SEISMIC ANALYSIS OF STEEL FRAME WITH BRACINGS USING PUSHOVER ANALYSIS

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ABSTRACT

Steel is by far most useful material for building construction in the world and in last decades steel structure has played an important role in construction industry. Providing strength, stability and ductility are major purposes of seismic design. It is necessary to design a structure to perform well under seismic loads. In this paper non linear push over analysis is carried out for high rise steel frame building with different pattern of bracing system. The shear capacity of the structure can be increased by introducing Steel bracings in the structural system. There are 'n' numbers of possibilities to arrange steel bracings such as Diagonal, X, K, V, Inverted V or chevron and global type concentric bracings. A typical 15th- story regular steel frame building is designed for various types of concentric bracings like Diagonal, V, X, and Exterior X and Performance of each frame is carried out through nonlinear static analysis. Three types of sections i.e. ISMB, ISMC and ISA sections are used to compare for same patterns of bracing.

Keywords: Pushover Analysis, Steel Frames with Different Types of Concentric Bracings

I. INTRODUCTION

Earthquake is a natural phenomenon, which is generated in earth's crust. Duration of earthquake is usually rather short, lasting from few seconds to more than a minute or so. But thousands of people loose their lives due to earthquakes in different parts of the world. Building collapse or damages are the major loss due to earthquake ground motion. In an earthquake, the building base experiences high-frequency movements, which results in inertial forces on the building and its components. The force is created by the building's tendency to remain at rest, and in its original position, even though the ground beneath it is moving. The assessment of the seismic vulnerability of structures is a very complex issue due to the non-deterministic characteristics of the seismic action and the need for an accurate prediction of the seismic responses for levels beyond conventional linear behavior.

Lateral stability has always been a major problem of structures especially in the areas with high earthquake hazard this issue has been studied and concentric, eccentric and knee bracing systems have been suggested and consequently used by civil engineers. Inelastic performance is one of the main factors influencing the choice of bracing systems. The bracing system that has a more plastic deformation before collapse can absorb more energy during the earthquake.

Seismic Analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent. Providing strength, stability and ductility are major purposes of seismic design.

There are three sources of deficiencies in a building, which have to be accounted for by the retrofitting engineer:

1. Inadequate design and detailing
2. Degradation of material with time and use
3. Damage due to earthquake or other catastrophe.

The three sources, suggest a retrofit scheme to make up for the deficiencies and demonstrate that the retrofitted structure will be able to safety resist the future earthquake forces expected during the lifetime of the structure Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based structures and is moving away from simplified linear elastic methods and towards a more non-linear technique.

Many methods were presented to apply the nonlinear static pushover (NSP) to structures. These methods can be listed as:

(1) Capacity Spectrum Method (CSM) (ATC)

(2) Displacement Coefficient Method (DCM) (FEMA-356)

(3) Modal Pushover Analysis (MPA)

1.1 Resent Research Work

K.K.Sangle,K.M.Bajori,V.Mhalungkar.,2012,[1] Presented paper on "Seismic Analysis Of High Rise Steel Frame Building With And With Out Bracing" The Aim of study was to compare the results of seismic analysis of high rise steel building with different pattern of bracing system and without bracing system. by using time history analysis for Northridge earthquake. The result of the study shows that bracing element will have very important effect on structural behaviour under earthquake effect.

Mohammad Eyni Kangavar.,(2012), Modelled a 1bay, 2D, 10 storey RC frame in ETABS by comparing a Knee Braced Frame and Concentric Braced Frame by static method And finding out the seismic parameters i.e. ductility, base shear, displacement, stiffness**,** the results of this study lead the conclusions that: The seismic performances of without braced frames are weak.

M.D. Kevadkar, P.B. Kodag,(2013), [2] presented paper on lateral load analysis of RCC building, In this study R.C.C. building is modelled and analyzed in three Parts I) Model without bracing and shear wall II) Model with different shear wall system III) Model with Different bracing system The computer aided analysis is done by using E-TABS to find out the effective lateral load system during earthquake in high seismic areas. The performance of the building is evaluated in terms of Lateral Displacement, Storey Shear and Storey Drifts, Base shear and Demand Capacity (Performance point). It is found that the X type of steel bracing system significantly contributes to the structural stiffness and reduces the maximum inter story drift, lateral displacement and demand capacity (Performance Point) of R.C.C building than the shear wall system.

