EFFECT OF VARIATION OF PLASTIC HINGE LENGTH ON THE RESULTS OF NON-LINEAR ANALYSIS

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Abstract

The nonlinear Static procedure also well known as pushover analysis is method where in monotonically increasing loads are applied to the structure till the structure is unable to resist any further load. It is a popular tool for seismic performance evaluation of existing and new structures. In literature lot of research has been carried out on conventional pushover analysis and after knowing deficiency efforts have been made to improve it. But actual test results to verify the analytically obtained pushover results are rarely available. It has been found that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Initial study is carried out by considering user defined hinge properties and default hinge length. Attempt is being made to assess the variation of pushover analysis results by considering user defined hinge properties and various hinge length formulations available in literature and results compared with experimentally obtained results based on test carried out on a G+2 storied RCC framed structure. For the present study two geometric models viz bare frame and rigid frame model is considered and it is found that the results of pushover analysis are very sensitive to geometric model and hinge length adopted.

***Keywords**: Pushover analysis, Base shear, Displacement, hinge length, moment curvature analysis*

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1. INTRODUCTION

Inelastic static analysis has been the preferred method for seismic performance evaluation because of its simplicity. Nonlinear static analysis called "pushover" hereinafter, per se is not a recent development and its genesis traced back to the 70's decade. [1]. The use of inelastic static analysis in earthquake engineering is traced to be the work of Takeda and Sozen (1970) when a realistic conceptual model for predicting the dynamic response of a reinforced concrete member was studied based on a static force- displacement relationship which reflects the changes in stiffness for loading and unloading the member.

In last decade, the majority of researchers had focused on the range of applicability and merit and demerits of pushover methods. After knowing the drawbacks of the preliminary pushover methods, efforts have been made to improve it. Ashraf Habibullah et al (1998) [2] proposed the procedure for modeling and performing three dimensional pushover analyses for a building structure using SAP2000. It documents the modeling procedure and defines force-displacement criteria for hinges as documented in ATC-40 and FEMA documents used in pushover analysis.

Although, in literature, pushover analysis has been shown to capture essential structural response characteristics under seismic action, the accuracy and the reliability of pushover analysis in predicting global and local seismic demands for all structures have been a subject of discussion and improved pushover procedures have been proposed to overcome the certain limitations of traditional pushover procedures. This paper aims to 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+2 storied RCC framed structure which is modeled in SAP-2000.

1.1 Details of Beam and Column Sections

The beam and column sections are 150mm x 200mm in size with 2-12Φ bars at top and bottom in case of beam and 2-16Φ bars at top and bottom in case of columns. The transverse reinforcement for both beams and columns is provided by 2-legged 6Φ stirrups/ties @ 150mm c/c. The slab is 50 mm thick. The section properties for the beams and columns is shown in Fig 1

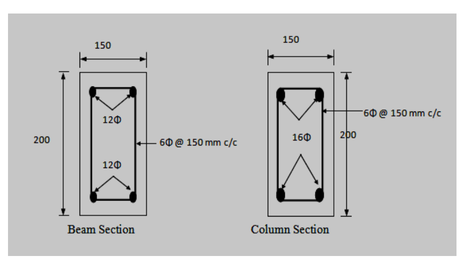

Fig 1 .Properties of section

1.2 Material Properties

The structure was tested and actual material properties from tests were found as:
Average concrete strength (fck) = 35 MPa
Average Reinforcement yield stress (fy) = 478 Mpa

1.3 Details of the Model

Making use of the graphical interface of SAP2000 a basic computer model is created. The material properties, Geometric properties are then defined. Sap2000 has several built-in default hinge properties that are based on average values from ATC-40 [3] for concrete members and average values from FEMA-273[4] for steel members. But in this paper user defined hinge option is used and this requires generation of the moment curvature values .These are obtained by considering IS recommended stress strain model for unconfined concrete and British code recommended (CP 110-1972) [5] stress-strain curve for steel as shown in Fig.2. Earlier study on the same model has been carried out by Monica Thapa [6] by considering Kent and Park stress-strain model for confined concrete and British code recommended (CP 110-1972) stress-strain curve for steel.

