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PUSHOVER ANALYSIS USING SAP 2000 FOR INCREASING MOMENT CAPACITY RATIO AT BEAM COLUMN JOINTS AND STUDY OF THE STRUCTURE LATERAL STRENGTH

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ABSTRACT: Reinforced concrete moment resisting frames (RCMRF) are structural systems that should be designed to ensure proper energy dissipation capacity when subjected to seismic loading. In this design philosophy the capacity design approach that is currently used in practice demands "strong-column / weak-beam" design to have good ductility and a preferable collapse mechanism in the structure. When only the flexural strength of longitudinal beams controls the overall response of a structure, RC beam-column connections display ductile behaviour (with the joint panel region essentially remaining elastic). The failure mode where in the beams form hinges is usually considered to be the most favourable mode for ensuring good global energy-dissipation without much degradation of capacity at the connections. Though many international codes recommend the moment capacity ratio at beam column joint to be more than one, still there are lots of discrepancies among these codes and Indian standard is silent on this aspect. So in the present work pushover analysis is being done using SAP 2000 for increasing moment capacity ratio at beam column joints and its effect on the global ductility and lateral strength of the structure is studied. To incorporate the uncertainties in material properties, a probabilistic approach is followed to observe the effect of ground motion intensity on probability of exceedance of any specific damage state for structures designed considering different moment capacity ratios (MCR) at the connections. For this objective fragility curves are developed considering the pushover curves obtained from the nonlinear static analysis. Ductility of the structure increases with increase of MCR. Also the buildings designed with lesser MCR values are found to be more fragile compared to the building with higher MCR.
Keywords: pushover, moment capacity ratio, fragility, ductility, lateral strength

I. SCOPE OF STUDY

The scope of present research work is limited to following structural considerations:

- Regular RC framed building is selected. Vertical and plan irregularity of the building is kept out of the scope of present study.
- The analysis is carried out considering unidirectional lateral loading and thereby only plane frame is considered for the analysis. The results may vary when the lateral load acts along both the horizontal direction simultaneously.
- The design of frame sections is assumed to be consistent with the prevailing Indian Standard which ensures no shear failure prior to flexure failure in the frames. Accordingly the nonlinear hinges for shear are not modeled for analysis.
- Fixity is assumed in all the column ends.Soil structure interaction is neglected.
- Only interior joints are considered in the present study

II. METHODOLOGY

- Five, seven and ten storey RC framed (Plane) buildings are designed using commercial software STAAD-Pro.
- Ultimate flexural capacity of beam ($M_{r,b}$) is determined from the design data obtained.
- Column reinforcement in the buildings is progressively increased to attain different column to beam moment capacity ratio (MCR) at maximum moment, at zero axial load and at design axial load.
- Considering the beam and column reinforcement, the same building is modelled using SAP2000 and nonlinear static analysis is being done.

III. BUILDING DESIGN AND MODELLING

The present study is based on analysis of a family of reinforced concrete multi-storeyed building frames. These buildings were first designed using STAAD-Pro. The input data required for the design of these buildings are presented in Table 3.1 (a-c).

Table 3.1(a) General building and location details

Type of structure	Multi storey RC frame
Zone	V
Exposure Conditions	mild
Soil type	medium
Damping	5 %
Storey height	3m
Bay width	4m

Design philosophy	Limit State method conforming to IS 456:2000

Table 3.1(b) Details of materials and section property

Beam	300mm× 300mm
Column	300mm×400mm
Concrete	f_{ck}= 25 MPa Poisons ratio = 0.3 Density = 25 kN/mm^3 Modulus of elasticity = 5000 $\sqrt{f_{ck}}$ =25000 MPa
Steel	f_y = 415 MPa Modulus of elasticity = 2×10^5MPa

Table 3.1(c) Loading details for the design

Dead load	20 kN/m
Live load	10 kN/m
Equivalent lateral loads	as per IS 1893 (Part I):2002

SUMMARY

- Plane building frames are designed with IS-456:2000 for loading requirement of IS- 1893:2002 and IS-875 (Part-1, 2) using STAAD-Pro for varying MCR.
- Nonlinear static analysis is being carried out to understand the effect of MCR in the response of framed building.
- It is found that with increase of MCR at design axial load upto 1.47 for uniaxial bending in a plane frame improves the ductility at an expense of extra reinforcement, with further increase of MCR there is not much increase in ductility. Increase in strength either at yield or maximum is not very significant with progressive increase in MCR for a seven storey building frame. but for 5 storey and 10 storey frames strength also increase significantly upto MCR 1.7.Since seismic design philosophy aims to achieve good ductility in a structure so we need not have to think for higher strength but for higher ductility.