Haroon Rasheed Tamboli & Umesh N. Karadi (2012), Performed seismic analysis using Equivalent Lateral Force Method for different reinforced concrete (RC) frame building models that included bare frame, in filled frame and open first story frame. In modelling of the masonry Infill panels the Equivalent diagonal Strut method was used and the software ETABS was used for the analysis of all the frame models. In filled frames should be preferred in seismic regions than the open first story frame, because the story drift of first story of open first story frame is Very large than the upper stories, which might probably cause the collapse of structure. The infill Wall increases the strength and stiffness of the structure.

Srikhanta Prasad, et al, (2009), presented an analytical study to evaluate nonlinear seismic performance of one bay and two bay RC frames at different storey levels. For this purpose a static nonlinear method namely pushover analysis was used. ETABS 9.6 finite element software was used to carry out pushover analysis. Capacity and demand curves were also plotted to study status of the structure and number of hinges formed.

1.2 Limitations of Existing Studies

The literature study reveals that many experimental and analytical works have been done by many researchers in the area of the pushover analysis of the RC frames with and without infill's the concept of pushover analysis is rapidly growing nowadays. However, not much work has been carried out on steel structures as per the provisions of IS: 1893 - 2002.

From the above studied we can conclude that there is enough research on braced frame but mostly it is either experimental study or Finite element analysis of single bay two storey frame.In the present study, an attempt has been made to perform the pushover analysis on 3D High rise steel frame structure with bracings using ETABS 2013.

II. PUSHOVER ANALYSIS

The pushover analysis is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. 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. Response of structure beyond maximum strength can be determined only by displacement controlled pushover analysis. Hence, in the present study, displacement-controlled pushover method is used for analysis of structural steel frames with and without bracings.

A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. Beyond elastic limit, different states such as Immediate Occupancy, Life Safety Collapse prevention and collapse are defines as per ATC 40 and FEMA 356.

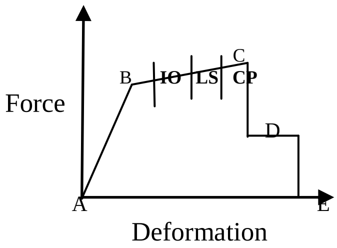

Fig 2.1 - Idealized Pushover curve

2.1 Capacity Curve

The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limits, some form of nonlinear analysis is required. This procedure uses sequential elastic analysis, superimposed to approximate force-displacement diagram of the overall structure.

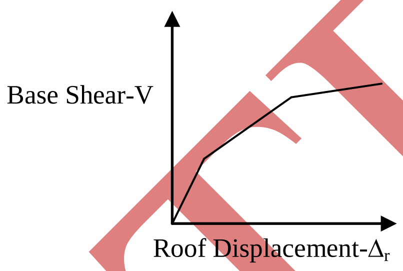

Fig 2.2 - Capacity Curve

2.2 Demand Curve

Ground motion during an earthquake produces complex horizontal displacement patterns which may vary with time. Tracking this motion at every time step to determine structural design requirements is judge impractical. Demand curve is a representation of the earthquake ground motion. It is given by spectral acceleration (Sa) Vs. Time period (T) as shown

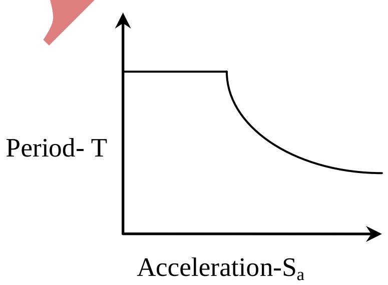

Figure 2.3 - Demand Curve

2.3 Performance Point

Performance point can be obtained by superimposing capacity spectrum and demand spectrum and the intersection point of these two curves is performance point.

