From Concept to Reality: Idaho Champions a Seismic-Resilient Precast Concrete Bridge Pier System

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Precast concrete offers many advantages over cast-in-place (CIP) concrete construction. It plays an important role in accelerated bridge construction, which aims to reduce traffic disruptions, improve quality, enhance on-site safety, and limit environmental impacts, among other benefits. Despite these advantages, the use of precast concrete in bridge substructures (such as piers) has been largely limited to non-seismic regions due to concerns about the strength and ductility of connections during earthquakes.

Recently, the Idaho Transportation Department (ITD) partnered with Idaho State University (ISU) to develop and validate the seismic performance of an innovative connection for precast concrete piers through large-scale experimental testing in ISU's structural laboratory. The project was conducted in two phases. The first focused on concept validation through large-scale testing of cantilever and bent specimens under simulated cyclic lateral loads and displacements, with performance compared against benchmark CIP samples.[1,2] The second phase focused on post-earthquake retrofitting strategies for the proposed precast concrete pier using ultra-high-performance concrete (UHPC).[3]

Concept

The precast concrete pier system uses precast concrete columns with concrete-filled steel (round, 8.625-in.-diameter HSS) tubes (CFSTs) protruding from each end (**Fig. 1**). The specified compressive strength for all test-specimen concrete was 4000 psi at 28 days. Each CFST fits inside a larger receiving HSS tube, with one receiving tube located in the precast concrete cap beam and another in the footing for the column-to-cap and column-to-footing connections, respectively. The gap between the CFST and the receiving tube (typically 0.5 to 1.0 in.) is grouted on site after assembly. The precast concrete cap may be solid or partially hollow, depending on size, weight, and transportation constraints.

