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Static Push Over Analysis of a 5 Storey Steel Building

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The use of steel structures has been increasing rapidly in recent years. This is due to the high strength and ductility of the steel. This makes steel stand out compared to concrete for earthquake resistant building design.The seismic performance of a multi-story steel frame structure is analyzed according to the provision of current Turkish Eartquake Code (DBYBHY 2018). Few guidelines like Applied Technology Council (ATC40) and Federal Emergency Management Agency (FEMA356) have used. Steel bracing is very useful for increasing the shear capacity of the structure. The use of steel brace is one of the most common methods to increase the earthquake resistance of buildings. In steel structures, the steel brace arrangement is arranged in two ways, concentric and eccentric. There are few possibilities to arrange steel bracings such as X, V, Diagonal, K (Concentric bracings) and some eccentric bracings as well.

In this study typical 5 storey steel frame buildings have analyzed, for X and invert V types of concentric bracings. Performance of each frame is studied through pushover analysis. The pushover analysis has been carried out using SAP2000 v18, a product of computer and structure international. The results of all models are analyze and compare in term of base shear, story displacement, pushover curve, spectrum curve, performance point of the structure.

Keywords: *Static Pushover Analysis, Steel Structures Sistems, Eearthquake Loads, Braced Steel Structures.*

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I. INTRODUCTION

Steel and concrete are two of the most widely used building materials.Steel is one of the most suitable building materials for making earthquake resistant structures considering its high strength, lightness and ductility as well as its cost. Steel brace use is one of the most preferred methods in steel structures to build earthquake resistant steel structures.

Numerous solution methods have been developed in the analysis of structural systems. Static push over analysis method is one of the most widely used methods recently.Static push over analysis is used in the design of multi-story steel frame buildings in Turkish Earthquake Code - DBYBHY 2018 [1].

Steel structures show a more ductile behavior than reinforced concrete structures. This situation provides a great advantage to steel structures under the effect of earthquakes. However, large lateral displacements in high-rise buildings can sometimes lead to negative situations. For this reason, steel cross members are used in high-rise buildings to prevent excessive lateral displacements and to add lateral rigidity to the structure. A braced frame is a structural system that is designed principally to resist wind and earthquake forces. Braced frames are classified as concentric braced frames (CBF) or eccentric braced frames (EBF). Concentric braced frames are frames in which the core line of the member that get together at a joint, intersect at a point to form a vertical truss system which resist lateral forces. These frames provide complete truss action with member subjected to the axial forces in elastic range. Concentric braced frames (CBF) are used to resists wind forces. Bracing arranged concentrically in structure pose difficulties in preventing foundation uplift. Because one diagonal of an opposing pair is always in tension, possibility of brittle failure is present [2].

Pushover is a static nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern that continuously increases through elastic and inelastic behavior until an ultimate condition is reached. By performing pushover analysis, it is possible to observe the successive damage states of a building. The method is relatively simple to implement, and provides information on strength, deformation and ductility of the structure and distribution of demands which help in identifying the critical state members during the earthquake and hence proper attention can be given while designing [3-4].

In order to obtain performance points as well as the location of hinges in different stages, we can use the pushover curve. In this curve, the range AB being the elastic range, B to IO is being the range of instant occupancy, IO to LS being the range of life safety and LS to CP being the range of collapse prevention (see **Fig. 1**) [5].

