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Studies on Seismic Performance of Braced and Unbraced Steel Frame by Non Linear Static Analysis

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ABSTRACT:Over the past few decades, Steel structures have taken the centre stage of our Construction industry. This progress, has been coupled with an additional need for safety against seismic forces, making seismic design of structures as our chief priority. Amongst an arsenal of procedures present at our disposal, in terms of seismic resistance, Steel bracing, being economical, easy and efficient, stands out from the rest. It can be used as a retrofit as well. The flexibility of the bracing system in design, to meet required strength and stiffness adds on to the workability of this method. There are various types of steel bracings such as Diagonal, X, K, V, inverted V type or chevron, zipper braced and ZX-braced frame. In this study, our aim is to analyse a (G+4) Steel bare frame with various bracings (X, V, Inverted V, Diagonal bracing etc.) with the help of SAP 2000 software, to obtain pushover analysis results. Comparing the results on the basis of seismic parameters, such as base shear, roof displacement, time period, storey drift would give us the idea about the suitability of a particular type of bracing under specific working condition.

KEYWORDS:Pushover Analysis, SAP 2000, Bracing Systems.

I. INTRODUCTION

In recent years, Steel has managed to edge past its competitors into becoming the most desired material in the modern construction industry. When compared with concrete, it is found that steel, as a construction material, increases the strength of the structure approximately by 10 times. It is easier to erect, prefabricate, and demount steel structures. The large strength to weight ratio deems steel as the most economical option for construction. Optimal service can be received by these structures if they are safeguard against corrosion and fire. Being 100% recyclable, steel is one of the most environmental friendly construction material.

With the increase in use, additional thought has been devoted into making these structures safe than they are now. One of the major step into ensuring safety has been the introduction of steel braces into steel structure.

Providing bracing in steel structures is an effective method used to enhance the global strength and stiffness of unbraced steel frames. It increases the energy absorption of structures which makes the structures better suited for withstanding earthquake forces. They might be aesthetically unpleasant, but the benefits prevail over the shortcomings. When designed properly, these systems have a huge impact in reducing the displacement of the structure and in turn making the structure stable.

SAP2000 meets the requirements head-on featuring a very sophisticated, intuitive and versatile user interface powered by an unmatched analysis engine and design tools for engineers allowing step-by-step large deformation analysis.

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II. LITERATURE REVIEW

A brief review of previous studies on the application of the pushover analysis and the seismic stability provided by bracing systems was done. This literature review focused on recent work done in the field of pushover analysis of concentrically braced steel frames and past efforts most closely related to the needs of the present work. Following were some of the papers reviewed:-

i) Mohammed Idrees Khan, Mr. Khalid Nayaz Khan, 2014:-

This paper explained about the non-linear static analysis of high rise steel frame building done with different types and pattern of bracing system. 15 storey regular steel frame building was modelled for different types of concentric bracing and the results were obtained through non-linear static analysis. The results showed that base shear carrying capacity of frames increased due to bracing. Displacement at roof level of braced frame reduced up to 70-80% as compared to bare frame model.

ii) K.K.Sangle, K.M.Bajori, V.Mahlungkar, 2012

This paper presented the compared results of seismic analysis of high rise building with various patterns of bracing systems and without the usage of bracing systems. For the construction of high rise buildings they are generally constructed for stiffness and lateral load resistance. We also get to know that bracings are strong in compression. Bracings with their enclosed frames has to be accounted for increase in lateral load counter capacity of structure. When bracings are situated in steel frame it acts as diagonal compression strut and imparts compression force to another joint. Distinctions in the column stiffness can impact the mode of failure and lateral stiffness of bracing.

iii) V.S.R. Pawan Kumar, Rayapolu and Raju, 2012

This study was based on a 5 storied RC framed building subjected to earthquake located in zone 5 using SAP 2000 software. The document puts forward the detailed procedure of the nonlinear static pushover analysis, depicting a higher degree of damage expected in a 5 storied building during an earthquake. Depending upon the seismic deficiency in the design and detailing of the building, inferring from the analysis, the building has to be strengthened properly in order to attain the desired level stability against seismic forces. They concluded that the pushover analysis is quite a simple way to explore the non-linear characteristic of the structures in question.