Figure 1 shows the shop drawings for the proposed connection in a cantilevered

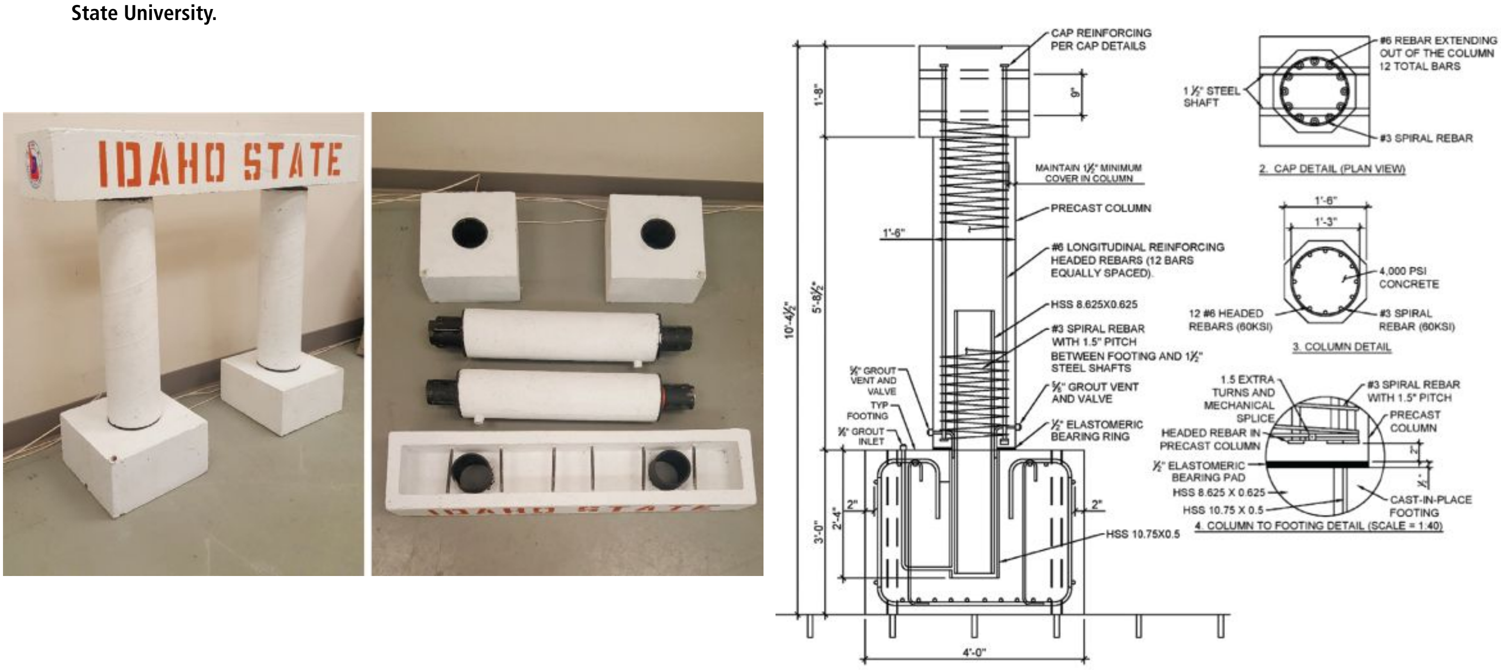

Figure 1. Components of the precast concrete pier system and shop drawings for the cantilever precast concrete pier. All Figures and Photos: Idaho State University.

precast concrete pier used for laboratory testing. An elastomeric pad is placed at the column-to-footing interface to help mitigate column cracking during smaller earthquakes by allowing limited rocking. For moderate to large earthquakes, the CFST located in the plastic-hinge zone provides shear strength, flexural resistance, and confinement. The proposed connection offers advantages, such as simplified construction and generous installation tolerances, which makes it a competitive alternative to other precast concrete connection systems such as grouted dowel connections.

Experimental Validation

Experimental validation of the ducts performed in ISU's structural laboratory involved four large-scale specimens: a CIP cantilevered column, a precast concrete cantilevered column, a two-pier CIP bent, and a two-pier precast concrete bent. The precast concrete connection concept for column-to-footing and column-to-cap are essentially the same (that is, CFSTs with HSS receiving tubes). For the cantilevered specimens, the focus was on the column-to-footing connection where the plastic hinge will be located. This plastic hinge location is applicable to both the CIP and precast concrete specimens. For the bent connection, both the column-to-footing and column-to-cap connections where plastic hinges will be formed were evaluated. **Figure 2** shows the experimental setup. Each specimen behaved as expected under quasi-cyclic lateral loading adopted from the loading protocol in the American Concrete Institute's *Guide for Testing Reinforced Concrete Structural Elements Under Slowly Applied Simulated Seismic Loads* (ACI 374).[4] The precast concrete specimens achieved greater energy dissipation and extended drift ratios for both the cantilevered (Fig. 2) and bent specimens, exhibiting better performance when subjected to seismic loading. Each test included a simulated vertical axial load throughout the experimental load protocol.

The CIP bent developed extensive cracking early in the test and ultimately failed after 15 cycles, following the fracture of the longitudinal reinforcement in the plastic hinges. In contrast, the precast concrete bent incorporating the HSS tubes in the plastic hinges showed noticeably less cracking but more pronounced spalling. Its failure occurred at 24 cycles, governed by deformation and eventual tearing of the HSS tube. Initial stiffness differed between the two specimens. The precast concrete bent reached 38.7 kip/in., compared with 56.7 kip/in. for the CIP bent. The difference was attributed to the flexibility in the precast concrete bent introduced by the elastomeric bearing. Although its stiffness was lower, the precast concrete bent achieved a higher ultimate lateral capacity of 71.4 kip, compared with 66.0 kip for the CIP bent.

