2021 SOURCES: Predicting Damage to Steel Rebar in Reinforced Concrete Structures Subjected to Earthquake Loading

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Abstract

High-intensity ground shaking can cause significant damage to structural components such as reinforced concrete (RC) columns during large earthquakes. A recent reauthorization of the National Earthquake Hazards Reduction Program (NEHRP) by Congress highlights the need to understand and predict the extent of damage to structures during large earthquake events, in order to minimize downtime and interruption of community functions. Commonly used nonlinear structural analysis tools can be deficient in predicting the deterioration of RC components due to the mesh sensitivity associated with finite element modeling of damage. In addition, estimating the parameters associated with the numerical modeling of material damage phenomena, such as buckling of steel reinforcement in RC components, can be difficult due to the sparsity of experimental test data. In this study, calibration of a mesh-independent structural analysis model that can represent the effect of steel buckling in RC structures is presented. Our findings show that predictions of the deterioration of the load-carrying capacity of RC columns are sensitive to the steel buckling model and associated material softening parameters. The agreement between the predictions of the numerical simulation models and experimental tests on RC columns subjected to cyclic lateral loading can be improved using the proposed buckling model for steel. The proposed model was implemented in OpenSees, an open-source structural analysis platform, and can be used by structural engineering researchers and practitioners to model the buckling of steel and predict the degradation of RC members under extreme earthquake events.

Problem

Commonly used distributed-plasticity structural analysis models cannot reliably predict the deterioration of reinforced concrete (RC) structures, due to their susceptibility to mesh-sensitivity issues. Furthermore, because of the difficulties associated with estimating the necessary parameters, distributed-plasticity models may not properly account for the buckling of steel reinforcement. This study addresses this problem by creating a mesh-independent steel material model and proposing statistical models to estimate the parameters associated with the buckling of steel rebar in RC columns.

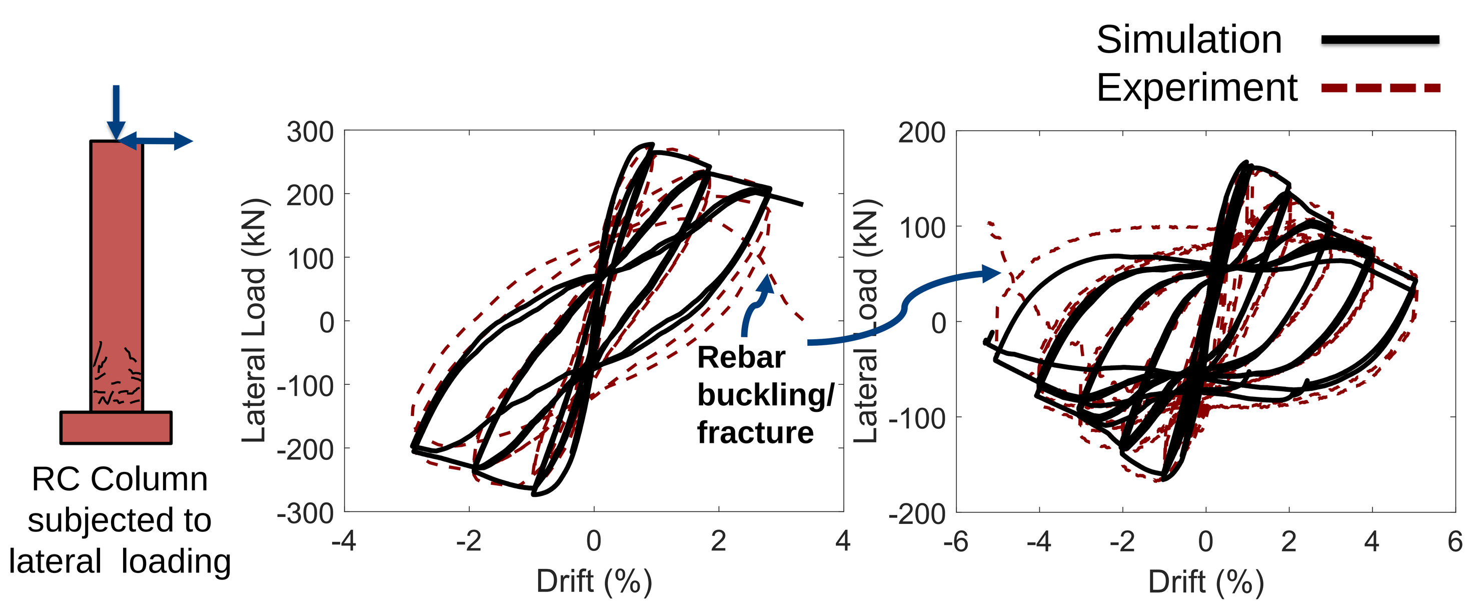

Figure 1: Mesh-independent models that do not incorporate steel rebar buckling can underestimate the loss in the load-carrying capacity.