IV. BUILDING MODELLING AND ANALYSIS

20 buildings are considered for fragility analysis corresponding to each MCR value. Non- linear static analysis(pushover) is carried out using SAP2000. This pushover analysis method is mostly used to obtain quantitative limit state values. The critical points like yield and ultimate response and initiation of a collapse mechanism are obtained from the pushover curves (in the form of base shear versus roof displacement) using bi-linear idealization.

Table 4.3 Median Spectral displacement (mm) corresponding to different damage grades

MCR	1.09		1.26		1.47		1.70		1.94	
Damage States	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4
5- storey	97	253	184	600	186	600	195	600	198	600
7-storey	160	430	170	441	215	618	260	800	263	800
10-storey	286	847	340	1059	354	1085	358	1074	397	1200

Using the Table 4.3 median spectral displacements for different damage states are obtained. Only damage states of Gr3 and Gr4 are considered in the present study for developing fragility curves. From the spectral displacements obtained for 20 cases median spectral displacement ($\bar{S}_{ds}$) are obtained. Median spectral response shows the threshold limit of a given damage state. Then using the normal distribution function probability of equal or exceeding a given damage state can be obtained.

V. PERFORMANCE OF 5-STOREY 3-BAY BUILDING FRAMES

Fragility curves for 5-storey 3-bay framed building is developed as per methods discussed above for different MCR values for the two damage states Gr3 and Gr4.
The slope of fragility curve developed depends on the log normal standard deviation value β. Smaller value of β indicates lesser variability of damage state and hence steeper fragility curve is generated. So the Gr3 curves are stiffer than Gr4 curves (β of Gr3 = 0.75 and for Gr 4 it is 0.85).

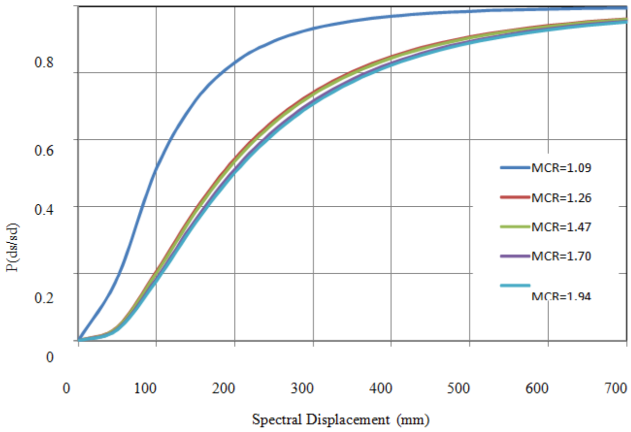

Fig. 4.2(a) Fragility curves for 5-storey framed building for Gr3 damage state

Fig. 4.2(a) shows fragility curves for 5-storey frames at different MCR values for Gr3 damage state. It is observed that the building designed for lesser MCR is more fragile than the same building designed with higher MCR. So for MCR 1.09 the structure is most fragile. For a assumed spectral displacement of 200 mm with increase of MCR to 1.26 reduces the probability of exceedance from 83 % to 55 %. There is a wider difference of fragility with increase of MCR from 1.09 to 1.26.With further increase from MCR

1.26 to 1.94 there is not much decrease in the fragility of considered building.

