DOI: http://dx.doi.org/10.12989/sem.2010.35.1.123
Structural Engineering and Mechanics, Vol. 35, No. 1 (2010) 123-126

Technical Note

Shear behavior of exterior reinforced concrete beam-column joints

F. Alemdar[1] and H. Sezen[2]*

[1]*Paul C. Rizzo Associates, Inc., 105 Mall Boulevard, Suite 270-E, Monroeville, Pennsylvania 15146, USA*
[2]*Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Ave., Columbus, Ohio 43210-1275, USA*

(Received February 16, 2009, Accepted September 21, 2009)

1. Introduction and previous shear strength models

Older reinforced concrete buildings designed before the introduction of modern seismic codes in the early 1970's, in general, do not meet the requirements of current design codes. In particular, beam-column joints in such existing buildings do not have appropriate detailing which leads to insufficient lateral strength or ductility to withstand the effects of a severe earthquake loading (Sezen *et al*. 2003). In this study, a new model is proposed to calculate the shear strength of beam-column joints.

Several models have been developed to predict shear strength of beam-column joints for design and evaluation purposes. Some of these models calculate the shear strength as sum of the contribution of concrete and transverse reinforcement. Most of the models, however, predict the shear strength as a function of concrete strength only and do not consider the effect of displacement ductility. Four models are briefly described here. Only the first model by Sezen and Moehle (2004) includes the strength contribution from transverse reinforcement. This model is developed for columns, and its concrete component is somewhat similar to that proposed by Park (2000). Both of these models and the model by Hakuto (1995) consider the effect of displacement ductility. The last model recommended in the FEMA 356 guideline (2000) is the simplest model.

Hakuto (1995) developed a shear strength model for interior beam-column joints without shear reinforcement. The model is based on experiments conducted without any axial load acting on the column. Therefore, the effects of axial load and shear reinforcement on shear strength of beam-column joints were not investigated in his study and not included in the proposed model. In Hakuto's model, the maximum joint shear strength, V_{jh} is calculated as (in MPa)

$$V_{jh} = kf_c' b_j h \tag{1}$$

where k is joint shear degradation factor, f_c' is the concrete compressive strength, b_j is effective width of joint, and h is depth of column.

*Corresponding author, Associate Professor, E-mail: sezen.1@osu.edu

The FEMA 356 document (2000) recommends Eq. (2) for the calculation of nominal shear strength of beam-column joints following the general procedures of the ACI 318 code (2008). The shear strength is calculated for expected material strengths, i.e., measured steel and concrete strengths for test specimens, using the procedures outlined in the ACI 318 (2008). According to ACI 318 specifications, the transverse reinforcement is used mainly to confine the core concrete and does not have any effect on shear strength of beam-column joints.

$$V_n = \lambda\gamma\sqrt{f_c'}A_j \tag{2}$$

where γ is the nominal strength coefficient, λ is equal to 1.0 for normal-weight concrete, A_j is the effective horizontal joint area defined as the product of the column dimension in the direction of loading and the joint width equal to the smaller of: 1) column width, or 2) beam width plus the joint depth, or 3) twice the smaller perpendicular distance from the longitudinal axis of the beam to the column side.

2. Proposed shear strength model

In this research, the model developed by Sezen and Moehle (2004) is evaluated and modified to calculate the shear strength of beam-column joints. The proposed model does not include the effect of joint geometry or aspect ratio. Gross cross sectional area of the column is used as the effective area of the beam-column joint and the joint area is not reduced as in Sezen and Moehle model. In addition, the shear strength degradation factor, k is defined differently in the proposed model. In Eq. (3), k accounts for ductility-related strength degradation and is equally applied to both concrete and transverse reinforcement contribution to shear strength (V_c and V_s).

$$V_n = V_s + V_c = k\frac{A_v f_y d}{s} + k\left(0.5\sqrt{f_c'}\sqrt{1+\frac{P}{0.5\sqrt{f_c'}A_g}}\right)A_g \text{ (MPa)} \tag{3}$$

where A_v is the cross-sectional area of transverse reinforcement oriented parallel to the applied shear and having longitudinal spacing s, d is the distance from extreme compression fiber to centroid of longitudinal tension reinforcement, f_y is yield strength of the transverse reinforcement, P is axial compressive force, a is the distance from point of maximum moment to point of zero moment, and A_g is the gross cross-sectional area. The parameter k depends on the member displacement ductility demand and is defined below.

3. Verification of proposed shear strength model using test data

Thirty-one exterior joint specimens are used to define the ductility-related factor k below, and to validate the proposed shear strength model. Geometrical, material and other test parameters required for shear strength calculations, measured joint shear strength, V_{test} and the shear strengths predicted from Eq. (3) ($V_{proposed}$), Eq. (2) (V_{FEMA}), and Eq. (1) (V_{Hakuto}) are provided in Alemdar (2007). The following specimens were used in this study: Specimens 2, 4, 5 and 6 (Clyde *et al.* 2000); 1A, 1B, 3, 4, 5, 6A and 6B (Pantelides *et al.* 2002); 1B, 2B, 3B, 4B, 5B and 6B (Ehsani 1985); B1, B2, B3 and B4 (Fujii and Morita 1992); JA-NN03, JA-NN05, JB-NN03, JA-NY03, JA-NY15 and JB-

NY03 (Wong 1991); and P1, Q1, R1 and S1 (Murty *et al.* 2003). Description of test specimens and details of shear strength calculations can be found in Alemdar (2007). Fig. 1 shows the ratio of predicted joint shear strengths before the application of shear degradation factor, k to experimental joint shear strength, V_{test} versus the displacement ductility for all exterior joints.