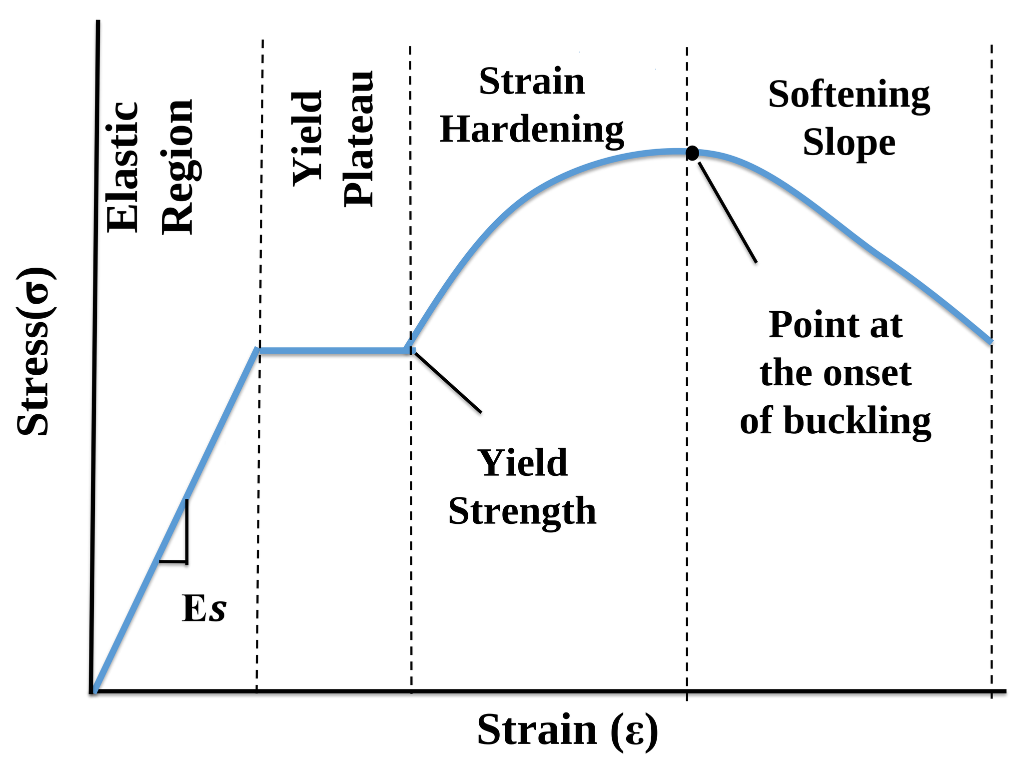

Figure 2: Stress Strain curve broken up into important components, highlighting the onset of buckling and softening slope

Data and Methodology

1: Develop a mesh-independent softening formulation for steel

2: Analyze experiments and models in the literature to estimate parameters (strain at onset of buckling, softening slopes)

3: Compare available models to experiments and study the best performing models

4: Propose new model to estimate the parameters associated with steel buckling

Figure 3: Steps taken to develop proposed steel buckling model utilized in this study

The available models in the literature which predict the parameters governing the buckling of steel rebar were found to overestimate the strain at the onset of buckling of steel bars compared to 106 surveyed experimental tests. No models were found in the literature to predict the softening slope associated with buckling of steel rebar.

Results

Based on the test results of Bae et al. (2005) and Monti and Nuti (1999), we propose the following models for estimating (1) the steel material strain at the onset of buckling (**figure 4**), and (2) the material softening slope after buckling (**figure 5**), to be used in combination with the mesh-independent nonlocal material model to simulate the buckling of steel bars.

