

Moment Capacity Ratio at Beam-Column Joint in Frame Structure

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Abstract - Reinforced concrete moment-resisting frames depend significantly on the performance of beam-column joints during seismic loading. Past earthquake damage has shown that brittle joint or column failure can lead to undesirable storey mechanisms and collapse. The present study examines the influence of moment capacity ratio (MCR), defined as the ratio of the sum of column moment capacities to the sum of beam moment capacities at a joint, on the global seismic response of reinforced concrete frame structures. Five-, seven- and ten-storey plane reinforced concrete frames were modelled and designed in SAP2000 for gravity and lateral loads. Column reinforcement was progressively increased to obtain different MCR values, and nonlinear static pushover analysis was performed using displacement control. The results indicate that increasing MCR improves ductility and promotes more desirable strong-column weak-beam behaviour up to an optimum range. For the studied frames, MCR values in the range of approximately 1.4 to 1.5 provided improved ductility and a favourable collapse mechanism without unnecessary strength increase. Hinge formation at the performance point remained below the immediate occupancy level, indicating satisfactory seismic performance for the considered models.

Key Words: Beam-column joint, Moment capacity ratio, Pushover analysis, Strong column weak beam, Ductility, seismic performance

1. INTRODUCTION

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Beam-column joints are among the most critical regions in reinforced concrete moment-resisting frame structures. Under earthquake loading, inertia forces are transferred between beams and columns through the joint core; therefore, insufficient joint strength, inadequate anchorage or poor ductile detailing can lead to brittle failure.

The strong column weak beam (SCWB) philosophy aims to ensure that plastic hinges form primarily in beams rather than columns. This is desirable because beam hinging is relatively ductile and localized, whereas column hinging may initiate a storey mechanism and cause global instability.

The moment capacity ratio (MCR) is expressed as $MCR = \Sigma M_c / \Sigma M_b$, where ΣM_c is the summation of moment capacities of columns framing into the joint and ΣM_b is the summation of moment capacities of beams framing into the joint. Although codes generally recommend MCR values greater than unity, a single universally suitable value is not available for all structural heights, geometries and seismic zones.

2. OBJECTIVES AND SCOPE OF STUDY

The main objectives of this study are: (I) to evaluate the effect of increasing MCR on ductility and strength of reinforced concrete frames; (ii) to study the influence of MCR on performance and failure mechanism; and (iii) to identify a practical MCR range that provides satisfactory safety and economy.

The study is limited to regular plane reinforced concrete frames. Soil-structure interaction, geometric irregularity and shear hinges are not considered. The column bases are assumed fixed, and the assessment is restricted to interior beam-column joints.

3. LITERATURE REVIEW

Previous research has emphasized the need for a capacity-design approach to prevent column failure and promote ductile beam hinging. Sugano et al. studied high-rise reinforced concrete frame behavior and highlighted collapse mechanism control. Nakashima observed that the required column overstrength increases with ground motion intensity.

International provisions recommend different column-to-beam strength ratios. ACI provisions have commonly recommended column moment capacity to be at least 1.2 times the beam moment capacity, New Zealand provisions recommend about 1.4, European provisions recommend about 1.3, and Indian recommendations have discussed a value of approximately 1.1 for earthquake-resistant moment-resisting frames.

Pushover analysis, as described in ATC-40 and FEMA 356, is a nonlinear static procedure used to estimate structural capacity, hinge formation sequence, performance point and likely collapse mechanism.

4. METHODOLOGY

Five-, seven- and ten-storey reinforced concrete plane frames were analyzed and designed using SAP2000. Beam ultimate flexural capacities were obtained from design data, and column reinforcement was progressively increased to generate different MCR values.

Gravity pushover analysis was first carried out under force control using $DL + 0.25LL$. Subsequently, lateral pushover analysis was performed under displacement control up to a target displacement of 4% of building height or until collapse. M3 hinges were assigned to beams and PMM hinges were assigned to columns at 5% distance from member ends, in accordance with FEMA and ATC-based modelling philosophy.

5. MODELLING DATA

Table -1: General Building and Location Details

Type of structure	Multi-storey RC frame
Seismic zone	Zone III
Exposure condition	Mild
Soil type	Medium

Damping	5%
Storey height	3 m
Bay width	4 m
Design philosophy	Limit state method conforming to IS 456:2000

Table -2: Material Properties

Concrete grade	$f_{ck} = 25 \text{ MPa}$
Concrete density	25 kN/m^3
Concrete modulus of elasticity	$5000\sqrt{f_{ck}} = 25000 \text{ MPa}$
Steel grade	$f_y = 415 \text{ MPa}$
Steel modulus of elasticity	$2 \times 10^5 \text{ MPa}$

Table -3: Section Properties

Storey	Beam Size	Column Size
5 storeys	300 mm $\times$ 450 mm	300 mm $\times$ 400 mm
7 storeys	300 mm $\times$ 530 mm	300 mm $\times$ 530 mm
10 storeys	300 mm $\times$ 630 mm	300 mm $\times$ 630 mm

Table -4: Reinforcement and MCR Values

Frame	MCR range considered	Column reinforcement range	Beam reinforcement
5 storeys	1.26 to 1.65	0.80% to 1.34%	0.26%
7 storeys	1.24 to 2.00	1.00% to 2.37%	0.26%
10 storeys	1.29 to 2.05	1.66% to 3.12%	0.26%

6. RESULTS AND DISCUSSION

The pushover curves for the selected frames show an initial linear elastic response followed by nonlinear behavior after hinge formation. In general, increasing MCR improved deformation capacity up to a certain level; beyond this level, additional column strength did not produce a proportional ductility gain.

For the five-storey frame, ductility increased up to an MCR of about 1.43, after which the response remained nearly constant. For the seven-storey frame, ductility improved significantly up to an MCR of about 1.40 and continued to increase at a lower rate thereafter. For the ten-storey frame, the highest significant ductility improvement was observed around an MCR of 1.48.

The hinge formation pattern indicated that an increase in MCR helped shift damage towards beam hinging, thus supporting the desired SCWB mechanism. At the performance point, hinge formation remained below the immediate occupancy level for all analyzed frames, indicating that the

considered structures achieved satisfactory performance under the adopted modelling assumptions.

7. CONCLUSIONS

The study confirms that MCR has a clear influence on the ductility, strength and collapse mechanism of reinforced concrete frame structures.

For the analyzed frames, an MCR range of approximately 1.4 to 1.5 appears to provide a favorable balance between seismic performance and economy.

Increasing MCR beyond the optimum range may increase strength demand or reinforcement requirement without a corresponding improvement in ductility.

The performance-point assessment showed hinge formation below the immediate occupancy level, indicating satisfactory seismic behavior for the studied models.

Future work may include irregular buildings, exterior and corner joints, shear-wall interaction and a wider set of frame configurations.

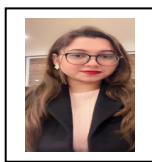
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