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Lateral Load Analysis of a Building with & Without Knee Bracing

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ABSTRACT
In last decades steel structures 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. Steel braced frame is one of the structural systems used to resist earthquake loads in structures. Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness. Bracing can be used as retrofit as well. There are various types of steel bracings such as Diagonal, X, K, V, inverted V type or chevron and global type concentric bracings. In the present study, it was shown that modelling of the G+4 steel bare frame with various bracings (X, V, inverted V, and Knee bracing) by computer software SAP2000 and pushover analysis results are obtained. Comparison between the seismic parameters such as base shear, roof displacement, time period, storey drift, performance point for steel bare frame with different bracing patterns are studied. It is found that the X type of steel bracings significantly contributes to the structural stiffness and reduces the maximum interstate drift of steel building than other bracing systems.
Keywords - Strength, Ductility, seismic loads, steel bracing, SAP2000, pushover analysis, storey drift, Performance point.

I. INTRODUCTION

Structures designed to resist moderate and frequently occurring earthquakes must have sufficient stiffness and strength to control deflection and to prevent damage. However, it is inappropriate to design a structure to remain elastic under severe earthquake because of economic constraints. The inherent damping of yielding structural elements can be advantageously utilized to lower the strength requirements, leading to a more economical design. This yielding provides ductility or toughness of structure against sudden brittle type structural failure. In steel structures, the moment resisting and concentrically braced frames have been widely used to resist earthquake loadings. The moment resisting frame possesses good ductility through flexural yielding of beam element but it has limited stiffness. It is necessary to design a structure to perform well under seismic loads. Shear capacity of the structure can be increased by introducing steel bracings in the structural systems. Bracing can be used as retrofit as well. There are n number of possibilities are there to arrange steel bracings. Such as X, K and V type Eccentric bracings. The present study develops a Pushover Analysis for Knee bracing steel frames designed according to IS 800 – 2007 and ductility behavior of each frame.

1.1 RECENT RESEARCH WORK

Krishnaraj R.Chavan et.al (2014) studied the seismic analysis of reinforced concrete (RC) buildings with different types of bracing (Diagonal, V type, Inverted V type, X type). The bracing is provided for peripheral columns. A seven-storey (G+6) building is situated at seismic zone III. The building models are analyze by equivalent static analysis as per IS 1893:2002 using Staad Pro V8i software. The main parameters consider in this paper to compare the seismic analysis of buildings are lateral displacement, storey drift, axial force, base shear. It is found that the X type of steel bracing significantly contributes to the structural stiffness and reduces the maximum inter storey drift of R.C.C building than other bracing system. The lateral displacement of the building is reduced by 50% to 56 % by the use of X Type steel bracing system, and X bracing type reduced maximum displacement. The steel braced building of base shear increase compared to without steel bracing which indicates that stiffness of building is increases.

M.G. Kalibhat et.al (2014) focused on the effect of a provision of concentric bracings on the seismic performance of the steel frames. In this paper study of two different types of concentric bracings (X and inverted V- type bracing) have been considered for the different storey levels. ETABS, Finite Element software has been used and the comparison between the performances of 1- bay X and inverted–V type and un-braced frames is made using pushover curves. Seismic performances of the frames are carried out the parameters such as Base shear, roof displacement and the number of hinges formed. Steel bracings can be used to strengthen or to retrofit the existing structure. The provision of bracing enhances the bases hear carrying capacity of frames and reduces roof displacement undergone by the structures. The lateral storey displacements of the building are reduced by the use of inverted-V bracing in comparison to the X bracing system.

M.I. Khan et. al (2014) in this paper nonlinear 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. 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. ISMC Sections reduces more displacement compare to angel and beam section for similar type of brace. It is shown that bracings have increased level of performance both in terms of base shear carrying capacity and roof displacement. ISMB Sections gives more stiffness compare to angel and channel sections for similar type of brace.