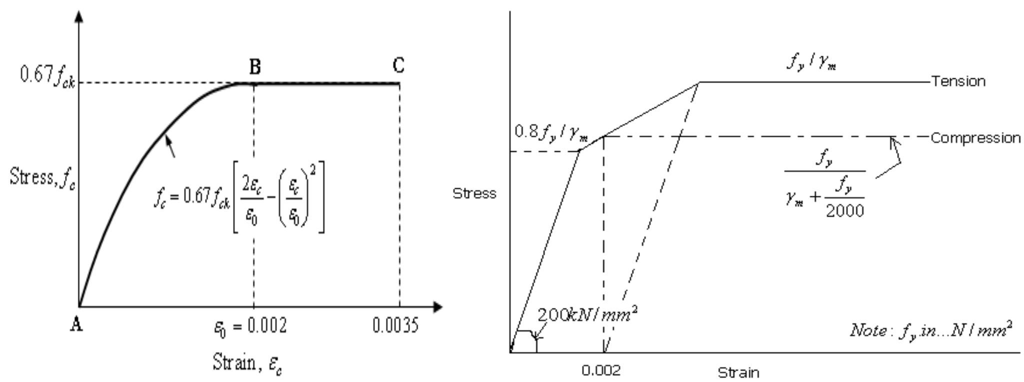

Fig2. Stress strain models for unconfined concrete and steel

Making use of Equilibrium and compatibility equations moment curvature values are generated which are tabulated in Table 1 and Table 2 for columns and beams respectively. Excel program was made to generate moment curvature values. The moment values are in kN-m.

Table 1 Moment curvature values for columns

Points	A	B	C	D	E
	Origin	yielding	ultimate	Strain hardening	Strain hardening
fy= 478N/mm^2 fck=35N/mm^2	M=0 Φ=0	M=21.55 Φ= 0.0134	M=23.34 Φ=0.088	M= 25.12 Φ=0.099	M=26.94 Φ=0.111

Table 2 Moment curvature values for Beams

Points	A	B	C	D	E
	Origin	yielding	ultimate	Strain hardening	Strain hardening
Fy= 478N/mm^2 Fck=35N/mm^2	M=0 Φ=0	M=12.76 Φ= 0.011	M=14.58 Φ=0.078	M= 16.40 Φ=0.090	M=18.23 Φ=0.105

Elemental nonlinearity is incorporated by user defined M3 plastic hinges which were assigned to beam and columns. The pushover load cases are then defined. The first pushover load case is used to apply gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity. Lateral load distributed across the height of the building is calculated based on the formula specified in FEMA 356 [7], given by equation as shown below and then in-cooperated in the model.

$$F_x = \frac{W_x h_x^k}{\sum_{i=1}^{N} W_i h_i^k} V \qquad (1)$$

$$C_{vx} = \frac{W_x h_x^k}{\sum_{i=1}^{N} W_i h_i^k}$$

Where, F_x is the applied lateral force at level 'x', W is the storey weight, h is the story height, V is the design base shear and N is the number of stories. C_{vx} is the coefficient that represents the lateral load multiplication factor to be applied at floor level 'x'. The pushover load case PUSH for the pushover analysis was calculated using above equations .The load was applied laterally as a point load at each storey in the ratio of 9:4:1 for roof: 2nd floor: 1st floor as generated by above equation and then applied to the model.

2. EXPERIMENTAL PUSHOVER RESULTS

Testing of the reinforced concrete frame model was carried out at SERC (Structural Engineering Research Centre) Chennai with sectional details as shown in (Fig 1). Application of the load is done monotonically in the ratio of 9:4:1 for roof: 2nd floor: 1st floor by pushing it with the help of hydraulic jacks. The experimental pushover curve was obtained. The maximum base shear observed was found to be 286.5 kN and the corresponding displacement was found to be 110mm i.e. 0.11m.