iv) K.G.Vishwanath, 2010, IJCSE

A four storey building was analysed for seismic zone – IV as per IS 1893:2002 using STAAD Pro software. Performance of steel bracing in rehabilitation of a four storey building was studied. Performance of the building was examined in terms of story and global drift. The study was also extended to eight storey, twelve storey and sixteen storey building. Lateral displacement of each storey was found out. X type of steel bracing was found to be the most efficient one.

v) Ghobarah A. et al., (1997)

The study showed that inter storey drift can be a parameter for uniform ductility in the storeys of the building. Storey drift can occur in a weak storey that may cause hazardous building collapse during a seismic event. Uniform ductility in all storeys of a building was preferred in seismic design.

Limitation:-

Not much work has been carried out on steel structures as per the provisions of IS: 1893 – 2002 and amongst of all the research on braced frame steel structure, most are either experimental study or finite element analysis of 2D frames.

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III.OBJECTIVE AND METHODOLOGY

OBJECTIVE:-

- a) To investigate the seismic performance of a multi-story steel frame building
 - Unbraced and then with different bracing arrangement such as cross bracing, 'X', 'V', Chevron, knee, diagonal bracing etc. using SAP2000 software to obtain Pushover analysis.
 - Under different earthquake loading and loading combinations.
- b) To investigate the seismic response of a multi-story steel frame building
 - Under same bracing configuration but with varying number of story i.e. with varying height of the building.
- c) Comparing the results on the basis of seismic parameters, such as base shear, roof displacement, time period, storey drift would give us the idea about the suitability of a particular type of bracing under specific working condition.

METHODOLOGY:-

i) PUSHOVER ANALYSIS

Pushover analysis is defined as an analysis where a mathematical model directly inculcating the nonlinear load-deformation characteristics of individual components and elements of the building is to be subjected to step by step increasing lateral loads which represents inertia forces in an earthquake until a target displacement is exceeded.

The structural Pushover analysis uses a nonlinear static analysis algorithm to assess performance by estimating the force and deformation capacity and seismic demand. The seismic demand parameters are storey drifts, global displacement (at roof or any other reference point), storey forces, and component deformation and component forces. The analysis accounts for material inelasticity, geometrical nonlinearity and the redistribution of internal forces.

ii) FORCE DEFORMATION BEHAVIOUR OF HINGES

- a) Point A corresponds to unloaded condition.
- b) Point B represents yielding of the element.
- c) At point C, the ordinate represents nominal strength and abscissa corresponds to deformation at which significant reduction occurs.

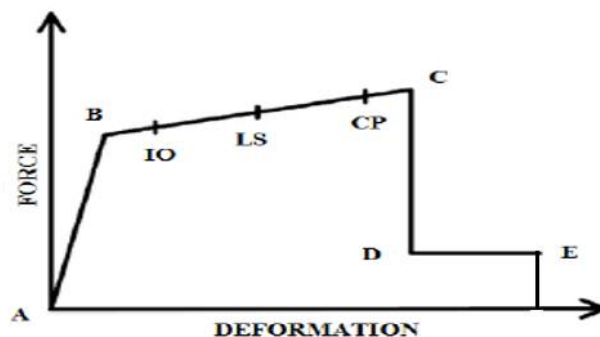


Fig-I Force vs Deformation curve

- d) The drop from C to D signifies initial failure of the element and beyond point C the resistance to lateral load is usually unreliable.
- e) The residual resistance from D to E allows the frame elements to sustain gravity loads.
- f) Point E represents the maximum deformation capacity; beyond which the gravity loads can no longer be carried

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iii) STEPS

A displacement-controlled pushover analysis is basically composed of the following steps:

- A three dimensional model that represents the overall structural behaviour was created.
- Load-deformation diagrams of all important members that affect lateral response were defined.
- Gravity loads composed of dead loads and a specified portion of live loads were applied to the structural model initially.
- A pre -defined lateral load pattern which was distributed along the building height and then applied.
- Analysis were run at this stage to assess the story drift and base reaction; the results were recorded
- Hinges were provided specifically to the columns, beams and bracings.
- A specific load case was defined for the pushover analysis and the displacement control method is used.
- Analysis is run again to check the formation of hinges.
- The roof displacement is plotted with the base shear to get the global capacity curve of the structure
- Inference from the analysis is used to compare the structural stability incurred from different types of bracing systems.

