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Hysteretic Capacity Modeling of Slab-Column Connections

I. N. Robertson, B. Enomoto, G. Johnson
University of Hawaii

Overview

Reinforced concrete flat slab floors are used throughout the world as an economical structural system for many building applications. In moderate and high seismic regions, a more rigid structural system, such as a shear wall or moment resisting beam column frame, is generally added to provide adequate lateral resistance. Nevertheless, the slab-column system must maintain its gravity load capacity even after numerous cyclic lateral displacements. In retrofit analysis of older buildings, it is also beneficial to include the lateral resistance provided by the slab-column frames as this may substantially reduce the cost of the overall building retrofit [Hueste 1999]. The objective of this project was to create a general, robust hysteretic model for the response of slab-column connections to earthquake excitation, with particular attention to older non-ductile construction. This model is now available for use in the OpenSEES non-linear analysis platform.

Applicability

The hysteretic model presented here is applicable to both interior and exterior slab-column connections of flat slab floor systems without drop panels or column capitals. The model is applicable to connections with or without continuous slab reinforcement, and with or without slab shear reinforcement. The model has been validated for columns with cross-section aspect ratios up to 2 to 1, and for both uniaxial and biaxial cyclic lateral displacements. The model is applicable for all levels of slab gravity shear. The model includes the lateral flexibility of the column assuming zero moment at column mid-height above and below the slab, but is independent of the level of axial load on the column.

Critical Issues

Seismic performance of older flat slab structures depends on numerous factors. One of the primary factors is the level of gravity shear at the slab-column connection during cyclic lateral displacement. The ultimate drift capacity of slab-column connections is directly affected by the gravity shear ratio, defined as V_g/V_o, where V_g is the shear on the critical perimeter due to gravity loads present during the earthquake, and V_o is the direct punching shear capacity of the connection as defined by the ACI 318-99 building code.

Considerable research has been performed on connections with continuous slab reinforcement, however, an overview of past research indicated a lack of data on the performance of slab-column connections with discontinuous slab reinforcement. Without continuous slab bottom reinforcement passing through the column, punching shear failure would likely be followed by progressive collapse. A series of tests on interior slab-column connections with discontinuous slab reinforcement was performed to evaluate their behavior under gravity and cyclic lateral load. Based on these and prior studies, punching shear failure does not appear to occur earlier than in equivalent specimens with continuous reinforcement, however, the consequences of punching are significantly more severe. Conservatism in estimating the lateral drift at which punching failure occurs is therefore warranted.

Backbone Development

An analytical model for the prediction of load-deformation backbone curves for interior and exterior slab-column connections was developed. This model utilizes limit states derived from the test series performed with PEER funding and previous research. These limit states include the peak lateral load capacity, based on a modified version of the FEMA 273 procedure, and the maximum lateral drift capacity, based on suggestions by Hueste and Wight [Heuste 1999].

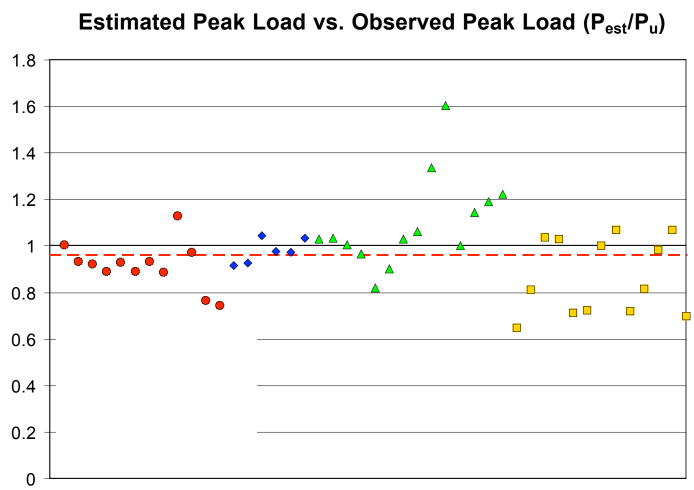

Figure 1: Theoretical vs. measured lateral

Peak lateral load capacity of an interior connection is determined from the nominal moment capacity of a slab width of c_2+5h centered on the column, where c_2 is the column width perpendicular to the loading direction, and h is the slab thickness. The strength of the slab flexural reinforcement is taken as 1.25 F_y, where F_y is the nominal yield strength, while the effective reinforcement ratio is capped at $\square_{max}$ = 0.0065. Figure 1 shows a comparison between the estimated and measured lateral load capacities for 22 test specimens.

