Development of ABC Course Module - Design of CFST Components and Connections for Transportation Structures

Quarterly Progress Report
For the period ending February, 29, 2020

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

In seismic design of transportation structures there are several competing demands that must be met: high strength and stiffness, large ductility, damage resistance and efficient construction. Prior research at the UW demonstrates that concrete-filled tubes (CFTs) can meet these competing demands. For a given diameter, CFTs have larger strength and stiffness than an RC component. Testing of CFT connections demonstrates their ductility, with drift capacities larger than 8%. When used with precast components, CFTs facilitates ABC. This research uses the prior CFT research for use in structural systems for high-speed rail (HSR) and other transportation structures to develop a course module appropriate for structural engineers, DOT personell, constractors, educators and other interested stakeholders.

2. Problem Statement

ABC techniques with adequate seismic resistance have become a priority for many DOTs in regions of high seismicity. Concrete filled steel tube (CFST) columns offer an attractive ABC alternative to conventional precast concrete or structural steel construction in both seismic and non-seismic regions. While CFSTs optimize the mechanical contributions of both the steel tube and concrete fill while increasing construction efficiency, to date their implementation has been limited mainly due to uncertain design expressions and reliable connections. Research was undertaken to develop design expressions and connections to use CFST columns in bridge systems. Results from CFST component tests demonstrate that these members have high flexural strength and stiffness and approximately 2.5 times the shear strength of a similar RC column, making them ideal for piles subjected to large lateral forces. There is no need for internal reinforcement, including spiral reinforcement, as the spiral is not activated where the tube is present and the longitudinal reinforcement does little to contribute to the flexural strength. Over 30 tests have been conducted on two types of connections, one in which the CFST is terminate with a ring that is embedded into the adjacent component and the second where dowels are welded to the tube prior to construction and these dowels are debonded and terminated with a head to enhance ductility and provide efficient force transfer. These connection reach approximately 8% drift without strength deterioration. The results from the research have been implemented in the WashDOT BDM and AASHTO.

The course module will address component, connection, system behavior and design. Both CFST components and connections have been thoroughly evaluated using experimental and numerical (high-resolution, finite element modeling) research approaches. In addition, system-level evaluations have been conducted. The results from the work include new design expressions that have been implemented in AASHTO as well as state department of transportation design manuals. Advantages of the system included: (i) larger strength and stiffness for a given diameter in comparison with conventional RC construction, (ii) facilitation of accelerated bridge construction, (iii) improved constructability, (iv) use of environmentally-friendly (low cement) concrete for the concrete fill, and (v) improved seismic performance through damage mitigation. The course module will provide an overview of the research conducted, design expressions for the CFST components and connections, nonlinear modeling techniques, system-level response to vertical and lateral demands including earthquake and tsunami loading, and design examples.

This presentation describes the test results, design expressions and connection details and their implementation in the field.

3. Research Approach and Methods

The primary objective of development of this course is to introduce engineers to applications and design of concrete filled tubes and their connections. It is envisioned that this course will be approximately 2.5 to 3 hours in length. The course modules will be as follows.

- Module 1- Overview of CFT components and application to ABC: testing, design, and engineering tools with specification language from AASHTO and WSDOT. Design expression for bending, combined loading, flexural stiffness and shear strength will be provided. (30 minutes)
- Module 2- Connections for CFT piers in transportation structures with results from experimental investigations for two types of connections, an embedded ring connection and interior RC connection. Design examples will be provided. (45 minutes)
- Module 3- Analysis of CFT bridges with a focus on seismic performance. This module will provide analytical modeling tools for implementation in CSI bridge and a comparison of the seismic performance of CFT and RC bridges. (30 minutes)
- Module 4- (Alternative) Use of sustainable concrete with supplementary cementitious materials. Course module will discuss mix design based on the chemical composition of the binder to meet target strengths. In addition shrinkage and creep within the CFT will be discussed. (30 minutes)
- Module 5- Field implementation. In collaboration with WSDOT, this course model will provide examples of field application of CFT, specification language, and advantages and challenges of using CFT in bridge applications. (30 minutes).

4. Description of Research Project Tasks

Project tasks are provided and status is given in parenthesis.

- Task 1 – Develop outline for course materials. (Completed)
- Task 2 – Develop Module 1:
    - Overview and System Configuration. This module will address the fundamentals of composite construction, configurations to facilitate accelerated bridge construction, advantages of CFST relative to RC and precast construction, and examples of CFST components and connections implemented in recent bridge construction. (Completed)
    - In addition, material savings will be provided. (This task is ongoing in collaboration with KPFF and Skyline Steel)
- Task 3 – Develop Module 2: Component Design. This module will address material selection and response, geometric limits, strength expressions, and stiffness expressions.
    - This module will include discussion of materials including testing on CFSTs with low-cement concrete for improved sustainability and tube types (spiral and straight seam). (Completed)

- Both carbon steel and high-strength, micro-alloyed tubes (40 to 70 ksi steel) will be discussed. . (Completed)
- Research results from approximately 60 large-scale component tests and large parameter studies will be presented. (Completed)
- Design guidelines and expressions will include: (i) D/t ratio limits depending on loading (i.e. seismic vs. non-seismic) and component demands (i.e. axial vs. combined loading). (ii) composite action, (iii) flexural strength, (iv) flexural stiffness, (v) shear strength, and (vi) creep and shrinkage. The participants will be provided with electronic versions of design examples for the salient connections as well as copies of specification language. (This task is ongoing in collaboration with KPFF and Skyline Steel)

- Task 4 – Develop Module 3: Connection Design. This module will address connection design for ABC.
  - The module will include discussion of: (1) four different connections including application to pier to cap beam, pier to foundation (footing or pile cap) and pile to pile cap connection, (2) experimental research results of large-scale testing of all connections, (3) parametric studies used to extend the research results, (4) design expressions for each connection type, (Completed)
  - (5) examples of application of connections in current bridge construction. (completed)
  - The participants will be provided with electronic versions of design examples for the salient connections as well as copies of specification language. (This task is ongoing in collaboration with KPFF and Skyline Steel)

- Task 5 – Develop Module 4: Nonlinear Models for CFST.

  This module will address nonlinear modeling approaches for CFST components and connections. CFST component modeling will include constitutive models for the steel tube and concrete infill including confinement effects.
  - CFST connection models will use concentrated springs or zero-length fiber sections to simulate yielding of the tube or dowel bars (depending on the connection) into the adjacent component (i.e., cap beam or foundation element). (Completed)
  - Results from a case study for an RC bridge redesigned using CFST components will be presented, where the nonlinear analysis has been conducted using these nonlinear models. (A limited case study has been completed)

5. Expected Results and Specific Deliverables

Results and deliverables are one and the same: a multi-module course on CFT research, design, and implementation. It is expected that the UW research team will work collaboratively with others including WSDOT and Caltrans engineers.

6. Schedule

The schedule will be determined to correspond to other research groups and their development of the affiliated course modules.

The project is 88% complete.