ISSN 2229-5518

Pushover Analysis of RC Building

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Abstract— In this study the seismic response of a ten storied reinforced concrete building is analysed by displacement controlled pushover analysis. It is assumed to be located in seismic zone 3. The building frame is simulated and analysed using the structural analysis and design software SAP2000. In non-linear analysis, moment-curvature relationship is used to model plastic hinge behaviour. Thus it was developed for modelling the user defined hinges for beam and column sections. Moment (M) and interactive P-M hinges were assigned to the both ends of beam and column sections respectively. The lateral forces were obtained as per IS 1893 (Part1):2002 and applied to the building. Top node displacement is incremented step by step up to the limiting displacement to obtain the pushover curve and the sequence of formation of plastic hinges and failure of beams and columns were recorded. The analysis results including the pushover curve and hinge formation are discussed. The maximum base shear capacity was found to be higher than the design base shear and hinges were formed in beams prior to columns.

Index Terms— Capacity curve, Hinge formation, Load- moment interaction curve, Moment-curvature relationship, Pushover analysis.

1 Introduction

EARTHQUAKE can cause greatest damages to humanity among all the natural hazards. Since earthquake forces are unpredictable and random in nature, proper analysis of the structures must be ensured to withstand such loads. The recent developments in the performance based engineering design have brought the non-linear static (NSP) or pushover analysis to the forefront. It has replaced the conventional analysis procedures due to its simplicity and proved to be a useful and effective tool for assessing the real strength of structures. Pushover analysis can be either force controlled or displacement controlled. The pushover analysis can provide significant perception and understanding about the weak links in the structure.

SAP2000 can perform static or dynamic, linear or nonlinear analysis of structural systems. To perform pushover analyses in SAP2000, users can create and apply hinge properties. SAP2000 is fully equipped with US, Canadian and International Design standards and codes like ACI concrete code, AISC building codes and AASHTO specifications [1]. These integrated design code features can easily generate wind, wave and seismic loads with comprehensive automatic steel and concrete design checks.

Pushover analysis is a static non-linear technique in which the magnitude of the structural loading is incremented in the lateral direction of the structure according to a certain predefined pattern. Generally, it is assumed that the behaviour of the structure is controlled by its fundamental mode and the predefined pattern is expressed in terms of either story shear or fundamental mode shape. FEMA-273 and its successor FEMA-356 describe about the non-linear static procedure (NSP) or pushover analysis and its uses in the structural engineering field. It is recommended as a standard tool for estimating seismic demands for buildings [2].

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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. There are three types of hinge properties in SAP2000. They are default hinge properties, user-defined hinge properties and generated hinge properties. Studies show that user defined hinge model gives better results than default hinge model [10]. Moment-curvature relationship is used to model plastic hinge behaviour in non-linear analysis. The seismic performance of a structure can be evaluated in terms of pushover curve, plastic hinge formation etc. The maximum base shear capacity of structure can be obtained from base shear versus roof displacement curve.

2 Building Description

The building used for analysis is a non-existing structure which is a ten storied RC building with floor to floor height of 3.2 m. The building is assumed to be located at seismic zone 3. The building is designed as a frame model with infill and constraints as fixed for the ground story columns. The building details and design data are given below. The plan and elevation of the building frame is shown in Fig. 1.and the 3D model is shown in Fig. 2. All dimensions are shown in mm.

2.1 Building Details

- Number of bays along X- axis : 6
- Number of bays along Y- axis : 4
- Spacing along X and Y axis : 4 m
- Size of column : 300 x 800 mm
- Size of beam : 200 x 600 mm
- Thickness of slab : 120 mm
- Thickness of infill : 200 mm
- Grade of concrete : M20

2.2 Design Details

- Live Load :1.5kN/m² on roof and 3kN/m² on other floors
- Earthquake Load : As per IS 1893(Part 1):2002
- Type of soil site : Medium

