EFFECT OF USER DEFINED PLASTIC HINGES ON NONLINEAR MODELLING OF REINFORCED CONCRETE FRAME FOR SEISMIC ANALYSIS

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Abstract - *Due to simplicity the engineers has been using nonlinear static procedure or pushover analysis. Modelling for such analysis requires the nonlinear properties of each component of the structure. Pushover analysis is carried out for either user-defined nonlinear hinge properties or default hinge properties which are available in programs based on FEMA 356 and ATC 40 guidelines. This paper studies the differences in the results of pushover analysis due to default and user-defined hinge properties. The parameter which is assumed to affect the base shear capacity and displacement capacity of frame is amount of transverse reinforcement. Comparison point out that increase in the amount of transverse reinforcement increases the displacement capacity. But the capacity curve for the default hinge model is reasonable because it takes average values. Compassion clearly shows that user-defined hinge model is better than the default-hinge model in capturing hinge mechanism. However, the default hinge model is preferred due to simplicity but user should be aware of what is provided in the program.*

Key Words: Nonlinear hinge properties, Pushover analysis, Plastic hinge length, Transverse reinforcement amount, User defined hinges

1. INTRODUCTION

Earthquakes have the potential for causing the greatest damages, amongst the outer natural hazards. Earthquakes are perhaps the most unpredictable and devasting of all natural disasters. The concern about seismic hazards has led to an increasing awareness and demand for structures designed to withstand seismic forces. The building, which appeared to be strong enough, may crumble during earthquake and deficiencies may be exposed. Hence performance analysis should be done to produce structure with predictable seismic performance.

Due to its simplicity, the structural engineering profession has been using the nonlinear static procedure or pushover analysis, described in FEMA-356 [1] and ATC-40 [2]. In the implementation of pushover analysis, modelling is one of the important steps. The model must consider nonlinear behaviour of structure/elements. Such a model requires the determination of nonlinear properties of each component. Lumped plasticity idealisation is commonly used approach in models for deformation capacity estimates. The ultimate deformation capacity of a component depends on the ultimate curvature and other factors which are proposed in the literature [3-4]. In practical use, most often the default properties provided in the FEMA-356 [1] and ATC-40 [2] documents are preferred, due to simplicity. These default properties can be implemented in well-known linear and nonlinear static and dynamic analysis programs. Some programs (i.e. SAP2000) have already implemented these default nonlinear properties. Although the documents provide hinge properties for several ranges of detailing, the programs may implement averaged values [9]

This paper aims to study the possible differences in the results of pushover analysis due to default and user-defined nonlinear component properties. And the effect of amount of transverse reinforcement on the capacity of the structure.

2. DESCRIPTION OF STRUCTURES

In this paper two structures are considered to represent low and mid-rise RC buildings for study. These consist of two typical beam-column RC buildings located in high seismicity region of India. These 4 and 7 story buildings were designed according to IS 456:2000 considering both gravity and seismic loads. The basic assumption is the type I soil is same as that of class C soil of FEMA-356. Material properties are assumed to be 25 MPa for beam and 30 MPa for column compressive strength and 500 MPa for the yield strength of both longitudinal and transverse reinforcements. Two layouts are considered for transverse reinforcement in the potential plastic hinge regions with 100 mm and 200 mm spacing.

Both 4 and 7 story buildings are 16 m by 12 m in plan (Fig.1) and floor-to-floor height is 3.0 m. The interior frame represents 2-D models as shown in Fig.1. The 4 story building is 12 m and 7 story building is 21 m in elevation. Column dimensions and the amount of longitudinal reinforcement are provided in Table 1 and Fig.2 and Fig 3 .

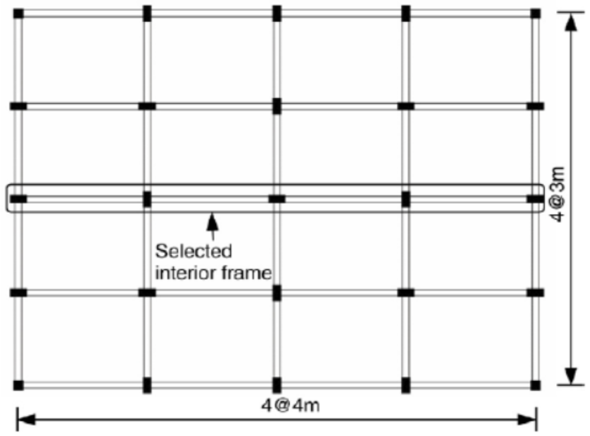


Fig. 1: Plan view of 4 and 7-story buildings

All beams are 300 mm x 450 mm and the amount of top and bottom reinforcement are shown in mm^2 in elevation view.