S.N.Tande et.al (2014) this paper provides an introduction and overview of the design and behaviour of seismic-resistant eccentrically braced frames (EBFs). EBF‘s have become a widely recognized lateral load resisting system for steel building in areas of high seismicity. In general, braces are the members that resist against lateral forces in a steel structure while the structures are under seismic excitation. In this paper six frames were exerted which were braced with three different eccentric braces (V, Inverted-V and Diagonal) in two different heights (4 and 8 storey). Then the frames were assessed by nonlinear static (pushover) analysis mainly based on FEMA 440. As a result of these frame analysis, it can be observed that the plastic hinges firstly occur at the fuse section of braces and then at the compressive members of the eccentric braces. The primary purpose of this paper is to present the best suitable bracing system up to 8 storey level in performance point of view and also economy point of view.

Vaseem Inamdar et.al (2014) investigated pushover analysis of complex steel frame building by ETABS software. These investigations were based on stiffness and ductility. This paper compare the performance of structure by using ISMB and ISNB (hollow pipes) steel sections as bracing element on 15-storey complex steel frame. Base shear obtained from all models using ISNB bracing is lesser then ISMB sections. Stiffness of models increased by an amount of 71.5% using ISMB bracing and 68% using hollow pipes sections. Exterior Steel bracing has more margin of safety against collapse as compared to other models. Spectral displacement of exterior ISMB bracing at performance point is greatly (62%) increased.

Kiran Kamath et.al (2015) studied the effect of different aspect ratios i.e. H/B ratio, where H is the total height of the building frame and B is the base width of the building frame, on the seismic performance of the steel frame structures. In the present study, seven different aspect ratios ranging from 1.0 to 3.75 have been considered for the ten storey steel frame building with concentric bracing i.e. X bracing and without bracing system. For this analytical study, ETABS is used and the comparison between the performances of bare frames with different aspect ratios is made using pushover curves. Roof displacement, base shear carried and performance point are the parameters used to identify the seismic performance of the frames. It is shown that provision of bracings to the frame structure increased the base shear carrying capacity, performance point and reduced the roof displacement for all types of aspect ratios considered. As aspect ratio increases, base shear carrying capacity decreases for both type of section considered in this paper. Steel frame with aspect ratio 1.0 and two bays X braced frame showed better performance.

1.2 LIMITATIONS OF EXISTING STUDIES

From the above literature study, it was concluded that the best form of knee brace is when the knee element and the diagonal brace parallel to the frame i.e. h/H = b/B. in this way the structure has its maximum seismic resistance [21]. In knee bracing frame the connection between beam-column & end of brace are pinned and knee-beam and knee column are rigid [24]. The literature study reveals that many experimental and analytical works have been done by many researchers in the area of the pushover analysis of RC frames and few works on steel frames with different type of bracing systems. However, not much work has been carried out on steel structures as per the provisions of IS 1893-2002. Hence it was decided to focus on the analysis of moment resisting bare frame with various types of bracings such as X, V type, inverted V type, and knee bracing systems using SAP 2000.

II. PUSHOVER ANALYSIS

2.1 Introduction

Many methods were presented to apply the non-linear static pushover analysis to structures. These methods can be listed as 1) Capacity

Spectrum method (ATC 40) 2) Displacement Coefficient Method (FEMA 356) 3) Modal 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. 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 the maximum force likely to be experienced by the structure during the design earthquake. Response of structures beyond maximum strength can be determined only by displacement-controlled pushover analysis.