ISSN 2229-5518

•Seismic Zone : 3

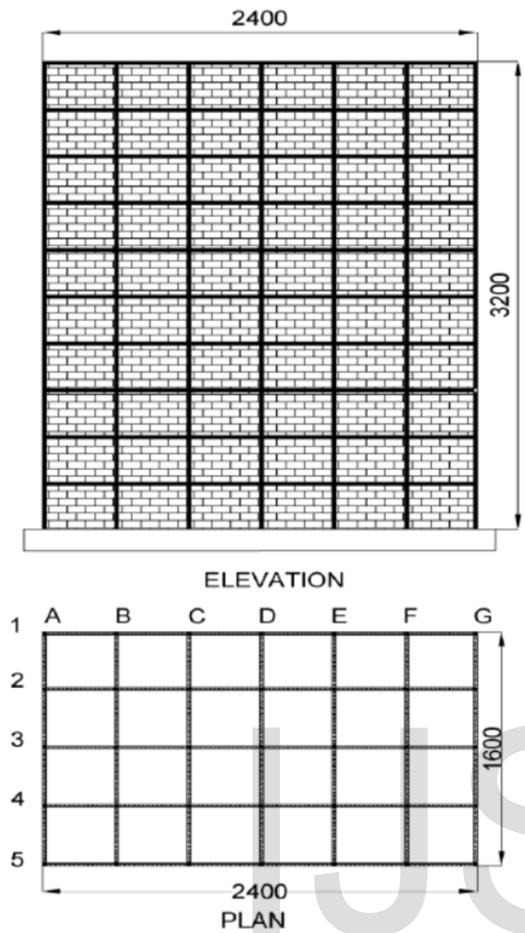

Fig. 1. Elevation and plan of the building frame

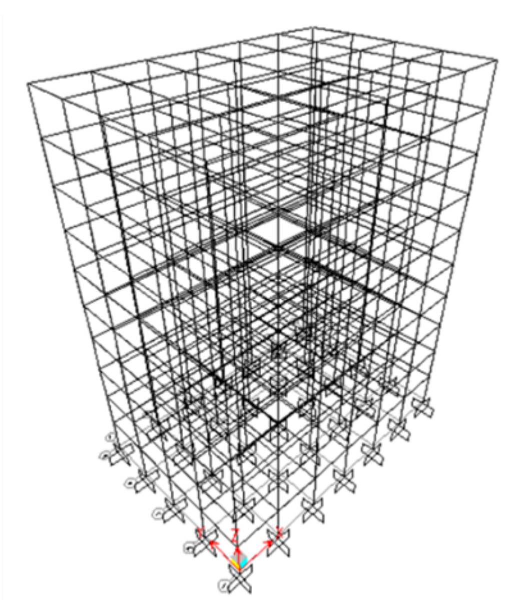

Fig. 2. 3-D building model in SAP2000

3 Moment-Curvature Parameters

Moment-curvature relation is a basic tool in the calculation of deformations in flexural members. It has an important role to play in predicting the behaviour of reinforced concrete (RC) members under flexure. In non-linear analysis, it is used to model plastic hinge reinforced concrete (RC) members under flexure. In non-linear analysis, it is used to model plastic hinge behaviour. The materials used in the design were M20 grade concrete and Fe415 steel reinforcements. The cross section of the beam and column used for the analysis are shown in Fig. 3 and Fig. 4 respectively. All the sections in the structure are of same cross-section and reinforcement detailing.

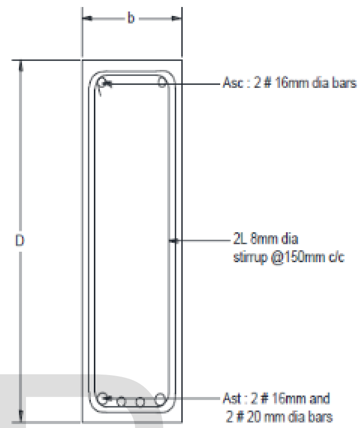

Fig. 3. Cross-section of beam

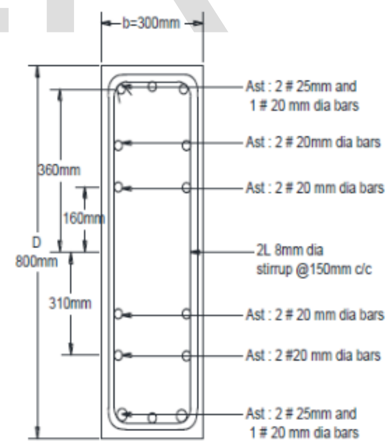

Fig. 4. Cross-section of column

Moment curvature curve for beam and column sections are generated for a specific confining steel using the stress-strain curves for concrete and steel as per IS 456: 2000 using an iterative algorithm [9]. The moment-curvature curve generated for the column section for an axial load of 500kN and that for beam is depicted in Fig. 5 and Fig. 6 respectively. The moment curvature curves were developed for different axial loads and the axial load-moment values were used for developing the P-M interaction curve as shown in Fig. 7. Using these relationships Moment (M3) and interactive load-moment

(P-M3) hinges were defined and were assigned at both ends of each beam and column respectively.