If the effect of displacement ductility or the k factor in Eq. (3) is ignored, the predicted shear strength ratios appear to decrease with increasing displacement ductility. This trend is represented by a linear best fit line in Fig. 1. To reflect the effect of displacement ductility on shear strength degradation, the piecewise linear model shown in the figure is proposed to define k. The shear

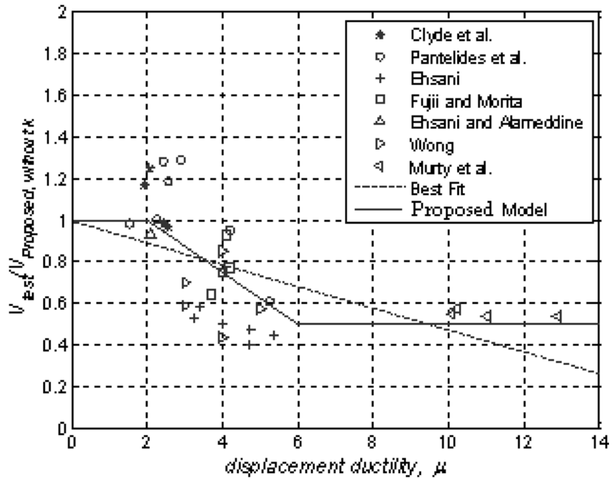

Fig. 1 Shear strength prediction as a function of displacement ductility, best fit linear line, and model representation

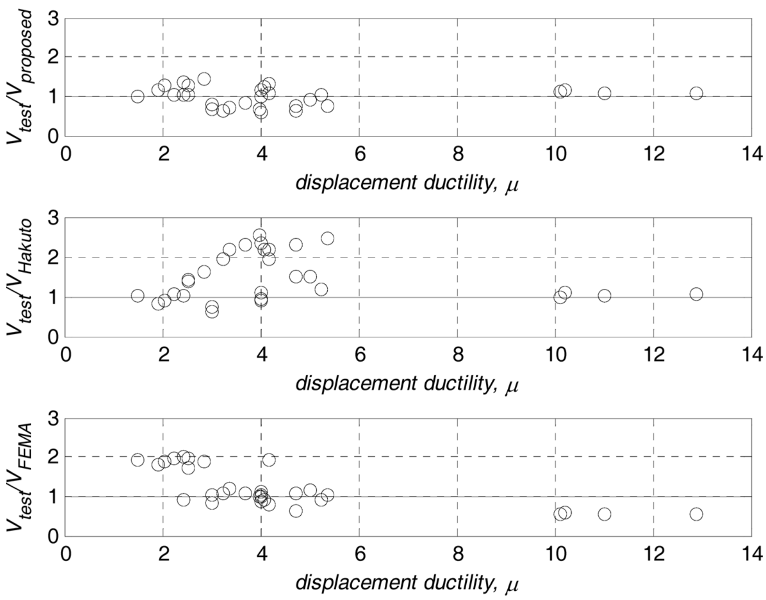

Fig. 2 Ratio of measured to calculated shear strength for the proposed, Hakuto and FEMA models versus displacement ductility

strength degradation factor equals to 1 if displacement ductility is smaller than 2, equals to 0.5 if displacement ductility is larger than 6 and varies linearly between 1 and 0.5 if the displacement ductility is between 2 and 6.

Fig. 2 shows the ratio of the experimental to predicted strength ratio as a function of displacement ductility. The shear strengths of joints were calculated using Eq. (3) including the effect of strength reduction factor, k defined above. The average of experimental to predicted strength ratio is 0.98 with a standard deviation of 0.25. This shows that the proposed model predicts the shear strength of exterior beam-column joints reasonably well. The average of experimental to predicted strength ratios are 1.46 and 1.19 for the FEMA 356 and Hakuto models, respectively.

3. Conclusions

A new model is proposed to predict the shear strength of beam-column joints with poorly detailed or insufficient transverse reinforcement. The joint shear strength is assumed to be sum of two components from concrete and transverse reinforcement and was multiplied by a factor to include the effect of displacement ductility. The model is evaluated using the test data representing a wide range of beam-column joint properties. The proposed model can be used to predict the shear strength of lightly reinforced beam-column joints as well as joints with no transverse reinforcement. Displacement ductility seems to be one of the major variables affecting the shear strength of joints and was considered in the model. Shear strengths of 31 exterior beam-column joints are predicted relatively accurately using the proposed model.

References

ACI-ASCE Committee 352 (1985), "Recommendation for design of beam-column joints in monolithic reinforced concrete structures", *J. Proceed.*, **82**(3), 266-284.

ACI Committee 318 (2008), "Building code requirements for structural concrete", American Concrete Institute, Farmington Hills, Michigan.

Alemdar, F. (2007), *Behavior of Existing Reinforced Concrete Beam-column Joints*, Masters Thesis, The Ohio State University.

FEMA 356 (2000), *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, Federal Emergency Management Agency, Washington DC.

Hakuto, S. (1995), *Retrofitting of Reinforced Concrete Moment Resisting Frames*, Ph.D. Dissertation, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand.

Park, R. (2002), "A summary of results of simulated load tests on reinforced concrete beam-column joints, beams and columns with substandard reinforcing details", *J. Earthq. Eng.*, **6**(1), 147-174.

Sezen, H., Whittaker, A.S., Elwood, K.J. and Mosalam, K.M. (2003), "Performance of Reinforced Concrete and Wall Buildings during the August 17, 1999 Kocaeli, Turkey Earthquake, and Seismic Design and Construction Practice in Turkey", *Eng. Struct.*, **25**(1), 103-114.

Sezen, H. and Moehle, J.P. (2004), "Shear strength model for lightly reinforced columns", *J. Struct. Eng-ASCE*, **130**(11), 1692-1703.