2.2 Pushover analysis Procedure

In the present study, displacement-controlled pushover method is used for analysis of structural steel frames with and without bracings. A displacement-controlled pushover analysis is basically composed of the following steps:

1. A two or three dimensional model that represents the overall structural behaviour is created.
2. Bilinear or tri-linear load-deformation diagrams of all important members that affect lateral response are defined.
3. Gravity loads composed of dead loads and a specified portion of live loads are applied to the structural model initially.
4. A pre-defined lateral load pattern which is distributed along the building height is then applied.
5. Lateral loads are increased until some members yield under the combined effects of gravity and lateral loads.
6. Base shear and roof displacement are recorded at first yielding.
7. The structural model is modified to account for the reduced stiffness of yielded members.
8. Gravity loads are removed and a new lateral load increment is applied to the modified structural model such that additional members yield. Note that a separate analysis with zero initial conditions is performed on modified structural model under each incremental lateral load. Thus, member forces at the end of an incremental lateral load analysis are obtained by adding the forces from the current analysis to the sum of those from the previous increments. In other words, the results of each incremental lateral load analysis are superimposed.
9. Similarly, the lateral load increment and the roof displacement increment are added to the corresponding previous total values to obtain the accumulated values of the base shear and the roof displacement.
10. Steps 7, 8 and 9 are repeated until the roof displacement reaches a certain level of deformation or the structure becomes unstable.
11. The roof displacement is plotted with the base shear to get the global capacity (pushover) curve of the structure (Figure 2.1).

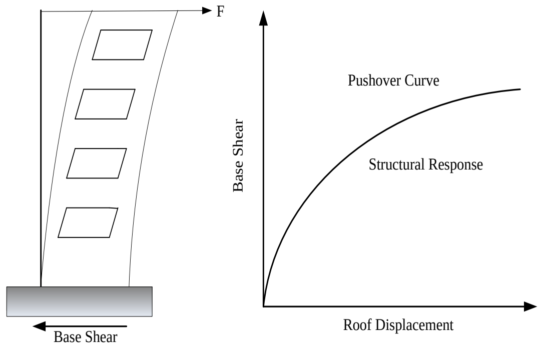

Fig. 2.1: (Pushover) Capacity Curve of the structure

2.3 Key Elements in Performance Point:

The key elements of performance based design procedure are:

1. Demand 2. Capacity 3. Performance point

2.3.1 Demand

Demand is representation of earthquake ground motion. Ground motions during an earthquake produce complex horizontal displacement patterns in structures that may vary with time. For given structure and ground motion, the displacement demand is an estimate of the maximum expected response of the building during the ground motion. For nonlinear methods it is easier and more direct to use a set of lateral displacements as a design condition. It is represented by in the form of spectral acceleration (Sa) Vs. Time period (T).

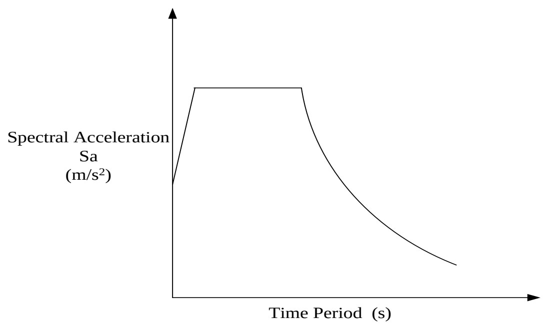

Fig.2.2: Demand Curve

2.3.2 Capacity

Capacity is representation of structural ability to resist the seismic demand. The overall capacity of structure depends on strength and deformation capacities of individual components of the structure. The capacity of structure is represented in the form of curve of base shear versus the roof displacement known as pushover capacity curve.

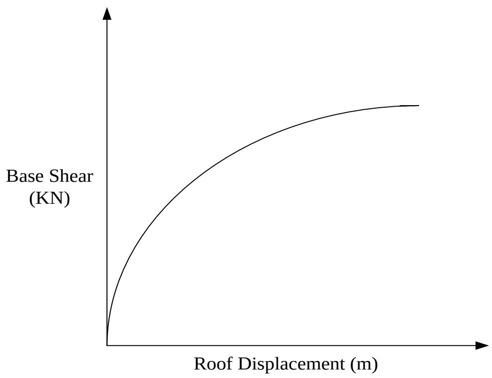

Fig.2.3: Capacity Curve

2.3.2 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.