IV. MODELLING

Three basic models of different storey height each representing one of low, medium and high rise buildings, were assigned with different types of bracings(X,V, Inverted V, Diagonal).

i)DETAILS OF BUILDING

Table-1 Dimension details of building

Type of building	No. of storeys	Height of each storey (Metres)	No. of bays in X direction	No. of bays in Y direction	Bay width (X dir.) (Metres)	Bay width (Y dir.) (Metres)	Plan dimension (Metres)
Low rise	G+4	3.5	3	3	7	7	21x21
Medium rise	G+9	3.5	3	3	7	7	21x21
High rise	G+14	3.5	3	3	7	7	21x21

Table-2 Sectional details

Type of building	Beam section	Column section	Brace section
Low rise	ISMB 200	ISHB 250 -2	ISA 75x75x10
Medium rise	ISMB 300	ISHB 350- 2	ISA 110x110x10
High rise	ISMB 350	ISHB 450-1	ISA 150x150x12

ii)SEISMIC PARAMETERS:-

- Zone IV has been considered in our modelling i.e., $Z= 0.24$
- Normal buildings has been considered in our models i.e., $I=1.5$
- Since our study is based on concentric braced frames, the response reduction factor of 4 has been considered.

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- Soil profile types are characterized based on the average soil properties for the upper 30 m of the soil profile. Upon investigation and referring to some of the journals and reports we decided to select medium soil (Type II) for our project.