3. ANALYSIS AND RESULTS

The frame modeled as bare frame and frame with slab modeled as rigid diaphragm was considered. Considering actual material properties from test results, user defined hinge properties and default hinge length, Pushover analysis was carried out and the corresponding P (Base Shear) and Δ (Displacement) were found to be 173.8KN and 267kN and 0.31m and 0.16m respectively. When compared with experimental it was evident that the bare frame model gives low values for base shear and high values for displacement as stiffness of slab present was not accounted in analysis. It was found that the base shear value was about 39% lower and displacement value was about 172% higher than experimental values. For slab modeled as rigid diaphragm the base shear was lower by 7.3 % and displacement was higher by 45% when compared to Experimental observations.

Further study is carried out to further investigate the possible variation in the results of pushover analyses by considering user defined hinge lengths by calculating hinge length using various hinge length formulations available in literature and adopting Bare frame and rigid frame model.

The plastic hinge length of a structural member is an essential parameter in evaluating the response of a structure and its damage due to seismic and various empirical expressions have been proposed for calculating the equivalent length of plastic hinge Lp. For considering user defined hinge lengths following formulations are considered [8]

Corley's formula

$$l_p = 0.5d + 0.2\sqrt{d}\left(\frac{z}{d}\right) \qquad (2)$$

Mattock's formula

$$l_p = 0.5d + 0.05z \qquad (3)$$

Sawyer's formula

$$l_p = 0.25d + 0.075z \qquad (4)$$

Pauley-Priestley formula

$$l_p = 0.08z + 0.022 d_b f_y \quad \text{(MPa)} \qquad (5)$$

Where,
db = diameter of main reinforcing bars in mm
fy = yield strength of reinforcement bars, in MPa.
Z = Distance of critical section from point of contraflexure
d = effective depth of the member.

Using above formulations and considering user defined hinge option and hinge located at ends the bare frame and frame with slab modeled as rigid diaphragm was considered and results of pushover analysis is shown in Table 3 and Table 4 respectively. The comparative graphs are shown in Fig 3 and Fig 4 respectively.

Table 3 Base shear and Displacement values (Bare frame model)

Hinge length formulation	Base shear (kN)	Displacement(m)
Paulay	167.62	0.097
Corley	165.28	0.0549
Sawyer	165.02	0.0556
Mattock	166.45	0.0675

Table 4 Base shear and Displacement values (Rigid Frame model)

Hinge length formulation	Base shear (kN)	Displacement(m)
Paulay	263.97	0.047
Corley	259.96	0.022
Sawyer	260.51	0.024
Mattock	261.432	0.028

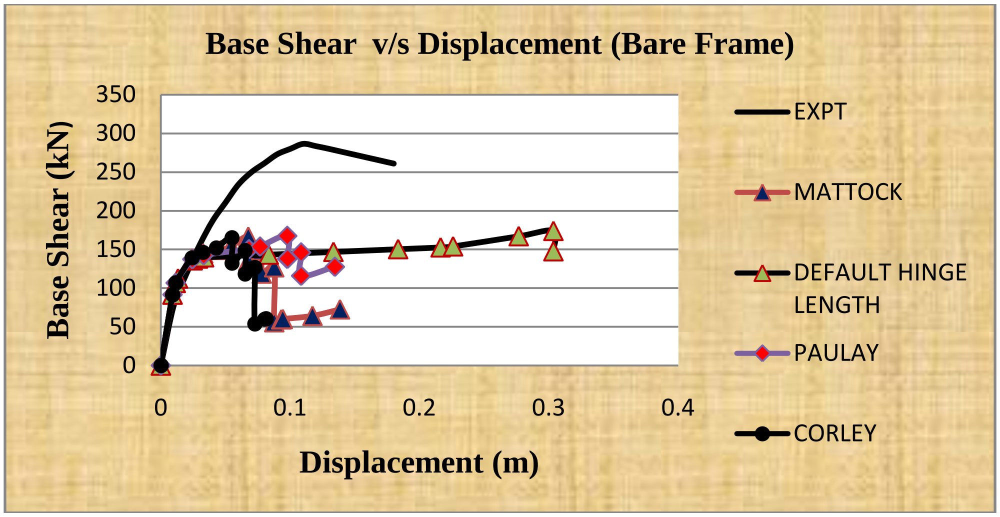

Fig3. Pushover results (Bare Frame model)

