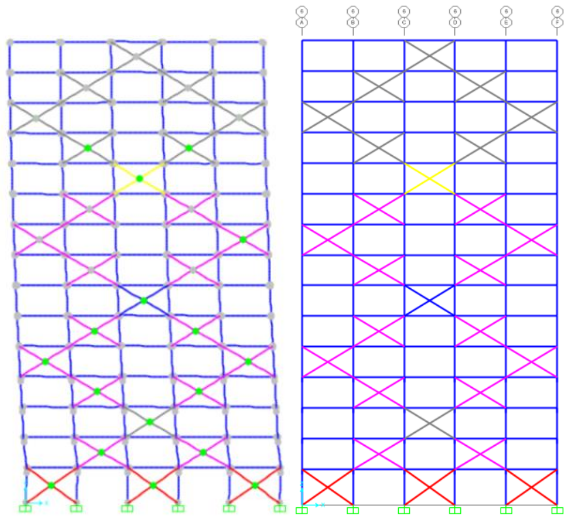

Fig.7. Model 4: distributed x

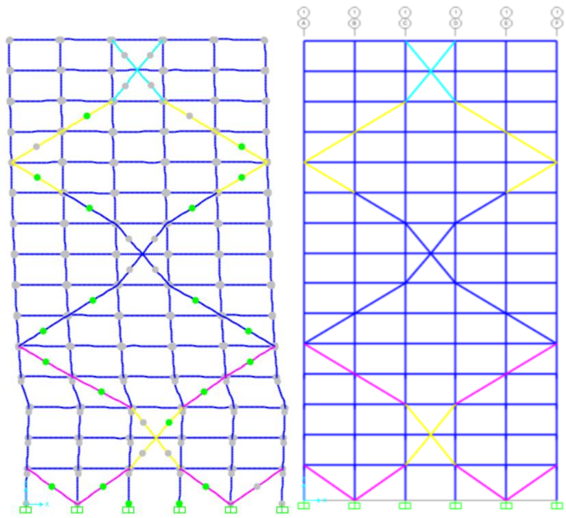

Fig .8. model 5: V with I bracing

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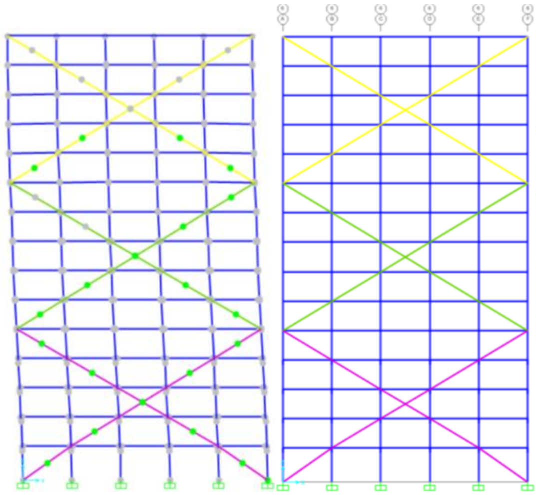

Fig .9. Model 6 Diagonal bracing

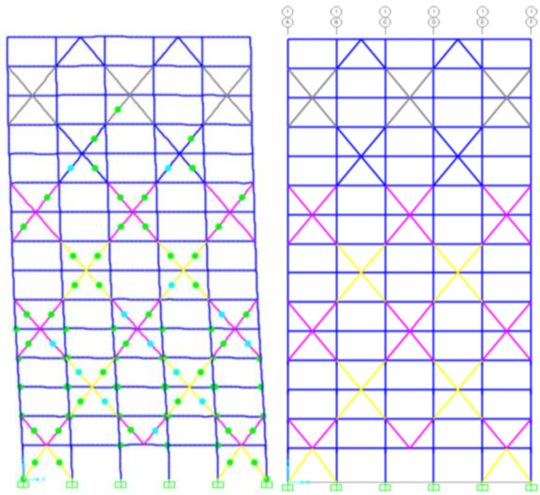

Fig.10. model 7 Hexagonal

5 ANALYSIS RESULTS

5.1 Time period

It is the natural movement of structural system after it has been disturbed from its static position and is allowed to move freely without any external force or damping. This analysis provides the natural frequency by the structure's mass, stiffness and damping characteristics.

The time requiered for copmleting one cycle of free vibration called natural period Tn as described in equation below:

$$T_n=2\pi\sqrt{\frac{m}{K}} \quad \text{units in sec…..} \qquad (2)$$

K is the stiffeness of building

M is the mass seismic weight wich is equal to the sum of the dead loads and 25% of the live loads according to ASCE 41-17

Equation 2 demonstrates that a decrease in the time period corresponds to an increase in the stiffness of the building.