V. MODELS AND ANALYSIS

MODELS:-

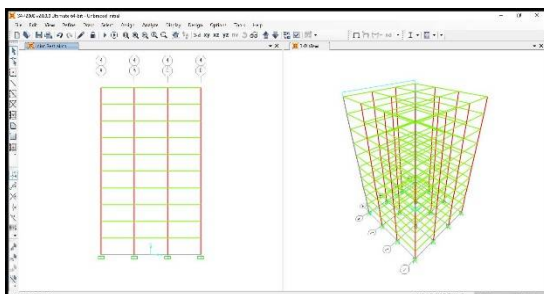


Fig-II Unbraced model for medium rise building

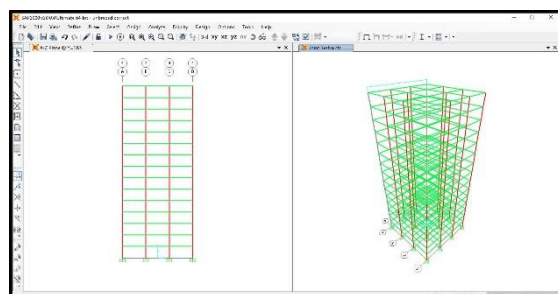


Fig-III Unbraced model for high rise building

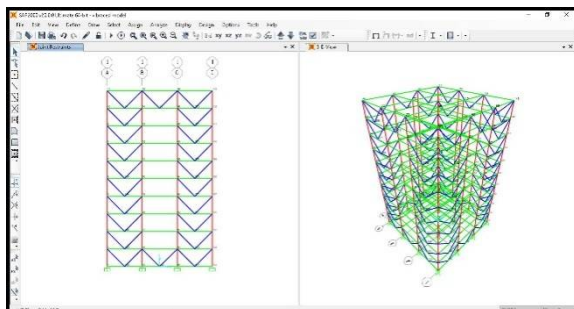


Fig-IV Placement of V bracings

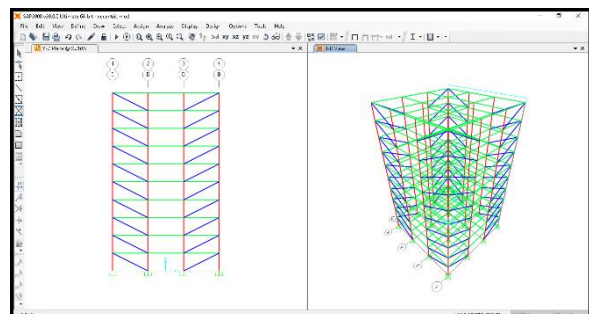


Fig-V Placement of Diagonal bracings

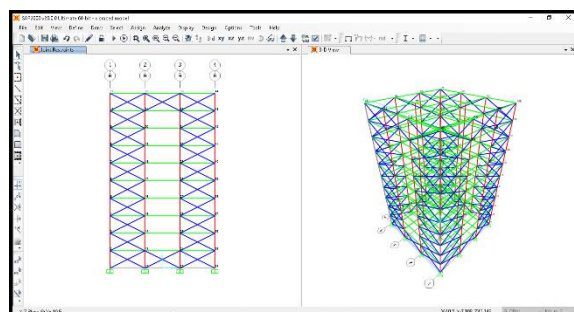


Fig-V Placement of X bracings

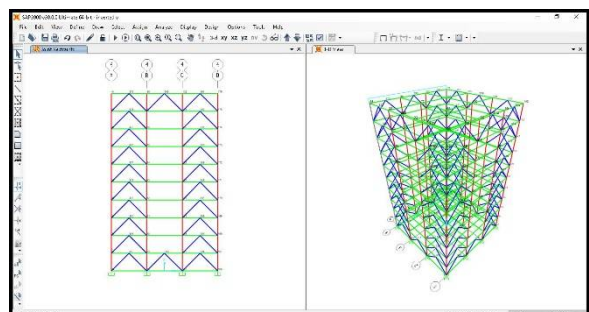


Fig-VI Placement of Inverted V bracings

ANALYSIS:-

The selected frame model were analyzed using pushover analysis in SAP 2000. Top storey drift, base shear, performance point (from the capacity curve) were selected as the seismic parameters around which our analysis and the consequent result revolved. Following graphs were used in our analysis:-

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a) BASE SHEAR VS ROOF DISPLACEMENT GRAPH

The result of the pushover analysis was plotted as a graph of base shear vs roof displacement which helped us in getting a detailed idea about the performance of the structure under seismic loads.

b) PUSHOVER CAPACITY SPECTRUM

Using the interaction of the base shear and the displacements calculated from the results of a Pushover analysis, the capacity spectrum of a structure were calculated. The demand spectrum was also generated for a design seismic load using the design response spectrum.

c) PUSHOVER CAPACITY CURVE RESULT

The output of performance point was used to find out the critical step(critical step being highlighted in every table) in the analysis; which in turn gave us the value of base shear and roof displacement at that particular point. The critical step was also significant to judge the local stability of the structure.

d) PERFORMANCE POINT

The Performance Point, which represents the state of maximum inelastic capacity of the structure, was found through the cross point of the Capacity Spectrum and Demand Spectrum for a given damping ratio.

Analysis of a X-braced steel frame(High rise Building) is shown below using the graphs:-

