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Probabilistic model for failure initiation of reinforced concrete interior beam–column connections subjected to seismic loading

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ABSTRACT

The results of previous experimental tests indicate that reinforced concrete interior beam column joints may exhibit significant strength and stiffness loss under earthquake loading, and the results of post-earthquake reconnaissance indicate that joint failure may result in structural collapse. Thus seismic evaluation and design of reinforced concrete frames requires accurate prediction of the potential for joint failure. This paper presents a binomial logit model, developed using data from 110 experimental tests, which define the probability that a reinforced concrete interior beam–column building connection, with a specific set of design parameters, will exhibit either a non-ductile joint shear failure prior to beam yielding or a ductile failure that initiates with beam yielding. The calibrated model identifies the relative importance of various design parameters in determining the connection's response mechanism. The model can be used by an engineer designing a new connection, constructed of normal or high-strength materials, to estimate the likelihood of joint failure initiation. The model can also be used by an engineer evaluating an existing structure to estimate the likelihood of joint failure, determine the factors that most significantly affect this likelihood, and, thereby, develop a suitable and efficient retrofit strategy.

1. Introduction

In a reinforced concrete frame subjected to earthquake loading, beam–column joints are critical for developing frame action and ensuring that inertial loads are transferred through the frame to the foundation. Post-earthquake reconnaissance efforts have attributed the collapse of many reinforced concrete frames to the failure of joints [1]. Similarly, analyses of building frames, using models that simulate joint stiffness and strength loss, show that nonlinear joint action reduces lateral load resistance and that joint failure may result in structural collapse [2]. Given the importance of these components, numerous previous experimental investigations have addressed the seismic behavior of beam–column joints, the mechanisms that determine behavior, and the design parameters that affect behavior.

The results of previous experimental investigations show that joints may exhibit significant stiffness and strength loss under lateral loading. The results of previous research suggest also that, in addition to material properties and geometric configuration, a number of different design parameters may affect joint response. These design parameters include joint shear stress demand [3–13], joint transverse reinforcement ratio [3,6,14–17], bond stress demand for beam longitudinal reinforcement passing through the joint [3,7,18–23], and column axial load [7,9,14,17,24–29]. For joints with sufficient strength to develop the yield strength of the beams framing into the joint, experimental data indicate also that drift history affects strength deterioration of the joint [30,31]. Experimental investigations at the University of Washington [30,31] also indicate that drift has minimal impact on connection strength.

The ACI Committee 352 [32] defines a beam–column joint as "that portion of the column within the depth of the deepest beam that frames into the column", and a connection as "the joint plus the columns, beams and slabs adjacent to the joint". The strength of a beam–column connection may be determined by the flexural yield strength of the beams or columns framing into the joint, or by the joint region. The results of previous research provide a basis for the current ACI Code [33] requirements that are intended to ensure that connection response is determined by flexural yielding of beams and that connection strength is determined by beam flexural strength. These requirements include a minimum volume of transverse reinforcement, a minimum anchorage length for beam longitudinal reinforcement, a minimum column-to-beam flexural strength ratio, and a limit on the joint shear stress demand. Joints designed prior to 1967 [18,27,30,34,35,31] typically do not comply with the current ACI Code [33] requirements and may

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