# Performance based design of Tall RC Structures considering Uncertainty in plastic hinge length

**Madanlal C N[1], Ashwini L K[2], M.Keshava Murthy[3]**

*[1]PG Student, UVCE, Bengaluru,*
*[2]Assistant professor, RRCE, Bengaluru,*
*[3]Professor, Dept. of civil Engineering, UVCE, Bengaluru.*

---

**Abstract -** *Different plastic hinge length are considered to be effective parameter in the user defined hinge properties. In this study the possible differences in the results of pushover analysis due to default and user defined hinge length using various hinge length formulation available in literature by considering G+7 storied RC structures which is modeled in SAP 2000. In present study is done assigning user defined hinges for beams and columns we given calculated moment curvature relations as input I account new plastic hinge length formula for this study. Base shear and displacement capacity of the structures for new formula are similar to various plastic hinge length formula's. The uncertainties in plastic hinge length does not effect on the performance of the building. The observations clearly show that the user-defined hinge model is better than the default-hinge model in reflecting nonlinear behavior compatible with the element properties. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should avoid the misuse of default-hinge properties.*

***Key words****: Performance based design, pushover analysis, Moment curvature analysis, plastic hinge length.*

## 1. INTRODUCTION

In Earthquake Engineering research area, which has been significantly improved especially in the last 40-50 years, recent researches have been significantly concentrated on the idea of "performance-based earthquake engineering (PBEE)". Performance-based design and assessment approaches have gained more popularity. The main objective of the PBEE is to answer the question of "what would be the performance (dynamic response and resulting damage) of a structure during the "expected earthquakes" at the site?" Performance based methods require reasonably accurate estimates of inelastic deformation and resulting structural damage.

The rapid growth of the urban population and the consequent pressure on limited space have considerably influenced city residential development. The high cost of land, desire to avoid a continuous urban sprawl, and the need to preserve important agricultural production have all contributed to drive residential buildings upward. Because of the local topographical restrictions, tall buildings are the only feasible solutions sometimes for housing needs. The probability and interest of high rise structures have always dependent on the available materials, the level of construction technology and the state of development of services necessary for the use of the building. As a result significant advances have occurred from time to time with the advent of a new material, construction facility or form of service.

### 1.1 PLASTIC HINGE MECHANISM

Plastic hinges form at the maximum moment region of reinforced concrete sections. The determination of the plastic hinge length is a critical step in predicting the lateral load-drift response of columns. As it is difficult to estimate the plastic hinge length by using sophisticated computer programs, it is often estimated based on experimental data or by using empirical equations. However, several factors influence the length of plastic hinge, such as: a) level of axial load; b) moment gradient; c) the value of shear stress in the plastic hinge region; d) the amount and mechanical properties of longitudinal and transverse reinforcement; e) strength of concrete; and e) level of confinement provided in the potential plastic hinge zone. The simplified equations available in literature do not contain all or most of the aforementioned factors.

### 1.2 SCOPE AND OBJECTIVES OF THE STUDY

#### Scope

The present study aims to evaluate the performance of the Tall RC building considering the various plastic hinge length formulations.

#### Objectives

Based on the review of literature survey, the following objectives have been aimed.

1. Develop 3D RC framed building model based on pushover analysis using SAP2000.
2. To evaluate the performance of the building Considering Uncertainties in the Plastic hinge length.
3. To study the possible differences in the results of pushover analysis due to default and user defined hinge length using various hinge length formulation.