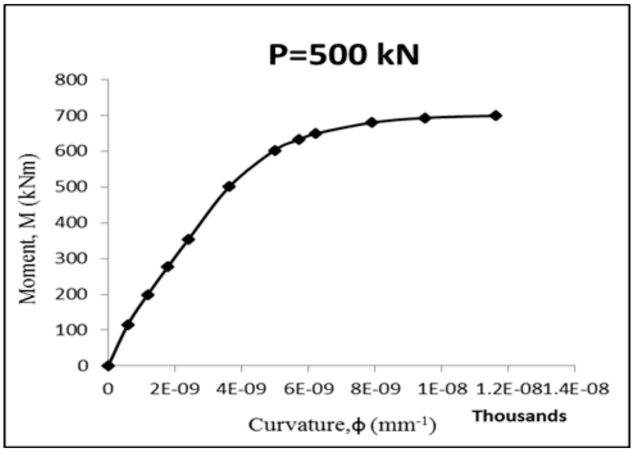

Fig. 5. Moment-curvature curve for column

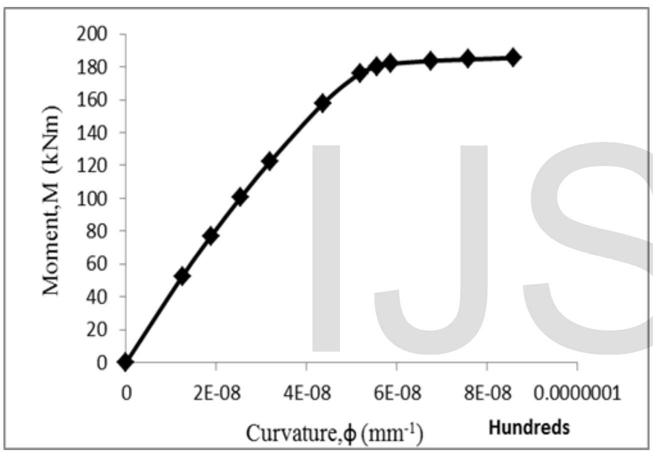

Fig. 6. Moment-curvature curve for beam

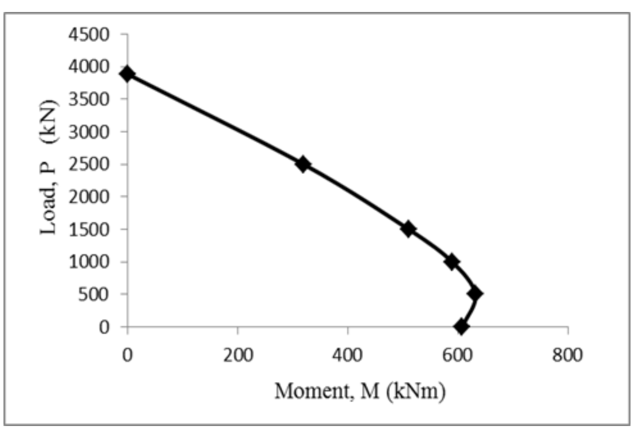

Fig. 7. Load-moment interaction curve for column

Moment-curvature parameters are used as the input for modeling the hinge properties and it can be idealized as shown in Fig. 8. The salient points in the idealized moment-curvature curve can be defined as follows:

- The point A corresponds to the unloaded condition.
- The point B corresponds to the nominal yield strength and yield rotation.
- The point C corresponds to the ultimate strength and ultimate rotation, following which failure takes place.
- The point D corresponds to the residual strength, if any, in the member. It is usually limited to 20% of the yield strength, and ultimate rotation can be taken with that.
- The point E defines the maximum deformation capacity and is taken as ten times that at the yield point.

