Alaska Department of Transportation & Public Facilities
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The Effect of Load History on Reinforced Concrete Bridge Column Behavior

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To satisfy the aims of performance based design, levels of damage which interrupt the serviceability of the structure or require more invasive repair techniques must be related to engineering criteria. In this report, the influence of displacement history on performance limit states, the relationship between strain and displacement, and the spread of plasticity in reinforced concrete structures is explored. An experimental study is underway to assess the performance of thirty circular, well-confined, bridge columns with varying lateral displacement history, transverse reinforcement detailing, axial load, aspect ratio, and longitudinal steel content. Eight of these columns, with similar geometry and detailing, were subjected to various unidirectional displacement histories including standardized laboratory cyclic loading and recreations of the displacement responses obtained from non-linear time history analysis of multiple earthquakes with distinct characteristics. Longitudinal reinforcing bars were instrumented to obtain strain hysteresis, vertical strain profiles, cross section curvatures, curvature distributions, and fixed-end rotations attributable to strain penetration. Results indicate that bar buckling was influenced by load history, but the relationship between strain and displacement along the envelope curve was not. The main impact of load history on bar buckling is its influence on accumulated strains within the longitudinal reinforcement and transverse steel.

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Summary of Findings

Results have shown that the damage control steel tensile strain limit was influenced by load history, but the relationship between strain and displacement was not. Specific earthquake time-history response characteristics were evaluated including: the number and amplitude of cycles prior to the peak, degree of symmetry, and the peak displacement in each direction of loading. The symmetric three cycle set load history is more severe than the displacement history produced by real earthquakes, when evaluated to the same peak displacement, because of the high number of inelastic reversals of loading of increasing magnitude. The earthquake load histories needed to be scaled to larger displacements to produce bar buckling. Large inelastic strains, caused by large concrete compressive demand, decreased the effectiveness of the transverse steel in restraining buckling of the longitudinal bars. Plastic curvatures followed a linear distribution and as curvature ductility increased, the extent of plasticity stretched higher above the footing. Improvements to the moment curvature prediction for the relationship between strain and displacement can be made by taking into account the curvature ductility dependent linear distribution of plastic curvatures.

Improvements to the plastic hinge method for member deformation are necessary to produce accurate limit state target displacements at levels of response other than the ultimate condition which the constant plastic hinge length was intended for. The Optotrak instrumentation system allows for measurement of cross section curvature profiles and fixed-end rotations due to strain penetration of longitudinal reinforcement into the footing. The use of a constant plastic hinge length does not take into account the response level dependent, linear distribution of plastic curvatures within the hinge regions. As the base section curvature increase, the height at which the linear plastic curvature distribution intersects the elastic curvature profile extends further above the footing. The spread of plasticity in bridge columns is primarily due to the effects of tension shift and hardening within the hinge region. Due to the effects of tension shift, compressive strains are concentrated near the column base and tensile strains are fanned out to a greater height following inclined crack distribution. The tensile strains at the beginning of an inclined flexural shear crack do not coincide with the perceived moment demand at that location based on its height above the footing and the applied lateral load.

This report focused on specimens 8-18 which included load history and transverse steel detailing as primary variables. The remaining specimens 19-30 in the research program will focus on aspect ratio, axial load ratio, and longitudinal steel content. Conclusions in the form of design recommendations for performance strain limits require inspection and comparison of the entire experimental dataset. For the purposes of this report, the influence of load history and transverse steel on column behavior was presented in the form of experimental observations. Similarly, improvements to the plastic hinge method for member deformations can only be made once additional design variables are explored in the remaining tests.

Analysis with fiber-based model showed that the relationship between strain and displacement was not influenced by load history. It is concluded based on considering a number of load histories and important structural variables which includes axial load ratio, transverse steel detailing, aspect ratio and longitudinal steel content. Analysis with other load histories will be conducted to confirm this statement.

A finite element model was developed to capture the longitudinal reinforcement bucking under cyclic loading. Results from analysis has shown that the model was able to capture the bar buckling and the load history effect on bar buckling. The bar buckling model will be implemented in the parametric study of the load history effect on the steel tensile strain limit.