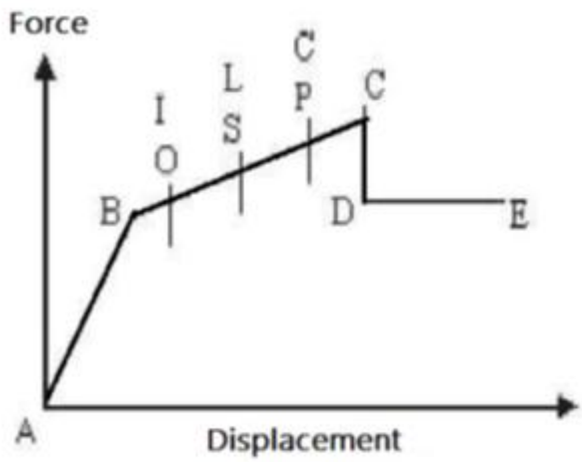


Fig. 1. Different stages of Plastic Hinges

In this study, static push-over analysis of a total of 5 5-storey steel structures was performed using the SAP 2000 Program. FEMA (Federal Emergency Management Agency) [6-7] and ATC Applied Technology Council) [8] codes were used when analyzing with Sap 2000 program. Storey displacemenets, base shear, pushover curve, spectrum curve, performans point of the structure were obtained at the end of the analysis. In the light of the analytical results obtained, the effects of steel cross use on the behavior of the structure were interpreted.

II. STATIC PUSHOVER ANALYSIS

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behaviour and load reversals being estimated by using a modified monotonic force- deformation criteria and with damping approximations. Pushover analysis may be classified as displacement controlled pushover analysis when lateral displacement is imposed on the structure and its equilibrium determines the forces. Similarly, when lateral forces are imposed, the analysis is termed as force-controlled pushover analysis. The target displacement or target force is intended to represent the maximum displacement or maximum force likely to be experienced by the structure during the design earthquake [9-10]. Displacement controlled pushover method is used for analysis of building structural steel frames with and without bracings in this study [11].
Static push over analysis method aims to produce structures with predictable seismic performance.
The three key elements of this method are: -

- Capacity: - It is a representation of the structures ability to resist the seismic demand.
- Demand: - It is a representation of the earthquake ground motion.
- Performance: - It is an intersection point of capacity spectrum and demand spectrum.

Different states such as Immediate Occupancy, Life Safety, Collapse prevention and collapse are defines as per ATC 40 and FEMA 356 (see **Table 1**) [6-8].

Table 1 Performance level of structure

Performance Level	*Structural Performance*	*Non Structural Performance*
Operational (O)	*Very light damage No permanent drift Substantially original strength and siffness*	*Negligible damage. Power and other utilities are available*
Immediate Occupancy (IO)	*Light damage No Structural Performance Substantially original strength and stiffness minor cracking Elevators can be restarted Fire protection operable*	*Equipments and content secure but may not operate due to mechanical/utility failure*
Life Safety (LS)	*Moderate damage Some permanent drift Residual strength and stiffness in all stories Gravity elements function building may be beyond economical repair*	*Falling hazars mitigated but extensive systems damage*
Collapse Prevention (CP)	*Severe damage Large permanent drifts Little residual strength and stiffness Gravity elements function Some exits blocked Building near collepse*	*Extensive damage*

Pushover analysis is one of the methods available to understand the seismic behavior of the structure. Nonlinear static pushover analysis was used to evaluate the seismic performance of the structures. The numerical analysis was done using SAP2000 18 and guidelines of ATC-40 and FEMA 356 were followed. The overall performance evaluation was done using capacity curves, storey displacements, base shear, spectrum curve and ductility ratios. Plastic hinge hypothesis was used to capture the nonlinear behavior according to which plastic deformations are lumped on plastic hinges and rest of the system shows linear elastic behaviour.

III. STEEL STRUCTURES

Reinforced concrete and steel structures are the most widely used building systems. steel structures are preferred structures because of their light weight and high earthquake resistance. The use of steel cross is one of the most common methods to prevent large lateral displacement of steel structures. The use of concentric and eccentric steel brace is a widely used construction technique to increase the resistance of steel frames against earthquakes. Bracing is an effective upgrading strategy to enhance the global stiffness and strength of steel frames. It can increase the energy absorption of structures or decrease the demand imposed by earthquake loads. With the inclusion of bracings, structures with augmented energy dissipation may safely resist forces and deformations caused by strong ground motions. Generally, global modifications to the structural system are conceived such that the design demands, often denoted by target displacement, on the existing structural components, are less than their capacities.

Lower demands may reduce the risk of brittle failures in the structure and avoid the interruption of its functionality. The present work assesses the seismic performance of steel frames with X and inverted-V type bracing and that of the structure without bracing. The inelastic seismic response has been quantified in terms of global deformation parameters derived by means of nonlinear static pushover analysis [10].