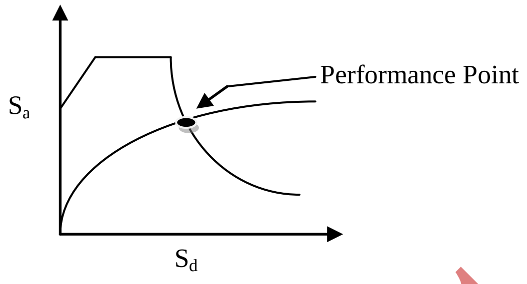

Figure 2.4 - Superimposing Demand Spectrum and Capacity Spectrum

2.4 Purpose of Non-linear Static Push-over Analysis

The purpose of pushover analysis is to evaluate the expected performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest.

III. STRUCTURAL MODELING

For the analysis work, Thirteen models of high rise steel frame building (G+15) floors are made to know the realistic behavior of building during earthquake. The length of the building is 24m and width is 12m.The columns are assumed to be fixed at the ground level. Non Linear static analysis i.e. pushes over analysis is used.

3.1 Studied Structural Configuration

Following two types of structural configuration is studied.
1. G+15 Steel Framed structure without bracing (MRF)
2. G+15 Steel Framed structure with different bracing patterns

Note:
Total 13 models are analysed in the study.
One bare frame model.
Four models of ISMB Sections.
Four models of ISA Sections.
Four models of ISMC Sections.
Same pattern of bracings I.e.(Diagonal, V, X, and Exterior X) are used for all types of sections and steel sections are selected by considering same cross sectional area.

3.2 Plan

Plan of the steel frame building which is used for the study is shown in figure 5.1.

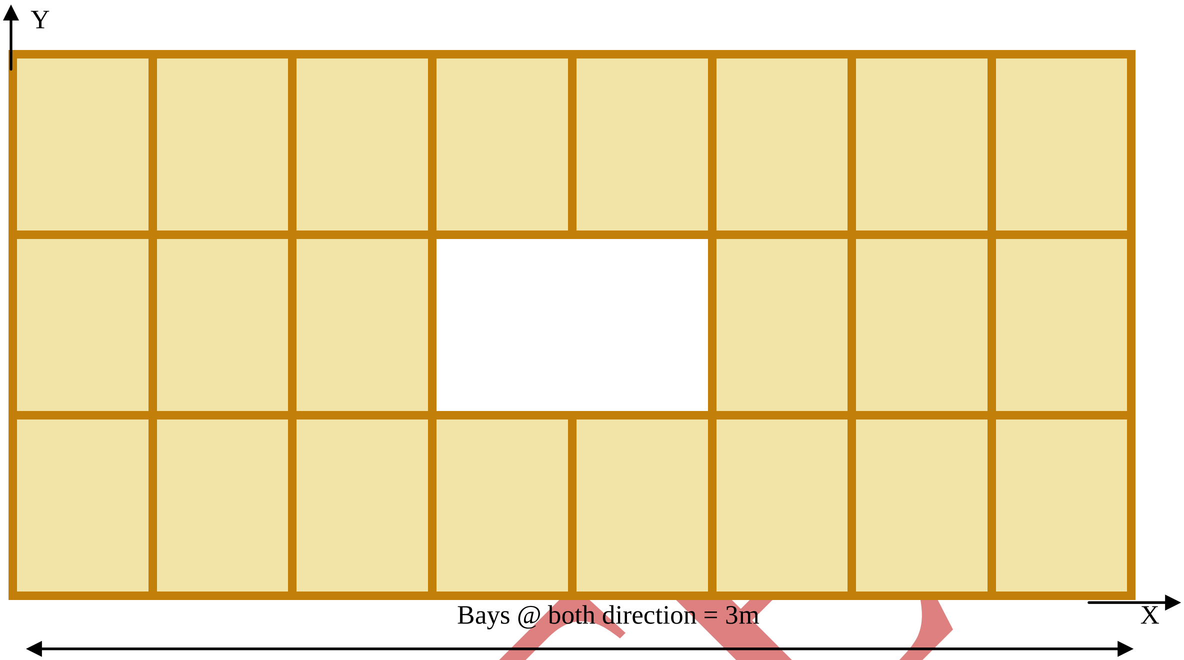

Figure 3.1 - Plan of High Rise Steel Framed Structure

3.3 Building Description

Table 3.1 – Building Description

Serial Number	Building Description	
1	Zone	V
2	Zone Factor	0.36
3	Response Reduction Factor	5
4	Importance Factor	1
5	Height of Building	45 m
6	Column Details	ISMB 550
7	Beam Details	ISMB 450
8	Bracing Details-1	ISMB 350
9	Bracing Details 2	ISA 150 x150 x12
10	Bracing Details 3	ISMC 400
11	Thickness of Slab	125 mm
12	Floor to Floor Height	3.0 m
13	Grade of Steel Section	Fe - 250
14	Grade of Concrete	M20
15	Floor Finish	1.0 kN/m^2
16	Live Load	3.0 kN/m^2

