NEW SESIMIC-RESISTING CONNECTIONS FOR CONCRETE-FILLED TUBE COMPONENTS IN HIGH-SPEED RAIL SYSTEMS

Quarterly Progress Report
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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 builds on the prior CFT research to develop connections specific for use in structural systems for high-speed rail (HSR). While the FIU study focuses on the column-to-cap connection, this study will investigate a new, untested direct column-to-pile connection. This connection is critical to the structural performance and cost of the system, but few studies have focused on it, in particular for ABC. This study will advance design and construction of pile connections for HSR.

2. Problem Statement

The research will investigate the connection and HSR system response using advanced, nonlinear analysis methods. A thorough literature review will identify types of connections and document their structural response; the UW team will work with the HSR team to identify one or more connections for further study. Using high-resolution finite element modeling, salient parameters of selected connections, including materials, geometry, and soil-structure interaction, will be studied. Those results will be used to develop spring and line-element nonlinear models of the components and connections as a function of the important connection parameters. The results will provide important initial guidelines for the connection design and seismic performance which will found a future experimental research study to validate the work.

3. Research Approach and Methods

The overall goals of the proposed research are to:

- Investigate CFT connections and other column-to-pile connections through a literature review.

- Select column-to-pile connections for study.

- Investigate the seismic response and resilience, including damage, of selected CFT connections using high-resolution finite element analyses.

- Develop simplified concentrated spring model for the connection.

- Report findings.

4. Description of Research Project Tasks

The following is a description of tasks. To date, the team is working on Tasks 1 and 3 and have initiated Task 2, in collaboration with FIU and other rsearchers at UW.

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 work is primarily completed although additional literature is being considered for model validation ongoing.

Task 2 –Collaboration and meeting(s) with CAHSR.
The UW research team has reached out to Parsons, the consultant on the first phase of the CAHSR. The have provided information to the PIs on the structural system and design criteria. The research team has not approached CAHSR at the request of PI Aziznamini.

Task 3 – Investigation of Connection Design Parameters though FEA

3.1 Model Validation Initial investigation of the CFT pile to column connection is ongoing. The to date the team has:
   (1) Validated the new concrete damage plasticity model in LSDyan with concrete material testing, as shown in Figure 2.
   (2) Validated the RC bond model using two different column tests (Figures 2 and 3)
   (3) Initiated the study of RC to CFT component tests that have been conducted previously to ensure the model is capable of capturing the salient transfer mechanisms and damage states. (Figures 4 and 5).

Figure 1 demonstrates the accuracy of the concrete damage plasticity model in LS Dyna to model cyclic response of plain concrete in both tension and compression.
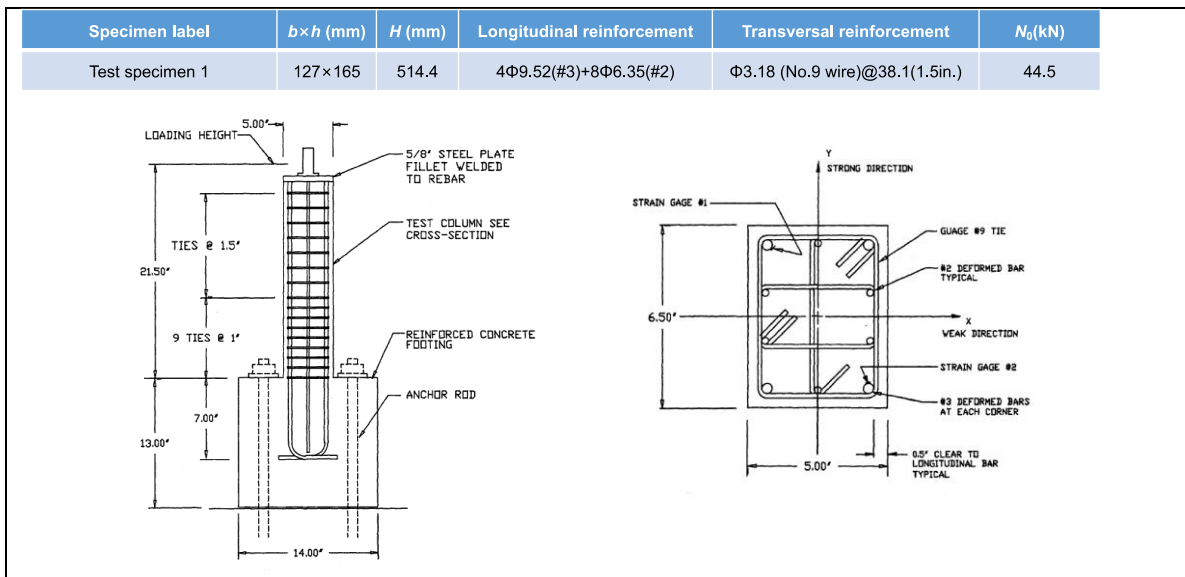