4. To compare the inelastic behavior of the different plastic hinge length.

## 2. FLOW CHART FOR METHODOLOGY 2

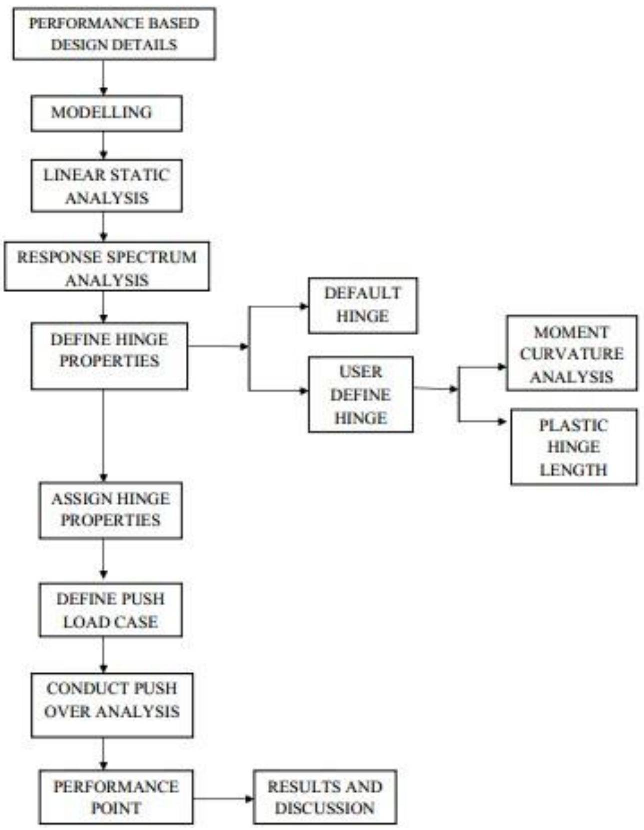



**Fig -1**: Flowchart for Methodology

## 3. PERFORMANCE BASED DESIGN

Performance based design using nonlinear pushover analysis involves tedious and intensive computational effort, is a iterative process needed to meet designer specified and code requirements.

### 3.1 Structural Modelling

All beams are 300x500mm, columns dimensions of ground storey and first storey of C1 is 500x800mm, C2 is 500x900mm and from 2nd storey to 8th storey the column dimension 350x750mm. The grade of the concrete is M26 and steel is Fe500.

**Table -1:** Section and reinforcement details of Beam

| Beam | Dimension (mm) | Top Reinforcement | Bottom Reinforcement | Transverse Reinforcement |
|---|---|---|---|---|
| B-1(0-5storey) | 300x 500 | 6-25ϕ | 5-25ϕ | 3L-8ϕ @ 100C/C |
| B-2(6-8) | 300x 500 | 5-25ϕ | 5-25ϕ | 2L-8ϕ @ 100C/C |

**Table -2:** Section and reinforcement details of Column

| Column Type | Dimension | Main Reinforcement | Transverse Reinforcement |
|---|---|---|---|
| C1-L(0-2) | 500X800 | 12-25ϕ | 5L-8ϕ @ 200C/C |
| C1-M(3-5) | 350X750 | 12-25ϕ | 5L-8ϕ @ 200C/C |
| C1-H(6-8) | 350X750 | 12-20ϕ | 5L-8ϕ @ 200C/C |
| C2-L(0-2) | 500X900 | 14-25ϕ | 6L-8ϕ @ 200C/C |
| C2-M(3-5) | 350X750 | 14-25ϕ | 6L-8ϕ @ 200C/C |
| C2-H(6-8) | 350X750 | 14-20ϕ | 6L-8ϕ @ 200C/C |