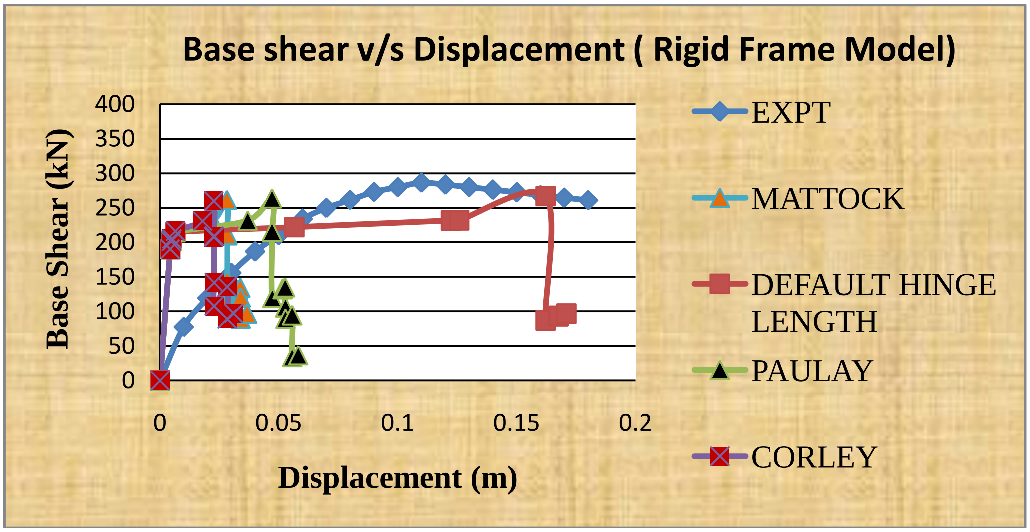

Fig4. Pushover results (Rigid Frame model)

CONCLUSIONS

The frame modeled as bare frame and frame with slab modeled as rigid diaphragm was considered and considering actual material properties, user defined hinge properties and default hinge length, Pushover analysis was carried out. When compared with experimental it was evident that the bare frame model gives low values for base shear and high values for displacement as stiffness of slab present was not accounted in analysis. It was found that the base shear value was about 39% lower and displacement value was about 172% higher than experimental values. For slab modeled as rigid diaphragm the base shear was lower by 7.3 % and displacement was higher by 45% when compared to Experimental observations.

Further investigation was carried on the same models by considering user defined hinge properties and various hinge length formulations It has been observed that for the geometric models considered there is not much variations in Base shear and displacement when compared with various hinge length formulation but there is considerable variations in terms of Base shear and displacement when compared to experimental results. For Bare Frame model it has been found that the variation in Base shear is about 40-41% less than experimental base shear 286.5 kN and the displacement is about10-54% less as compared to experimental value of 0.11m. For Rigid Frame model it has been found that the variation in Base shear is about 7- 9 % less than experimental base shear and the displacement is about 57-80 % less as compared to experimental value for various formulations considered. For bare frame model Paulay's formulation gives displacement values nearer to experimental value but base shear value is very less when compared to experimental value. Thus results of pushover analysis are very sensitive to geometric model and hinge length adopted. The final conclusion the authors tend to make is that the simulated pushover results are sensitive to geometric model, material models for concrete and steel, hinge length and location, modeling of joints etc adopted by the analyzer and expresses need to identify the effective analytical methodology that predicts the pushover curve more closely to experimental pushover curve.

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