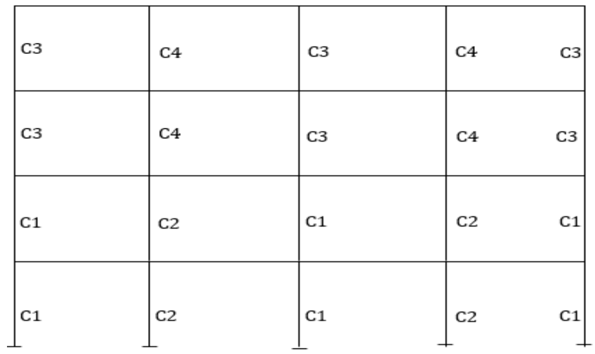
Table 1: Column sizes for 4 and 7-story buildings

Column No.	Column size in mm	
	4 story	7 story
C1	350 x 600	750 x 530
C2	300 x 480	600 x 450
C3	350 x 530	700 x 530
C4	300 x 450	530 x 380

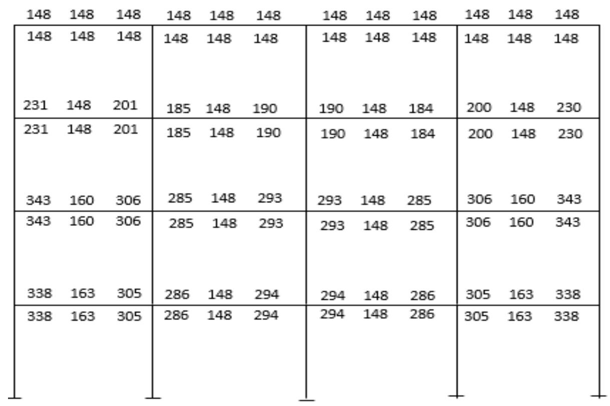
3. MODELLING

The analysis of the models is done using SAP2000, which is used for structural analysis program for static and dynamic analyses of structures. Two dimensional model of each structure is created in SAP2000 to carry out nonlinear static analysis. Beam and column elements are modelled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both the ends of the beams and columns. SAP2000 provides default-hinge properties and assigns PMM hinges for columns and M3 hinges for beams [9]. After modelling of structure the default hinges are assigned to the structure. Here there is no need of vast calculation for each member.

To define user-defined hinge properties it requires moment-curvature calculation of each element. The modified Kent and Park model[7] for confined concrete Mander[7] stress-strain model for steel is used in moment-curvature analysis. While defining user-defined hinges, for each column moment-curvature analyses are carried out considering section properties and axial loads on the elements. On the beams axial forces are assumed to be zero. Then after the calculation the ultimate rotation capacity of element acceptance criteria are defined viz. IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.



(a) Column Labelling



(b) Longitudinal beam reinforcement amount (mm^2)

Fig. 2: 4-story frame properties

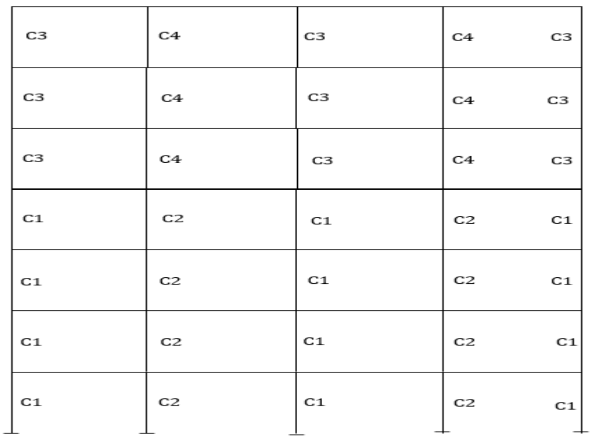
4. PUSHOVER ANALYSIS

In this paper three cases are considered for analysis of each frame as shown in Table. The default hinge properties of SAP2000 termed as Case A and two user defined hinge properties including the variation of transverse reinforcement spacing. Spacing between the transverse reinforcement is kept 100 mm and 200 mm. In the rest of paper, the transverse reinforcement cases are termed as well-confined and poorly-confined for s = 100 mm and s = 200 mm cases respectively.

