NUMERICAL INVESTIGATION OF THE EQUIVALENT PLASTIC HINGE LENGTH FOR STAINLESS STEEL-REINFORCED CONCRETE PIERS

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Extended Abstract

Stainless steel (SS) reinforcement offers excellent corrosion resistance, high ductility, and pronounced strain-hardening characteristics, making it a promising alternative for bridge piers serving in marine environments and de-icing salt conditions. However, the equivalent plastic hinge length (L_p), as a key parameter for evaluating displacement capacity, plastic rotation, and nonlinear seismic response of bridge piers, has been extensively studied for conventional reinforced concrete (RC) members but remains largely uninvestigated for SS-reinforced concrete (SS-RC) bridge piers. Existing empirical L_p models, developed for carbon-steel RC columns, may not capture the unique plastic development mechanisms, strain-penetration effects, and enhanced deformation capacity of SS-RC piers. Therefore, this study aims to establish a validated numerical model, systematically investigate the effects of key parameters on L_p, and propose a dedicated empirical formula for SS-RC bridge piers.

An *OpenSees* numerical model was developed based on quasi-static test results of circular SS-RC bridge piers. The pier shaft was modelled using fibre beam-column elements with appropriate concrete constitutive models (*ConfinedConcrete01* for core, *Concrete02* for cover) and the *ReinforcingSteel* material to capture the nonlinear behaviour of B1.4362 duplex stainless steel bars, including isotropic hardening and cyclic degradation. A *zero-length* element with the *Bond_SP01* model was used at the column base to simulate strain penetration and bond-slip effects. After successful validation against experimental hysteretic curves and deformation components (flexural, bar-slip, and shear), a controlled-variable parametric study was conducted to investigate the effects of axial load ratio (n=0.10-0.45), pier height

(L=1.5-3.5 m), longitudinal reinforcement ratio (ρ=1.26-2.57%), reinforcement yield strength (f_y=550-750 MPa), and bar diameter (d_b=8-20 mm).

The parametric results reveal that L_p decreases significantly with increasing axial load ratio, because higher axial compression intensifies concrete crushing and damage localization at the pier base, restraining upward extension of the plastic region. In contrast, L_p increases with increasing pier height, longitudinal reinforcement ratio, yield strength, and bar diameter. A larger pier height reduces the moment gradient and allows wider flexural plastic development; higher reinforcement ratios and larger bar diameters enhance flexural capacity and strain penetration; and higher-strength SS bars promote greater stress development along the column base. Comparison with classical L_p models shows that most existing formulas cannot simultaneously capture these parameter effects and generally underestimate L_p for SS-RC bridge piers.

Based on the parametric analysis, a new empirical formula for SS-RC bridge piers is proposed: $L_p=-1998.32n+108.00\rho+0.18403L+0.02816fyd_b$, where L_p and L are in mm, ρ in %, f_y in MPa, and d_b in mm. The proposed formula achieves excellent agreement with numerical results and significantly outperforms all the classical models in terms of accuracy and dispersion control. When different L_p models were further used to predict ultimate rotation, the proposed formula again demonstrated superior performance, whereas classical models generally exhibited underestimation or large scatter. These findings indicate that the proposed L_p formula is not only suitable for calculating equivalent plastic hinge length but also provides a reliable parameter basis for displacement-based design, concentrated plastic hinge modelling, and seismic fragility analysis of stainless steel reinforced concrete bridge piers. Further validation with more experimental data and different pier scales is recommended to refine the applicability range.

Keywords: *Stainless steel-reinforced concrete bridge piers, equivalent plastic hinge length, numerical simulation, parametric analysis, empirical equation, seismic performance*