

# **BEHAVIOR AND DESIGN OF POST-INSTALLED REINFORCEMENT FOR LOW-INVASIVE RC BRIDGE SLAB WIDENING**

## **Abstract:**

Post-installed reinforcing bars are widely used in reinforced concrete (RC) bridge slab widening and rehabilitation, particularly for repairing deteriorated slab edges. Despite their extensive use in practice, current design approaches for post-installed bars remain inconsistent. Existing provisions either treat post-installed bars as equivalent cast-in reinforcement or as adhesive anchors, leading to large discrepancies in required embedment depths and uncertainty in governing failure modes. The primary objective of this study was to develop rational development-length and splice-length design models for post-installed reinforcing bars used in RC bridge slab widening. To address the limitations of current practice, a comprehensive experimental and numerical research program was conducted to understand force transfer mechanisms, bond behavior, and failure modes of post-installed bars and to establish a unified, semi-empirical design framework.

The investigation was conducted at multiple scales. Specimen-level single-bar and double-bar pull-out tests were used to study local bond behavior and bond-splitting failure, which commonly governs when post-installed bars are installed close to slab edges. The results showed that closely spaced bars interact significantly, leading to a reduction in load-carrying capacity compared to isolated bars. These interaction effects are particularly relevant for bridge widening applications, where post-installed bars are typically installed in groups.

Large-scale RC beam tests were conducted to study force transfer between post-installed bars and cast-in reinforcement splices under critical flexural loading. These tests were designed to simulate realistic bridge widening conditions and to evaluate the performance of post-installed bars under critical flexural loads. The results showed that inadequate splice length can lead to premature bond-splitting and reduced load capacity, before the yielding of steel is achieved. Furthermore, importance of using shear connectors to limit the crack width at the critical section was highlighted by these tests.

The experimental results were complemented by validated three-dimensional finite element simulations. The numerical analyses were used to systematically quantify the influence of individual parameters and to extend the experimental findings beyond the tested range. Based on the combined experimental and numerical results, a bond-splitting strength model for post-

installed bars was developed. This model was then used to derive mean-level development-length and splice-length expressions. Once the models were verified at the member level, a reliability analysis was performed to establish design-level provisions consistent with the safety concepts used in reinforced concrete design.

Finally, full-scale bridge slab widening tests were performed to serve as the proof-of concept tests to validate the proposed design models under realistic boundary conditions. Slab extensions constructed using post-installed bars were compared with conventional cast-in splice details. The results demonstrated that, when designed using the models developed within this project, post-installed bars can be designed reliably and generally result in reduced construction effort and minimal intrusion into the existing slab.

In addition, a nonlinear spring model was developed to represent the bond-splitting behavior of post-installed bars. The model captures strength, stiffness degradation, deformation capacity, and governing failure modes at the component level. The model was further extended to flexural members using proposed moment-rotation relationships and a lumped plasticity approach. This spring-based approach enables evaluation of the overall response of post-installed bar connections, supporting performance-based assessment and design.