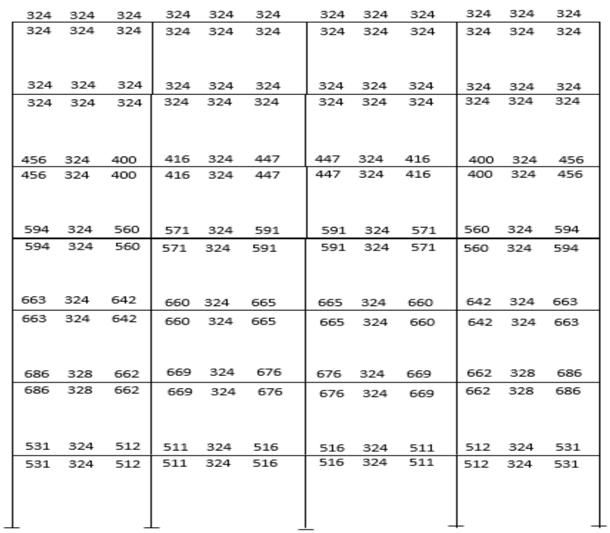
Table 2: Pushover analysis cases

Default hinge	Case A	
User-defined hinges	s = 100 mm	s = 200 mm
	Case B	Case C

The pushover analysis consist of application of gravity loads and a representative lateral load pattern. The frames were subjected to gravity analyses and simultaneous lateral loading. In all cases, lateral forces were applied monotonically in step-by-step nonlinear static analysis. P-Delta effects were not taken into account. In pushover analysis the capacity curve is produced that represents the relationship between the base shear force and the displacement of the roof.



(a) Column labelling



(b)Longitudinal beam reinforcement amount (mm^2)

Fig. 3: 7-story frame properties

4.1 Capacity Curve

Due to assumed compressive strength of concrete there are no shear failures were observed. Even in the case of a 200 mm transverse reinforcement spacing, the shear strength of members was sufficient to carry shear forced that are developed. The capacity curves of the 4 and 7 story frames are shown in Chart 1 and 2 For different transverse reinforcement spacing. A comparison 0f displacement capacities points out their dependence on transverse reinforcement spacing. Charts shows the capacity curves of 4 and 7 story frames for different reinforcement spacing. It shows that increase in amount of transverse reinforcement improves the displacement capacity. The transverse reinforcement is more effective for smaller spacing. It means reducing the spacing from 200 mm to 100 mm provides an increase of about 50% in displacement capacity for 7 story and 15% for 4 story frame.

FEMA-356 or ATC-40 provides nonlinear hinge properties for a wide range of RC beams and columns. SAP2000 covers all these properties for default-hinge model. The model with default-hinge properties provide reasonable displacement capacity for well-confined case, the displacement capacity is quite high compared to that of poorly-confined case.

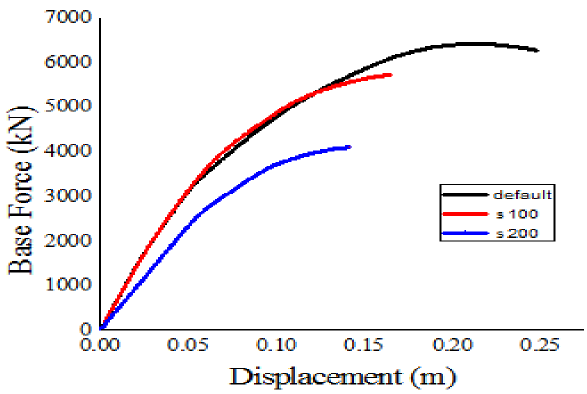


Chart 1: Capacity Curves of 4-story frames for different transverse reinforcement spacing