The concentric bracings increase the lateral stiffness of the frame and usually decrease the lateral drift. However, the increase in the stiffness may attract a larger inertia force due to earthquake. Further, while the bracings decrease the bending moments and shear forces in columns, they increase the axial compression in the columns to which they are connected.

IV. BUILDING MODELLING

For the analysis work, 5 models of building which 5 storey are made to know the realistic behavior of building during earthquake. In this study, concentric bracings and bare frame have taken for the pushover analysis. Typically, bay width is taken 3 m in X direction and 4 m Y direction. No. of bays in X directions are 5, in Y direction are 3. Total height of building is 15 meter. All the joints of beam column and bracings are rigid. There are assigned diaphragm in all joints because; it is horizontal or nearly horizontal system which transmits lateral forces to vertical resisting system like bracing system [11]. The models were analyzed as per Turksih Earhquake Code [1] and Fema356 [6,7] and ATC 40 [8]. Different arrangement of steel braced frame and a bare frame considered below. All columns are fixed from base for foundation. Common plan for all building model is shown in **Fig. 2** and structural configuration is shown in the **Fig. 3**.

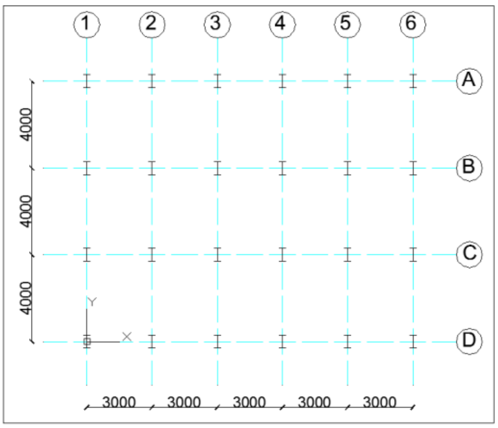


Fig. 2 Common plan for all building model (mm)

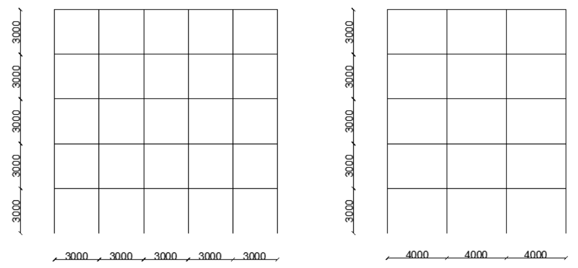
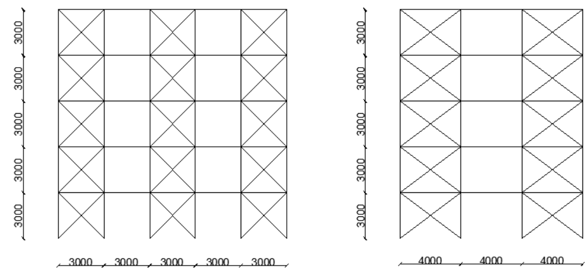
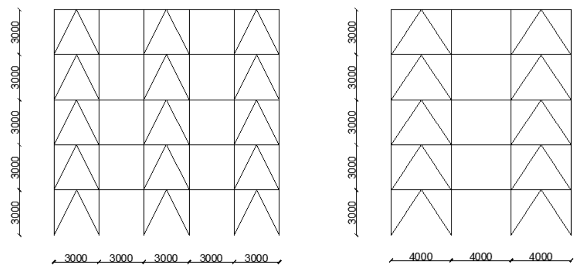
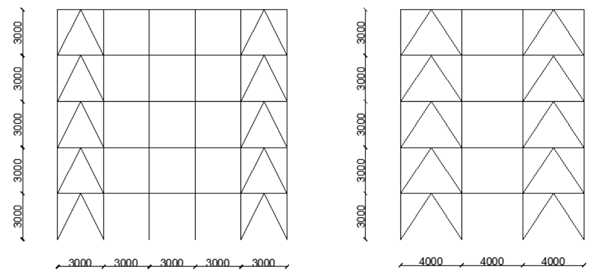
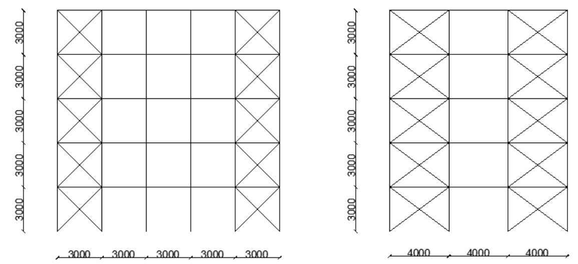
Type	Properties	Elevation in XZ direction and YZ direction
1	5 Storey bare frame	
2	5 Storey X concentric braced frame (B)	
3	5 Storey invert V concentric braced frame (B)	
4	5 Storey invert V concentric braced frame (A)	
5	5 Storey X concentric braced frame (A)	
	(A) Bracing members are only available in corner openings (B) Bracing members are available both corner and mid span	