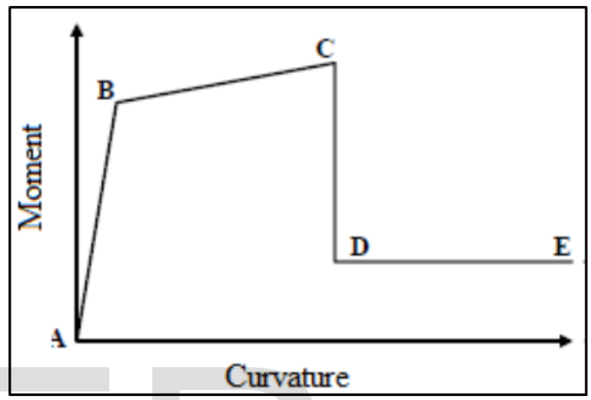

Fig. 8. Idealized moment-curvature relationship

4 Result and Discussion

Pushover analysis is carried out by vertical loading (gravity load) followed by a gradually increasing displacement controlled lateral load in both +x and +y direction. The design base shear calculated as per IS specifications is compared with the overall capacity of the structure obtained from the pushover curve.

The analysis results that include pushover curves, sequence of formation of hinges are briefly discussed below.

4.1 Pushover Curve

The capacity curve also known as pushover curve is a plot of base shear versus displacement of the roof of the structure. From the pushover curve the maximum displacement at the roof and base reaction of the structure during displacement controlled analysis can be obtained. The capacity curve is a good indicator of the inelastic behaviour of the building beyond the elastic stageshows The pushover curves for building when analyzed by displacement controlled pushover analysis in both +x and +y direction are shown in Fig. 9 and Fig. 10. The Pushover curve shows that the building has high base shear capacity than the design base shear. Hence the building is safe for the designed level of earthquake The design base shear (V_B) was found to be 3435 kN and 2804 kN for x and y axis loading and the corresponding capacity obtained from the pushover curves are 3884.855 kN and 3534.256 kN respectively. The base shear capacity of the building was obtained to be 13.09% and 26.04% higher than design base shear for x and y axis loading respectively. The maximum roof displacement were 167.35mm and 240.712mm for x and y axis loading respectively.

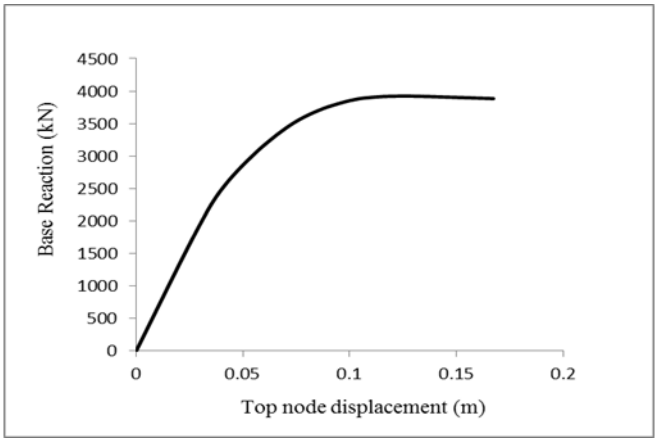

Fig. 9. Pushover curve for x axis loading

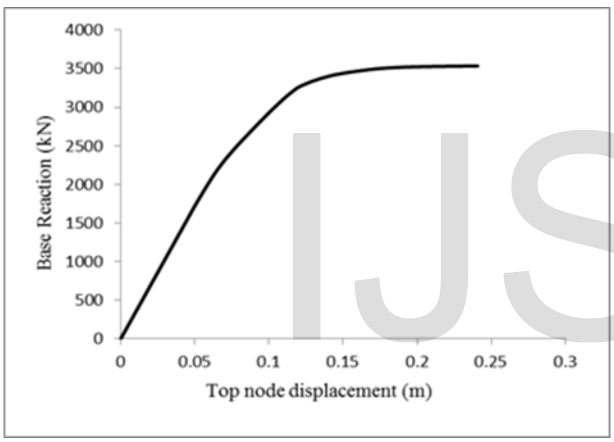

Fig. 10. Pushover curve for y axis loading

4.2 Hinge Formation

Pushover analysis result gives the sequence of plastic hinge formation and state of hinge at various levels of building performance. This gives the information about the weakest member in the structure. So the member which is to be strengthened in case if the building need to be retrofitted can be thus identified. The detailing of the member can be done accordingly in order to achieve the desired pattern of failure of members in case of severe earthquakes. The Acceptance Criteria IO (Immediate Occupancy), LS (Life Safety) and CP (Collapse Prevention) is indicated by different colors to indicate the state of the hinge at various stages. Pushover analysis is carried out as displacement controlled where the maximum displacement is incremented in 1200 steps.