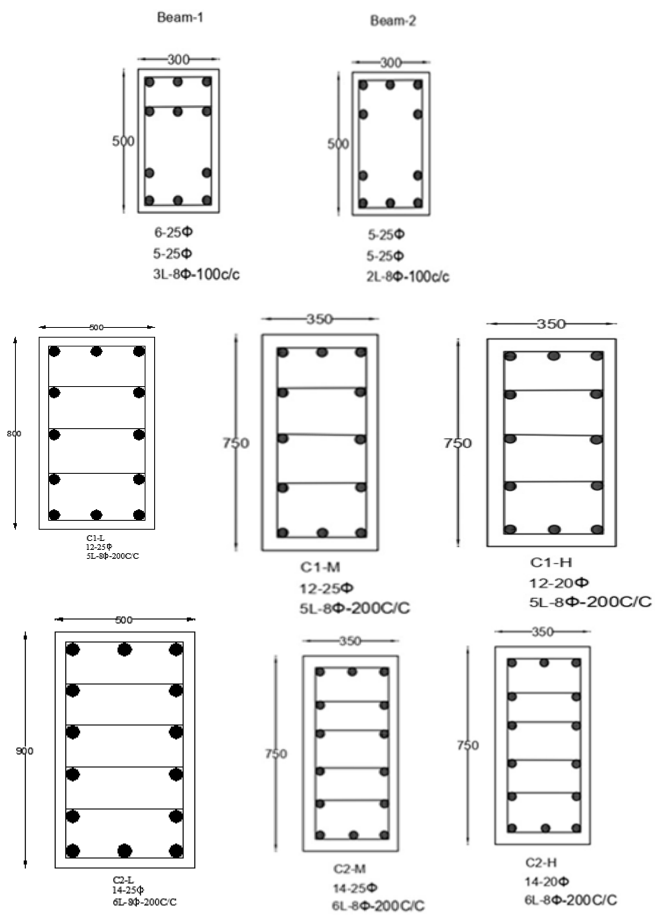



**Fig -2**: performance based design details

### 3.2 MOMENT CURVATURE RELATIONSHIPS

Moment curvature analysis is a method to accurately determine the load deformation behaviour of a concrete section using nonlinear material stress-strain relationship. It is the representation of strength and deformation of the section in terms of moment and corresponding curvature of the section. The relationship between the moment and curvature of reinforced concrete sections is an important parameter for carrying out pushover analysis considering user defined hinge length. These moment curvature data obtained from Microsoft excel office.

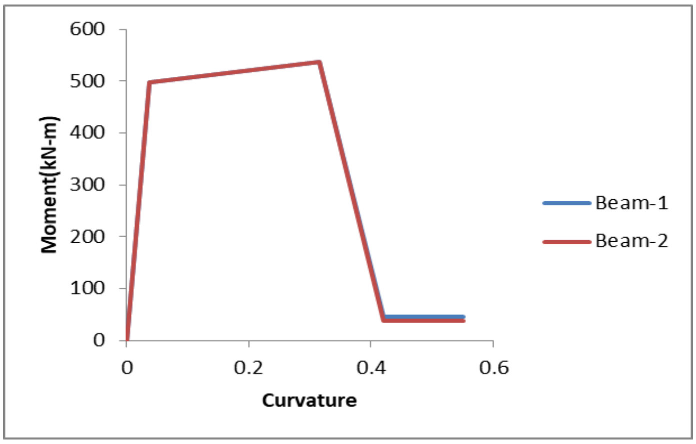
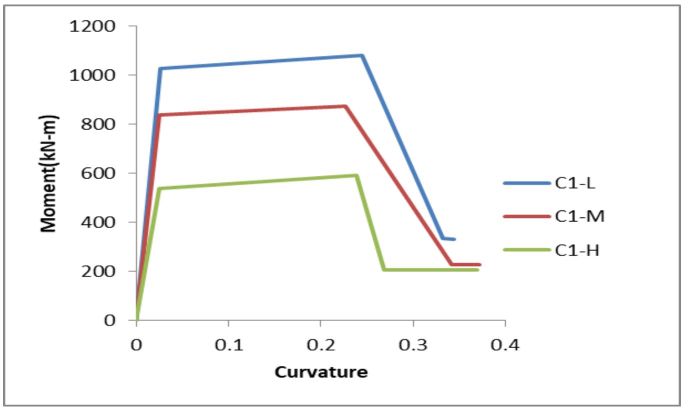



**Chart -1**: Moment curvature relationship for beams



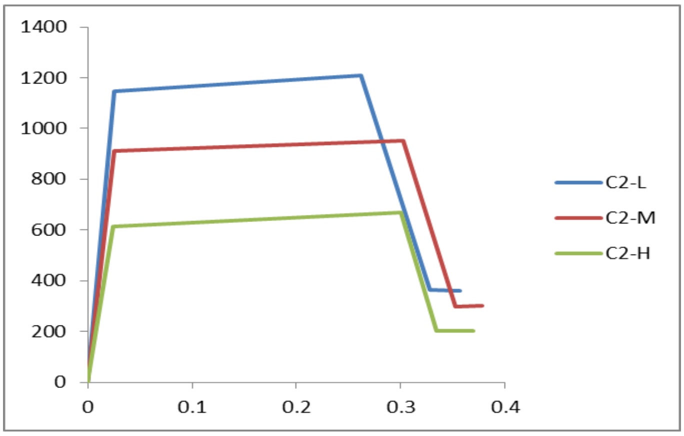




**Chart -2**: Moment curvature relationship for columns

### 3.3 PLASTIC HINGE LENGTH FORMULATION

Various empirical expressions have been proposed by investigators for the equivalent length of plastic hinge Lp.