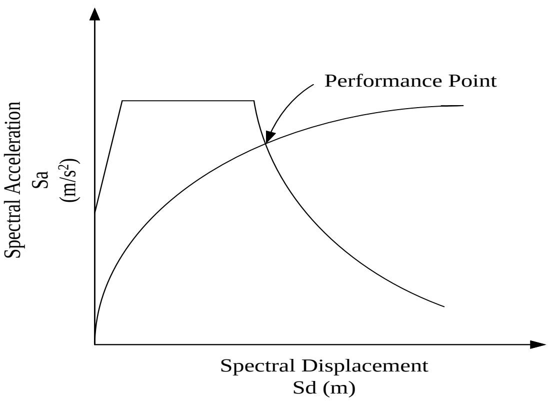

Fig. 2.4: Performance Point

2.4Plastic Hinge Properties

Comprehensive and complete information about plastic hinge properties of all of the structural segments are rendered by Federal Emergency Management agency in their Table that is fulfilled by engineers throughout the world. All the information relevant to this table is at disposal as default hinge properties in SAP2000 software.

2.5 Column Hinge Properties

In accordance with FEMA 356, occurrence of a plastic hinge in a column is as a result of the interaction amongst axial force (P), moment in the stronger (M2) and weaker (M3) direction of the section. Therefore, interaction of P-M2-M3 is exerted to illustrate plastic hinges at the two ends of the columns (beginning and ending positions) that are in fact considered as the junction points with the other structural elements (Table 5-6 of FEMA 356).

2.6 Brace Hinge Properties

Nonlinear behaviour of brace elements can be best modelled by assuming a hinge (being made under pure axial load) in the middle of the element. An axial load plastic hinge is modelled in the 0.5 relative distances of all bracing elements as per Table 5-6 of FEMA 356 [Appendix] in this study.

2.7 Beam Hinge Properties

Considering the fact that the beam to column connections is rigid, two plastic hinges (one at the beginning and the other one at the end) will be obtained. But for the beams that are braced with eccentric braces, the plastic hinges will occur at the place of fuses. For these kinds of beams the M3 and V2 are taken into consideration.

2.8 Element Description of SAP2000

In SAP2000, a frame element is modelled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modelled as hinges represented by a series of straight line segments. A generalized force-displacement characteristic of a non-degrading frame element (or hinge properties) in SAP2000 are:

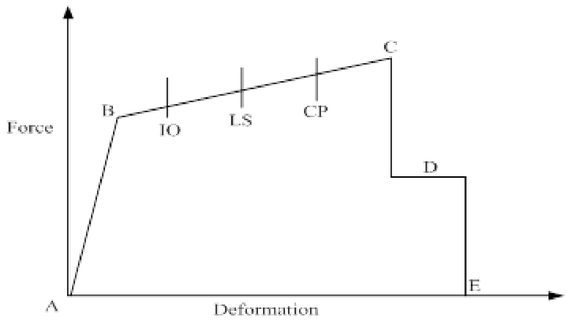

Fig.2.5: Force Vs Deformation Curve

2.9 Acceptance Criteria

Acceptance criteria for failure of steel components such as Beams, Bracing and Columns are as per the FEMA 356.

III. STRUCTURAL MODELING & DESIGN

3.1 Frame geometry

Three bay 3 D five storied steel moment resisting frame is selected for analysis. The length and width of building is 9 m. height of typical storey is 3m. Building is symmetrical to X and Y axis. The non-structural element and components that do not significantly influence the building behaviour were not modelled. The joint between Beams and columns are rigid. The columns are assumed to be fixed at the ground level. Following are the Description of a building.

