Economic Pier-to-Pile Connections for Permanently Cased Shaft (CFST) Piles

Quarterly Progress Report
For the period ending June 30, 2021

Submitted by:
Dawn Lehman (PI)
Charles Roeder (co-PI)

Affiliation: Department of Civil and Environmental Engineering
University of Washington
Seattle, WA

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
Florida International University
Miami, FL

1. Background and Introduction

For seismic design of transportation structures, there are competing demands including: economy, strength, stiffness, inelastic deformation capacity, and seismic resilience. Prior research at the University of Washington (UW) demonstrates that concrete-filled steel tubes (CFSTs) can meet these competing demands. This proposed research builds on the prior CFST research to develop connections specific for use in wide range of transportation systems including bridges, high speed rail (HSR), and port structures. This study builds on a prior analytical investigation that directly connected reinforced concrete (RC) piers to steel cased shaft foundations with a focus on the length of the reinforcing bar and the need for supplemental internal connectors to enhance mechanical bond.

Accelerated bridge construction (ABC) of transportation systems is important and advantageous because it (1) reduces traffic interruption and downtime of the system, (2) reduces labor, and (3) reduces on-site construction time, which in turn, reduces cost. However, most ABC techniques focus on the superstructure and substructure, however, they do not address the foundation construction. However, foundations require a large percentage of the site construction time and more than 50% of the cost. The proposed system in this research uses CFSTs as piles and/or piers to address many of these issues. CFSTs will improve constructability and reduce cost, while improving seismic performance and resilience.

Using the prior finite element analysis (FEA) results as a basis for the future work and specimen design and selection, the research project will investigate the connection experimentally with a focus on the impact of the pier and pile diameters, bar size, bar length (embedment) and connector design. It is expected that two tests will be conducted which will be complementary with and extend current research that is being sponsored by Pacific Earthquake Engineering Research (PEER) center (referred to as PEER herein). The results will be used to determine design methods and nonlinear analytical models for these new connections.

2. Problem Statement

The research will investigate the connection and HSR system response using advanced, experimental methods. The team used high-resolution finite element modeling, salient parameters of selected connections, including materials, geometry, and soil-structure interaction which will be studied. Using the prior analytical work as a starting point, this project will investigate: (1) new seismically resilient pile-to-pier connections, and (2) developing new PBEE tools to inform design and evaluation of post-earthquake functionality. In addition, the PEER project, which is cost-sharing with this research, will study the system-level response.

The project includes two major tasks, jointly funded by PEER and FIU ABC, with the following objectives.

1. Experimentally investigate new pile-to-CFST pier connections for seismic resilience and ABC for the wide range of transportation modalities including bridges, ports and HSR. ***Deliverable***: design expressions and specification language for new construction. ***Milestones***: completion of testing (Month 8) & completion of design expression (Month 12). ***Joint/matching funding***: PEER
2. New nonlinear models for connections and CFST piles (and piers) for implementation in OpenSEES. ***Milestones***: completion of testing (Month 11) & completion of design expression

(Month 12). ***Deliverables***: new connection models implemented in OpenSEES. ***Joint/matching funding***: PEER

3. Research Approach and Methods

The overall goals of the proposed research are to:

- Investigate CFST connections and other column-to-pile connections through a literature review.
- Select column-to-pile connections for study based on the FEA results.
- Investigate the seismic response and resilience, including damage, of selected CFST connections using large-scale testing.
- Develop, in collaboration with WSDOT and Caltrans as well as other interested transportation agencies, new design methods for these connections.
- Develop a simplified nonlinear spring element to simulate the connection and pair the engineering demand parameters from the model to the damage states to provide tools for PBEE.

4. Description of Research Project Tasks

The following research tasks are proposed to achieve these objectives.

