PUTTING RESEARCH TO WORK

BRIEF

# Composite Bridge Piles Show Hidden Strength

Wisconsin's approximately 13,700 bridges on the state and local highway systems are supported with tubular piles—steel cylinders filled with concrete that is poured at the construction site. The steel shell thickness ranges from 0.25 to 0.375 inches (with contractors often using thicker shells for drivability), yielding cast-in-place (CIP) pile diameters of 10.75 to 14 inches. These piles are driven 30 to 120 feet into the soil to support retaining walls and bridges. Engineers determine the size and number of CIP piles needed for a project based on the piles' load-bearing capacity and the frictional characteristics of the soil at the site.

## What's the Problem?

WisDOT's standard practice has been to design CIP piles conservatively by only considering a portion of the concrete core, neglecting both the structural contribution of the steel shell, and the full cross-sectional area of the concrete column in calculating the load-bearing capacity of the pile. With this approach, designers also do not consider the composite strength of the dual-material pile. This design methodology is consistent with procedures in the AASHTO LRFD design guide.

LRFD design guidance also allows for consideration of composite action if the area of the steel shell is at least 4% of the entire cross sectional area. The composite approach allows for consideration of the bond between the steel and concrete materials and the strength of the composite structure in estimating load bearing capacity. As a result, piles may offer considerably more strength than is accounted for in current designs. This may mean fewer CIP piles are needed per project, which would reduce project costs. Research was needed to examine the contributions of these factors to CIP piles' load-bearing capacity.

## Research Objectives

The overall objective of this project was to characterize the axial capacity of typical CIP piles as a means to evaluate which design approach is more representative of the piles used by WisDOT in bridge and retaining wall structures. In addressing this issue, the research would quantify the effect of composite action in pile capacity. In order to do so, two primary factors must be considered: the actual compressive strength of the in-place concrete, which free-falls into the steel shells as it is poured; and the composite action between the concrete core and the steel shell.

## Methodology

Investigators approached these goals with a series of laboratory experiments and with finite element modeling. They examined four piles: two 10.75-inch-diameter piles, one with a steel thickness of 0.375 inches and one with a thickness of 0.5 inches; and two 12.75-inch piles, both with steel shells 0.375 inches thick.

Steel shells were partially driven into the ground at a construction site in south-central Wisconsin and filled with concrete following WisDOT's standard practice. The piles were allowed to cure, and were then pulled from the ground and cut into sections for laboratory testing.

The strength was examined by testing various cross-sections in compression, including composite steel-concrete stub sections, concrete cores of the stubs, and composite stub sections where only the core area was loaded. The core compression test results were compared to results from concrete cylinders that had not been poured into steel shells in order to examine the quality of the concrete that had consolidated after free-falling into the steel shells.

The bonding of the steel and concrete was measured with flexural tests of pile sections and with push-through tests on the concrete cores within the steel shells. Finally, finite element modeling was used to compare the laboratory results with simulated performance under loading conditions realized on site.

Investigator

*"The in-place strength of these CIP piles was shown to be significantly greater than design strength."*

—Devin K. Harris
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The concrete-filled steel piles tested in this project significantly exceeded their design capacity.

## Results

The composite strength of each tested CIP pile exceeded current design values, in some cases by a factor of more than three. The bond between the steel and concrete was sufficient to establish composite action, enhancing performance. The test results also indicated that the method used for filling the steel shells with concrete provides a sound concrete core with adequate bond capacity and consolidation. Specific results included:

- **Composite sections.** During compression testing, the ultimate load-bearing capacity of the composite and concrete-only sections exceeded the loading machine's capacity, so the samples' true ultimate capacity could not be determined. All of the tested specimens achieved composite capacities that were 190 to 340 percent greater than the design capacity used by WisDOT.
- **Concrete sections.** Core-only testing found that the compressive strength of the concrete-only piles exceeded that of standard concrete cores not poured into steel shells. The method of filling pile shells with free-falling concrete appeared to enhance concrete strength.
- **Flexural testing of bond strength.** Four 11-foot pile sections were loaded laterally at three points to test the strength of the concrete-steel bond. One of the four specimens experienced interface slip due to a weld break. Internal cracking of the concrete occurred, but no slippage.
- **Push-through testing of bond strength.** For the 10.75-inch specimens, after initial slippage, resistance of the concrete cores decreased as loading increased. Friction between materials offered the only remaining resistance. For the 12.75-inch specimens, after initial slippage, the concrete cores supported further loading without slipping. Finite element modeling indicated that the shear stresses at the interfaces of the composite sections were small, suggesting that the bond is sufficient to withstand the required axial stresses.

## Implementation and Further Research

This study may lead to revisions in the WisDOT Bridge Manual to reflect higher load capacities for CIP piles. Follow-up research in this area could be undertaken in a number of directions. These include testing pile sections to establish upper load-bearing limits; evaluating core-only strength gain compared with control specimens; evaluating potentially less expensive alternative core materials; and conducting cost-benefit analyses of composite piles versus other pile systems.

*This brief summarizes Project 0092-09-04, "Evaluation of Constructed, Cast-in-Place (CIP) Piling Properties," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research Program, 4802 Sheboygan Ave., Madison, WI 53707.*

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Project Manager

***"If each pile can safely bear higher loads than accounted for in the design, we may be able to reduce the number of piles, saving time and dollars."***

—Jeff Horsfall
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Brief prepared by
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