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# Pushover Analysis of Complex Steel Frame with Bracing Using Etabs

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***Abstract:***
*Steel bracing is economical, easy to erect, occupies less space and has flexibility to design for meeting the required strength and stiffness. In the present study, pushover analysis of complex steel frame building was investigated. These investigations were based on stiffness and ductility. This paper is intended to compare the performance of structure by using ISMB and ISNB(hollow pipes) steel sections as bracing element on 15-story complex steel frame. Displacement analyses were performed using the Extended 3D Analysis of Building Systems (ETABS) software for investigating stiffness of these system and pushover analysis were performed. The results of these outputs indicated that performance of structure greatly influenced by the way and sections adopted for bracing system.*

***Keywords****: Complex steel structure, Pushover analysis, ISNB (hollow pipes) sections, pushover curve, performance point*

## 1. Introduction

Seismic Analysis is a subset of structural analysis and is the calculation of the response of a structure to earthquakes. Nowadays High Rise Steel frame building is well establishing in metro cities. For construction of high rise building bracing are constructed for stiffness and lateral load resistance purpose. Steel frame usually refers to a building technique with a “skeleton frame” of vertical steel columns and horizontal I-beams, constructed in a rectangular grid to support the floors, roof and walls of a building which are all attached to the frame. The development of this technique made the construction of the skyscraper possible. Bracings are strong in compression. Bracing with their surrounding frames has to be considered for increase in lateral load resisting capacity of structure. When bracings are placed in Steel frame it behaves as diagonal compression strut and transmits compression force to another joint. Variations in the column stiffness can influence the mode of failure and lateral stiffness of the bracing.

## 2. Description of the Building

For the analysis work, seven models of steel frame building of 15 floors are made to know the realistic behaviour of building during earthquake. The length of the building is 84m and varying width from 12 to 36m as shown in fig.2. Height of typical story is 3.5m.Building is symmetrical about X and Y-axis. Material concrete grade M25 is used, while steel Fe 250 (mild steel) is used. Beams and columns are modelled as frame element and joined node to nodes. The columns are assumed to be fixed at the ground level.

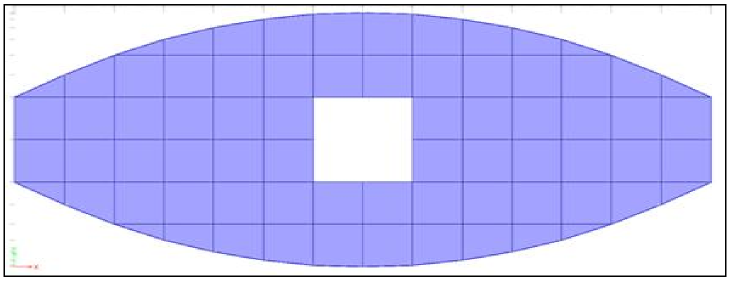
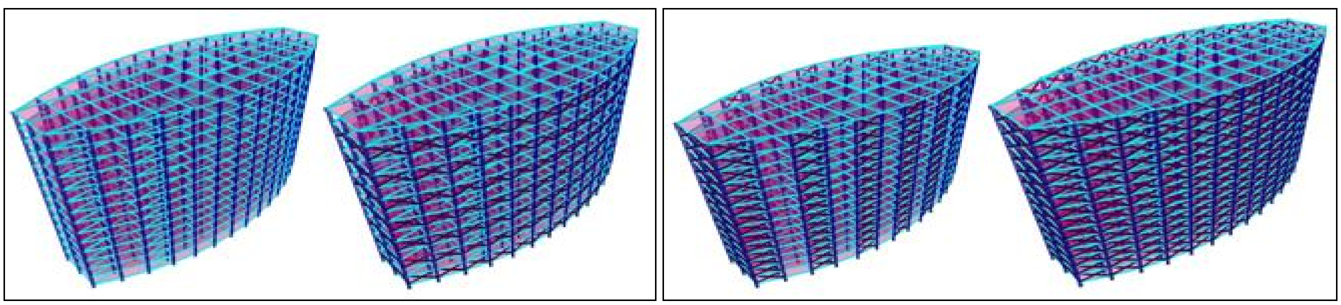