Figure 1. Validation of CDPM in LSDyna
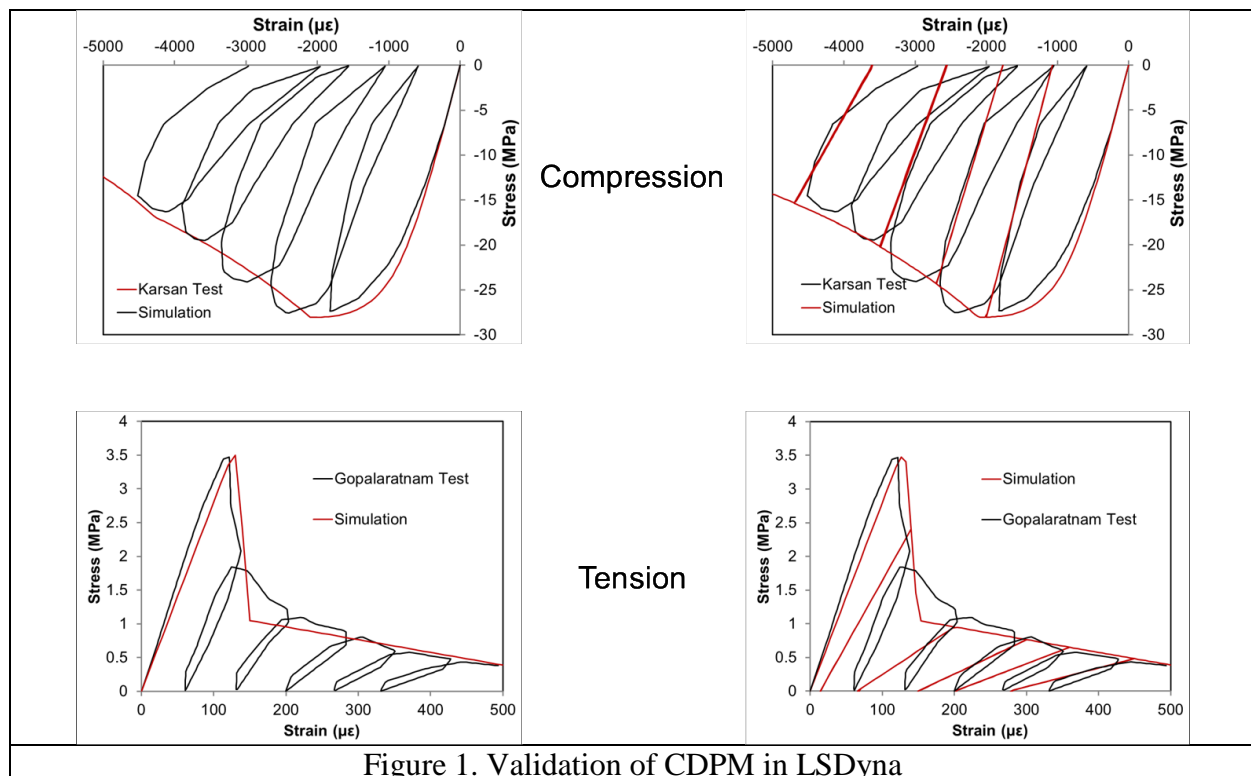
The current work is focusing on validating the LS-Dyna modeling approach including simulating RC and RC to CFT connection tests.