Table 3.1 Building Description

Sr. No.	Building Description	
1.	Bay width	3m
2.	Floor to floor height	3m
3.	Total height of building	15m
4.	Assume thickness of slab	150 mm
5.	Grade of concrete	M 20
6.	Grade of steel	Fe 250
7.	Live load	3 KN/m^2
8.	Zone	V
9.	Zone factor	0.36
10.	Response reduction factor	5
11.	Importance factor	1.0
12.	Soil type II	Medium
13.	Column details	ISHB 250
14.	Beam details	ISLB 200
15.	Bracing details	ISMB 175

3.2 Load and Load Combinations

Earthquake loads shall be calculated as per IS 1893 (Part I), expect that the reduction factors are recommended in IS 1893 may be used. In the limit state design of frames resisting earthquake loads, the load combination shall conform to table no. 4 from IS 800: 2007.

3.3 Structural Configuration

Following two types of structural configurations is studied.

1. G + 4 steel moment resisting bare framed structure
2. G + 4 moment resisting steel bare frame with different bracing patterns such as X, V type, Inverted V type and Knee bracing frame.

Following identical rolled steel sections are used for beams, columns and bracings.

Beam: ISLB 200
Column: ISHB 250
Bracing: ISMB 175

3.4 Different type of bracing pattern

Same identical rolled steel sections are used for bare frame and other bracing patterns. Different type of bracing patterns such as X, V type, Inverted V type and Knee bracing frame are shown in fig.3.1

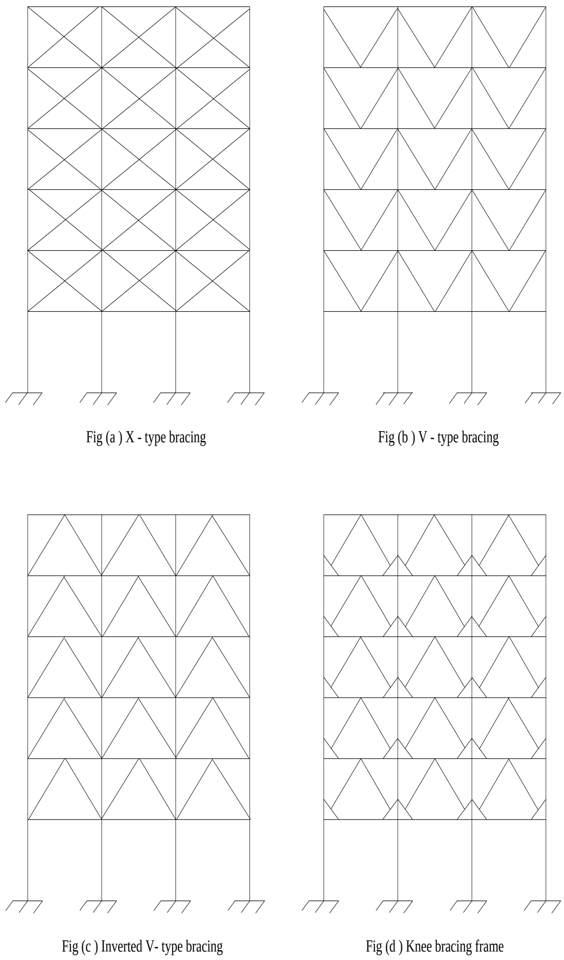

Fig.3.1: Diff. types of bracing configurations

3.5 Preliminary Design of Building

Both the equivalent lateral force and response spectrum analysis procedures lead directly to lateral forces in the direction of the ground motion component. The main differences between the two methods are in the magnitude and distribution of the lateral force over the height of building. The equilateral force method is mainly suited for preliminary design of the building. The preliminary design of the building is then used for spectrum analysis. Equivalent lateral force analysis and Response spectrum analysis is carried out by SAP 2000. The equilateral force analysis and response spectrum analysis in X- direction and it is as follows.

