The Necessity of Modeling the Column Beam Joint Panel Zone in Reinforced Concrete Structures with Behavioral Degradation

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ABSTRACT

This study investigates the impact of incorporating panel zones into the numerical modeling of reinforced concrete moment-resisting frames (RC MRFs). Eight- and twelve-story RC MRF models were created using OpenSees software. The effects of panel zone inclusion were analyzed by comparing the results of nonlinear static (cyclic), dynamic, and incremental dynamic analyses. All models employed the Ibarra-Medina-Krawinkler (IMK) degradation model to account for material behavior.

The static analyses revealed minimal differences between models with and without panel zones. However, the influence of panel zones became significant in the dynamic analyses. Fragility curves demonstrated that models incorporating panel zones reached the collapse limit state at lower earthquake intensity levels. Additionally, nonlinear time-history analysis showed that while panel zone effects were negligible in the linear response range, structures with modeled panel zones exhibited larger displacements upon entering the nonlinear region.

These findings highlight the importance of considering panel zones in numerical models, particularly when evaluating the seismic performance of RC MRFs. Panel zones play a crucial role in capturing the inelastic response and collapse behavior of structures under earthquake loading.

KEYWORDS

Moment resistant Reinforced concrete bending frame, Ibarra-Medina-Krawinkler model, dynamic analysis, panel zone, OpenSees software

1. Introduction

In structural frames, joints are crucial components located at the intersections of beams and columns. These joints consist of two distinct parts: the panel zone and the connector. The panel zone is responsible for transferring shear forces between adjacent frame members. In reinforced concrete joints, the panel zone is not always visually distinct and often requires conceptual interpretation to define. Due to its location and confinement, the panel zone possesses greater stiffness and strength than typical frame elements, significantly influencing the structural response. Additionally, the joint length impacts the frame's behavior by effectively reducing the lengths of the columns and beams. [1, 2]. Accounting for these two effects likely yields a more accurate representation of the frame's initial stiffness, potentially influencing the outcomes of static and dynamic analyses.

Paulay and Priestley [3] report that joint deformations can contribute up to 20% of the interstory displacement experienced during an earthquake. This highlights the importance of incorporating member end regions within finite element models for accurate structural response simulations.

This study investigates the challenges and importance of modeling beam-to-column joint panel zones in moment-resisting reinforced concrete (RC) frames, particularly when considering behavioral deterioration. We achieve this by comparing numerical models of RC structures with and without panel zones, employing concentrated plasticity. The objective is to assess the influence of panel zone modeling on the results of static and dynamic analyses under deteriorating structural conditions. Through static analysis, incremental dynamic analysis (IDA), and the Ibarra-Medina-Krawinkler deterioration model, this research facilitates a numerical comparison of the two modeling approaches.

2. Buildings and models

o perform nonlinear static and dynamic analysis of moment-resistant reinforced concrete frames, we utilize two frames (one eight-story and one twelve-story) sharing the same plan.

Numerical modeling was performed in OpenSees using concentrated plasticity. The cyclic behavior of plastic regions was captured by rotational spring elements employing the Ibarra-Medina-Krawinkler degradation model, incorporating a peak-oriented cyclic law [4]. Joint behavior was modeled using five 2D joint spring elements (designated as joint2d-SPR5) within the numerical model. This approach captures both the shear deformations and the interface slip (sliding effects) between concrete and reinforcement during seismic response analysis.

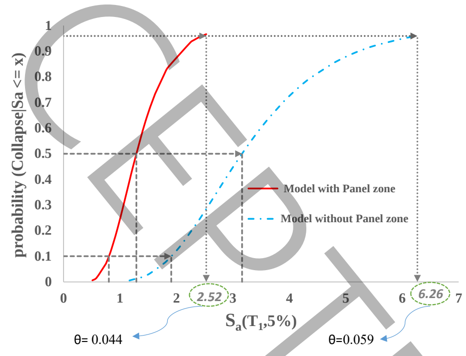
A uniaxial material model was employed to define the shear stiffness of both the panel zone and the connected frame members. The modified Ibarra-Medina-Krawinkler (IMK) model was utilized to capture the hysteretic behavior, incorporating various degradation mechanisms: cyclic deterioration, post-yield softening, and residual strength. To validate the modeling approach, the previously published 8-story concrete structure by Erol Kalkan was recreated and subjected to static load analysis for comparison [5]. The results exhibited good agreement between the two analyses, validating the adopted modeling approach. Subsequently, time-history analysis and Incremental Dynamic Analysis (IDA) were conducted using a suite of 22 ground motion records (encompassing 44 components) obtained from the PEER-NGA database, as recommended by FEMA P-695 [6].