3.4 Different Types of Bracing Patterns used in the Study

Different types of bracing pattern used in the study are shown in below figures,

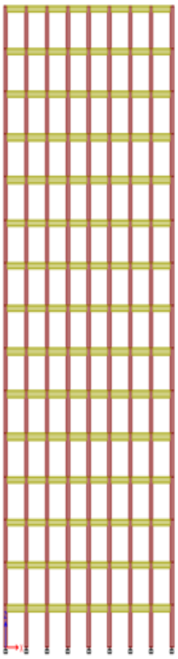

Figure 3.2 - Steel Framed model of building without bracing

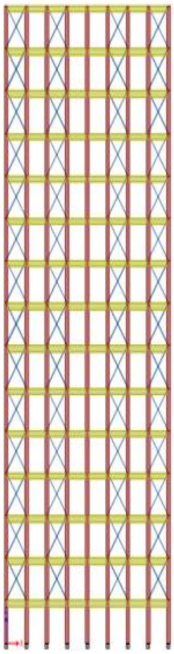

Figure 3.3 - Steel Framed model of building with X-Brace

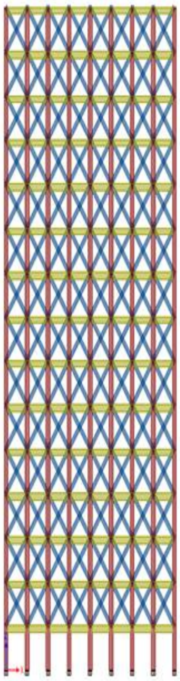

Figure 3.4 - Steel Framed model of building with Exterior X-Brace

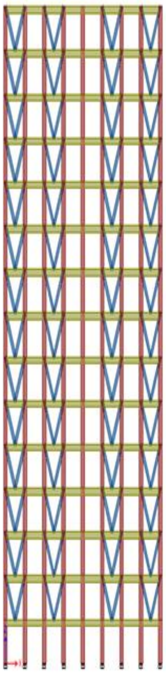

Figure 3.5 - Steel Framed model of building with V-Brace

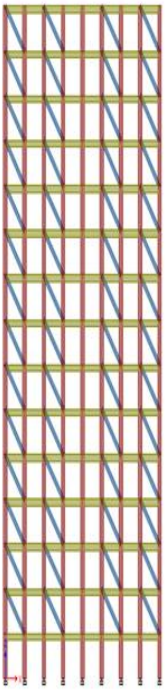

Figure 3.6 - Steel Framed model of building with Diagonal-Brace

NOTE:

Same pattern of bracings are used for all the sections i.e. (ISMB, ISA, ISMC) for comparative study.

IV. RESULTS

4.1 Base Shear

Table 4.1 - Base shear (kN) in X-Direction

Base shear (kN) in X-direction			
Type of Bracing	**Without Bracing**	**With Bracing**	**% Difference Increases**
ISMB Sections			
Diagonal Brace	4,043.06	6,821.00	40.73
V-Brace	4,043.06	7,563.64	46.55
X-Brace	4,043.06	7,769.00	47.96
Exterior X-Brace	4,043.06	13,576.87	70.22
ISA sections			
Diagonal Brace	4,043.06	7,089.98	42.98
V-Brace	4,043.06	7,376.59	45.19
X-Brace	4,043.06	7,387.31	45.27
Exterior X-Brace	4,043.06	13,032.26	68.98
ISMC Sections			
Diagonal Brace	4,043.06	7,150.81	43.46
V-Brace	4,043.06	7,544.98	46.41
X-Brace	4,043.06	7,613.97	46.90
Exterior X-Brace	4,043.06	12,724.00	68.22