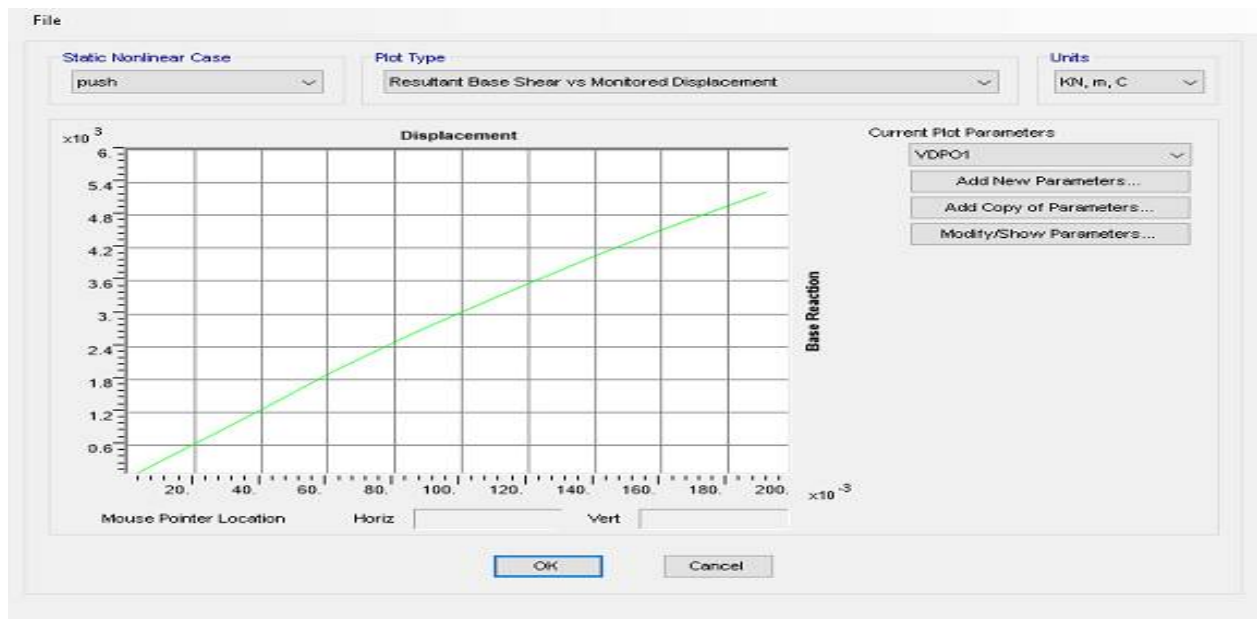


Fig-VII Graph showing variation of displacement and base shear

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Fig-VIII Graph showing Capacity and Demand Curve

Note:- The intersection point of capacity and demand curve gave the performance point. The figure shows that it is at effective time period of 0.675 sec.

Pushover Curve Demand Capacity - ATC40

File View Edit Format-Filter-Sort Select Options

Units: As Noted Pushover Curve Demand Capacity - ATC40

Filter:

	LoadCase Text	Step Unitless	Teff Sec	Beff Unitless	SdCapacity m	SaCapacity Unitless	SdDemand m	SaDemand Unitless	Alpha Unitless	PFPphi Unitless
	push	0	0.666236	0.05	0	0	0.297894	2.701747	1	1
	push	1	0.666236	0.05	0.04534	0.411209	0.297894	2.701747	0.575232	0.421264
	push	2	0.666236	0.05	0.090679	0.822417	0.297894	2.701747	0.575232	0.421264
	push	3	0.666236	0.05	0.136019	1.233526	0.297894	2.701747	0.575232	0.421264
	push	4	0.666236	0.05	0.149264	1.353751	0.297894	2.701747	0.575232	0.421264
	push	5	0.667474	0.051172	0.202224	1.827274	0.296752	2.681418	0.576826	0.429256
	push	6	0.671905	0.055152	0.259458	2.313614	0.293131	2.613674	0.583857	0.444369
	push	7	0.675573	0.057775	0.304205	2.68325	0.291244	2.568927	0.589552	0.45628
	push	8	0.678392	0.0594	0.34152	2.9874	0.290369	2.539963	0.593823	0.465417
	push	9	0.686194	0.066522	0.381869	3.264819	0.285075	2.437274	0.597505	0.46812
	push	10	0.69415	0.073925	0.410135	3.42657	0.280242	2.341347	0.598955	0.4657

Fig-IX Pushover Curve Demand Capacity

Note:- The performance point occurred at Step 7 and the displacement and base shear at step 7 was considered.

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Pushover Capacity Curve

File View Edit Format-Filter-Sort Select Options

Units: As Noted Pushover Capacity Curve

Filter:

LoadCase Text	Step Unitless	Displacement	BaseForce KN	AtoB Unitless	BtoI0 Unitless	I0toLS Unitless	LStoCP Unitless	CPtoC Unitless	CtoD Unitless	DtoE Unitless	BeyondE Unitless	Total Unitless
push	0	3.366E-06	0	1712	0	0	0	0	0	0	0	1712
push	1	0.019103	602.191	1712	0	0	0	0	0	0	0	1712
push	2	0.039203	1204.381	1712	0	0	0	0	0	0	0	1712
push	3	0.057303	1806.572	1712	0	0	0	0	0	0	0	1712
push	4	0.062683	1982.488	1708	4	0	0	0	0	0	0	1712
push	5	0.086809	2683.35	1688	24	0	0	0	0	0	0	1712
push	6	0.115299	3438.951	1666	46	0	0	0	0	0	0	1712
push	7	0.138806	4027.282	1648	64	0	0	0	0	0	0	1712
push	8	0.159953	4516.26	1638	74	0	0	0	0	0	0	1712
push	9	0.178764	4966.258	1610	102	0	0	0	0	0	0	1712
push	10	0.191003	5224.951	1566	126	0	0	0	0	0	0	1712

Fig-X Table showing displacement and base shear at various steps

All other frames were analysed in the same manner and results were obtained.