1. Corley's formula( park and pauley1975, corley 1966)

   Lp= 0.5d+0.2√d (z/d)

2. Sawyer's formula ( park and pauley1975, sawyer 1964)

   Lp=0.25d+0.075z

3. Pauley- Priestley formula [ pauley & Priestley 1992 ]

   Lp=0.08z+0.022dbfy

4. Mattock's formula ( park and pauley1975, mattock 1967)

   Lp=0.5d+0.05z

Where, z= distance of critical section from point of contraflexure

d = effective depth of the member

db = diameter of main reinforcing bars

Based on the literature above plastic hinge length formulas are used. But research purpose I account new simple form of plastic hinge length equation.

Lp = 0.25H

Where, H is the section depth

### 4. RESULTS AND DISCUSSION

The objective of this study is to see the variation of load-displacement graph and check the maximum base shear and displacement of the frame. From nonlinear static pushover analysis conducted, base shear v/s roof displacement was obtained from SAP2000. The resulting base shear and roof displacement obtained considering uncertainties in plastic hinge length

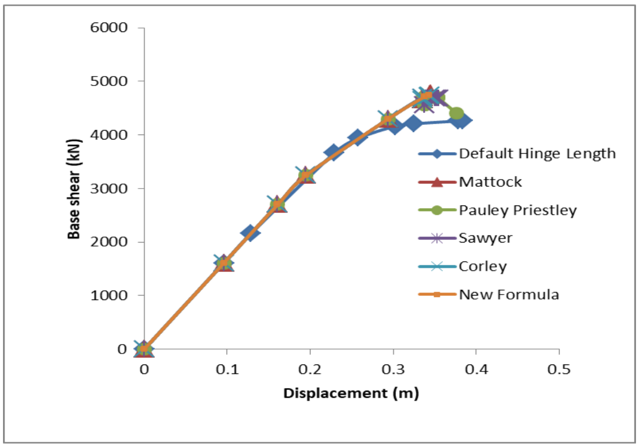



**Chart -3**: pushover curve (x direction) for different plastic hinge length

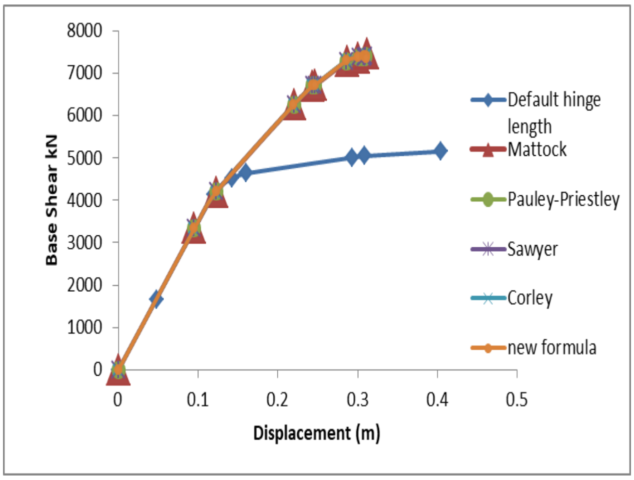



**Chart -4**: pushover curve (y direction) for different plastic hinge length

The maximum base shear of the structure in the user defined hinge model is greater than the default hinge model in both X and Y directions. Maximum roof displacement of the building in the default hinge model is greater than user defined hinge model in both X and Y directions.

### 4.1 PERFORMANCE EVALUATION OF BUILDING

The seismic performance of building is evaluated using capacity spectrum method (CSM). The intersection point of capacity spectrum and demand spectrum such that capacity equals demand is performance point.. Tables 3.3 and 3.4 displays performance point of the structure for an earthquake in X and Y direction respectively in terms of base shear, roof displacement from FEMA 356 and spectral acceleration and spectral displacement obtained from ATC 40

The performance of the building (base shear and displacement capacity) are similar in various user defined plastic hinge length formulation: the variation in the performance of the structures is less than 5%.