Table5.

model	First period	second period
1	4.22106	3.808510

2	3.30488	2.75532
3	2.62521	2.49361
4	1.15719	1.13988
5	1.21344	1.13211
6	1.149618	1.132018
7	1.09700	1.08384

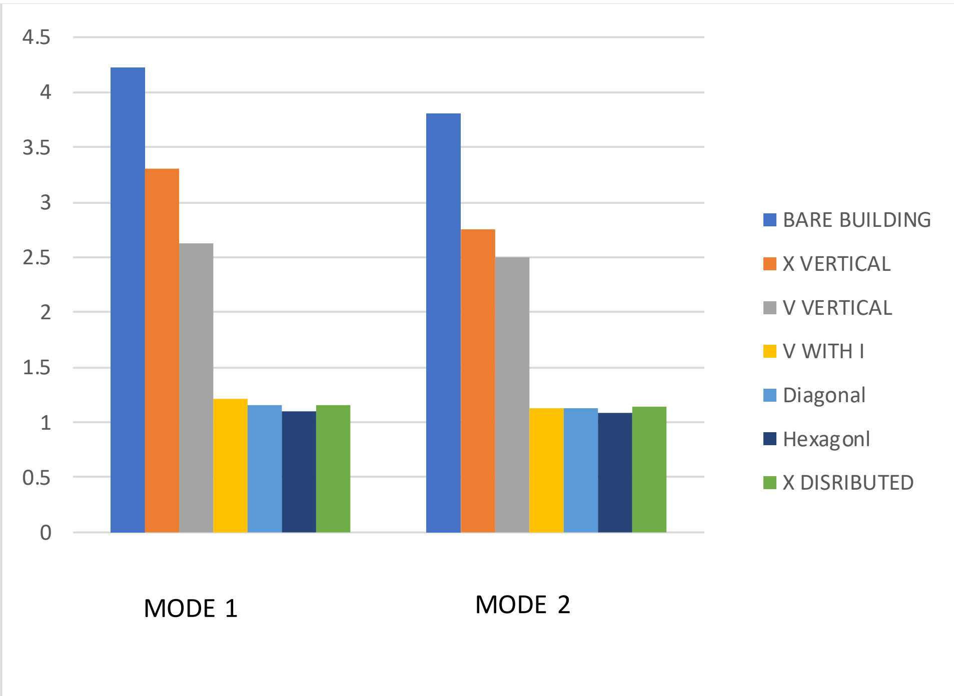

Fig.11. Natural Time period (Tn)

5.2 Inter drift story (IDS) and maximum roof displacement

IDR is the difference of the roof displacement between two adjacent storys. The allowable story drift is supposed according to risk category III of 0.015 h_{sx} [table 12.12.1 ASCE7-16]

From the models , it is assessed that the maximum reduction in roof displacement the Mega X braces, x distributed, Hexagonal model , v with I, inverted v vertical and x vertical of 60.64%, 60.5%, 59.1 %, 59.03 %,37.4% and 25.8% consequensivly.figure (13)

For the inter story drift all the models did not exceed the limit suggested, model 6 surpassed the others, as seen in figure (12).