Validation of bond model. A study was conducted using selected experimental specimens from the following reference:

> *S. S. Low and J. P. Moehle, "Experimental study of reinforced concrete columns subjected to multi-axial cyclic loading," EERC Report 87/14, Earthquake Engineering Research Center, University of California, Berkeley, Berkeley, Calif, USA, 1987.*
> Figure 4a shows the specimen configuration, reinforcement and geometry. The concrete was modeling using the approach above. The bond was modeled using a bond slip element shown in Figure 2b, which includes degradation in the bond-slip response, a critical aspect of the proposed connection. Figure 2c compares the measured and simulated response. The LS-Dyna model is stiffer than the specimen; this might be because the bond-slip model is too stiff, the elastic modulus of the concrete was not correct and/or the model did not account for shrinkage. However, since the purpose of this validatation was to simulate the cyclic nonlinear response of the RC specimen, this is not critically important. The model simulates the strength of the specimen and drift response. However it overestimates the capacity in the negative loading direction. This simulation was considered sufficient to continue the model validation to including RC/CFT specimens.
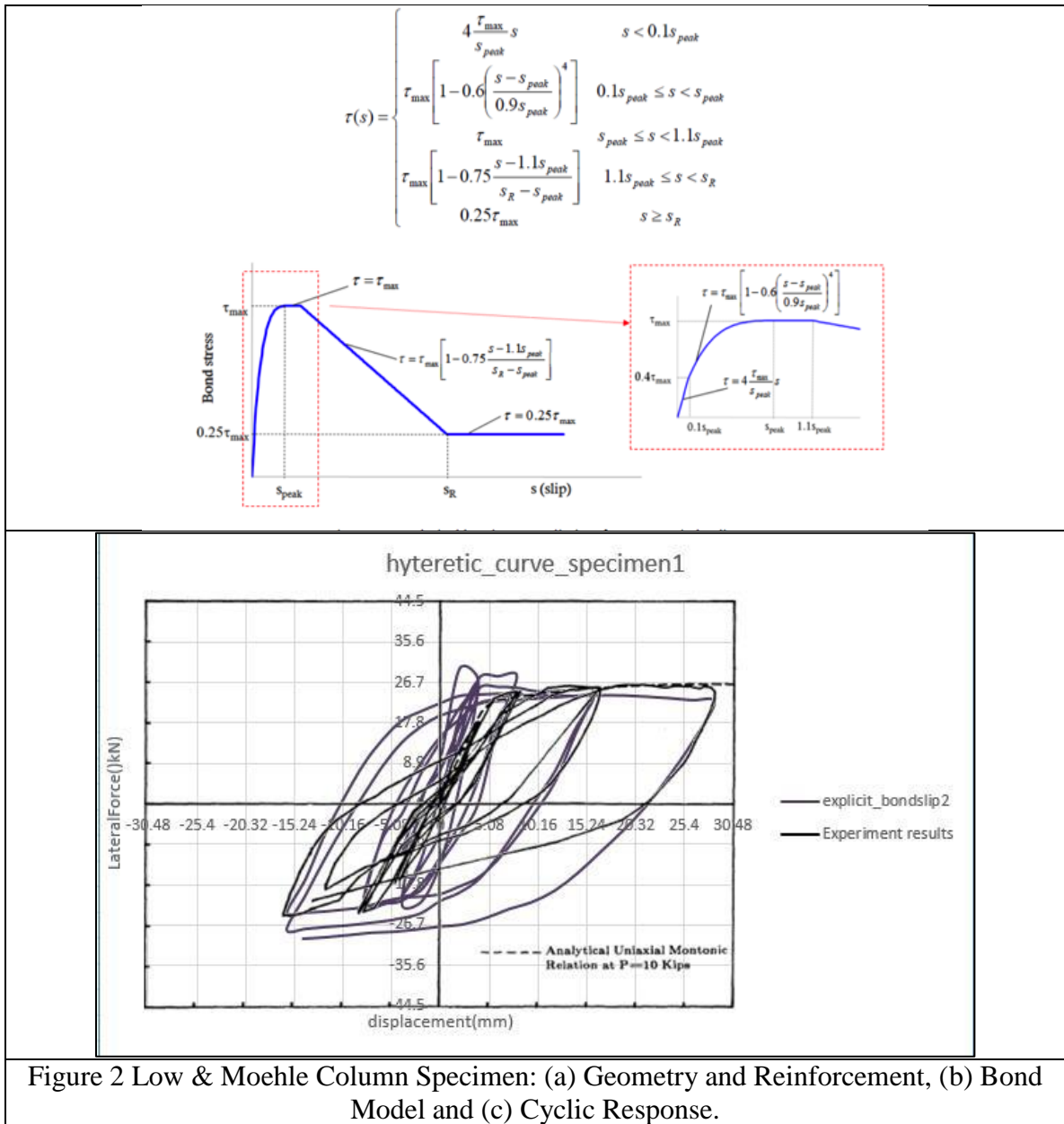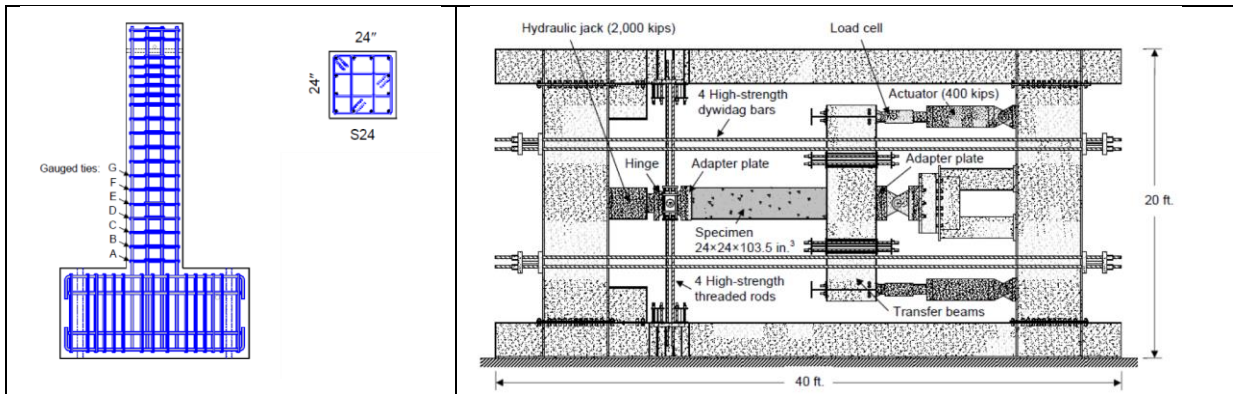
Specimen label	$b \times h$ (mm)	H (mm)	Longitudinal reinforcement	Transversal reinforcement	N_0(kN)
Test specimen 1	127×165	514.4	4Φ9.52(#3)+8Φ6.35(#2)	Φ3.18 (No.9 wire)@38.1(1.5in.)	44.5