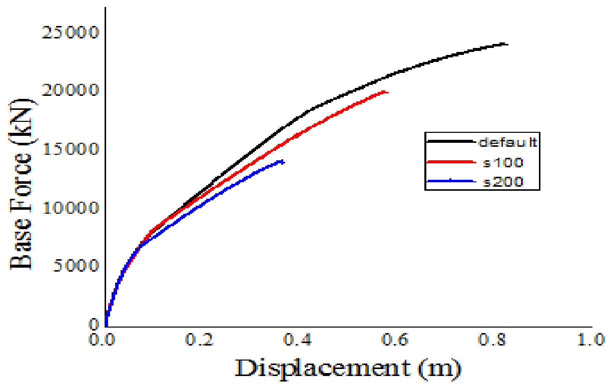
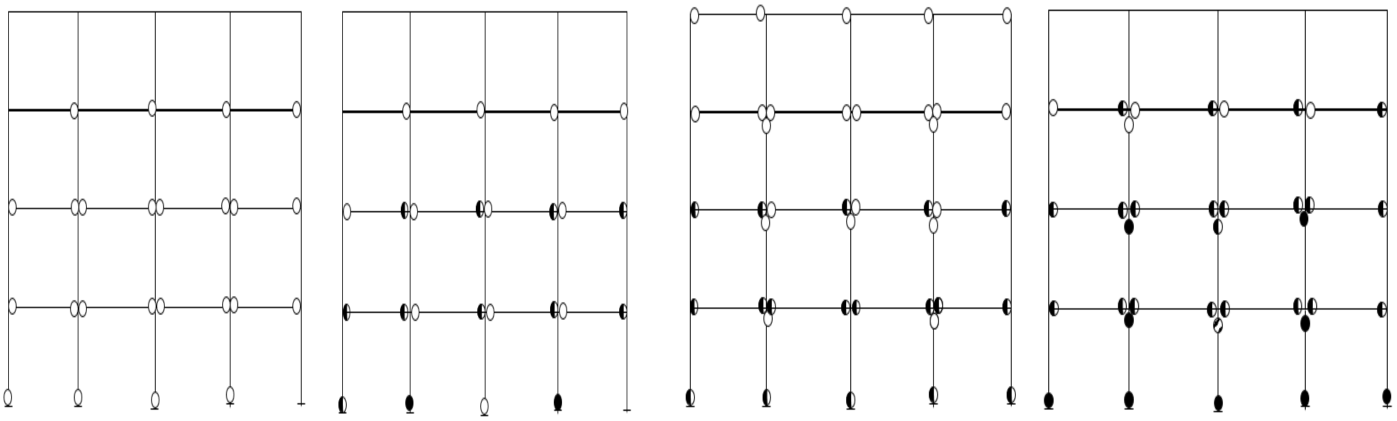


Chart 2: Capacity Curves of 7-story frames for different transverse reinforcement spacing

4.2 Plastic hinge mechanism

Plastic hinge patterns of the 4 and 7 story frames are compared at different levels of roof displacements to provide information about local and global failure mechanisms in the structure.

