Nonlinear Stability and Structural Resilience of Interlocking Jetty Systems for Bridge Support

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In the development of modular bridge infrastructure, the structural resilience of interlocking jetty systems heavily depends on robust connection strategies. Ensuring efficient load transfer between the substructure and superstructure is critical, particularly at complex beam-to-pile interfaces utilizing a Doweled Collar Interlock (DCI), and at beam-to-beam connections secured by bolted steel splice plates. This research aims to perform a comprehensive forensic structural appraisal of these hybrid assemblies to identify vulnerabilities leading to localized shear failure. The system was modeled with explicit full-scale structural dimensions, featuring a 3m long, 300mm wide pier cap beam with a depth tapering dynamically from 250 mm to 900mm, consisting a 400mm pile cap that interfaces with a 300mm diameter foundation pile. The study utilized Abaqus finite element analysis to simulate the complex contact mechanics of the DCI joints and splice plate connections, employing a surface-to-surface contact formulation with penalty friction behavior. The numerical model was validated against experimental load-testing data of a single-beam prototype, showing strong correlation in both initial elastic stiffness and ultimate failure modes. Two numerical approaches were evaluated: the standard General Static solver and the Modified Riks (arc-length) method. The computational models assessed geometric instabilities, material softening, and sudden contact chatter inherent to the joint interfaces. Numerical simulations revealed that the General Static solver frequently failed to converge due to unresolvable contact singularities. Conversely, the Modified Riks method successfully traced the unstable post-buckling "snap-through" equilibrium path. Analysis pinpointed critical stress concentrations at the dowel interfaces, collar roots, and bolt-hole boundaries. Quantitative results demonstrated that modifying the joint geometry increased peak shear capacity from 44.1 kN to 62.9 kN. Additionally, introducing strategic reinforcement reduced residual displacement by up to 80% and increased residual shear force by 33%, effectively preventing localized brittle concrete tearing. Ultimately, the study concludes that pairing optimized reinforcement strategies with the Modified Riks model is essential for accurately quantifying ultimate stability, providing engineers with a superior predictive framework for designing robust modular infrastructure under extreme loading conditions.

Keywords: finite element analysis, interlocking jetty systems, Modified Riks method, modular bridge infrastructure, nonlinear stability