*Figure 1: Plan of a Complex Structure*

| **Member Properties** | |
|---|---|
| Thickness of slab | 0.15 m |
| Beam size | ISMB 0.3m |
| Column size | ISMB 0.6m |
| Bracing | ISMB 0.3m<br>and<br>ISNB 0.125m |
| **Assumed Dead load intensities** | |
| Floor finishes | 1.0 kN/m2 |
| Live load intensities | 3.0 kN/m2 |
| **Earthquake LL on slabs as per clause 7.3.1 and 7.3.2 of IS 1893 (Part 1):2002** | |
| Roof | 0 kN/m2 |
| Floor | 0.25 X 3= 0.75 kN/m2 |
| **As per IS 1893 (Part 1) :2002** | |
| | Zone V |
| Zone factor, Z | 0.36 |
| Importance factor, I | 1 |
| Response reduction factor, R | 5 |
| Soil/Rock type | Medium |

*Table 1: Description of building*

*2.1. Analytical Model*



*Bare frame* *Alternative-x* *Alternative-y* *Exterior*

*Figure 2: Steel framed models showing bare frame along with alternative x, y and exterior bracing*

**3. Methodology**

*3.1. Equivalent Static Analysis*

In equivalent static design the total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure generally used for the equivalent static analysis is explained below:

(i) Determination of fundamental natural period (Ta) of the buildings

$T_a = 0.075h^{0.75}$ Moment resisting RC frame building without brick infill wall

$T_a = 0.085h^{0.75}$ Moment resisting steel frame building without brick infill walls

$Ta = (0.09h)/\sqrt{d}$ All other buildings including moment resisting RC frame building with brick infill walls.

Where,

h -is the height of building in m

d -is the base dimension of building at plinth level in m, along the considered direction of lateral force.

(ii) Determination of base shear (VB) of the building

$V_B = Ah \times W$

Where,

Ah=Z*I*Sa/2Rg is the design, horizontal seismic coefficient, which depends on the seismic zone. Factor (Z), importance factor (I), response, reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

(iii) Distribution of design base shear

The design base shear $V_B$ thus obtained shall be distributed along the height of the building as per the following expression:

$$F = \frac{W.Hi}{\sum_{j-1}^{i} W.Hj}.1$$

*3.2. Pushover Analysis Procedure*

Following are the steps followed in the present study to carry out analysis, design and performance study of steel frames

- Create 3D model of complex steel frame.
- Assign the corresponding section and loads for the beam and column.
- Analysis has been carried out for both gravity and earthquake loads.
- Design has been carried out using ETABS-13.
- Assign default hinge properties at assumed potential points (near beginning and ending of the element)
- For column P-$M_1$-$M_2$ hinge property has been assigned and for beam P-$M_3$ hinge property has been assigned. These points will have pre-defined properties as per ATC-40.
- Define non-linear/pushover cases, in which first case is force control and second case is displacement control with gravity, push-x and push-y loads.
- For displacement control case, earthquake force is used to push the frame laterally upto maximum displacement (4% of building height).
- Run the static non-linear analysis to get pushover curve.

*3.3. Plastic Deformation Curve*

For each degree of freedom, one can define a force displacement (moment-rotation) curve that gives the yield value and the plastic deformation following yield. This is done in terms of a curve with values at five point A-B-C-D-E as shown in fig 3.

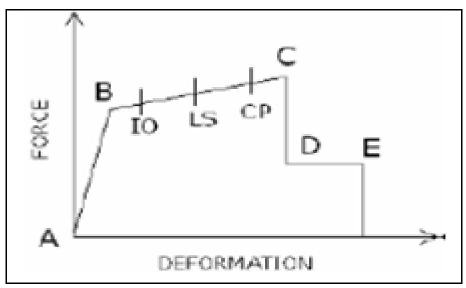



*Figure 3: Force V/s Deformation curve*

The shape of this curve as shown in fig.3.is intended for pushover analysis. The following points should be noted:

- Point A is always the origin.
- Point B represents yielding. No deformation occurs in the hinge up to point B, regardless of the deformation value specified for point B. The displacement at point B will be subtracted from the deformation at point C, D, and E.
- Only plastic deformation beyond point B will be exhibited by the hinge.
- Point C represents the ultimate capacity for pushover analysis.
- Point D represents a residual strength for pushover analysis. However, you may specify a positive slope from C to D or D to E for other purposes.
- Point E represents total failure. Beyond point E the hinge will drop load down to point F (not shown).

*3.4. Plastic Hinges and its Parameters*

Plastic hinges are assigned to represent elasto-plastic behaviour of members. Stages of plastic hinges under lateral loads are obtained by curve of generalised force "Q" versus generalised displacement as shown in figure 3. As per the mechanical behaviour of members, two types of hinges are assigned as P-$M_3$ and P-$M_2$-$M_3$. The hinge P-M3 are assigned at the middle of beams and braces which mainly resist axial force, while the P-M2-M3 hinges are assigned at the end of columns which subjected to axial force and bending moments.