Table 4.2 - Base shear (kN) in Y-Direction

Base shear (kN) in Y-direction			
Type of Bracing	**Without Bracing**	**With Bracing**	**% Difference Increases**
ISMB Sections			
Diagonal Brace	1465.1	1613	9.17
V-Brace	1465.1	1620.64	9.60
X-Brace	1465.1	1610.3	9.02
Exterior X-Brace	1465.1	1648.24	11.11
ISA sections			
Diagonal Brace	1465.1	1619.2	9.52
V-Brace	1465.1	1627.51	9.98
X-Brace	1465.1	1613.06	9.17
Exterior X-Brace	1465.1	1648.99	11.15
ISMC Sections			
Diagonal Brace	1465.1	1613.98	9.22
V-Brace	1465.1	1621.68	9.66
X-Brace	1465.1	1610.08	9.00
Exterior X-Brace	1465.1	1648.72	11.14

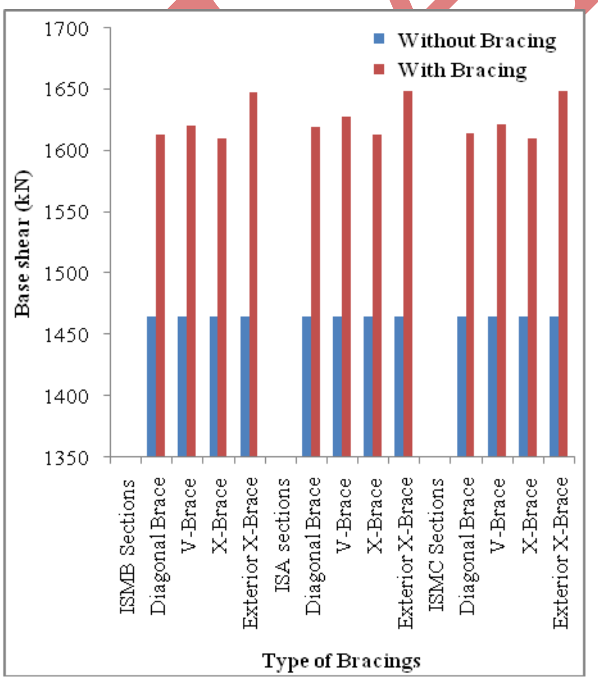

Fig 4.1: Base shear (kN) in X –Direction

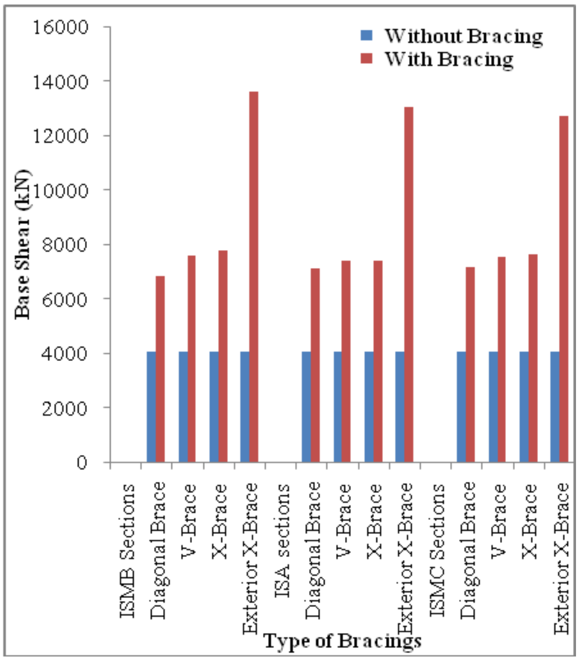

Fig 4.2 - Base shear (kN) in Y –Direction

4.2 Joint Displacement

Table 4.3 – Joint Displacement (mm) in X-Direction

Joint Displacement (mm) X-Direction			
Type of Bracing	**Without Bracing**	**With Bracing**	**% Difference Decreases**
ISMB Sections			
V-Brace	789.8	219.2	72.25
X-Brace	789.8	205.1	74.03
Diagonal Brace	789.8	184	76.70
Exterior X-Brace	789.8	73.5	90.69
ISA sections			
V-Brace	789.8	214.1	72.89
Diagonal Brace	789.8	173.6	78.02
X-Brace	789.8	173.7	78.01
Exterior X-Brace	789.8	83.6	89.42
ISMC Sections			
V-Brace	789.8	219.5	72.21
X-Brace	789.8	184	76.70
Diagonal Brace	789.8	162.7	79.40
Exterior X-Brace	789.8	62.5	92.09