VI. RESULTS

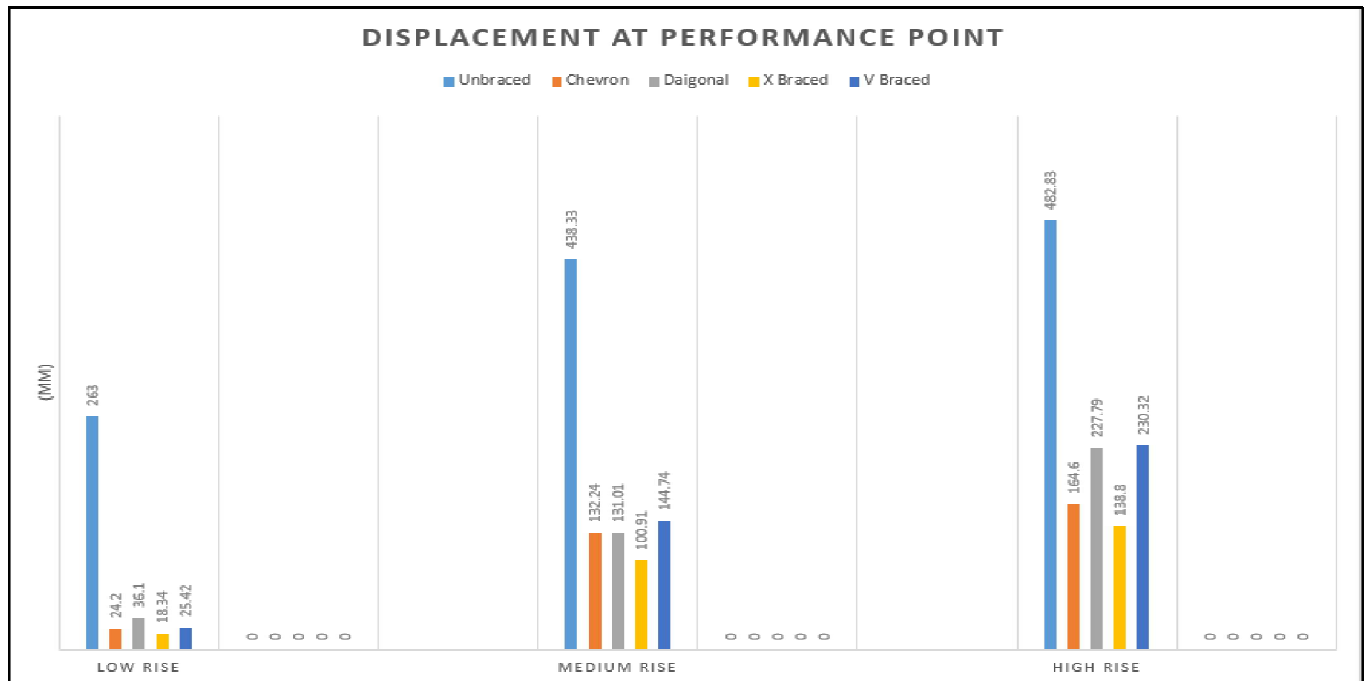


Fig-XI Displacement at performance point in different types of building