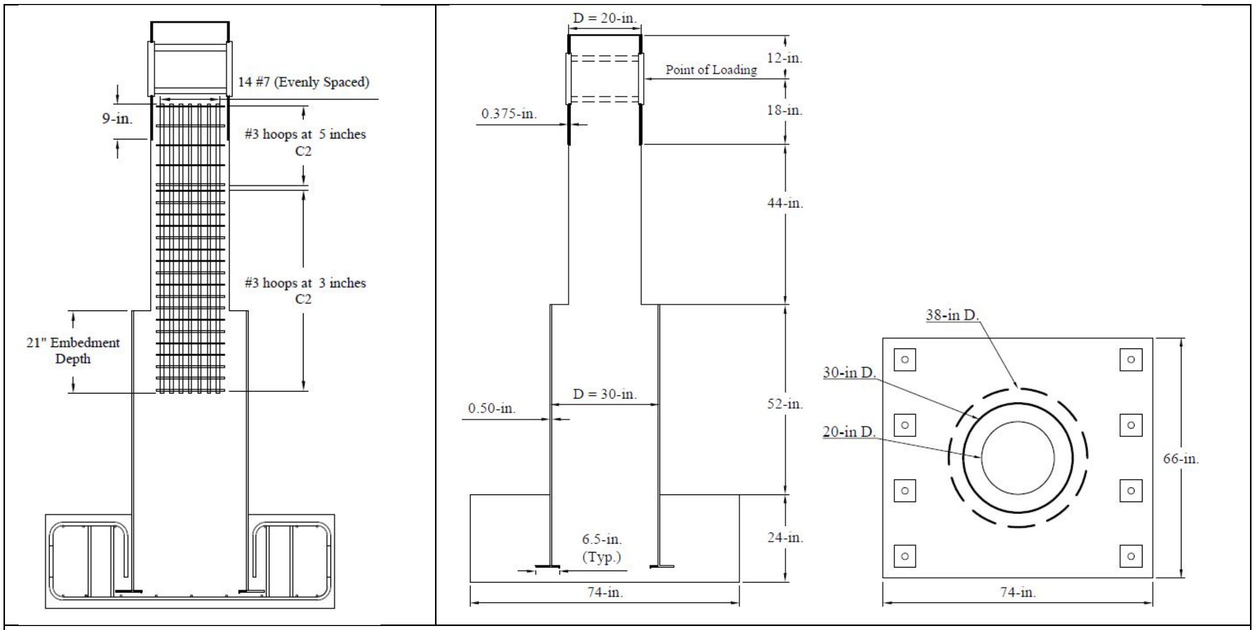
Note: Text in Bold indicates new work completed.

Task 1 – Literature Review and Agency Discussions.
A comprehensive review of past experimental research will be completed. Experimental results evaluating resistance, stiffness, and force-deflection of direct column-to-pile connections will be studied. This task is expected to be completed quickly, because the researchers are familiar with most of the past work through research performance on other CFST research projects funded by Caltrans and WSDOT. It is anticipated that Task 1 will be completed within the first two months of the research study.