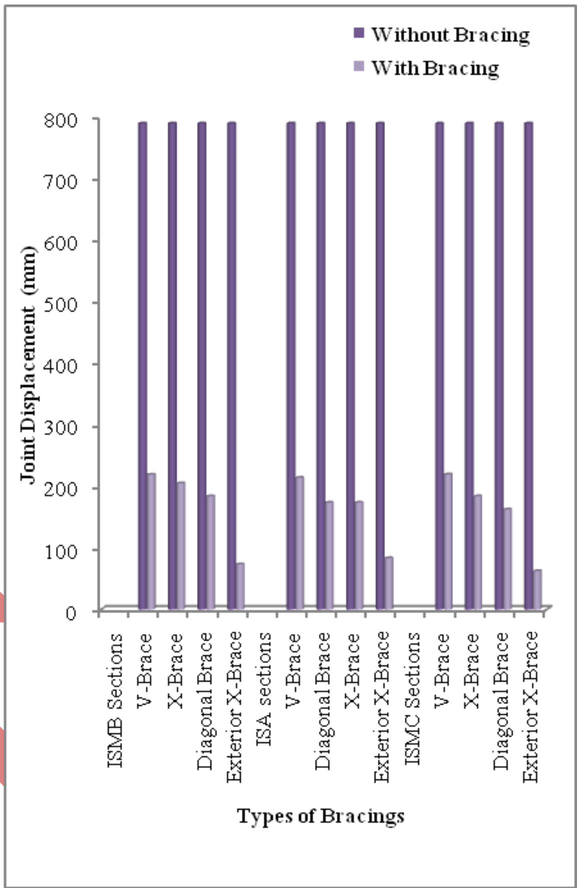

Fig 4.3 – Joint Displacement (mm) in X-Direction

4.3 Pushover Curve

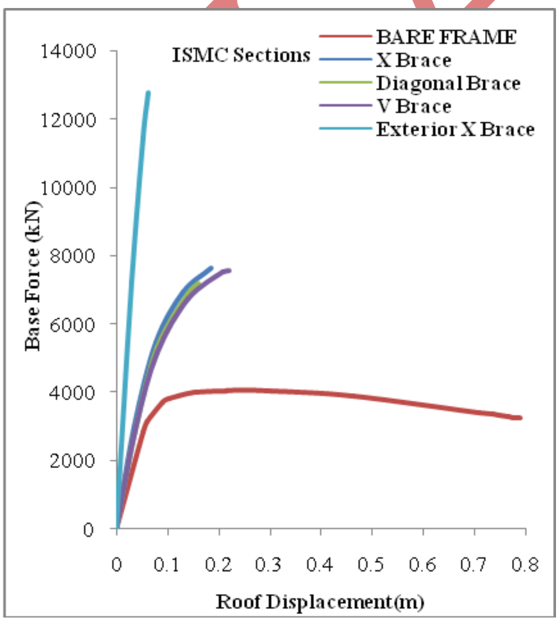

Fig 4.4 - Pushover curves of ISMC Section of all models

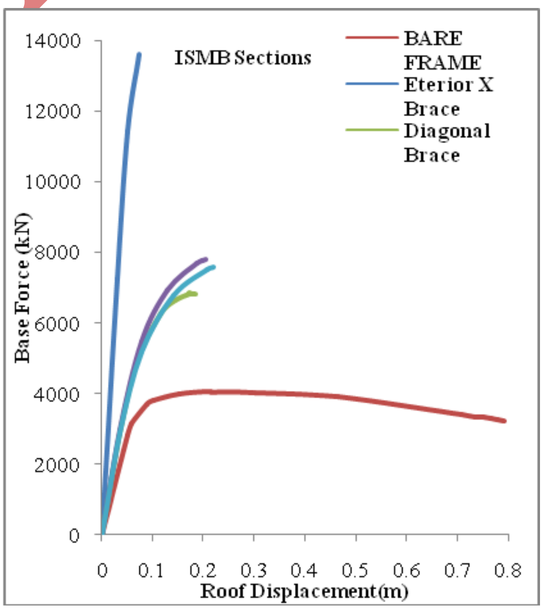

Fig 4.5 - Pushover curves of ISMB Section of all models

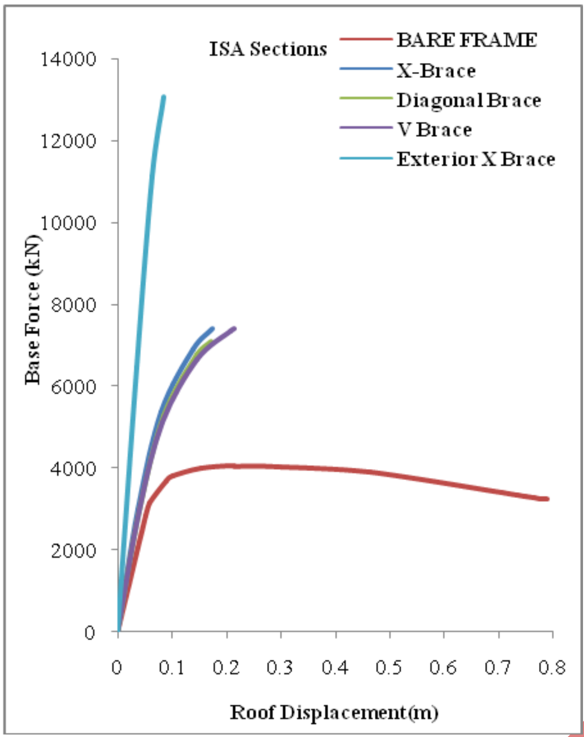

Fig 4.6 - Pushover curves of ISA Section of all models

4.4 Performance curve

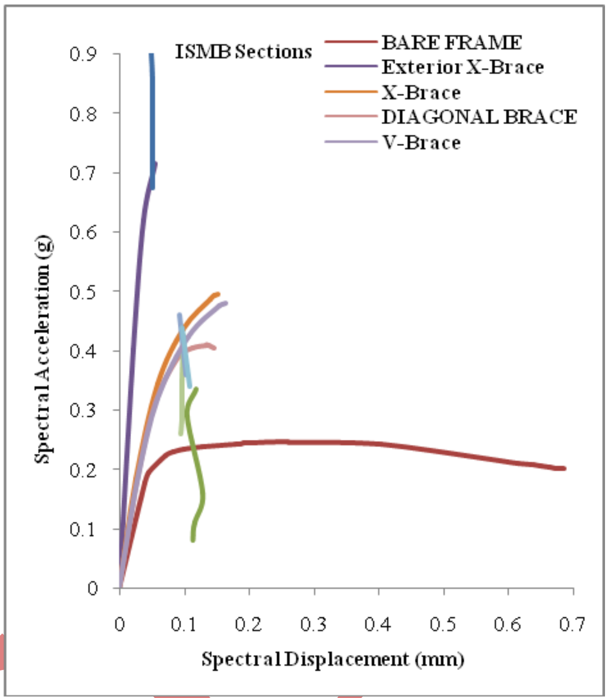

Fig 4.7 - Performance curves of ISMB Section of all models

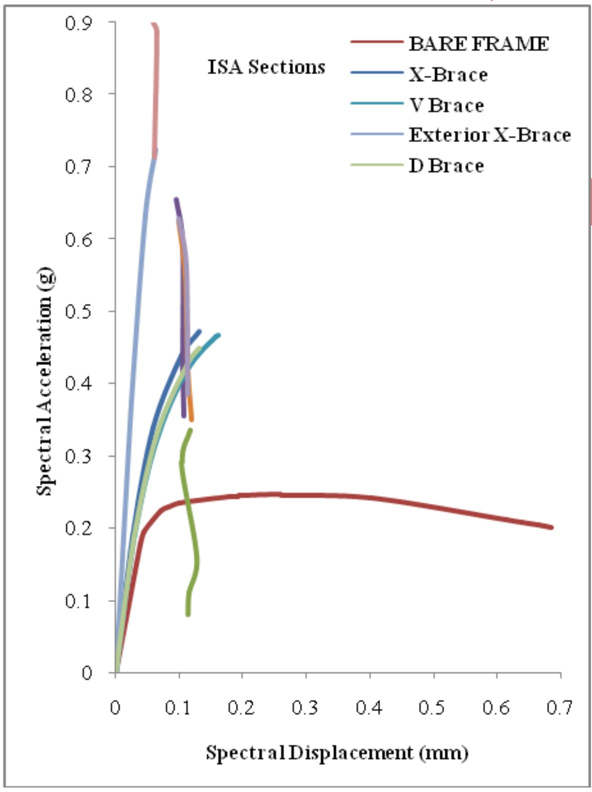

Fig 4.8 - Performance curves of ISA Section of all models

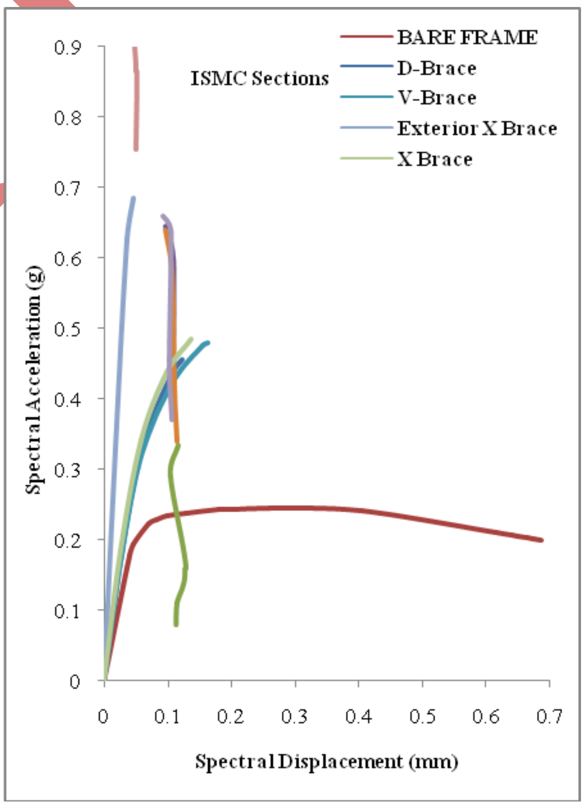

Fig 4.9 - Performance curves of ISMC Section of all models

V. CONCLUSION

1. The provision of bracing enhances the base shear carrying capacity of frames. The effects are more pronounced in taller structures.From table and Graph (4.1 and 4.2), it is observed that due to bracing in both direction base shear capacity for