3. Results and Discussion

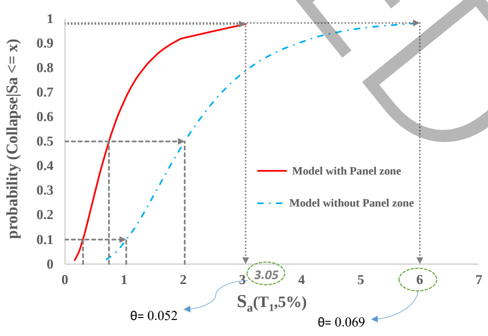
Figure 1 presents a comparison of fragility curves for the eight-story and twelve-story structures. These curves illustrate the probability of collapse for each structure under various ground motion intensities, considering models with and without panel zones. The figure reveals that the inclusion of the panel zone in the structural model results in increased stiffness. Consequently, collapse occurs at lower ground motion intensities for models with panel zones compared to those without.

Based on the results, it is evident that incorporating the panel zone in both structures significantly alters their response. Specifically, in the structure without the panel zone, the intensity level leading to a response of 0.035 is approximately twice as high compared to when the panel zone is included. For instance, in the 8-story structure, the collapse threshold occurs at an intensity of 3.15 without a panel zone, whereas with a panel zone, it occurs at a lower intensity of 1.45. Similarly, in the 12-story structure, the collapse threshold is reached at an intensity of 1.89 without a panel zone, whereas with a panel zone, it occurs at a lower intensity of 0.85. Thus, including the panel zone in the numerical model results in a response that is significantly higher or lower depending on the structure, emphasizing its critical influence on structural behavior.

The fragility curves reveal a significant influence of the panel zone on collapse resistance. Structures with modeled panel zones exhibit a 50% reduction in ground motion intensity required to reach collapse compared to models without the panel zone. However, it's important to acknowledge a potential underestimation of the collapse limit state for models with panel zones. This is indicated by a 30% discrepancy in the predicted relative displacement at collapse compared to the expected complete structural failure.



8-story reinforced concrete structure



12-story reinforced concrete structure

Figure 1: Comparison of the fragility curve of the structures with and without panel zone

4. Conclusions

In this paper, numerical modeling of concrete structures with two modeling approaches include "with panel zone" and "without panel zone" was investigated. In both approaches, the behavior of the beam and column elements is assumed to be linear and the nonlinear behavior is concentrated in the joint area at the end of the members.

Within the "without panel zone" model, the connection between members was represented by a zero-length spring element. The nonlinear behavior of this spring was captured using a uniaxial material model following the Ibarra-Medina-Krawinkler (IMK) formulation. Conversely, the "with panel zone" model employed four springs at each member end to account for the panel zone's influence. One of these springs specifically represented the joint's shear behavior.

Static analysis results revealed a marginal influence of the panel zone. While the model incorporating the panel zone exhibited increased stiffness and resistance due to its inherent rigidity and member length reduction, the overall difference compared to the model without the panel zone was negligible. This suggests that for purely static loads, the presence or absence of the panel zone may not significantly impact the results, and the modeling approach might not be critical.

Nonlinear time-history analysis, which simulates the response of structures under strong ground motions, revealed a more pronounced influence of the panel zone. While the difference between models was insignificant in the linear regime (with small displacements), it became more substantial as the structure entered the nonlinear region. Here, models with panel zones exhibited higher relative displacements. This observation aligns with the fragility curves, where the model incorporating the panel zone reached the collapse limit state at lower earthquake intensities. This suggests that the panel zone plays a more critical role in capturing the inelastic response and collapse behavior of structures under seismic loads.

5. References

[1] A. Mehrabi Moghadam, A. Yazdani, S. Motaghed, Considering the Yielding Displacement Uncertainty in Reliability of Mid-Rise RC Structures, Journal of Rehabilitation in Civil Engineering, 10(3) (2022) 141-157.

[2] S. Motaghed, A.R. fakhriyat, Modeling inelastic behavior of RC adhered shear walls in opensees, Journal of Modeling in Engineering, 18(63) (2021) 15-25. (in Persian)

[3] T. Paulay, M.N. Priestley, Seismic design of reinforced concrete and masonry buildings, Wiley, New York, 1992.

[4] L.F. Ibarra, R.A. Medina, H. Krawinkler, Hysteretic models that incorporate strength and stiffness deterioration, Earthquake engineering & structural dynamics, 34(12) (2005) 1489-1511.

[5] E. Kalkan, Prediction of seismic demands in building structures, University of California, Davis, 2006.

[6] C. Applied Technology, Quantification of building seismic performance factors, US Department of Homeland Security, FEMA, 2009.