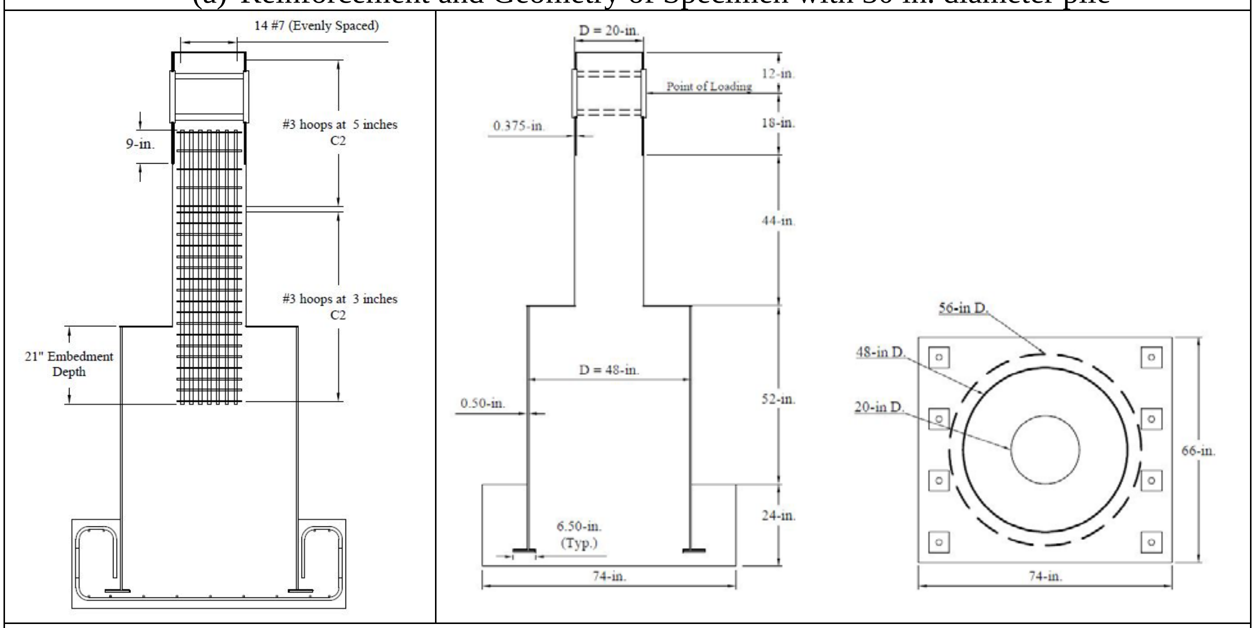
This work has been completed. It was summarized in a paper that the team has submitted for publication. The prior work on column to pile connections was primarily on RC systems; the team also unearthed some connection for RC to CFST components.

Task 2 – Select and Design Test Matrix.
The team, in collaboration with an oversight committee consisting of prominent engineers from WSDOT, ODOT and Caltrans, will select the test matrix using the results of the FEA. The UW team will arrange a call or calls to present the research results from the prior study funded by the FIU ABC center, including the impact of cyclic loading, bar size, relative pier to pile geometry and the connector size and layout. After two calls, a specimen test matrix will be designed and approved.

The team has met with WSDOT. An initial test matrix has been established. The reinforcing bar size will not be varied. Two different tube diameters will be studied. With and without supplemental mechanical connectors. (There are four specimens total). This task has been completed.



(a) Reinforcement and Geometry of Specimen with 30 in. diameter pile



(b) Reinforcement and Geometry of Specimen with 48 in. diameter pile

Figure 1. Test Specimens

The research team has constructed 4 test specimens. Figure 1 shows the basic test specimens with the primary differences in geometry is tube diameter for the pile. The other study parameters include: (a) use of a supplemental ring

1. **Specimen 1: <u>30-inch diameter</u> (Fgure 1a), no supplemental ring, conventional (2 cycles at increasing drift) drift history.**

2. **Specimen 2: 48-inch diameter tube (Figure 1b): no supplemental ring, conventional (2 cycles at increasing drift) drift history.**
3. **Specimen 3: 30-inch diameter (Fgure 1a), supplemental ring, conventional (2 cycles at increasing drift) drift history.**
4. **Specimen 4: 30-inch diameter (Fgure 1a), no supplemental ring, long-duration displacement history (TBD).**

Task 3 – Testing of Specimens.
PBEE of CFST piles foundation systems requires validated design and connection models. This task will provide the fundamental tests data for both. It is expected that two tests will be conducted, complementary to the testing being conducted as part of the PEER project. That project is focusing on one CFST pier-to-CFST pile and one RC pier-to-CFST pile connection. This project focuses on the connection between the RC pier and CFST pile specifically investigating the impact of connector layout and relative pier/pile diameter. The specimen is designed to test the transfer mechanism between the pier and CFST shaft with the objective of full hinging of the pier without connection damage.

The team has designed the specimens and instrumentation schemes.