**4. Results and Discussions**

| BASE SHEAR(KN) | | |
|---|---|---|
| **MODELS** | **ISMB SECTIONS-300** | **ISNB PIPES-300** |
| MODEL-1 | 17817.1356 | 17817.1356 |
| MODEL-2 | 37119.4441 | 34148.4271 |
| MODEL - 3 | 39620.3824 | 36663.9838 |
| MODEL - 4 | 47035.0926 | 46090.4195 |

*Table 2: Design base shear of ISMB bracing and ISNB (hollow pipes) models (push-X)`*

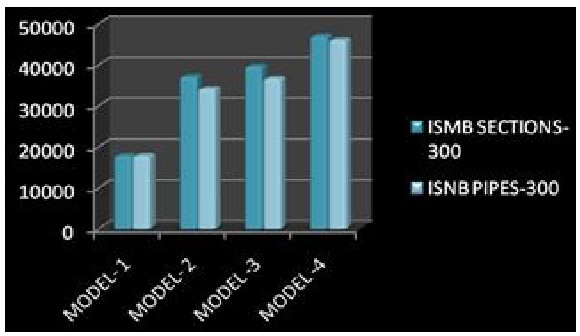



*Figure 4: Design base shear of different bracing models (push-X)*

| Storey displacement in X - direction by Equivalent Static Method (Ux-mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **NO. OF STORIES** | **bare frame** | | **Alternative-x** | | **Alternative-y** | | **exterior** | |
| | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** |
| 15 | 534.3 | 534.3 | 112.1 | 153.9 | 196.7 | 224.9 | 29.3 | 61 |
| 10 | 403 | 403 | 82.2 | 115.1 | 120.5 | 147.4 | 20.9 | 45.3 |
| 5 | 169.2 | 169.2 | 37.6 | 52.3 | 41.6 | 56.1 | 10.4 | 21.6 |
| 1 | 3.6 | 3.6 | 1.1 | 1.3 | 1.3 | 1.6 | 0.7 | 0.9 |
| | | | | | | | | |
| **Storey displacement in Y - direction by Equivalent Static Method (Uy-mm)** | | | | | | | | |
| **NO. OF STORIES** | **bare frame** | | **Alternative-x** | | **Alternative-y** | | **exterior** | |
| | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** |
| 15 | 1595.5 | 1595.5 | 261.2 | 391.1 | 262.4 | 379.2 | 120.7 | 243.5 |
| 10 | 1233.6 | 1233.6 | 181.1 | 282.6 | 179.4 | 274.8 | 94.9 | 190.1 |
| 5 | 578.2 | 578.2 | 90.2 | 139.6 | 87.9 | 134.7 | 56.1 | 101.4 |
| 1 | 14.9 | 14.9 | 34.3 | 37 | 38.4 | 40.6 | 19.4 | 34.6 |
| | | | | | | | | |
| **Storey displacement in X - direction by Pushover Method (Ux-mm)** | | | | | | | | |
| **NO. OF STORIES** | **bare frame** | | **Alternative-x** | | **Alternative-y** | | **exterior** | |
| | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** |
| 15 | 1002.7 | 1002.7 | 247.8 | 299.5 | 434.5 | 426.6 | 84.4 | 157.8 |
| 10 | 898.7 | 898.7 | 205.9 | 250.1 | 284.6 | 297.2 | 70.6 | 131.7 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 471.5 | 471.5 | 117.4 | 136.7 | 115.8 | 130.7 | 46.4 | 77.5 |
| 1 | 10.3 | 10.3 | 3.9 | 4.1 | 5 | 5 | 4.4 | 4.7 |
| | | | | | | | | |
| **Storey displacement in Y - direction by Pushover Method (Uy-mm)** | | | | | | | | |
| **NO. OF STORIES** | **bare frame** | | **Alternative-x** | | **Alternative-y** | | **exterior** | |
| | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** | **ISMB** | **ISNB** |
| 15 | 941.2 | 941.2 | 635.7 | 820.9 | 456.4 | 780.8 | 345.9 | 154.7 |
| 10 | 823.7 | 823.7 | 484.6 | 651.6 | 341.7 | 584.9 | 294.8 | 133.7 |
| 5 | 530.2 | 530.2 | 289.2 | 386.2 | 201.5 | 300.5 | 206.3 | 91.2 |
| 1 | 12.5 | 12.5 | 142.2 | 138.8 | 111.1 | 75.6 | 97.7 | 53.7 |