Fig. 3 Elevation of all buildings

V. STATIC PUSHOVER ANALYSIS AND RESULTS

5.1 Material properties

The material used in structure is steel in beam, column and bracing member; the material considered in slab is concrete. S235 grade of steel and C25 grade of concrete are used for all the frame models used in this study. The material properties are taken as per Turkish Eartquake Code (DBYBHY 2018) [1] and TS5-EN 1991-1-4 [12]. Parameters considered for the study is given below in **Table 2**.

Table 2 Building parameter considered for the study

Particular	Details
Live load	3.5 KN/m^2 Typical Floor
Dead Load	3.0 KN/m^2
Wind Load	TS EN 1991-1-4
Earthquake	Turkish Eartquake Code (DBYBHY 2018)
Type of Soil	Z2
Place of Building	Kütahya- Turkey
Plan Size	15 m x 12 m
Height of buildings	9 m (3 Stories), 15 m (5 Stories)
No. Of Bay in X direction	5
No. Of Bay in y direction	3
Building Importance Factor	1
Responce Reduction Factor for Bare /Concentric Braced Frame	8 / 5
Beams- Columns-Brace Section	The design of each building was done separately in the SAP 2000 program using the AISC ASD-89 regulation.

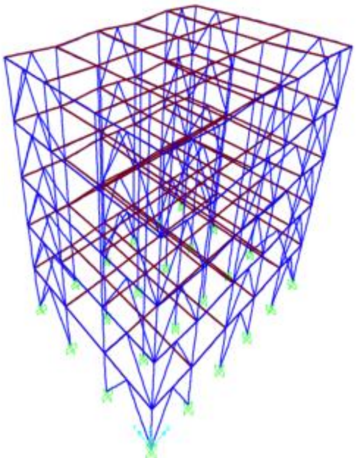
5.2 Anaysis and results

Procedure of pushover analysis

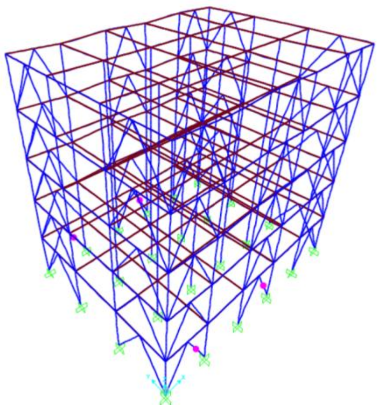
- Define all the material properties, frame sections, load cases and mass source.
- Assign hinge properties available in SAP2000 Nonlinear as per ATC-40 to the frame elements. For the beam default hinge that yields based upon the flexure (M3) and shear (V2) is assigned, for the column default hinge that yields based upon the interaction of the axial force and bending moment (P M2 M3) is assigned, and for the equivalent diagonal strut default hinge that yields based upon the axial force (P) only is assigned.
- Define three static pushover cases. In the first case, gravity load is applied to the structure, in the second case lateral load.
- After defining, the all load cases run the analysis for the pushover load case and nonlinear gravity load case.
- Pushover curve of all braced frame structure and bare frame structure have found after analysis. The capacity of the building is determined by pushover curve. All types of results are discussed below.

