Connection Details and Field Implementation of UHPC Piles – Phase II

tech transfer summary

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RESEARCH PROJECT TITLE

Connection Details and Field Implementation of UHPC Piles – Phase II

SPONSORS

Iowa Highway Research Board (IHRB Project TR-615)
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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Development of ultra-high-performance concrete (UHPC) pile connections and performance monitoring of a UHPC pile installed in a bridge were completed in this study to support field implementation of this new pile type.

Objective

The primary objective of this research was to improve the design of ultra-high-performance concrete (UHPC) piles through the development of suitable connection and splice details, and the verification of their performance under laboratory and field conditions.

Problem Statement

In current practice, bridges are generally founded on piles made of normal strength concrete, wood, steel, or a combination thereof. Such piles are susceptible to deterioration in harsh ground conditions and may be prone to damage during driving, thereby resulting in higher maintenance costs of bridges and reduced service lives.

Background

Through laboratory and field studies, the first phase of this project showed that UHPC can be efficiently used in precast and prestressed piling to improve foundation durability, reduce bridge maintenance costs, and extend the service life of a bridge.

UHPC is a cement matrix often used with steel fibers, and it has several advantages over other materials often included in bridge foundations. These advantages include strength, ductility, durability, and aesthetic design flexibility, which are achieved by eliminating the characteristic weaknesses of normal concrete.

Abutment where UHPC pile was installed in Sac County, Iowa

Project Description

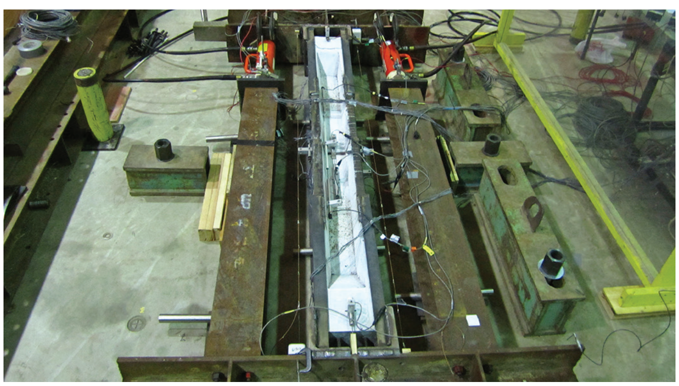
This study developed and evaluated the performance of UHPC pile connection details through both laboratory and field experiments. A production pile was then installed in a bridge abutment, and its performance was monitored for an extended period.

Laboratory Experiments

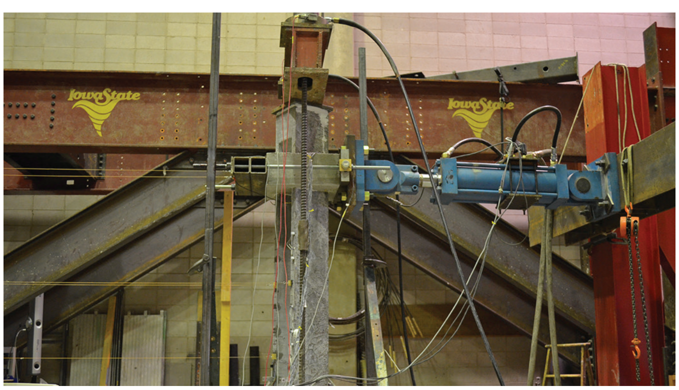
The research team investigated performance of a new splice detail that was developed for UHPC piles and a UHPC pile-to-abutment connection using a detail that is typical to Iowa Department of Transportation (DOT) abutments. In both experiments, full-size UHPC pile segments of various lengths were used, and the splice and connection were designed to be stronger, forcing any potential failure in the pile.

The splice design included steel angles with shear studs welded to an H-section plate, facilitating a dry connection in the field by welding two steel plates. Performance was evaluated under various loading conditions, including tension, shear, weak-axis bending, and strong-axis bending.