The yielding performance of the specimens also varied. The CIP bent exhibited an initial drift of 0.5%, whereas the precast concrete bent yielded at 1.13%, which again reflects the added flexibility of the bearing pad. Global yield measurements showed the CIP bent reaching yield at 0.596 in. and 392 kip-ft, while the precast concrete bent yielded at 1.246 in. and 433 kip-ft. Energy dissipation further distinguished the precast concrete specimens as the higher-performing system. The lower stiffness of the precast concrete bent resulted in reduced early-cycle energy dissipation. However, as cycling progressed, the stabilizing effect of the HSS tube allowed the precast concrete system to develop a more consistent

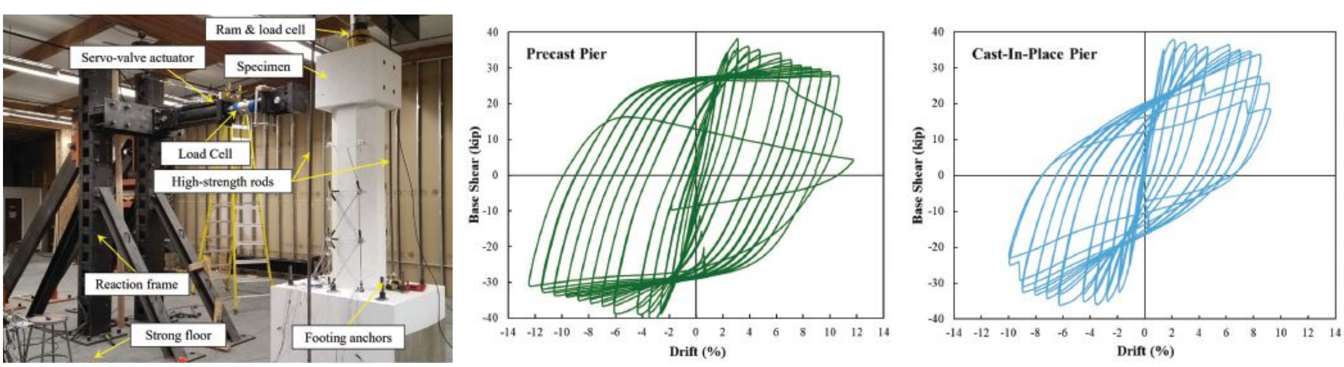

Figure 2. Experimental test setup and lateral force–drift hysteresis response for cantilevered piers.

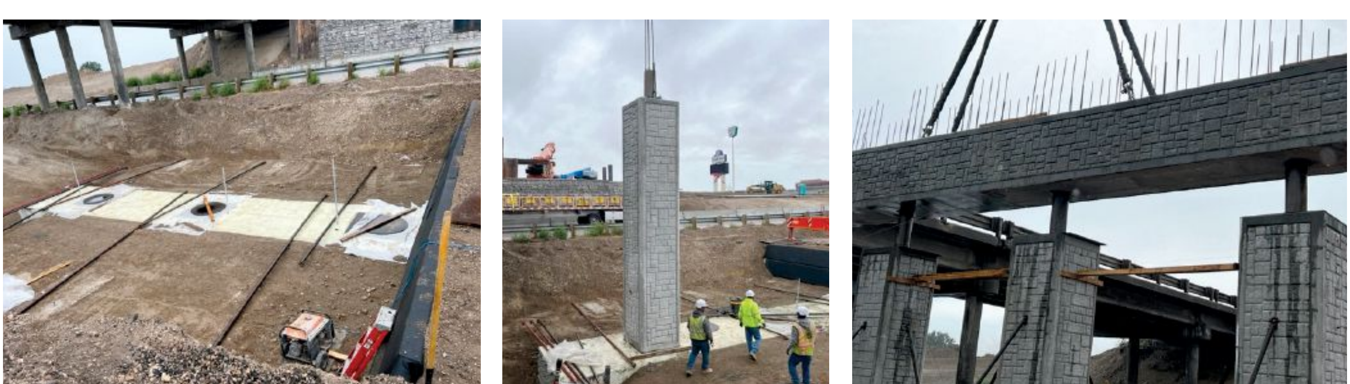

Figure 3. Construction of the Fort Hall Interchange Bridge over Interstate 15 in southeast Idaho. This project introduced seismically resilient precast concrete pier-element connections developed by Idaho State University and the Idaho Transportation Department.