- pushover curves of building have obtained, from the Pushover curve the data about displacement and base shear have obtained.
- Capacity spectrum curve is useful for calculate the overall demand of the structure and capacity of the structure. It is useful to obtain the performance point of the structure.

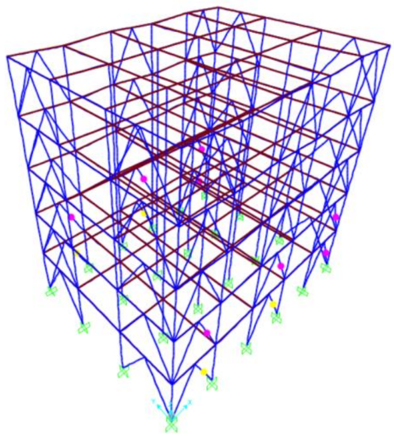
Fig. 4 shows the location of hinges obtained from Type 3 building with invert V Bracing in X direction



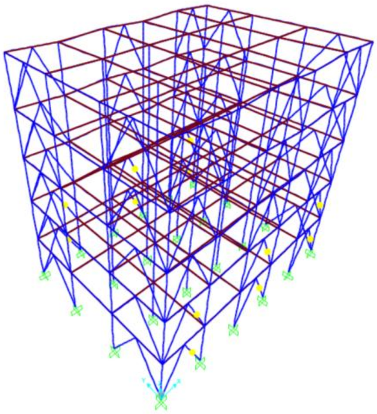
Plastic hinge formation



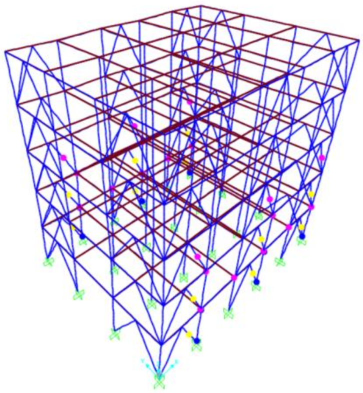
2. Plastic hinge formation



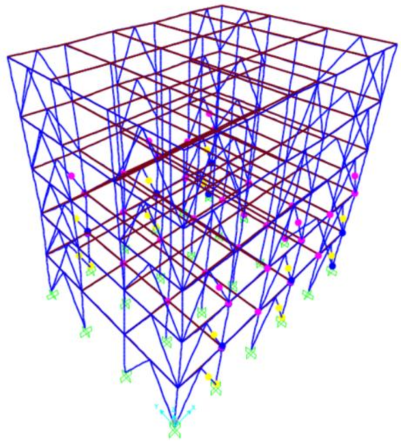
3. Plastic hinge formation



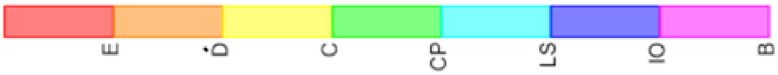
4. Plastic hinge formation



8. Plastic hinge formation



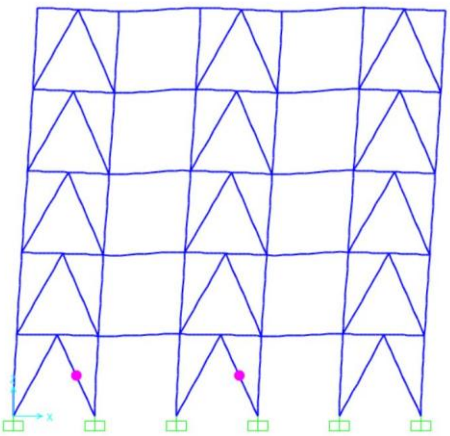
11. Plastic hinge formation



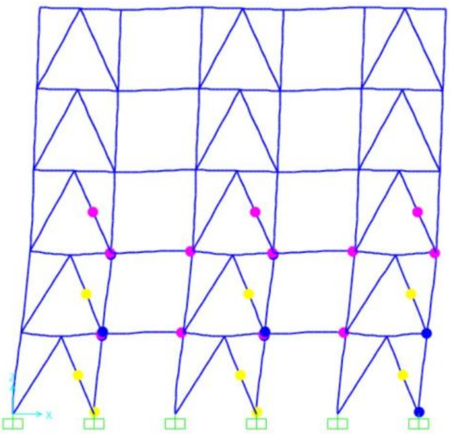
Plactic hinges formation

Fig. 4 Location of hinges obtained from Type 3 building with invert V Bracing in X direction