The team further investigated the behavior of the UHPC pile-to-abutment connection under weak-axis bending, strong-axis bending, and 30-degree-skew-direction bending. An additional reference test that included a steel HP 10 × 57 pile was also performed.



Tension testing the UHPC pile splice



Lateral load testing of a UHPC pile connected to an abutment block

The tests included a detailed instrumentation plan that allowed strains, curvature, and deflections to be captured at various locations of the test units.

Field Testing and Implementation

The splice performance was further investigated in a field testing program that included two instrumented UHPC piles. One pile did not include any splice and was used for the vertical load test, while the other included a splice and was the test unit in the lateral load test.

The piles were driven at a site that predominantly consisted of clay and silty clay, as determined from the borehole and cone penetration test (CPT) performed at the site.

A drivability analysis was conducted in DRIVEN and GRLWEAP to predict driving stresses and ensure that the stresses would be within acceptable limits. The pile instrumentation also included pile driving analyzer (PDA) equipment to monitor stresses during driving.

The UHPC test piles were driven after installation of the reaction-frame-anchor steel piles. While the lateral load test pile sustained no visible damage at the head after driving, slight damage was observed on the vertical load test pile.

UHPC pile driving in the field

UHPC pile toward the end of driving

Lateral load testing of a UHPC pile

The UHPC production pile was built, instrumented, and installed in the foundation of an actual integral bridge abutment. The pile was monitored over a period of 32 months to evaluate its performance under time-dependent cyclic lateral movements. Three of the HP 10 × 57 piles supporting the bridge abutments were also instrumented and monitored so that their performance could be compared with that of the UHPC pile.

Key Findings

Laboratory and field tests, as well as the implementation of a UHPC pile in an actual bridge project, provided strong evidence that UHPC piles can be a viable option for deep foundations. Further, the splice detail performed well during both laboratory and field experiments. More specific findings include the following:

- The newly designed UHPC pile splice with a welded connection was found to be suitable for use in design practice.
- In all pile-to-abutment connection tests, the piles and abutment blocks sustained only minimal cracking even at levels of pile displacements that are beyond those expected for piles in bridges.
- The measured strains in the reinforcing steel of the abutments were found to be well below the yield strain, confirming that the current Iowa DOT pile-to-abutment connection details can be satisfactorily used for UHPC piles for bending in the weak axis, strong axis, or with a 30-degree skew.
- Over the monitoring period, the UHPC production pile experienced an estimated maximum moment of 114 kip-in. with a corresponding lateral displacement of 0.2 in. Given that this moment is well below the value of 536 kip-in., which is the moment at which micro-cracking is expected to occur, the performance of the UHPC pile is considered satisfactory.

Implementation Readiness and Benefits

- The analysis showed that pile flexibility may be improved by a factor of two in the presence of a prebored hole.
- Both UHPC and steel piles performed satisfactorily under service and maximum allowable displacement; therefore, UHPC piles can be used in lieu of steel piles.
- The splice and connection details developed in this research aim to advance the use of UHPC piles in bridge foundations.
- Implementation of UHPC piles using the recommended design details has the potential to improve the durability and service life of bridges and reduce maintenance costs.
- By advancing the knowledge of UHPC piles and connections, this project provides a better foundation alternative for bridges.

Conclusions

The conclusions drawn from the pile analysis, production, handling, installation, feasibility, and performance of the piles in the laboratory and field are summarized as follows.

Pile Analysis

The parametric study of the UHPC pile in comparison with the HP 10 × 57 pile proved that the UHPC pile could be a viable option for supporting integral abutment bridges. At higher axial loads, such as 200 kips, it was found that the UHPC pile resisted cracking even at large target lateral displacements of 1.0 in. and 1.55 in. In comparison, HP 10 × 57 piles resisted yielding at the same target displacements. The strength benefits associated with increasing axial loads on UHPC piles supported their use in integral abutments.