Figure 2 shows the instrumentation scheme to measure the applied load, strains in the reinforcing steel (measured with traditional foil gages), strains in the steel tube (measured with vibrating wire gages), displacements along the height of the specimen and relative movement (slip) between the concrete and steel tube.

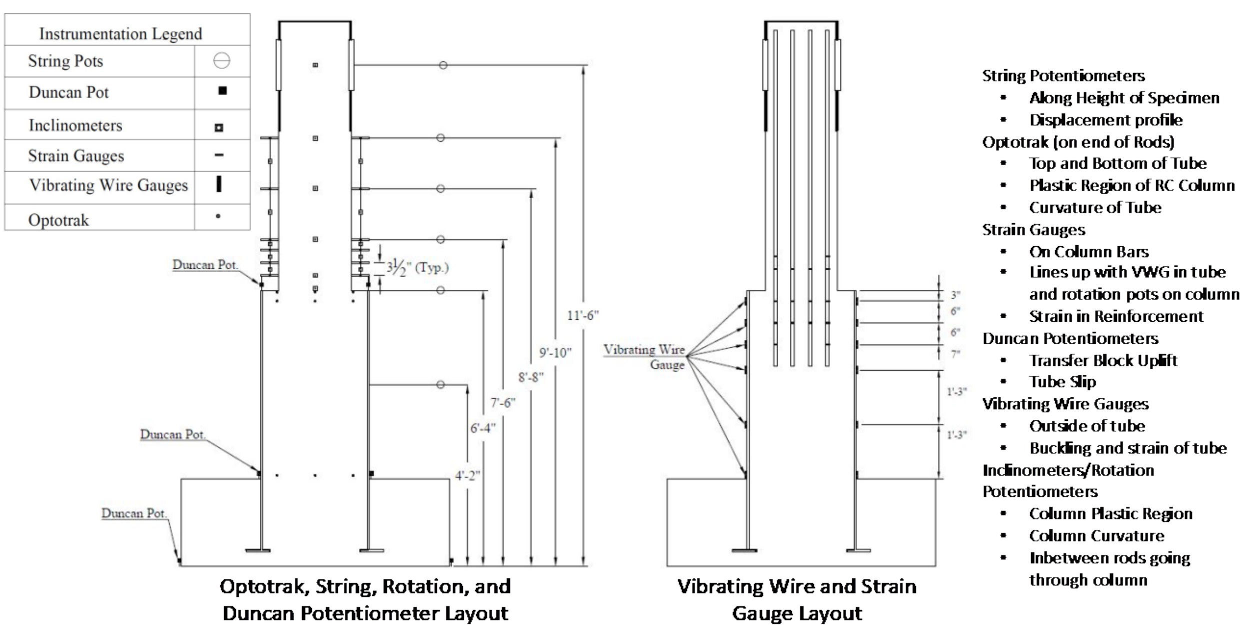


Figure 2. Instrumentation Used for Testing

Figure 3 shows selected test results for teh new direct reinforced column to cased shaft pile connection. A recent publication in Engineering Structures using high-resolution FEA to

demonstrate the need for additional mechanical bond to transfer the forces from the column to the pile if the pile-to-column diameter ratio is close to one; research shows that for a pile-to-column diameter ratio is close to two there is sufficient concrete to transfer the bond forces. In addition to pile diameter, this study investigations use of supplemental mechanical bond.

This is the link to the published paper:
https://www.sciencedirect.com/science/article/pii/S0141029620342139

Figure 3 shows some of the preliminary test results for the first two specimens without the ring. The progression of damage and base moment (note the base moment is plotted to eliminate the P-Delta component) for Specimen 30-21 (where 30 indicates the pile diameter and 21 indicates the embedement depth). The figure shows the difference in the response of the specimens with a pile (30 in.) to column (24 in) diameter ratio of 1.25 and a pile to column diameter of 2 (24 in. diameter column & 48 in. diameter pile). The figure on the left show the difference of the response of two different piles. Where degradation in strength for the specimen with the 30 in. diameter pile (left) initiates at approximately 4% drift, the specimen with the 48 in. diameter pile sustains its strength until 6% drift.