Figure 4. The completed Fort Hall Interchange project features a 222-ft-long, 88-ft-wide bridge spanning Interstate 15 in Fort Hall, Idaho, with newly developed elements crucial for its location in a high-seismic region.

hysteretic response. At 15 cycles (the CIP bent failure point), the precast concrete bent had dissipated 466 kJ compared with 342 kJ for the CIP bent. The higher deformation capacity of the precast concrete bent enabled that specimen to complete 24 cycles, reaching a total cumulative energy dissipation of 2125 kJ.

Overall, the precast concrete system matched or exceeded the CIP performance, validating the proposed connection as an effective emulation of CIP behavior under seismic loading.

Implementation

The precast concrete pier connection was implemented in the design and construction of the Fort Hall Interchange over Interstate 15 in southeast Idaho, which is the most seismically active region in the state. The bridge is 222 ft long and consists of two spans. The innovative connection was used at the middle pier for the column-to-footing interface, while the column-to-cap connection was designed as "pipe pins."

The task of designing these innovative elements presented an engaging challenge for the bridge designers at ITD. The department consistently seeks methodologies to streamline and expedite construction processes, and the development of these CFST connections in collaboration with ISU constituted a significant achievement. Although there was a learning curve associated with integrating the new connection into ITD's standard design practices, the assistance provided by ISU's team facilitated smooth implementation without any complications.

The use of the CFST connection demonstrated a significant improvement over the conventional precast concrete connections. Typically, precast concrete elements are assembled by inserting multiple reinforcing bars (dowels) protruding from one element into corresponding ducts of the other element, a process that is time intensive and requires a high degree of precision during both casting and erection phases. In contrast, CFST construction simplified the assembly process from the precaster's yard to the jobsite, as it involved only a single component that needed to be placed and fitted (**Fig. 3**). The CFST system allows the contractor to erect the elements more efficiently and accelerates the overall timeline of the bridge. ITD received positive feedback about the connections from the contractor, who appreciated the ease of assembly. Furthermore, the contractor conveyed their desire for ITD to use CFSTs in future projects involving accelerated bridge construction.

Following the successful implementation at the Fort Hall Interchange (**Fig. 4**) and the favorable response from the contractor on that project, ITD is planning to employ CFST construction on upcoming bridges along the Interstate 15 corridor from Pocatello to Idaho Falls, Idaho. This corridor experiences high traffic volumes and provides access to several national and state parks. Therefore, any construction activities on this corridor must be expedited to minimize the disruption to the traveling public. The Fort Hall Interchange project demonstrated that CFST elements can effectively reduce the impact of construction for all parties involved.

Summary

The proposed precast concrete pier system offers advantages in seismic regions because of its simplicity and ease of installation. The precast concrete system uses HSS tubes filled with concrete to dissipate seismic energy, enhancing its performance and accelerating construction schedules.

References

1. Mashal, M., A. Ebrahimpour, M. Acharya, J. Cantrell, C. Marshall, and A. Shokrgozar. 2021. *A Precast Pier System for Accelerated Bridge Construction (ABC) in Idaho*. Idaho Transportation Department (ITD) Report 281. Boise, ID: ITD. https://apps.itd.idaho.gov/apps/research/Completed/RP281.pdf.
2. Acharya, M., J. Duran, A. Ebrahimpour, J. Cantrell, and M. Mashal. 2023. "A Fully Precast Pier System for Accelerated Bridge Construction in Seismic Regions." *ASCE Journal of Bridge Engineering* 28 (10). https://doi.org/10.1061/JBENF2.BEENG-6154.
3. Hogarth, K., M. Acharya, A. Ebrahimpour, and M. Mashal. 2023. Experimental *Validation of Repair Methods for Earthquake-Damaged Bridges Incorporating ITD's Precast Pier System*. ITD Report 302. Boise, ID: ITD. https://apps.itd.idaho.gov/apps/research/Completed/RP302.pdf.
4. American Concrete Institute (ACI). 2013. *Guide for Testing Reinforced Concrete Structural Elements Under Slowly Applied Simulated Seismic Loads*. ACI PRC-374.2-13. Farmington Hills, MI: ACI.

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