**Table 3.3**: performance point (x direction) for different plastic hinge length

| Hinge length | Plastic hinge | Base shear(kN) | Displacement (m) |
|---|---|---|---|
| Default | Default | 3508.62 | 0.219 |
| User defined | Mattock's | 3492.061 | 0.218 |
| | Pauley-Priestley | 3491.87 | 0.218 |
| | Corley's | 3491.878 | 0.218 |
| | Sawyer's | 3492.596 | 0.218 |
| | new | 3492.842 | 0.218 |

**Table 3.4** : performance point (y direction) for different plastic hinge length

| Hinge length | Plastic hinge length formulas | Base shear(kN) | Displacement (m) |
|---|---|---|---|
| Default | Default | 4509.645 | 0.142 |
| User defined | Mattock's | 4754.77 | 0.149 |
| | Pauley-Priestley | 4759.011 | 0.149 |
| | Corley's | 4759.025 | 0.149 |
| | Sawyer's | 4761.001 | 0.149 |
| | new | 4760.526 | 0.149 |

## 4.2 HINGES

**4.2.1 Hinge status at ultimate :** The details of the hinges formed in the structure in X direction and Y direction is given in the Table 6.5 and 6.6

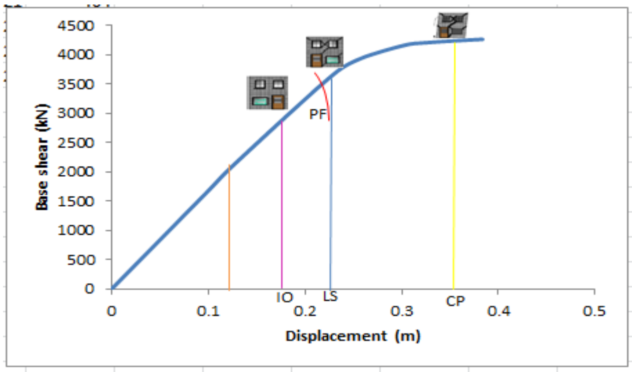



**Chart 5**: performance level for default hinge length in Y direction

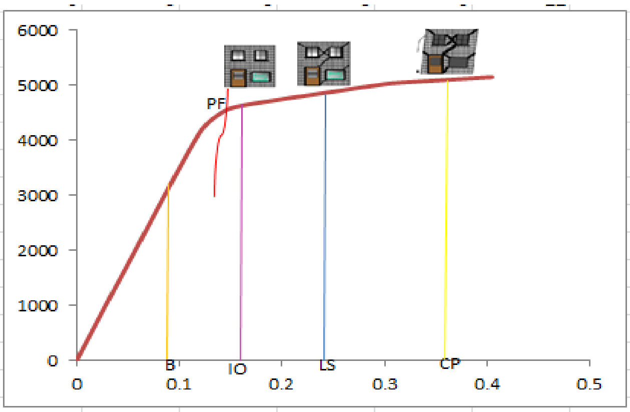



**Chart 6**: performance level for default hinge length in Y direction

**Table -3.5:** Summary of plastic hinging for pushover analysis at different damage level

| Plastic hinge length | Direction | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Default | X | 418 | 24 | 16 | 0 | 0 | 6 | 0 | 0 | 464 |
| | Y | 416 | 30 | 14 | 0 | 0 | 4 | 0 | 0 | 464 |

**Table -3.6:** Summary of plastic hinging for pushover analysis at different damage level

| Plastic hinge length | Direction | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| User defined | X | 424 | 28 | 12 | 0 | 0 | 0 | 0 | 0 | 464 |
| | Y | 418 | 41 | 5 | 0 | 0 | 0 | 0 | 0 | 464 |