$$\tau(s) = \begin{cases} 4\dfrac{\tau_{max}}{s_{peak}}s & s < 0.1s_{peak} \\[2mm] \tau_{max}\left[1-0.6\left(\dfrac{s-s_{peak}}{0.9s_{peak}}\right)^4\right] & 0.1s_{peak} \leq s < s_{peak} \\[2mm] \tau_{max} & s_{peak} \leq s < 1.1s_{peak} \\[2mm] \tau_{max}\left[1-0.75\dfrac{s-1.1s_{peak}}{s_R - s_{peak}}\right] & 1.1s_{peak} \leq s < s_R \\[2mm] 0.25\tau_{max} & s \geq s_R \end{cases}$$

Figure 2 Low & Moehle Column Specimen: (a) Geometry and Reinforcement, (b) Bond Model and (c) Cyclic Response.

The model was further validated using an RC specimen tested by Bae.
Reference: Bae (2006) "*Seismic Performance of Full-Scale Reinforced Concrete Columns*" PhD Dissertatioon, University of Texas, Austin. Figure 3 shows the geometry and reinforcement of the column. The predicted response matches the measured response well.

(a) Column Geometry and Test Setup

Specimen label	b×h (mm)	H (mm)	Longitudinal rebar	Transversal rebar	N_0(kN)
S24-5UT	554.5×554.5	2630	12Φ22.2(#7)	Φ12.7 (#4)@152.4(6 in.)	2955