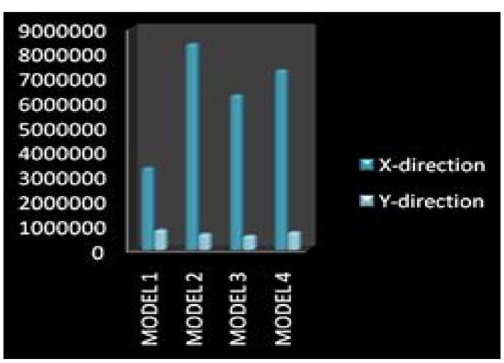
*Table 3: Storey displacement of ISMB bracing and ISNB (hollow pipes) models in both X and Y-direction.*

| **Maximum Stiffness(ISMB) (kN/m)** | | |
|---|---|---|
| MODELS | X-direction | Y-direction |
| MODEL 1 | 3345911.5 | 809107.211 |
| MODEL 2 | 8379465.754 | 644107.92 |
| MODEL 3 | 6291569.759 | 572325.195 |
| MODEL 4 | 7309515.311 | 719764.268 |

*Table 4: Maximum stiffness of ISMB models*

| **Maximum Stiffness(ISNB) (kN/m)** | | |
|---|---|---|
| MODELS | X-direction | Y-direction |
| MODEL 1 | 3345911.5 | 809107.211 |
| MODEL 2 | 6876621.309 | 574215.787 |
| MODEL 3 | 5433201.673 | 589354.996 |
| MODEL 4 | 6379951.686 | 616200.762 |

*Table 5: Maximum stiffness of ISNB models*



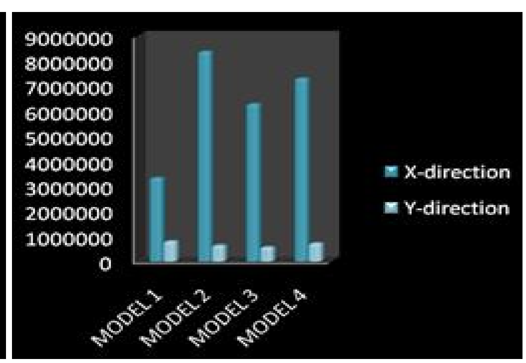



*Figure 5: Graphical Representation of Stiffness of ISMB models*
*Figure 6: Graphical Representation of Stiffness of ISNB models*

*4.1. Pushover Curves*

The first step in construction of capacity and demand spectra curves is the conversion of pushover curve (eg , base shear vs displacement) to an equivalent capacity curve (eg, spectral acceleration vs spectral displacement).