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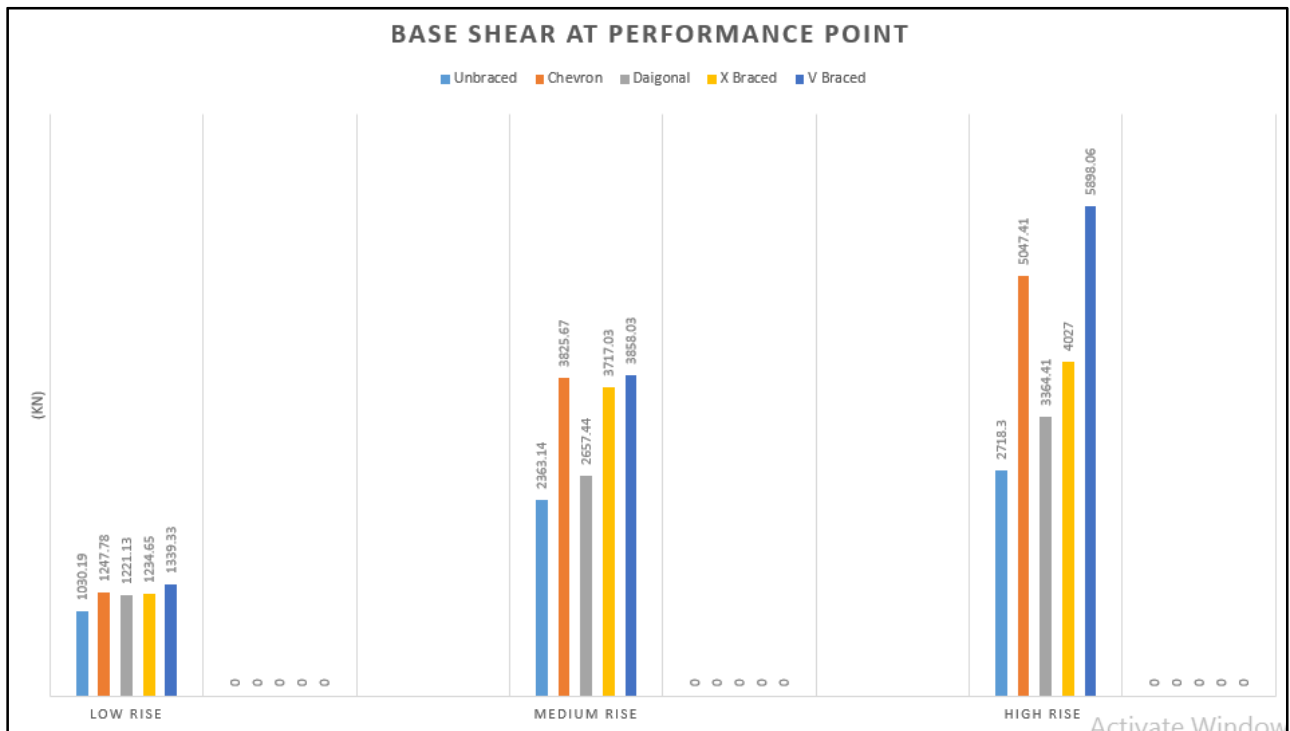