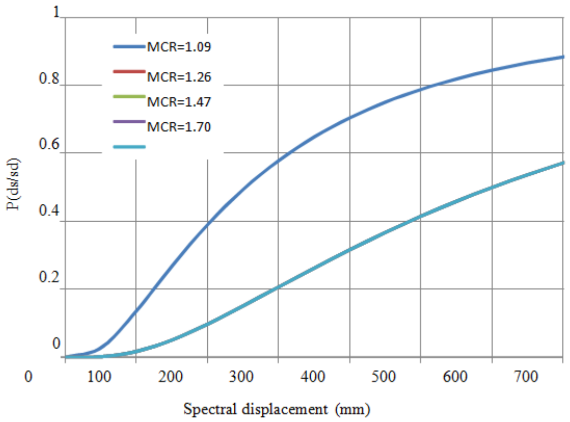

Fig 4.2(b) Fragility curves for 5-storey framed building for Gr4 damage state

Fig. 4.2(b) shows the fragility curve for 5-storey building frame for Gr4 or complete damage state in terms of probability of exceedance and spectral displacement. This curve also shows the similar pattern as Gr3 damage state curve. The building with MCR 1.09 is most fragile and with increase of MCR to 1.26 the probability of exceedance of the specified damage state decreases to a greater extent. However, beyond MCR 1.26 there is no change in the fragility curve because of same median spectral displacement. Since for a given damage state all other parameters being constant the probability of reaching or exceeding that state depends only on the median spectral displacement.

SUMMARY

The performance of regular RC framed buildings is considered by developing fragility curves as per HAZUS (2003). Uncertainties in concrete and steel material properties are considered. 5,7 and 10 storey buildings are modelled for different MCR values by increasing the column reinforcement. Damage state definition is considered from Barbat *et.al.*(2006).Variability parameters are considered as per HAZUS (2003).The fragility curves are developed to find out the vulnerability of buildings without designed as per strong column weak beam concept. The fragility curves for different progressively increasing MCR values are compared for different damage state for a given spectral displacement.

It is observed that a structure designed with lower MCR (*e.g.* 1.09) shows much higher damage probabilities. Fragility of a structure decreases if the columns are made stronger than beams maintained by increasing MCR values.

The results for 5 storey building show little different trend than other two building category (7 and 10storey).The damage probabilities for 5-storey building do not show much variation after MCR 1.26. For 7-storey building frame the probability of exceedance of a given damage state shows a continuous decreasing trend with higher MCR. However the variation after MCR 1.47 is comparatively less. 10-storey building frame also shows the similar trend as a seven storey frame. Gr4 damage state that considers complete damage of the structure shows flatter slope as compared to Gr3 which is extensive damage state due to higher variability associated with it.

VI. CONCLUSIONS AND FUTURE SCOPE

RC framed buildings regular in plan are designed using commercial software STAADpro and modelled using SAP2000. Pushover analysis is done first to study the effect of increase of MCR on ductility and lateral strength of a structure. The effect of increasing moment capacity of column at an expense of extra reinforcement is also observed by obtaining reinforcement ratio as a function of MCR. Reinforcement ratio obtained to achieve different MCR is found to be well within the limits of 6 % as specified in IS 456 and also within 3 % considered for practical purpose.

Conclusions from fragility analysis

Probabilistic analysis is done to evaluate the damage statistics, and distinguish the buildings on the basis of their relative seismic performance. From the fragility analysis of different building using the capacity curves obtained from pushover analysis the following conclusions can be drawn:

- The fragility curves indicate much higher damage probabilities for building designed with considering very low MCR value of 1.09.
- The incorporation of higher MCR values reduces the damage probabilities irrespective of number of storey and damage level.
- For 5-storey building increase of MCR beyond 1.26 does not decrease the probability of damage to an appreciable extent.
- For 7-storey building wider variation of damage probability is observed from MCR
- 1.09 and 1.26 to MCR 1.47 for a given spectral displacement. From MCR 1.47 to 1.70
- the probability of exceedance of a given damage state decrease but the difference is comparatively less. For MCR 1.7 to MCR 1.94 almost same damage probability is observed.
- 10-storey building also shows same trend of fragility curves as of seven storey building frame.

FUTURE SCOPE

- The analysis can be extended with considering more number of buildings with different varying parameters.
- Here only regular RC framed buildings are considered. The analysis can be extended for irregular building having torsion effects.
- Only internal joints are considered in the present work. For external and corner joints also analysis can be done.
- Effect of infill wall can also be evaluated in the analytical models.
- The ground motion parameter can be selected not only as spectral displacement but also in terms of

PGA or PGV etc. By taking more MCR values the analysis can be done for more number of buildings

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