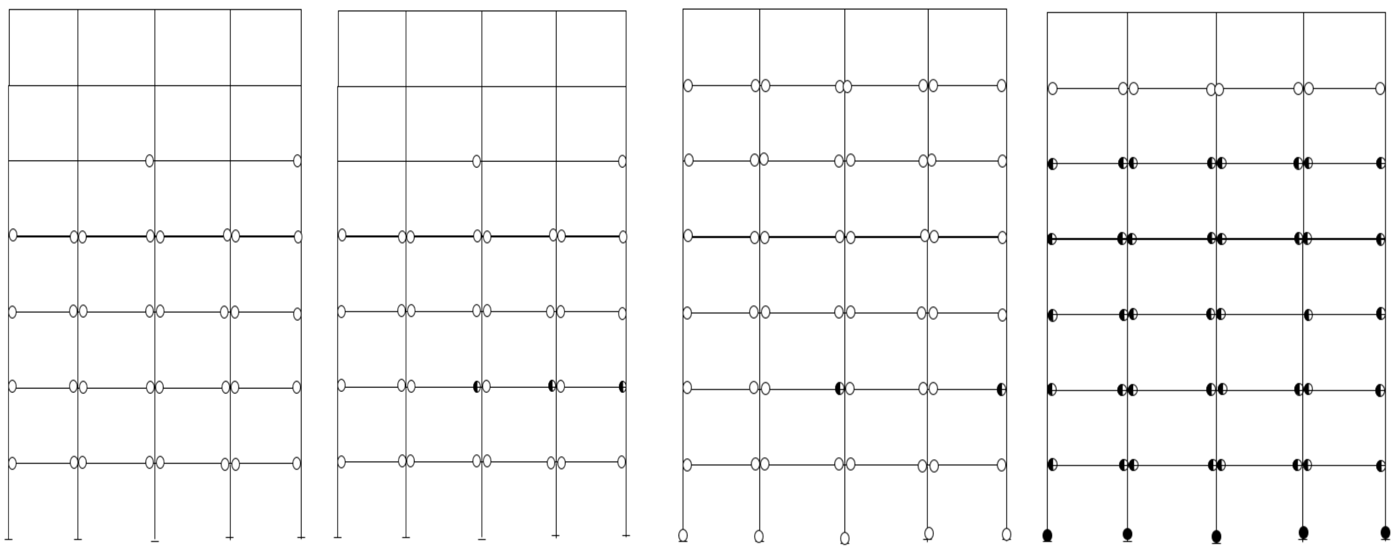
The hinging patterns of 4 and 7 story frames ae plotted in Figs.4 and 5 For both cases A and B at different levels of roof



Default hinge model at yielding | User-defined hinge model at yielding | Default hinge model at ultimate | User-defined hinge model at ultimate

Fig. 4: Plastic Hinge patterns for 4-story frame at global yielding and ultimate states

Damage level	Yielding	Significant yielding	Near Collapse	Collapsed
Symbol	○	◐	●	◍



Default hinge model at yielding | User-defined hinge model at yielding | Default hinge model at ultimate | User-defined hinge model at ultimate

Fig. 5: Plastic Hinge patterns for 4-story frame at global yielding and ultimate states

displacement. Comparison of the figures shows that the patterns at the yielding state are approximately similar for case A and B except bottom columns and beams of upper stories. But there is significant difference in hinging patterns at ultimate state. The hinge locations are same but significant damage or failure occur at the beams for model with default hinges while the base columns experience major damage or failure for the model with user-defined hinges. Table 3 summarizes the number of hinges at different damage levels. The default hinge model assumes the same deformation capacity for all columns regardless of their axial load and their weak or strong axis orientation. The outermost and middle base columns of the frames have the same cross-sectional properties. In such a case, the middle columns are expected to have greater damage level than the outermost columns because of larger axial force level. Hence observation point out that column yielding.

Table 3: Summary of plastic hinging for pushover analysis at different damage levels

Hinge damage states			A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	> E	Total
4 story	Yield	Default	398	122	0	0	0	0	0	0	520
		User-defined	402	61	44	3	0	10	0	0	520
	Ultimate	Default	292	148	80	0	0	0	0	0	520
		User-defined	314	29	103	8	0	66	0	0	520
7 story	Yield	Default	740	170	0	0	0	0	0	0	910
		User-defined	738	167	5	0	0	0	0	0	910
	Ultimate	Default	654	261	4	0	0	0	0	0	910
		User-defined	645	44	196	0	0	0	0	0	910

5. DISCUSSION OF RESULTS

The interior frames of 4 and 7 story buildings were considered in pushover analysis to represent low and medium rise reinforced concrete (RC) buildings for study. The frames were modelled with default and user-defined hinge properties to study possible differences in the results of pushover analysis.

The following results were observed.

1. The base shear capacity of models with default and with user-defined hinges for different transverse reinforcement spacing are similar the variation in base shear capacity is less than 5%. Thus, the base shear capacity does not depend on whether the default or user-defined hinge properties are used.

2. Displacement capacity depends on the amount of transverse reinforcement in the frames. Comparisons clearly point out that an increase in the amount of transverse reinforcement improves the displacement capacity. Reducing the spacing from 200 mm to 100 mm provides an increase of up to 50% in the displacement capacity, and increase of 15% for 4-story frame.

3. Comparison of hinging patterns indicates that both models with default and user defined hinges gives plastic hinge formation at the yielding state approximately well. However, there are significant differences in the hinging patterns at the ultimate state.

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