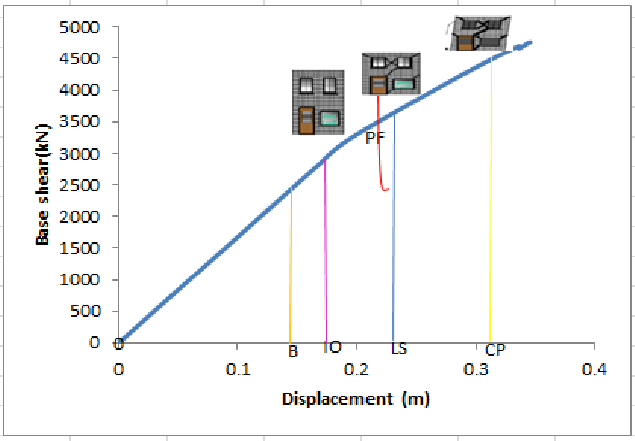



**Chart 7**: performance level for user defined hinge length in X direction.

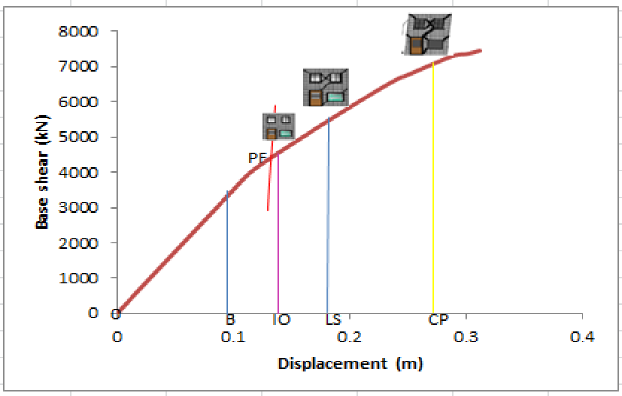



**Chart 8** : performance level for user defined hinge length in Y direction.

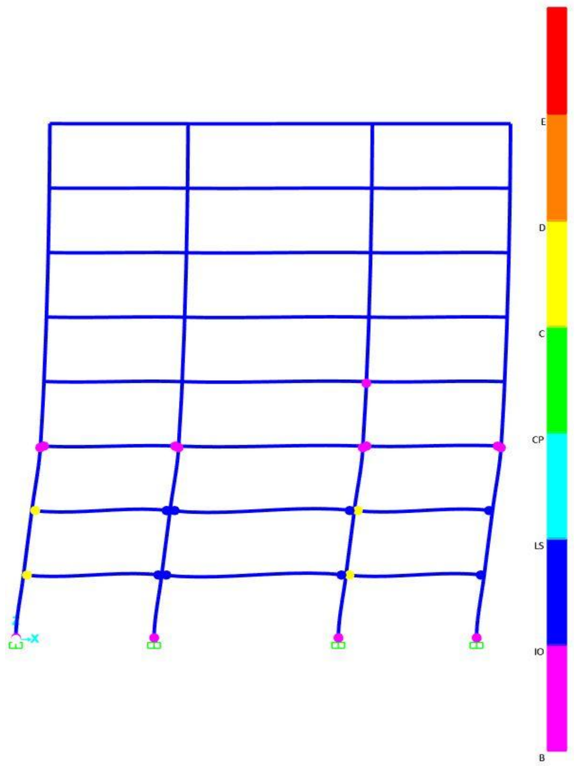



**Fig -3**: default hinge model at ultimate

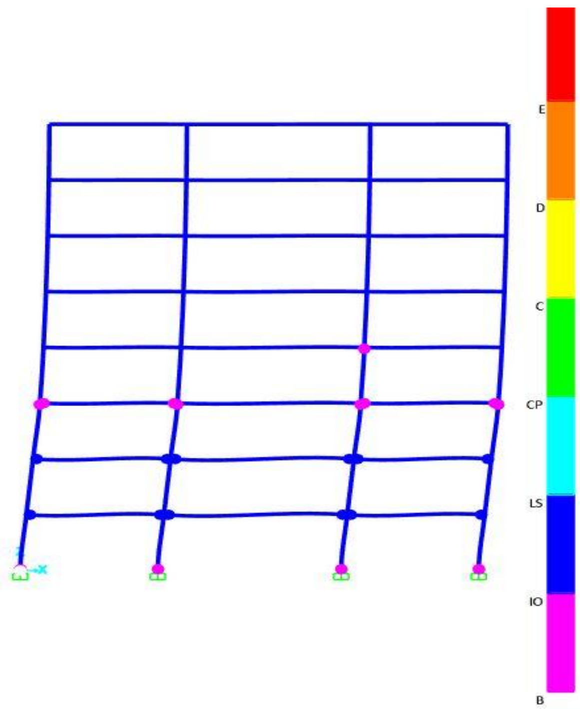



**Fig -4**: user defined hinge model at ultimate

**Following are the discussion:**

- It was observed that, both the models, the performance level lied between Immediate occupancy and life safety level for an earthquake in X direction.
- It was observed that, both the models, the performance level lied between B and Immediate occupancy level for an earthquake in Y direction.
- It was found that, Default hinge length, 90.1% of members are in A to B, 5.2% of members are in B to immediate occupancy [ B-IO ], 3.5% of members are in immediate occupancy to life safety [ IO- LS ] zone. Remaining 1.2% of members reach collapse zone in X direction.
- It was found that, Default hinge length, 89.6% of members are in A to B, 6.5% of members are in B to IO, 3% of members are in IO to LS zone. Remaining 0.86% of members reach collapse zone in Y direction.
- Damage members can be strengthen or retrofitted based on the requirement.
- It was found that, various user defined hinge length, 91.3% of members are in A to B, 6.2% of members are in B to immediate occupancy [B-IO], 3.5% of members are in immediate occupancy to life safety [IO- LS] zone in X direction.
- It was found that, various user defined hinge length, 90% of members are in A to B, 9% of members are in B to IO, 1% of members are in IO to LS zone in Y direction.
- It was found that none of the members reach collapse zone for user defined hinge model in both X and Y direction. Hence the building poses some residual strength.
- The present building model is safe for minor earthquakes.

## 5. CONCLUSIONS

The following conclusions were observed:

- Performance of the building increases when the sectional size of columns is increased while keeping same reinforcement.
- The uncertainty in plastic hinge length does not effect on the performance of the building. The performance of the building (base shear and displacement capacity) are similar in different plastic hinge length: the variation in the performance of the structures is less than 5%.
- The differences in Default hinges and user defined hinges for various plastic hinge length has considerable effects on the maximum base shear and displacement capacity of the structures; the variation in the base shear and displacement capacity is 10% in X direction and 30% in Y direction.