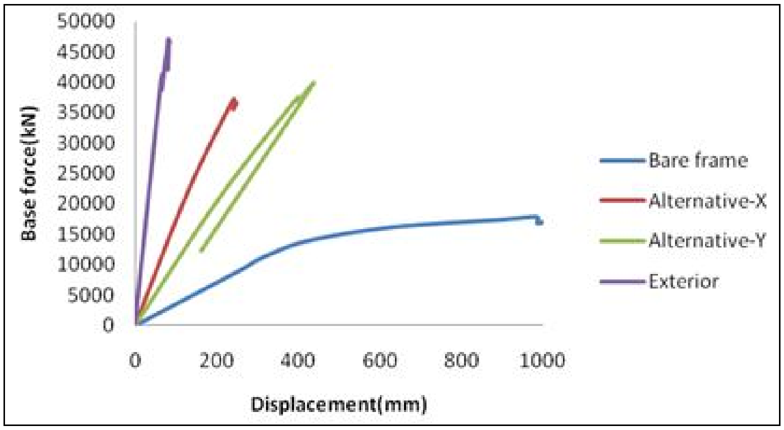



*Figure 7: Pushover curve of all ISMB models*

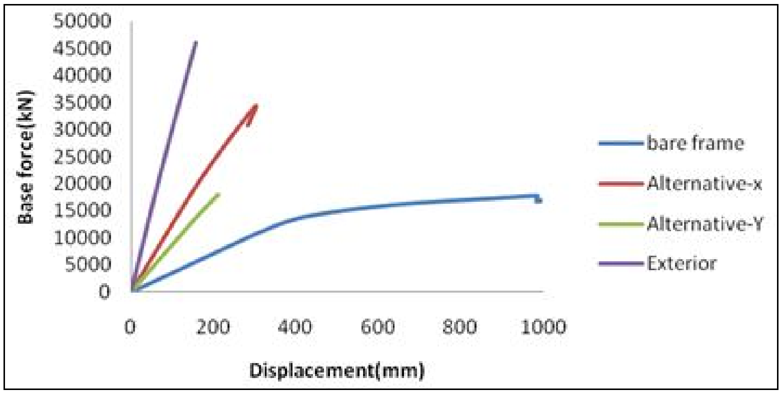



*Figure 8: Pushover curve of all ISNB-125 models*

*4.2. Performance Point*

From pushover analysis the capacity spectrum curves of two structures are obtained. The elastic acceleration response spectrum curve (Sa versus T) for severe earthquakes can be obtained from "Code for Seismic Design of Buildings". The elastic acceleration response spectrum curve can be transformed into demand spectrum curve (Sa versus Sd) for both structures. Then the capacity spectrum curve is superimposed on the demand spectrum curve and the intersection point is considered to be the performance point. From values of Sa and Sd of performance point, responses of the structure under severe earthquakes are obtained.

| **Parameters** | **Bare frame** | **Exterior ISMB bracing** |
|---|---|---|
| Shear (kN) | 16.93 | 42.177 |
| Displacement (mm) | 790.7 | 68.5 |
| Sa | 0.046 | 0.2371 |
| Sd (mm) | 653.8 | 243.9 |
| Ductility ratio | 2.14 | 1.659 |
| Damping ratio | 0.098 | 0.0684 |
| Modification factor | 0.838 | 1.076 |
| Ca | 0.36 | 0.36 |
| Cv | 0.5 | 0.5 |

*Table 6: Performance Point Parameters*

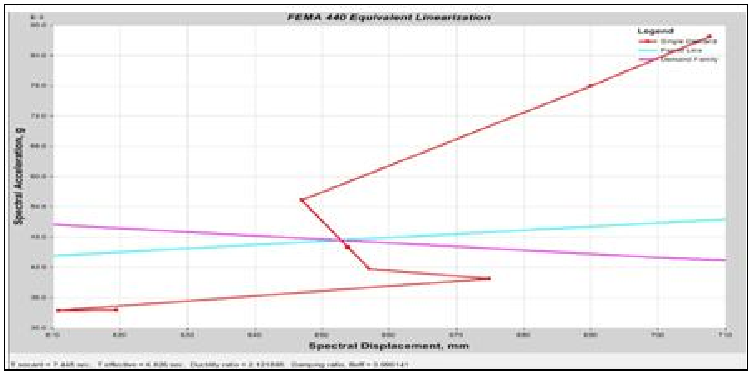



*Figure 9: Performance point of bare frame*


*Figure 10: Performance point of Exterior ISMB bracing*

*4.3. Plastic Hinge Mechanism*

Model with alternative bracing shows better performance than bare frame model. Model with exterior steel bracing shows better performance. The yielding of the model with Exterior steel bracing occurs at event B-IO the amount of damage in this structure will be limited. In the analysed modes, based on elastic analysis results and the importance of structural member's 2400 number of beam hinges and 1320 number of column hinges are assigned.

| HINGE RESPONSE OF COLUMN (M2 & M3) (KN-M) | | | | | | |
|---|---|---|---|---|---|---|
| Step no. | BARE FRAME | | EXTERIOR ISMB BRACING | | | |
| | Hinge(M2) | Hinge(M3) | Hinge(M2) | Hinge(M3) | State | Status |
| 1 | 12.8447 | 48.5381 | 8.1783 | 43.8174 | A to <=B | A to <=IO |
| 2 | 13.0311 | 49.2427 | 8.8445 | 47.3868 | A to <=B | A to <=IO |
| 3 | 13.0653 | 49.3734 | 8.8694 | 47.5258 | A to <=B | A to <=IO |
| 4 | 13.1075 | 49.5004 | 8.9011 | 47.7073 | A to <=B | A to <=IO |
| 5 | 13.1115 | 49.5118 | 8.9112 | 47.7643 | A to <=B | A to <=IO |
| 6 | 13.1825 | 49.7259 | 8.9148 | 47.7881 | A to <=B | A to <=IO |
| 7 | 13.1875 | 49.7388 | 9.0761 | 48.6902 | A to <=B | A to <=IO |
| 8 | 13.3279 | 50.2624 | 9.0846 | 48.7376 | A to <=B | A to <=IO |
| 9 | 13.361 | 50.4151 | 9.1397 | 49.0509 | A to <=B | A to <=IO |
| 10 | 13.3621 | 50.4282 | 9.2402 | 49.6241 | A to <=B | A to <=IO |
| 11 | 13.5302 | 51.0643 | 9.2476 | 49.6674 | A to <=B | A to <=IO |
| 12 | 14.58 | 55.3757 | 9.2527 | 49.6974 | A to <=B | A to <=IO |
| 13 | 14.5927 | 55.4308 | 9.574 | 51.5383 | A to <=B | A to <=IO |
| 14 | 14.5958 | 55.444 | 9.5875 | 51.6311 | A to <=B | A to <=IO |
| 15 | 38.3268 | 158.303 | 14.9245 | 87.7453 | A to <=B | A to <=IO |