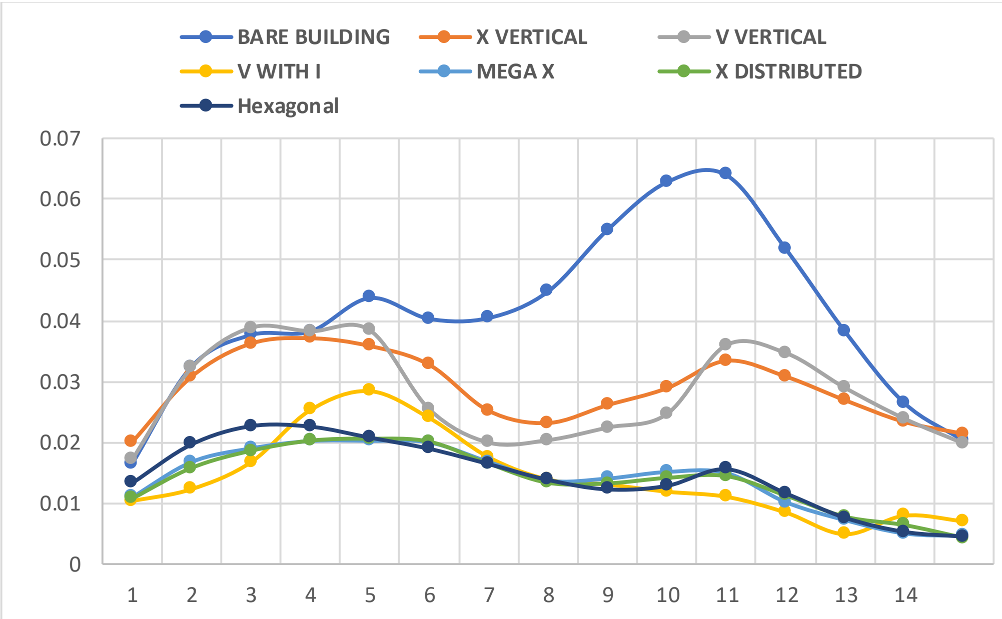

Fig.12. INTER DRIFT STORY

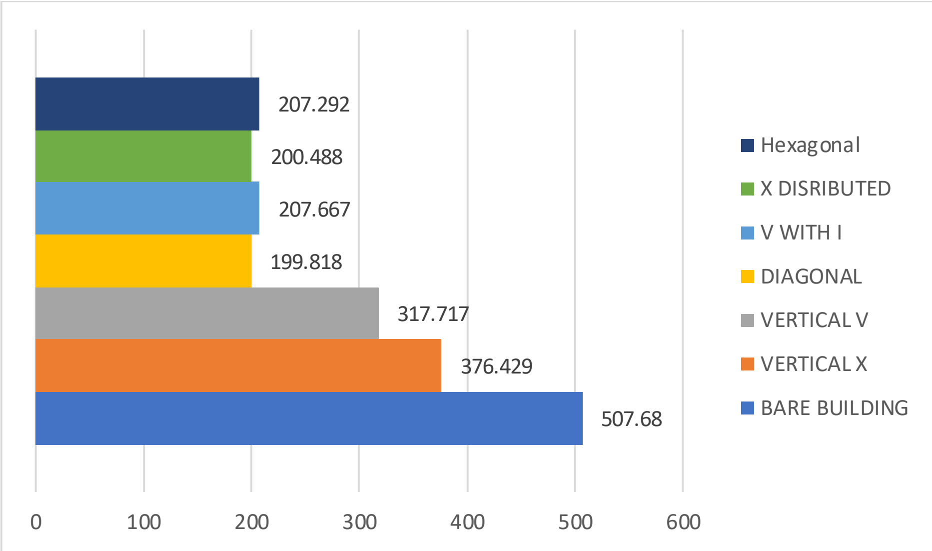

Fig.13. Maximum roof displacement in (mm)

5.3 BASE SHEAR

It is the lateral forces induced from earthquake loads subjected to the storys. As seen the results showed that higher increasing to base shear was in X vertical model while smaller incresing in V with I model as in fig (14), it is normal increasing due to increment in global stiffeness due to additions of bracings which lead to increase in demand on members [11].

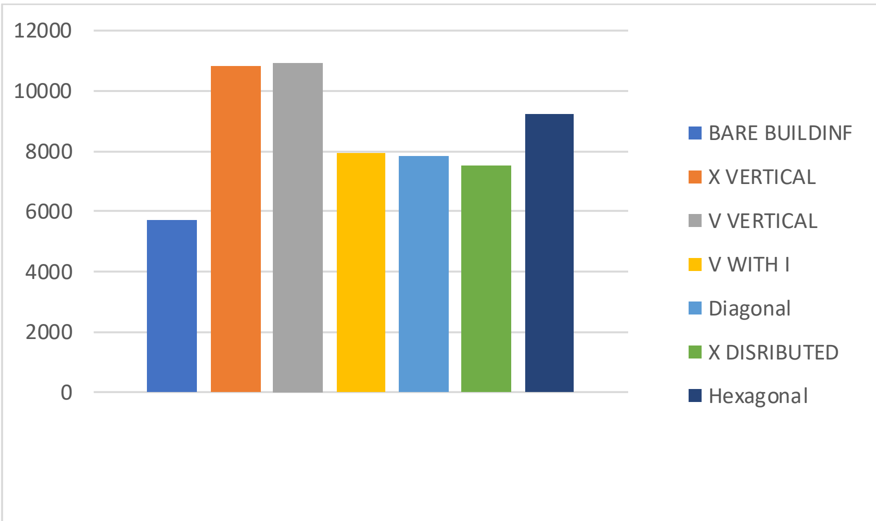

Fig.14. Base shear in kN

5.4 Plastic Hinges

When a material reaches its elastic limit, as indicated by plastic deformation, the deformation develops. This concept is often applied in structural engineering to investigate the behavior of structures designed over their elastic limits, especially when designing structures that may experience large deformations.

ASCE 41-13[13] states that braces should be represented as columns with a potential plastic hinge (PLH) in the middle to account for flexural and axial impacts.

Many plastic hinges formed in the bare building due to seismic load in the form of life safety from C to D. using the correct arrangement fewer hinges formed in the braces that the building remains safe for the model (4,5,6 and 7).

6 Discussion

1- The vertical layout of both the X and V bracing configurations exhibited inadequate performance in terms of plastic hinges and base shear.
2- According to the plate frame theorem, the optimal method for positioning steel braces is to align them with the load path. This approach yields four layouts that are considered suitable in terms of roof displacement and plastic hinges.
3- The model 6 exhibits the most optimal performance in minimising roof movement.
4- Based on the assessment conducted in this research, it was determined that the most optimal models for all the aforementioned limitations are models 4 and 6 .These models resulted in a 32% and 37% increase in base shear, as well as a 60.64% and 60.5% improvement in roof displacement, respectively.

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