- The stiffness of structure in the Y direction is more than that in X direction. That is particularly due to orientation of columns along Y axis.
- Comparison of hinging pattern indicates that both models with default hinges and the various user defined hinges estimate plastic hinge formation at the ultimate state there are significant differences in the hinging patterns.
- Most of the hinges developed in the beams and few in the columns of both models it indicates strong column and weak beam.
- This study is carried out to investigate the possible differences between pushover analyses of the default-hinge and user-defined hinge models. The observations clearly show that the user-defined hinge model is better than the default-hinge model because damage is limited. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should definitely avoid the misuse of default-hinge properties.

### 5.1 SCOPE FOR THE FUTURE WORK

- This study focuses on Non-linear Static Analysis procedure to check the performance of the structure. But, the study can be extended to Non-Linear Time History Analysis and the results can be checked for more accuracy.
- In this study pushover analysis was carried out. Further studies compare the results with experimental observations.
- To study the differences in results of various plastic hinge length for different storey height.

## REFERENCES

[1] Inel, M., & Ozmen, H. B. (2006). Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings. Engineering structures, 28(11), 1494-1502.

[2] Hede, N. P., & Babunarayan, K. S. (2013, November). Effect of variation of plastic hinge length on the results of non-linear analysis. In International Journal of Research in Engineering and Technology (IJRET), IC-RICE Conference Issue (pp. 2319-1163).

[3] CM, R. K., Choudhary, V., Narayan, K. S., & Reddy, D. V. (2014). Moment Curvature Characteristics for Structural Elements of RC Building.

[4] Biradar, S. H. (2015, August) 3D RC Multistorey Building Seismic Assessment with User Defined Hinges.

[5] Sonwane, D. P., & Ladhane, K. B. (2015). Seismic performance based design of reinforced concrete buildings using nonlinear pushover analysis. International Journal of Engineering Research and Technology, 4(06).

[6] Subramanian, N. (2009). Plastic Hinge Length of Reinforced Concrete Columns. Paper by Sungjin Bae and Oguzhan Bayrak. ACI Structural Journal, 106(2), 233.

[7] Ashraf Habibullah, S. E., & Stephen Pyle, S. E. (1998). Practical three dimensional nonlinear static pushover analysis. Structure magazine, winter.

[8] Bento, R., Falcao, S., & Rodrigues, F. (2004, August). Nonlinear static procedures in performance based seismic design. In Proceedings of the 13th world conference on earthquake engineering, Vancouver, Canada.