Higher value of multiple steps is chosen to get a clear perception about the formation of hinges at each stage of displacement increment. Fig. 11 and Fig. 12 show the formation of hinges for various cases. In the case of pushover analysis with respect to x axis loading maximum displacement was obtained in 288 incremental steps where as for y axis loading maximum displacement was obtained in 205 incremental steps. The sequence of formation of hinges show that collapse mechanism occurs in beams earlier than columns in all cases. According to the concept of strong column weak beam, this failure mechanism is adaptable.

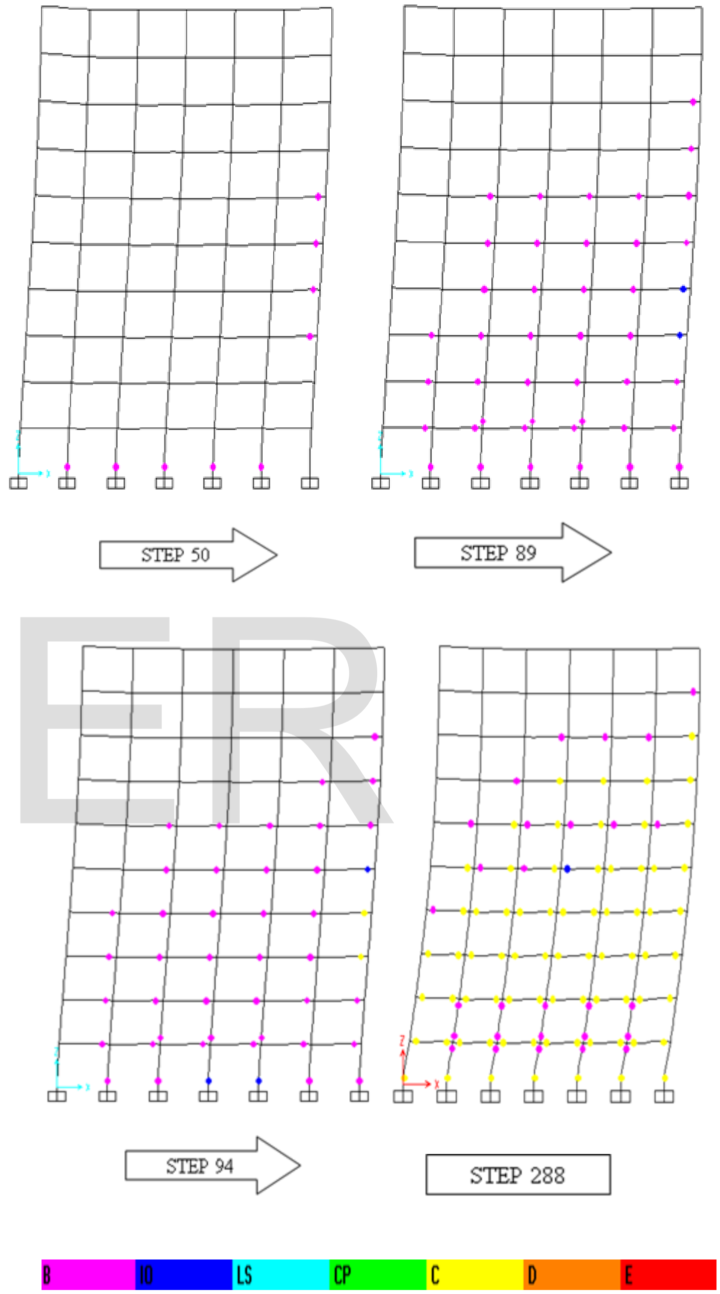

Fig. 11 : Hinge formation for frame loaded in x direction (Total steps=288)