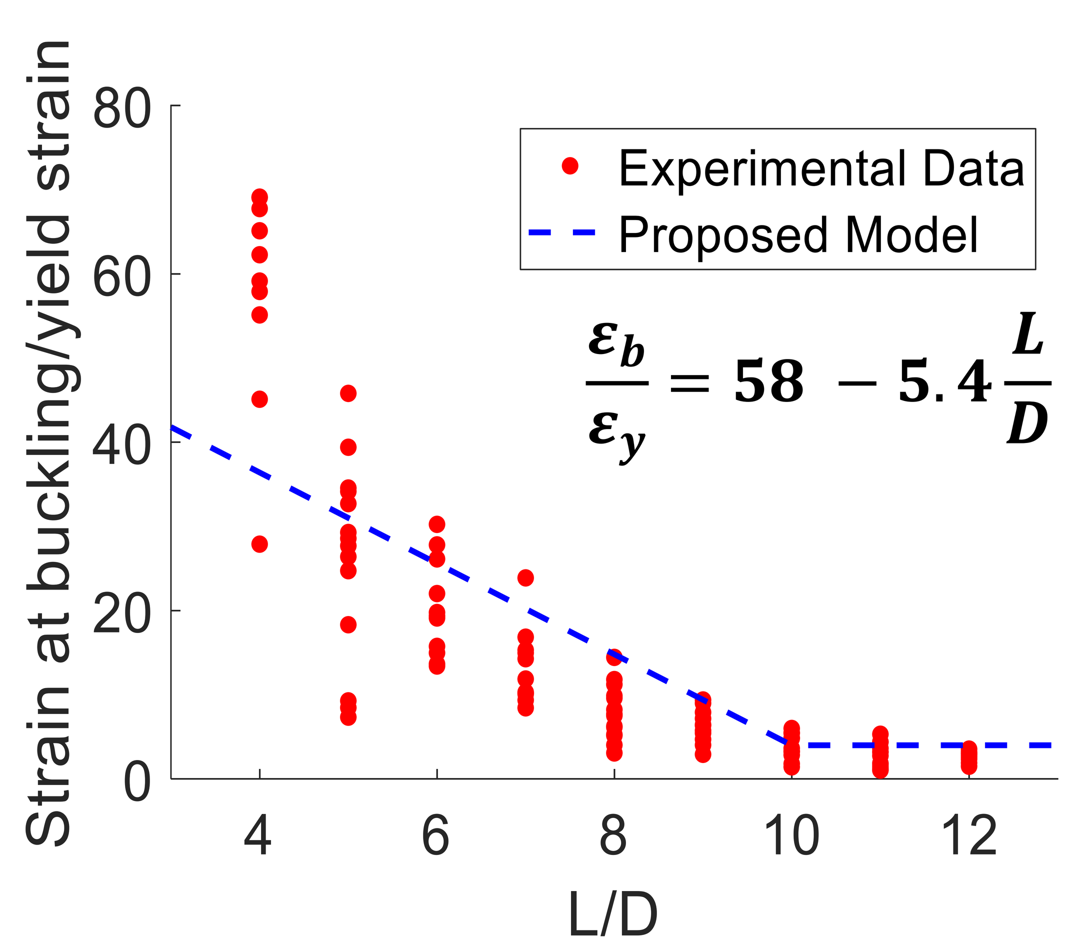

Figure 4: Proposed model to estimate the strain at buckling of steel bar as a function of bar length to diameter (L/D).

