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Deformation Demands at the Onset of Bar Buckling in Reinforced Concrete Columns

M.O. Eberhard[1], M. Parrish[2] and M. Berry[3]

Overview

To implement Performance-Based Earthquake Engineering for reinforced concrete columns, it will be necessary to explicitly estimate the deformation demands that correspond to the onset of longitudinal bar buckling. At this level of damage, occupants will likely feel unsafe and repair methods start to become expensive. This study correlated the level of displacement imposed on reinforced concrete columns at the onset of bar buckling with the axial-load ratio and effective transverse-reinforcement ratio. Based on the observed trends, simple relationships are proposed to predict the onset of bar buckling.

Applicability

The results provide engineers with the means of estimating the onset of bar buckling for reinforced concrete columns subjected to earthquake loading. The empirical relationships were calibrated with data from well-documented, one-directional tests of flexure-critical columns. Consequently, the reported accuracies of the proposed relationships do not consider the influence of biaxial loading, or of uncertainties in column geometry, material properties and boundary conditions likely to occur under field conditions.

Observations of Bar Buckling

The reported maximum displacements preceding the onset of bar buckling were collected for 43 tests of rectangular reinforced concrete columns. For each test, the corresponding drift ratio, nominal concrete strain, displacement ductility and plastic rotation were computed. Statistical properties of these deformation demands are reported in Table 1. The coefficients of variation for these quantities are high, ranging from 32% to 42%.

[1] Associate Professor, Dept. of Civil and Environmental Engineering, University of Washington, Seattle.
[2] Structural Engineer, Berger/ABAM, Seattle, Washington.
[3] Research Assistant, Dept. of Civil and Environmental Engineering, University of Washington, Seattle.

Table 1 - Deformation Demands at Onset of Bar Buckling (Rectangular Columns)

	Mean	StDev	COV
Nominal Concrete Strain	0.019	0.0061	32%
Drift Ratio (%)	4.9	1.9	38%
Displacement Ductility	9.8	4.1	42%
Plastic Rotation	4.4	1.8	42%

As shown in Figure 1, the values of the critical drift ratios, ductility ratios and plastic rotations decreased consistently with increasing axial load, and these ratios increased with increasing level of transverse reinforcement. As expected, the critical concrete compressive strain (at the centroid of the longitudinal reinforcement) did not vary consistently with the level of axial load.

Estimating Column Deformation at Onset of Bar Buckling

Based on the observed influence of the axial-load ratio and the effective transverse reinforcement ratio ($\rho_s f_{ytrans}/f'_c$) on drift ratio (Fig. 1), the displacement at onset of bar buckling, Δ_{buckle}, can be estimated as follows:

$$\Delta_{buckle} = 2.5 \cdot L_{meas} \cdot \left(1 - \frac{P}{f'_c A_g}\right)\left(1 + \frac{k\rho_s f_{ytrans}}{f'_c}\right)$$ **Equation 1**

where

k is equal to 8 for rectangular-reinforced concrete columns
$k\rho_s f_{ytrans}/f'_c$ is limited to 0.25 in Equation 1
L_{meas} : length of column to point of inflection
$P/A_g f'_c$: axial-load ratio
ρ_s : transverse reinforcement ratio
f_{ytrans} : yield strength of the transverse reinforcement
f'_c : concrete compressive cylinder strength

The displacement at the onset of bar buckling was calculated with Equation 1 for each of the tests. The resulting ratio of measured-to-calculated displacement for bar buckling had a mean of 1.14 and a coefficient of variation 28%.