*Table 7: Hinge properties of column members (push-x)*

| HINGE RESPONSE OF BEAM (M3) (KN-M) | | | | | | |
|---|---|---|---|---|---|---|
| | BARE FRAME | | | EXTERIOR ISMB BRACING | | |
| STEP NO | HINGE(M3) | STATE | STATUS | HINGE(M3) | STATE | STATUS |
| 1 | 16.9876 | A to <=B | A to <=IO | 14.1862 | A to <=B | A to <=IO |
| 2 | 17.2342 | A to <=B | A to <=IO | 15.342 | A to <=B | A to <=IO |
| 3 | 17.2785 | A to <=B | A to <=IO | 15.3855 | A to <=B | A to <=IO |
| 4 | 17.3107 | A to <=B | A to <=IO | 15.4413 | A to <=B | A to <=IO |
| 5 | 17.314 | A to <=B | A to <=IO | 15.4591 | A to <=B | A to <=IO |
| 6 | 17.3731 | A to <=B | A to <=IO | 15.4658 | A to <=B | A to <=IO |
| 7 | 17.3764 | A to <=B | A to <=IO | 15.7483 | A to <=B | A to <=IO |
| 8 | 17.561 | A to <=B | A to <=IO | 15.763 | A to <=B | A to <=IO |
| 9 | 17.614 | A to <=B | A to <=IO | 15.8594 | A to <=B | A to <=IO |
| 10 | 17.6184 | A to <=B | A to <=IO | 16.0352 | A to <=B | A to <=IO |
| 11 | 17.8408 | A to <=B | A to <=IO | 16.0485 | A to <=B | A to <=IO |
| 12 | 18.982 | A to <=B | A to <=IO | 16.0576 | A to <=B | A to <=IO |
| 13 | 18.9963 | A to <=B | A to <=IO | 16.6245 | A to <=B | A to <=IO |
| 14 | 18.9997 | A to <=B | A to <=IO | 16.6459 | A to <=B | A to <=IO |
| 15 | 45.5583 | A to <=B | A to <=IO | 26.5926 | A to <=B | A to <=IO |

*Table 8: Hinge properties of Beam members (push-x)*

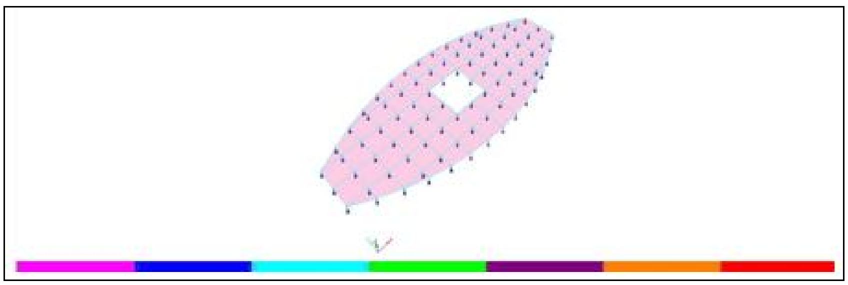


*Figure 11: Plastic Hinge Mechanism of Bare frame model in (Push X)*

**5. Conclusion**

15 storey bare frame, Alternative-x, Alternative-y and Exterior Steel bracing model is analyzed using standard software. The following conclusions are drawn based on present study.

- Base shear obtained from all models using ISNB bracing is lesser then ISMB sections.
- The lateral displacement of complex steel frame studied is reduced to greater extent by the provision of exterior steel bracing.
- Stiffness of models increased by an amount of 71.5% using ISMB bracing and 68% using hollow pipes sections.
- The results obtained from lateral forces and hinge mechanism gave an insight into the real behavior of structures.
- Column beam hinge mechanism obtained is 3.5 times more for bare frame with exterior bracing.
- 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.

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