Table 3.2 Base shear in X- direction by ESA and RSA for different models

Type of Models	Equivalent Lateral force Analysis in X – direction	Response Spectrum Analysis in X- direction
	Base Shear (KN)	**Base Shear (KN)**
Bare Frame	195.635	87.5
Frame with X-Bracing	231.498	267.271
Frame with V bracing	240.8	242.811
Frame with Inverted V Bracing	240.8	236.658
Frame with Knee Bracing	216.813	213.265

Table 3.3 Base shear in Y- direction by ESA and RS for diff. models

Type of Models	Equivalent Lateral force Analysis in Y - direction	Response Spectrum Analysis in Y– direction
	Base Shear (KN)	**Base Shear (KN)**
Bare Frame	193.635	73.91
Frame with X-Bracing	234.498	284.247
Frame with V bracing	240.8	266.975
Frame with Inverted V Bracing	241.8	266.491
Frame with Knee Bracing	216.813	236.055

The time period for diff. models in X- direction are shown in following table.

Table 3.4 Time period in X- direction by ESA and RSA for diff. models

Type of Models	Equivalent Lateral force Analysis in X - direction	Response Spectrum Analysis in X – direction
	Time period (S)	**Time period (S)**
Bare Frame	0.637	1.15
Frame with X-Bracing	0.637	0.250
Frame with V bracing	0.637	0.315
Frame with Inverted V Bracing	0.637	0.304
Frame with Knee Bracing	0.637	0.322

The time period for diff. models in Y- direction are shown in following table.

Table 3.5 Time period in Y- direction by ESA and RSA for diff. type of models

Type of Models	Equivalent Lateral force Analysis in Y - direction	Response Spectrum Analysis in Y – direction
	Time period (S)	**Time period (S)**
Bare Frame	0.637	1.39
Frame with X-Bracing	0.637	0.32
Frame with V bracing	0.637	0.376
Frame with Inverted V Bracing	0.637	0.361
Frame with Knee Bracing	0.637	0.37

It is observed that the values of time period in X and Y- direction is Maximum by ESA. Also the time period of bare frame is more as compared to diff. types of models. Therefore, the base shear is compared according to clause 7.8.2 IS Code 1893 (Part I): 2002. For pushover analysis, the values of base shear by Equivalent static analysis are considered. After this, pushover analysis of moment resisting steel bare frame with different bracing patterns such as X, V type, Inverted V type and Knee bracing frame is carried out by SAP 2000 Version 14.

IV. RESULTS & DISCUSSIONS

4.1 Pushover Curves

From the below graph, it is observed that the value of base shear for steel bare frame is less as compared to diff. types of bracing patterns (such as X, V bracing, Inverted V type bracing, knee bracing). Also the roof displacement of diff. types of bracing patterns(such as X, V bracing, Inverted V type bracing, knee bracing) is less as compared to steel bare frame.

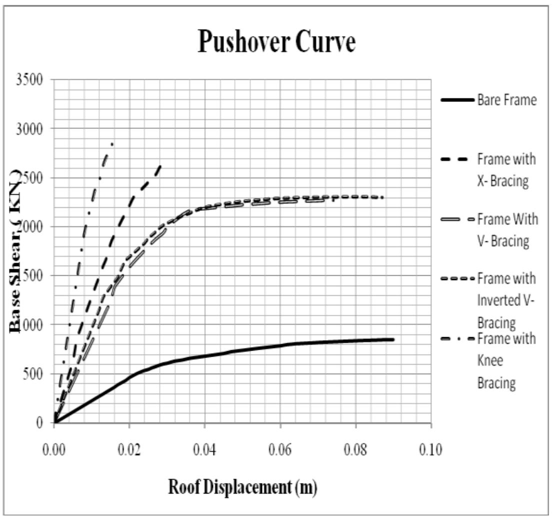

Fig.4.1: Pushover Curve for bare frame with diff. types of bracing patterns

4.2 Inter Storey drifts in X- direction

Following table shows the storey level, storey displacement and inter storey drift for steel bare frame and different types of bracing patterns such as X, V bracing, Inverted V type bracing, knee bracing in X- direction by RSA as shown in Table 4.1.