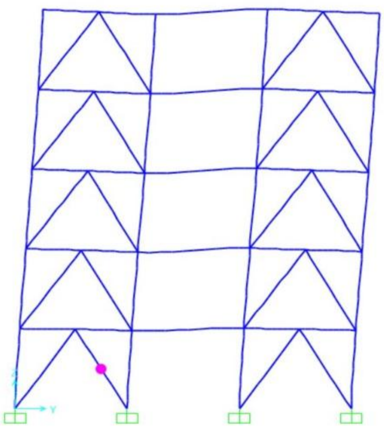
Fig. 5 shows the location of hinges obtained from Type 3 building with invert V Bracing in X and Y



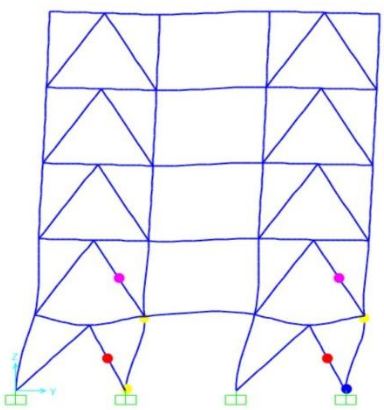
The fisrth plactic hinge formation in X direction



The last plactic hinge formation in X direction



The fisrth plactic hinge formation in Y direction



The last plactic hinge formation in Y direction

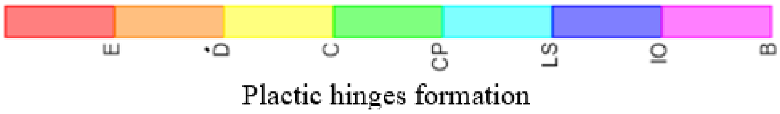


Fig. 5 Location of hinges obtained from Type 3 building with invert V Bracing in X and Y direction

The pushover analysis results of all frames are given in the **Table 3** and **Fig. 8-9**.

Table 3 Pushover analysis results of all buildings

Type	Base Shear in X direction (KN)	Base Shear in Y direction (KN)	Displacement in X direction (mm)	Displacement in Y direction (mm)	Properties
1	1123,1	793,9	160,2	218,6	5 Storey bare frame
2	2818,2	2453,1	59,9	58,7	5 Storey X concentric braced frame (B)
3	2279,5	1513,5	55,7	50,8	5 Storey invert V concentric braced frame (B)
4	1728,2	1514,3	65,1	50,8	5 Storey invert V concentric braced frame (A)
5	2317,0	2452,5	69,8	58,6	5 Storey X concentric braced frame (A)