Fig-XII Base shear at performance point in different types of building

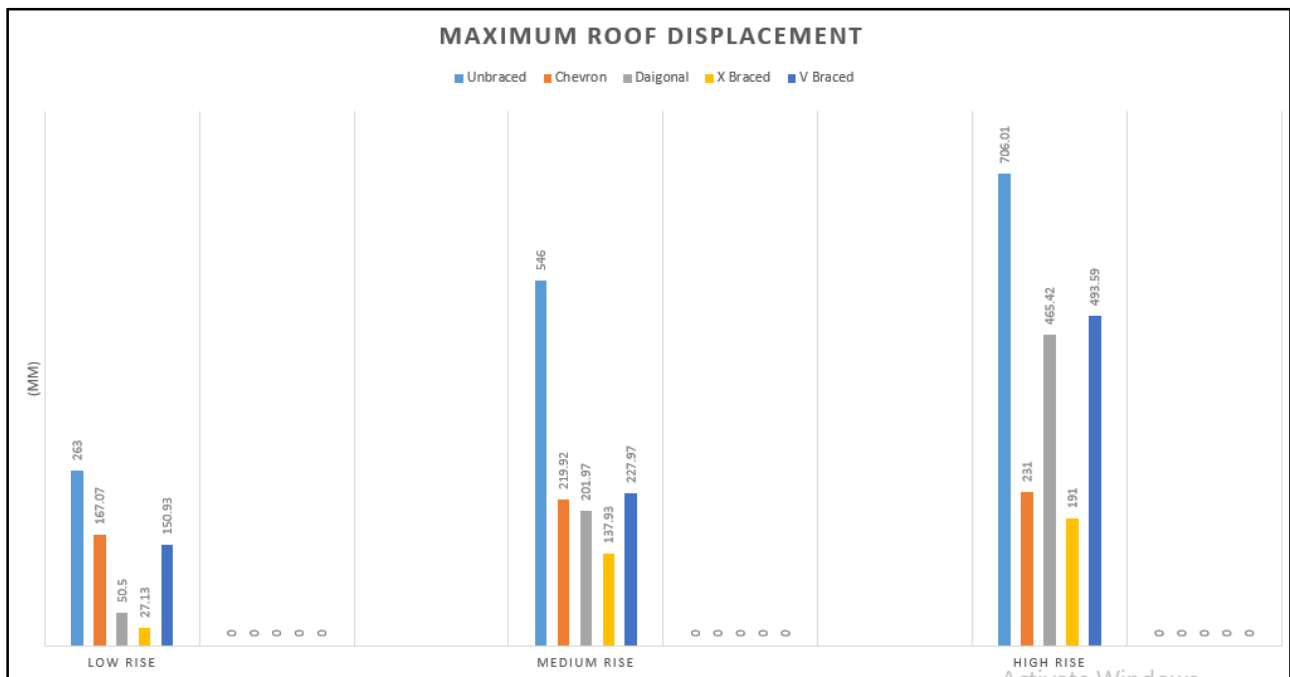


Fig-XIII Maximum roof displacement in different types of building

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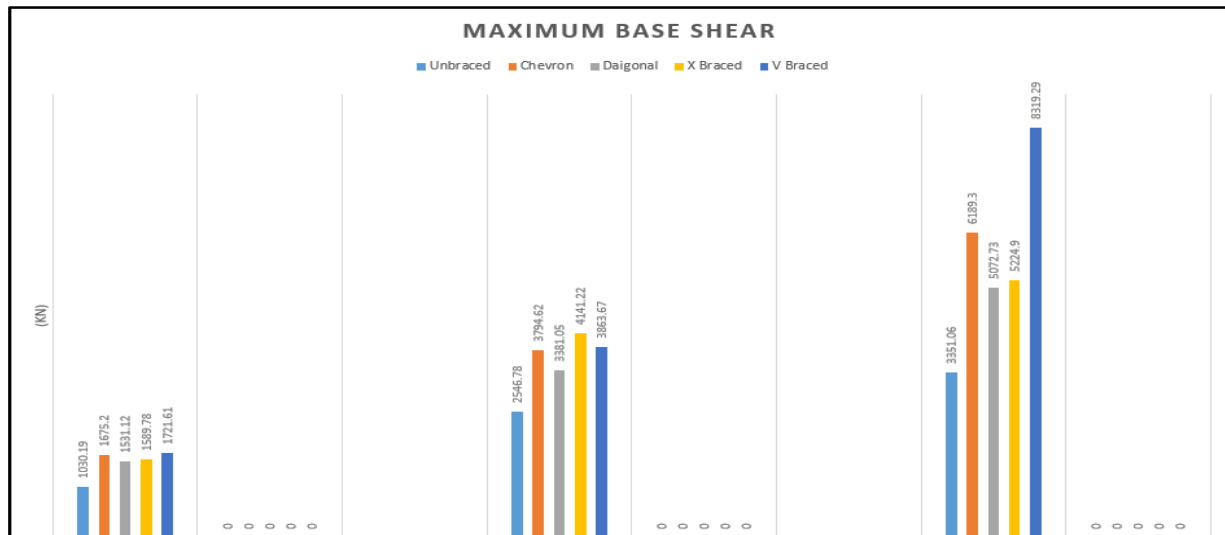


FIG-XIV MAX BASE SHEAR IN BUILDINGS

VII. CONCLUSION

FOLLOWING CONCLUSIONS WERE DRAWN FROM THE STUDY:

- Application of steel bracings increased the stability of a steel frame by drastically reducing the storey drift and increasing the base shear
- In the case of low rise buildings, frames braced with X and Diagonal type of bracing system gave the best result in terms of stability. The choice of the preferred bracing in this case is dependent on the economic efficiency of the structure as a whole
- In the case of medium rise and high rise buildings, X bracing system edged past all the other options and is, according to our analysis, the best suited bracing system for steel structures.

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