4.3Inter Storey drifts in Y- direction

Following table shows the storey level, storey displacement and inter storey drift for steel bare frame and different types of bracing patterns such as X, V bracing, Inverted V type bracing, knee bracing in Y- direction by RSA as shown in Table 4.2.

4.4 Performance point

Following table shows the values of performance point for steel bare frame with different types of bracing patterns such as X, V bracing, Inverted V type bracing, knee bracing as shown in table 4.3.

Table 4.1 Inter storey drift ratio in X- direction

Storey level	Bare frame	Frame with X bracing	Frame with V bracing	Frame with inverted V bracing	Frame with knee bracing	IS 1893 :2002
6	0.0014	0.000066	0.0001	0.000066	0.0001	0.004
5	0.0022	0.0001	0.00013	0.0001	0.0001	0.004
4	0.0029	0.0001	0.00016	0.00013	0.00016	0.004
3	0.0034	0.000066	0.00013	0.00013	0.00016	0.004
2	0.0029	0.0001	0.0002	0.00013	0.00016	0.004
1	0.0005	0.00026	0.00023	0.00023	0.0002	0.004
0	0	0	0	0	0	0.004

Table 4.2 Inter- Storey drift ratio in Y - direction

Storey level	Bare frame	Frame with X bracing	Frame with V bracing	frame with inverted V bracing	Frame with knee bracing	IS 1893: 2002
6	0.00163	6.67×10^{-05}	0.0001	0.0001	0.0001	0.004
5	0.00296	0.0001	0.00013	0.00013	0.00013	0.004
4	0.00416	6.67×10^{-05}	0.00016	0.00016	0.00016	0.004
3	0.00506	0.0001	0.00016	0.00016	0.00016	0.004
2	0.0051	0.0001	0.00016	0.00016	0.0002	0.004
1	0.00086	0.00066	0.00063	0.00063	0.0005	0.004
0	0	0	0	0	0	0.004

Table 4.3 Performance point for steel bare frame with diff. bracing patterns

Sr. No	Type of model	V	D	Sa	Sd
1)	Bare frame	524.645	0.130	0.282	0.101
2)	Frame with X bracing	2137.49	0.020	0.799	0.015
3)	Frame with V bracing	1831.02	0.027	0.736	0.023
4)	Inverted V bracing	1701.05	0.023	0.699	0.021
5)	Knee bracing	2031.31	0.028	0.829	0.023

The graphs are plotted according to table 4.1, 4.2 and 4.3 are as follows.

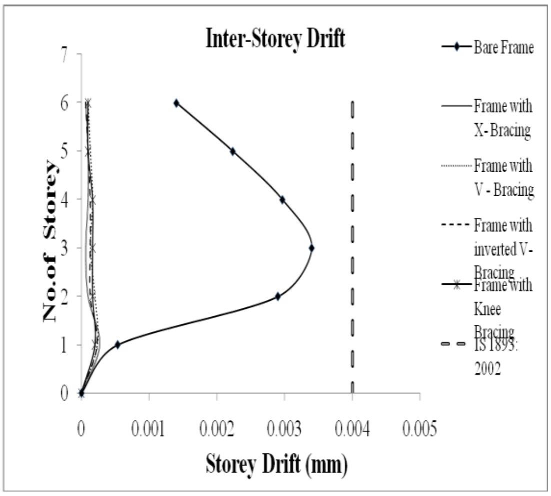

Fig.4.2: Inter storey drift ratio for steel bare frame with diff. bracing patterns in X- direction

From the fig. 4.2, it is observed that inter storey drift ratio in X direction for bare frame is nearer to the 0.004 i.e. specified by the IS 1893 :2002 and Diff. types of bracing patterns such as X, V, Inverted V and Knee bracing are within IS Code limit.