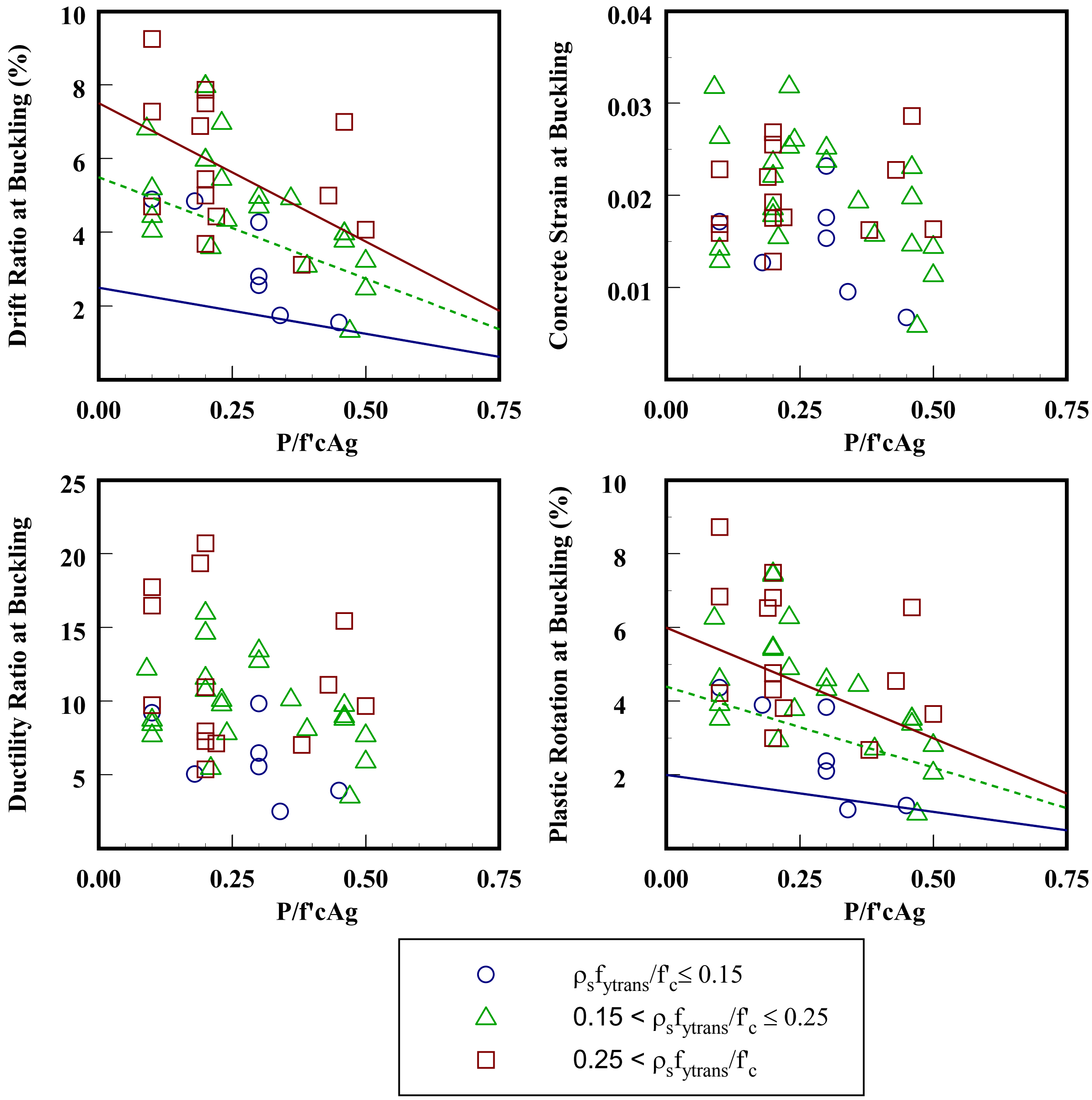

Figure 1 - Deformation Demands at Onset of Bar Buckling (Rectangular Columns)

Based on the observed influence of the axial-load ratio and the effective transverse reinforcement ratio ($\rho_s f_{ytrans}/f'_c$) on plastic rotation (Fig. 1), the displacement at onset of bar buckling, Δ_{buckle}, can be estimated as follows:

$$\Delta_{buckle} = \Delta_{yc} + 0.02 \cdot L_{meas} \cdot \left(1 - \frac{P}{f'_c A_g}\right)\left(1 + \frac{k\rho_s f_{ytrans}}{f'_c}\right) \qquad \textbf{Equation 2}$$

where Δ_{yc} is the calculated yield displacement, and $\rho_s f_{ytrans}/f'_c$ is limited to 0.25.

For Equation 2, the ratio of the measured-to-calculated displacements for bar buckling had a mean of 1.05 and a coefficient of variation 28%.

For Further Information

The Parrish and Eberhard reference listed below provides further details. For additional information, please contact Mike Berry at mpberry@u.washington.edu or Marc Eberhard at eberhard@u.washington.edu. Column force-displacement and damage data can be obtained at *http//www.ce.washington.edu/~peera1*

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Reference

Parrish, M. and Eberhard, M.O., "Accuracy of Seismic Performance Methodologies for Rectangular Reinforced Concrete Columns," Proceedings, Third US-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building Structures, Seattle, Washington, August 2001, 11pp.

Keywords
columns, reinforced concrete, deformation, evaluation, damage, bar buckling