This type of connection holds promise for accelerated bridge construction as well as mitigating geohazards including scour, lateral spreading and liquefaction. In comparison with RC piles, piles with steel casings have more than twice the shear capacity and mitigate damage.

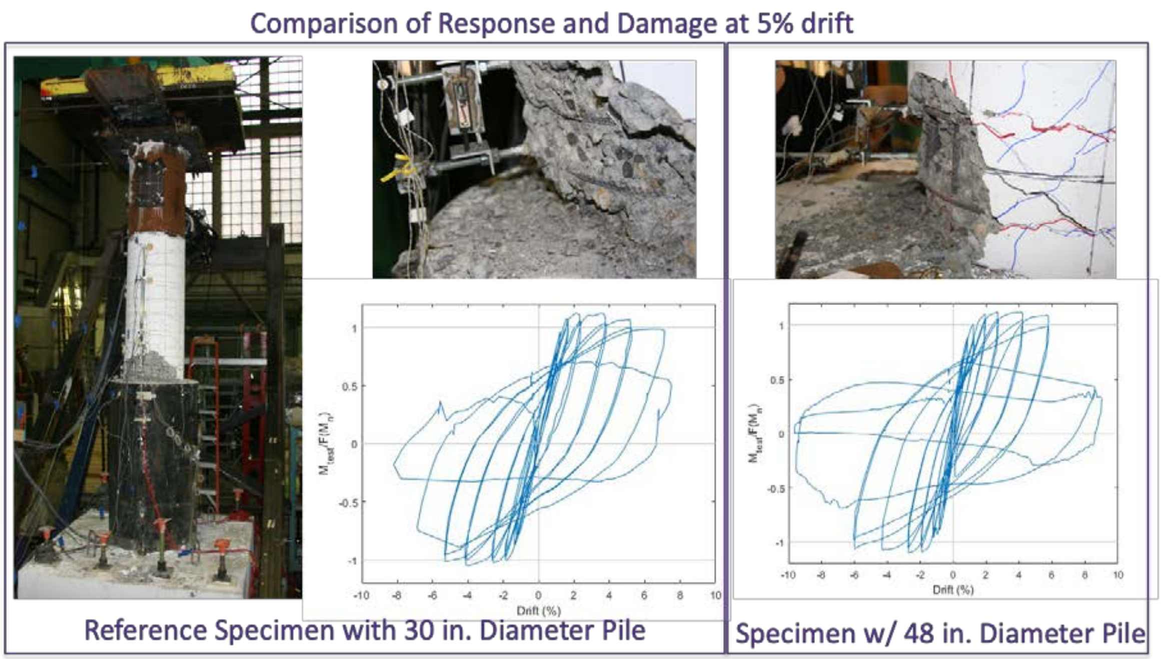


Figure 3: Comparison of Reference and Speicmen with Larger Pile Diameter: Response and Damage at 5% Drift

Task 4 – Development of Design and Analytical Tools.

In development.

Task 5 – Interim and Final Reporting.
The team will submit timely quarterly reports and present annually at the Research Days meeting. A final paper and report will be written that summarizes the methods used and the findings reached during the project. In addition, the results will be incorporated into the CFST course module.

5. Expected Results and Specific Deliverables

- Design expressions for the connections.
- Moment-rotation relations to enable nonlinear analysis of a system using the connections.
- A webinar that summarizes the project.
- Addition of these findings to the CFST module.
- Final Report and relevant journal publications

6. Schedule

Quarter 1 is going to be in Spring 2020 after a student is hired and a visiting student joins the project team.

Item	% Completed
Percentage of Completion of this project to Date	45%

Research Tasks	Q1	Q2	Q3	Q4
Task 1. Literature Review				
Task 2. Design of Test Specimen Matrix				
Task 3. Testing				
Task 4. Development of Design and Analysis Tools				
Task 5. Reporting				