PROJECT SUMMARY REPORT

0-7113: The Service and Ultimate Behavior of Bent-to-Column Joints in TxDOT Substructures

Background

Bridge substructures in Texas, particularly multi-column bents (Figure 1), have historically been designed with bent-to-column connections detailed primarily for axial loads, assuming a simple, pinned connection. However, low-probability, high-consequence extreme events such as vehicular collisions or the loss of a column from scour, place demands on these connections that far exceed their original design intent. These events can introduce significant moments and shear forces into the joint. Without a design philosophy that accounts for these forces, the connection can become a weak link, potentially leading to a brittle failure before the structure can develop a ductile, energy-dissipating response. This research was initiated to investigate the true behavior of these critical connections under extreme loads and to develop a modern, resilient design methodology to ensure the safety of TxDOT bridges.

Figure 1 Texas bridge substructure

What the Researchers Did

The researchers employed a multi-phase approach beginning with analytical modeling of typical TxDOT multi-column bents. Using plastic collapse mechanism analysis, they determined the flexural strength required to withstand the AASHTO-specified 600-kip vehicular collision load. This analysis established that while a ductile flexural failure in the columns is the ideal outcome, factors such as insufficiently anchored longitudinal bars or lack of joint confinement could lead to premature failure. Following this, the team conducted large-scale experimental testing on thirteen full-scale bent-to-column joint specimens under lateral loading (Figure 2). These tests simulated lateral loading from vehicle collisions to evaluate various detailing strategies, including different anchorage types (straight, hooked, and headed bars), joint confinement methods, and construction techniques. Finally, the experimental data was used to validate high-fidelity nonlinear finite element models (Figure 2), providing a deeper look at stress distributions and reinforcing bar development lengths under various conditions.

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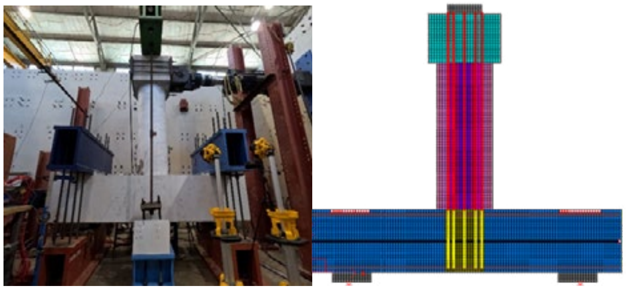

Figure 2 Experimental Program and Finite Element Model

What They Found

The combined analytical and experimental program produced several findings that directly inform new design standards. Most notably, the tests proved that standard TxDOT connections transfer significant moment, rendering the traditional "pinned" joint assumption inaccurate for extreme event analysis. While current standard details generally result in ductile performance, the research demonstrated that improved detailing significantly enhances capacity and damage tolerance. Specifically, the use of hooked or headed bars improved performance over straight bars by controlling bar slip and maintaining integrity at large deformations. Furthermore, adding transverse hoop reinforcement within the joint region enhanced post-peak behavior. Interestingly, the results indicated that current AASHTO and ACI code provisions for development lengths are conservative; the actual embedment required to develop reinforcement capacity was 30% to 40% less than calculated, offering an opportunity for more efficient designs in the future.

What This Means

This research provides a path for TxDOT to adopt a capacity-based plastic design philosophy for Extreme Event limit states. This approach ensures that during a collision or column loss, the structure responds in a predictable and ductile manner. For bridge engineers, this necessitates a design process that "protects" the connection and other components from brittle failure by ensuring the column's flexural capacity is the controlling factor. Key actionable recommendations include calculating shear demand based on the column's flexural overstrength (ΩM_n) to ensure a plastic hinge can form. Additionally, engineers should ensure the embedment length of column reinforcement satisfies AASHTO LRFD standards and provide dedicated transverse reinforcement, such as No. 4 hoops at 4-inch spacing, through the joint region if enhanced post-peak behavior is desired. By incorporating these recommendations into the TxDOT Bridge Design Manual, engineers can ensure that new bridges are significantly more robust, protecting both the infrastructure and the traveling public.

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