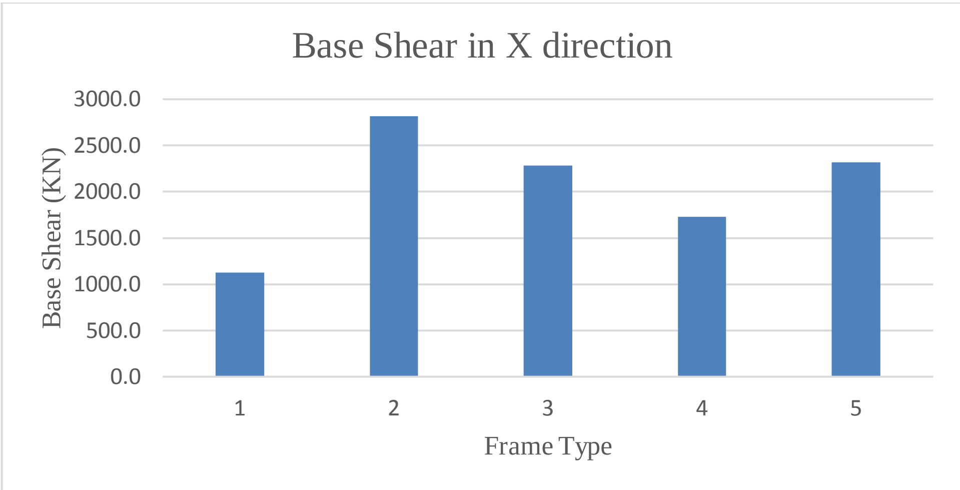


Fig. 8 Base shear-displacement graph in X direction

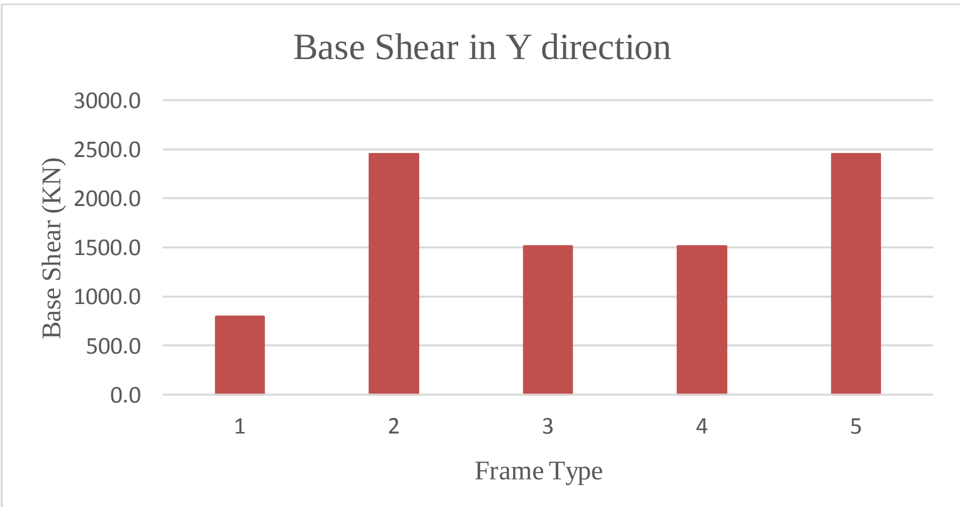


Fig. 9 Base shear-displacement graph in Y direction

Table 4 - 5 show the increase in base shear carriying capacity in X and inverted V type braced steel frame.

Table 4 Percentage increse in shear carriy capacity in X direction

Storey	Bare frame (KN)	Invert V concentric braced frame (B) (KN)	Percentage increase (%)	X concentric braced frame (B) (KN)	Percentage increase (%)	Invert V concentric braced frame (A) (KN)	Percentage increase (%)	X concentric braced frame (A) (KN)	Percentage increase (%)
5 storey	1123,09	2279,5	103	2818,23	151	1728,2	54	2316,99	106

Table 5 Percentage increse in shear carriy capacity in Y direction

Storey	Bare frame (KN)	Invert V concentric braced frame (B) (KN)	Percentage increase (%)	X concentric braced frame (B) (KN)	Percentage increase (%)	Invert V concentric braced frame (A) (KN)	Percentage increase (%)	X concentric braced frame (A) (KN)	Percentage increase (%)
5 storey	793,87	1513,49	91	2453,14	209	1514,3	91	2452,54	209

VI. CONCLUSION

From the above results the location of different types of hinges for different types of the buildings are obtained.

1. Concentric steel bracings can be used to strengthen or to retrofit the existing structure.
2. The greatest increase in base shear forces compared to the empty frame is provided in the X-braced system.
3. The provision of bracing enhances the base shear carrying capacity of frames and reduces roof displacement undergone by the structures.
4. Group B cross arrangements are more effective than group A cross arrangements.
5. The present analytical work has shown that steel frames with insufficient lateral stiffness can be retrofitted with braces. Braces are the viable solutions to provide both global lateral stiffness and strength of the frame.

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