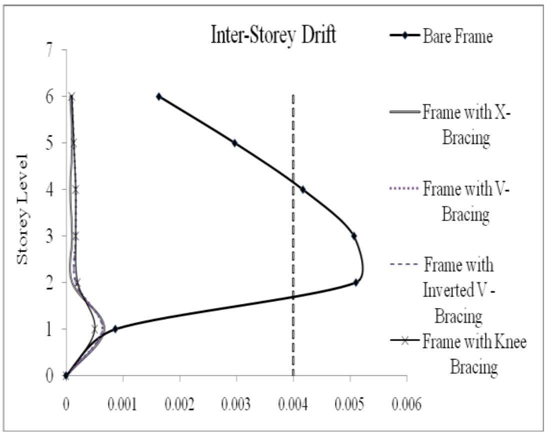

Fig.4.3: Inter storey drift ratio for steel bare frame with diff. bracing patterns in Y- direction

From the fig. 4.3, it is observed that inter storey drift ratio in Y direction for bare frame beyond the IS Code limit i.e. 0.0051 and Diff. types of bracing patterns such as X, V ,Inverted V and Knee bracing are within IS Code limit.

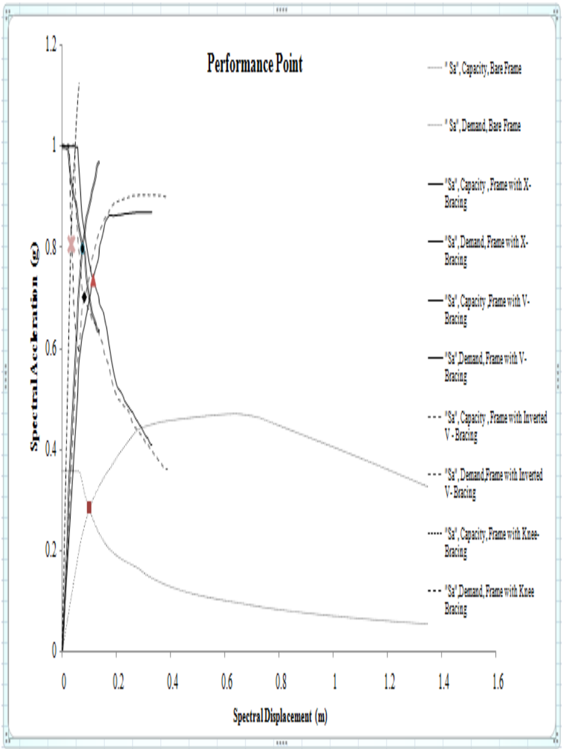

Fig.4.4: Performance point for steel bare frame with diff. bracing patterns

V. CONCLUSIONS

The effects of bracing on seismic behavior of five models of G + 4 steel structures with different bracing arrangements were investigated. The results yield the following conclusions.

1. Storey drift ratio of the bare frame in X-direction is close to the permissible drift ratio as per I.S.1893:2002 hence, the different bracing systems have a significant effect on the reduction of the global lateral displacement. Here, X-bracing has shown effective results than K-bracing.

2. Storey drift ratio of the bare frame in Y-direction has to the permissible drift ratio for storey second, third and fourth as per I.S.1893:2002 hence, the different bracing systems have a significant effect on the reduction of the global lateral displacement. Here, X-bracing has shown effective results than K-bracing.

3. There is 1.19, 1.24, 1.24 and 1.14 times increase in base shear and 4.7, 3.74, 3.92 and 3.70 times decrease in time period in case of X-bracing, V-bracing, inverted V-bracing and K-bracing as compared to bare frame. V- Bracing increases base shear as compared to other bracing systems. X Bracing reduces time period as compared to other bracing systems. Hence, V bracing is more effective than the other bracing system as the percentage increase in base shear is more.

4. After studying the performance of the structure as shown in figure 5.4 the steel frame with K bracing system shows increase in the overall capacity of the structure as compared to the other bracing systems, though the structure doesn‘t show the effective results in increase of base shear and reduction of time period.

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