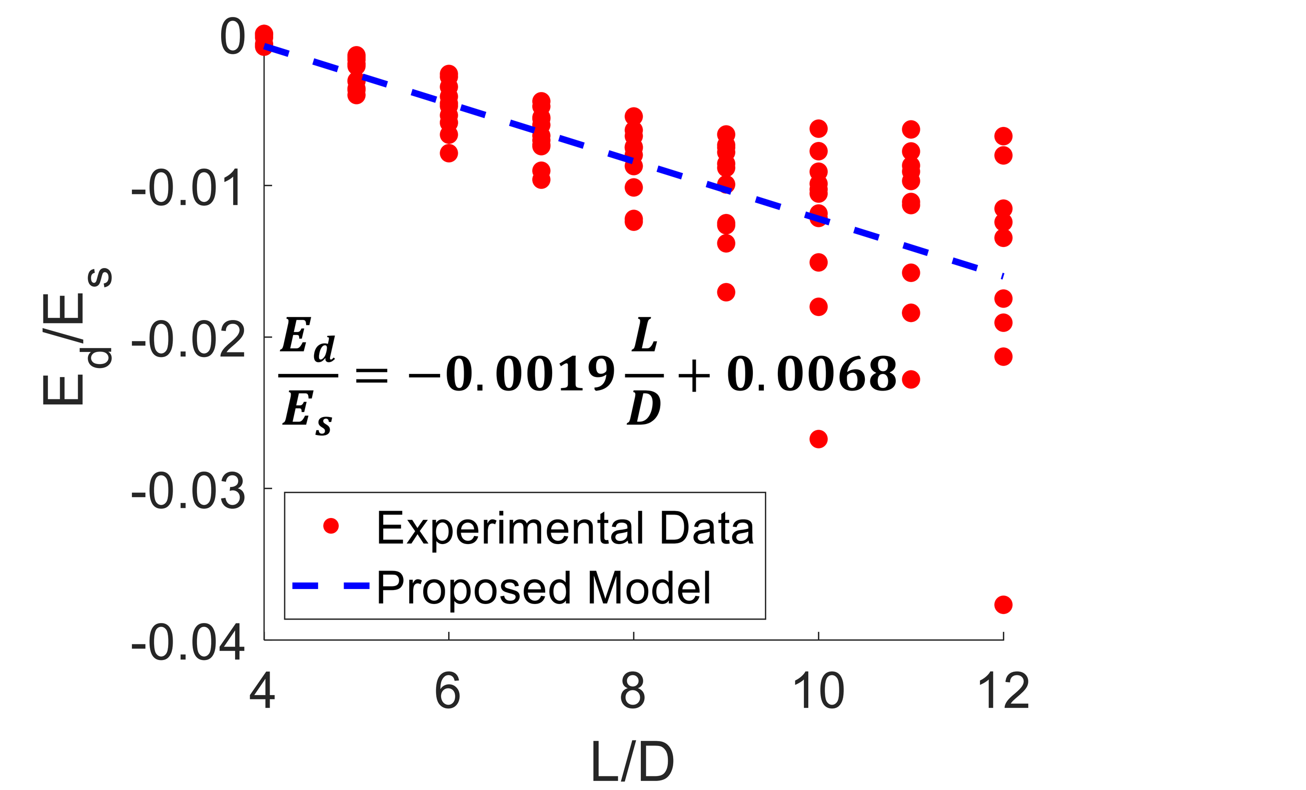

Figure 5: Proposed model for estimating softening slope after buckling (Ed) as a ratio of the elastic modulus (Es) as a function of bar length to diameter (L/D).

Summary and Conclusion

Test data from experiments on steel bars can be used to develop practical equations to estimate the strain at buckling and the softening slopes of individual steel bars. Applying these predicted values to steel reinforcement in RC columns may overestimate the strain at buckling and underestimate the softening slopes. When using the developed nonlocal steel model to predict the deterioration of RC columns, we recommend the use of 20-50% of the buckling parameter values predicted for single bars; however, more research is necessary to verify these values. Figures 6 and 7 show that using only 20% of the buckling strain predicted by the model can result in better agreement between the numerical simulations and experimental test data for RC columns.