ISSN 2229-5518

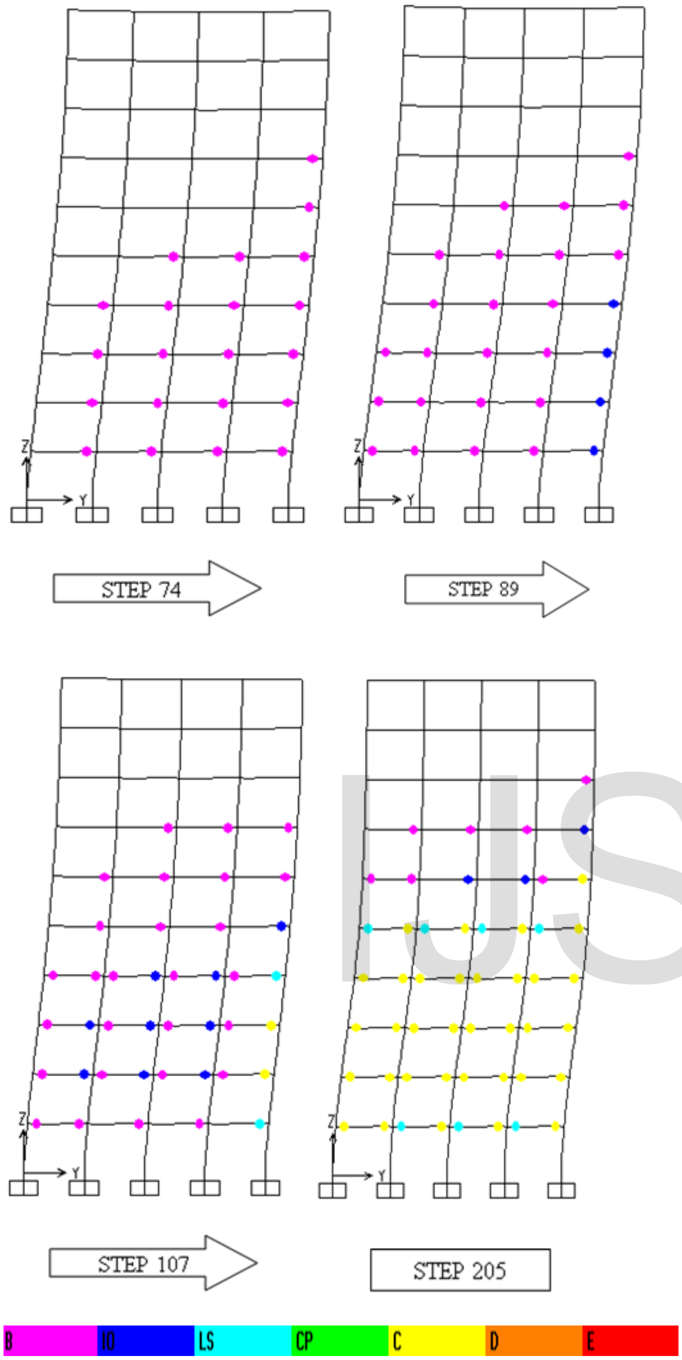

Figure 12 : Hinge formation for frame loaded in y direction (Total steps=205)

From table 1, 77.6 % and 84.56 % of hinges were formed within life safety level for X axis and Y axis loading respectively. Only 20.2% and 12.8% of hinges were formed beyond the collapse prevention level respectively for X axis and Y axis loading.

TABLE 1

LOCATION OF HINGES FOR X AND Y AXIS LOADING

Load case	Maximum displacement (m)	Maximum base shear (kN)	Location of hinges					
			A to B	B to IO	IO to LS	LS to CP	C to D	Total
X-axis loading	0.1673	3884.855	1387	51	6	40	376	1860
Y-axis loading	0.2407	3534.256	1501	55	17	49	238	1860

5 Conclusion

• Pushover analysis is an ideal method to explore the non-linear behaviour of structure

• Moment-curvature relationship is an essential tool to define the user defined plastic hinge properties of the sections

•Load–moment interaction curve is required for defining column hinges

• In all cases the maximum base shear capacity was higher than the design base shear

• Sequence of formation of hinges showed that localized collapse occur in beams prior to columns. 77.6 % and 84.56 % of hinges were formed within life safety level for X axis and Y axis loading respectively

• The building is acceptable and it is safe for the assumed level earthquake in terms of base shear capacity

Acknowledgment

The authors gratefully acknowledge Ms. Indu Geevar, Researcher in the field of structural engineering for her contribution.

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