V-Brace, Diagonal Brace, X-Brace, increases up to 40-50 % as compared with bare frame model, where as in Exterior X-Brace maximum base shear increases up to 70 % as compared with bare frame model and ISMB Sections gives more base shear compare to angel and channel section for similar type of brace.
2. From Table and Graph (4.3), it is observed that the displacement at roof level of the steel frame structure for V-Brace, Diagonal Brace, X-Brace, reduced up to 70-80 % as compared with bare frame model, where as in Exterior X-Brace maximum displacement also reduced up to 90 % as compared with bare frame model and ISMC Sections reduces more displacement compare to angel and beam section for similar type of brace.
3. From the graph (4.4, 4.5 and 4.6), we can observed that bare frame has got more performance displacement and less performance base force when compared to other models.It can be seen that bracings have increased level of performance both in terms of base shear carrying capacity and roof displacement. The V-Brace, Diagonal Brace, X-Brace models has got more performance displacement and less performance base force compared to X-Brace, Exterior X-Brace. X-Brace, Exterior X-Brace models increases the stiffness compare to other models and ISMB Sections gives more stiffness compare to angel and channel sections for similar type of brace.
4. From the graph (4.7, 4.8 and 4.9), shows that capacity and demand curve are drawn for steel frames with and without bracings for seismic zone 5, The exterior ISMB X Brace model have increased performance level compare to other types of bracing models and it can also be seen that the frames with bracings have lesser vulnerability compared to the frames without bracings.ISMB Sections gives more Performance point compare to angel and channel section for similar type of brace.
5. Pushover analysis is a good approach to assess the adequacy of a structure to seismic loading

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