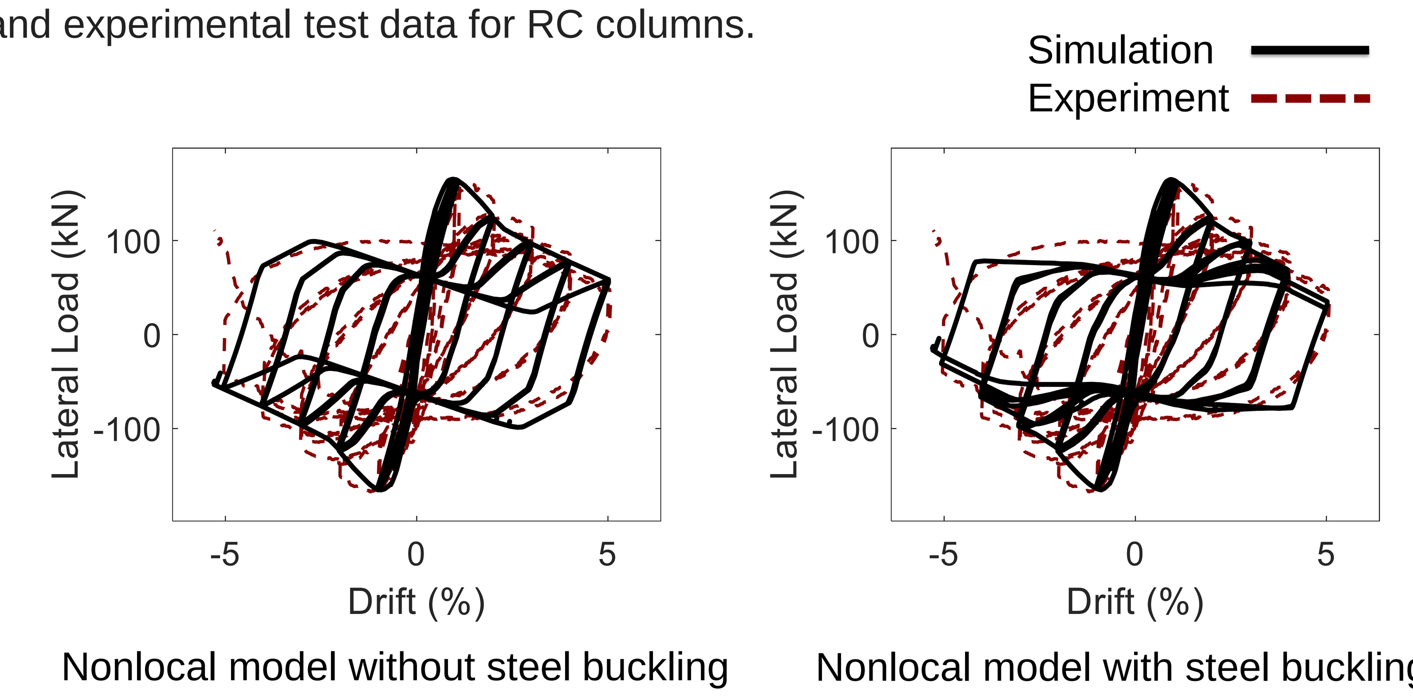

Figure 6: Using the proposed steel buckling parameters may result in little improvement in the agreement between simulations and experiments.

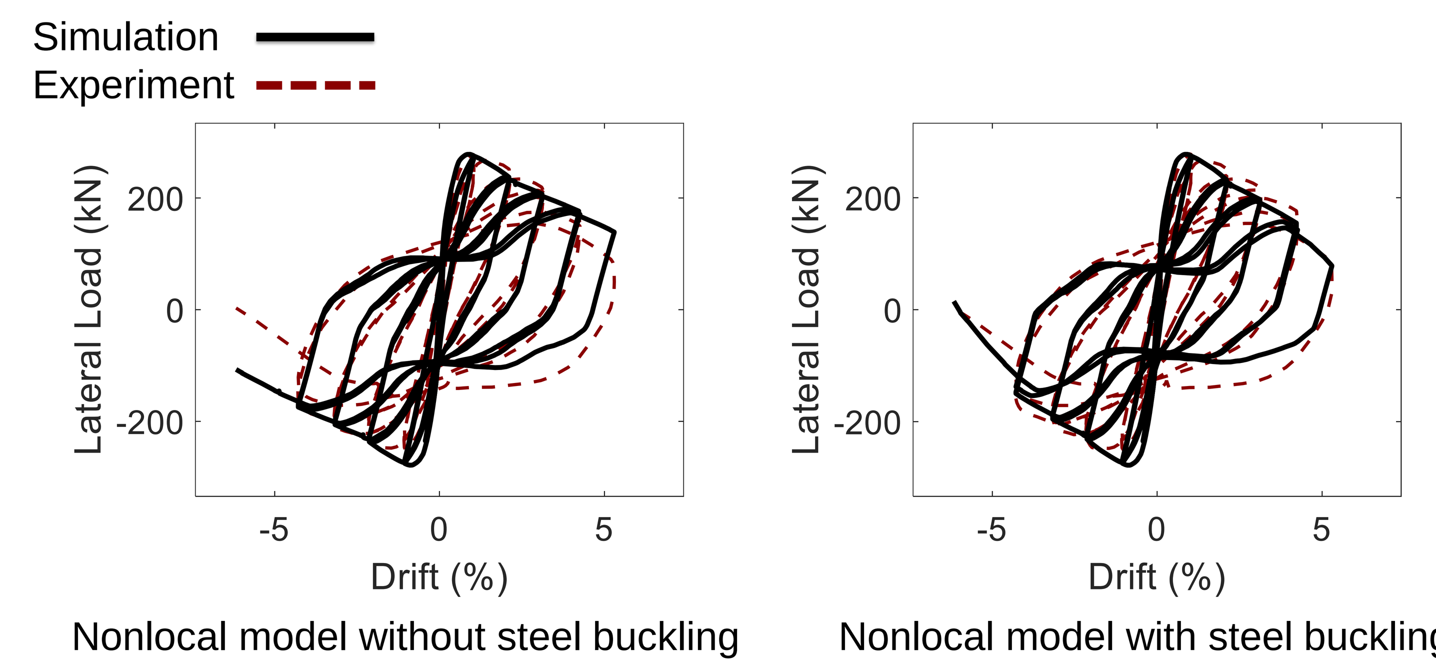

Figure 7: Using the proposed steel buckling parameters may result in better agreement between the simulations and experiments.

References

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Monti, G., & Nuti, C. (1992). Nonlinear cyclic behavior of reinforcing bars including buckling. Journal of Structural Engineering, 118(12), 3268–3284. https://doi.org/10.1061/(asce)0733-9445(1992)118:12(3268)

Acknowledgements

Thank you to SCEC for such an amazing summer internship, Dr. Noriega for leading cohort discussions, and Dr. Kenawy for being a great mentor!