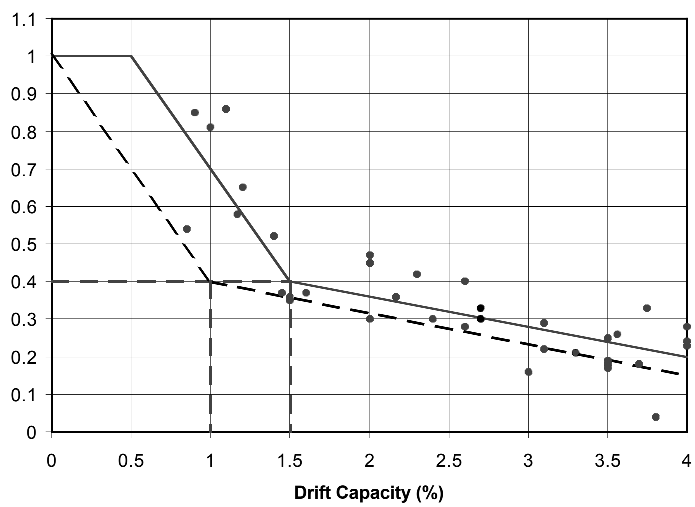

Figure 2: Drift capacity relative to gravity shear ratio

The maximum drift capacity of a slab-column connection is related to the gravity shear ratio on the slab critical perimeter as shown in Figure 2. Hueste and Wight propose a tri-linear drift prediction model, which was incorporated in the backbone curve model for specimens with continuous slab reinforcement. For specimens without continuous slab bottom reinforcement passing through the column, a more conservative bi-linear drift capacity is proposed as illustrated in Figure 2.

In addition, prior testing by Lee and Robertson [Lee 2001] was used to derive the initial stiffness and stiffness degradation for the model. The backbone curves generated using this model closely match those for a variety of slab-column connection tests performed by various researchers (Figure 3). The development of this model and the comparisons with experimental results are presented in more detail in the PEER State-of-the-art report on performance of non-ductile reinforced concrete buildings.

Based on this backbone curve, hysteretic loops are generated for the particular connection subjected to a prescribed displacement routine or ground motion. The analytical hysteretic behavior compares well with the specimens tested as part of the PEER program, as well as with numerous other specimens from prior research programs. All test data used in the development of this model are presented in a web-based catalogue of slab-column connection test programs.

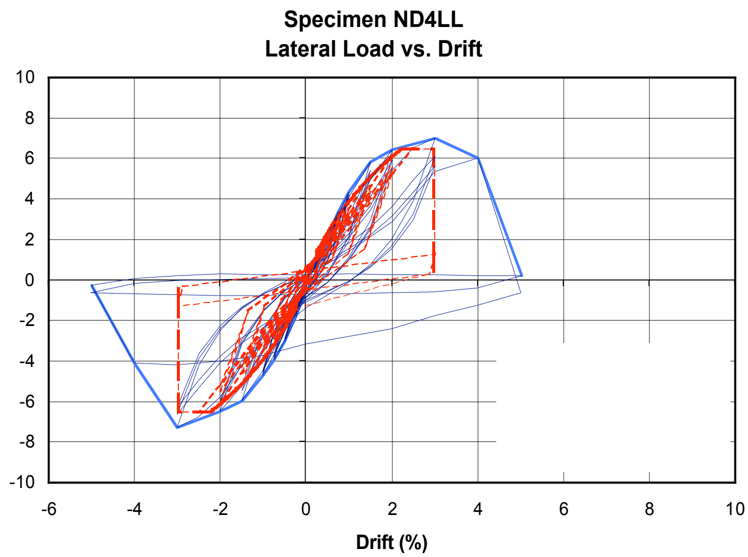

Figure 3: Predicted response for non-ductile specimen

For further information

See Enomoto and Robertson reference below, or contact Ian Robertson by email at ianrob@hawaii.edu.

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