The lateral load analysis conducted in LPILE supported the use of prebored holes for both UHPC piles and HP 10 × 57 piles, which are currently required by the Iowa DOT for bridges over 130 ft long. The benefit of the prebored holes was found to be that they minimize or prevent cracking of UHPC piles and yielding of H-piles to an acceptable level during the cyclic expansion and contraction of the bridge due to thermal movements.

Production, Handling, and Installation of UHPC Piles

The newly design pickup point for UHPC piles, which used a 1 in. diameter high-strength threaded rod, washers, and a nut, proved to be successful, but somewhat labor intensive, since a crew member had to be lifted by the crane to unhook the pile from the crane head before driving could begin. A release mechanism similar to that used for steel H-piles needs to be established to increase the efficiency during installation of UHPC piles in the field.

After the pile was positioned to be vertical, the UHPC pile could be set in the prebored hole in the same way as an HP 10 × 57 pile.

The benefit of the new pickup point was to have the pile hang in the vertical position as straight as possible to provide easy insertion into the prebored hole, which was successful in the field.

During installation, a void in the soil opened up near the web on both sides of the UHPC piles. The void for the 46 ft long test pile had a depth of approximately 5 ft, while the void for the 30 ft long test pile was 3 ft deep. This possibly indicates the occurrence and depth of the void to be related to the embedment length of the pile. Another likely parameter that may affect the size and occurrence of the void could be the soil condition at the site of installation. Analysis of UHPC piles should take this void into account when establishing the vertical load capacity and lateral load performance, as the void can have some limited influence on pile performance.

In some cases, minimal damage to the UHPC pile head was seen in the field after driving. The 30 ft test pile did not have any visible damage to the pile head after installation. The longer 46 ft and 56 ft UHPC piles sustained minor damage to the corners of the pile heads. This was believed to be due to not placing the hammer at the center of the pile head during installation, which should be given attention in the field.

Feasibility of Using UHPC Piles in Integral Abutments

The tests of the pile-to-abutment connection confirmed that the current Iowa DOT design of integral abutments with steel piles was robust and would accommodate UHPC piles as well. Even though two hairline tension cracks with negligibly small widths developed at 12 kips of the lateral load during testing in the laboratory under an axial load of 100 kips, they were considered acceptable based on previous experience with testing and use of UHPC members.

During the UHPC vertical load test in the field, the UHPC test pile reached an ultimate capacity of 297 kips, which was 49% greater than the estimated nominal capacity of 200 kips. The capacity measured during the field testing confirmed that a 16% shorter UHPC production pile compared to the HP 10 × 57 piles was appropriate for the Sac County bridge.

The UHPC lateral load piles in the field were tested to a maximum lateral load of 20.6 kips with a corresponding lateral displacement of 8.3 in. for the weak-axis pile. The weak-axis pile failed 3 ft above the splice. The soil was excavated around the 30 ft long test pile where a significant tension crack was discovered at approximately the location of the expected maximum moment. Within the design lateral movements of 1.55 in., the UHPC piles performed well and indicated no damage.

Performance of Pile Splice

The splice located 15 ft from the pile head performed very well during installation. No visible damage from driving or the lateral load test was found on or near the splice after excavation. Based on the field testing and additional laboratory tests, the performance of the splice in the field can be expected to meet the required shear, moment, and tensile demands.

Recommendations for Future Research

Although the research demonstrated that UHPC piles can be a practical option for bridge foundations, future work should be conducted with the following goals:

- Develop consistent tolerances and procedures to ensure quality production and prevent defects in piles
- Verify the performance of prebored holes through additional lateral load tests
- Investigate the use of battered UHPC piles in bridge piers, including their connections to pile caps and abutments
- Investigate additional sizes of the UHPC pile section to make it feasible for various soil and structural conditions
- Perform additional vertical load tests to improve UHPC pile capacity prediction and optimize pile length
- Develop improved installation procedures and pickup-point design
- Perform a detailed life-cycle cost analysis to increase cost efficiency of UHPC piles