(b) Specimen Reinforcement, Geometry and Axial Load
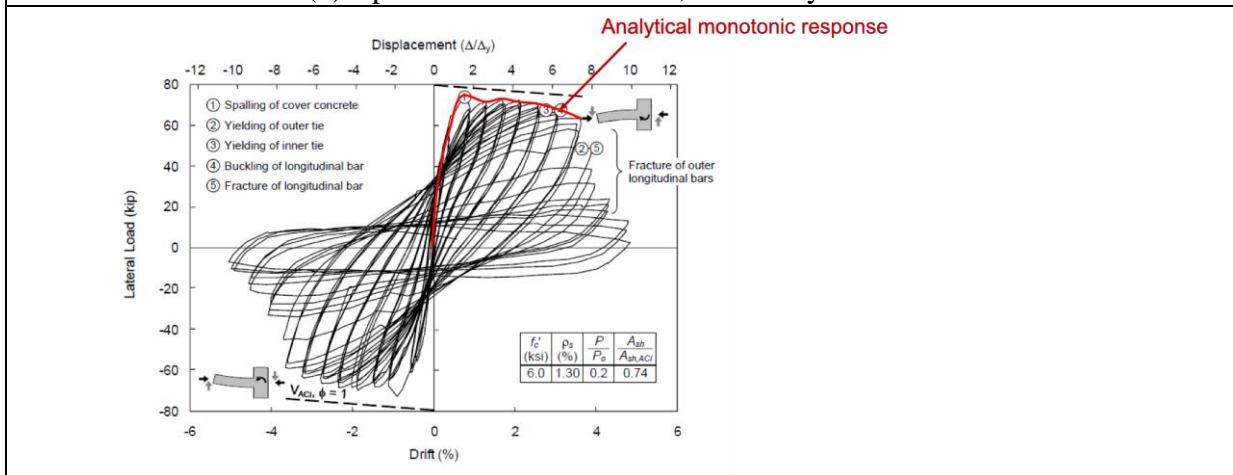

(c) Comparison of Measured and Simulated Responses (note only monotonic simulations were conducted).

Figure 3. Comparison of Tested and Simulated Responses of Bae RC Column Test

Validation of Modeling Approach for RC to CFT columns.

The PIs identified two relevant research projects that used RC columns embedded in concrete-filled steel tubes. Unfortunately one of the references, Lia et al. (2019) Seismic behavior of encased CFT column base connections, Engineering Structures, did not provide sufficient information for the specimen of interest. Instead the research team has focused on work conducted by the research group lead by L. H. Han, a very well known researcher in composite construction. The test specimen, results and comparison with the LS-DYNA model are provided in Figure 4. It is noted that the specimen had a sexagonal shape, which is different than the circular columns that will be studied as part of this research and the collaborative experimental effort that is funded by the PEER research center (https://peer.berkeley.edu/research/transportation-systems/projects). However the modeling has already been shown to be robust in simulating circular CFT specimens. This study was conducted to validate the bond model. As shown in Figure 4c, the specimen is simulated well by
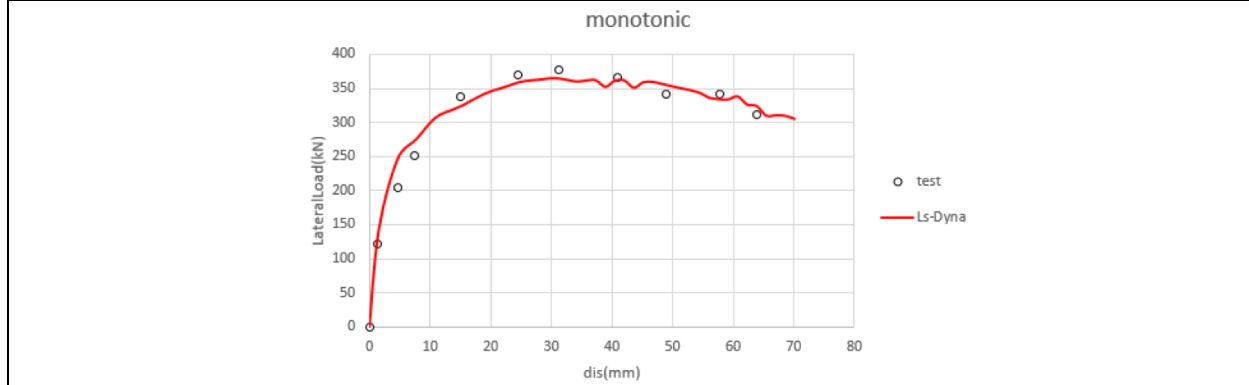
the proposed bumerical model with the bond model and additional confinement for the concrete in the CFT component.
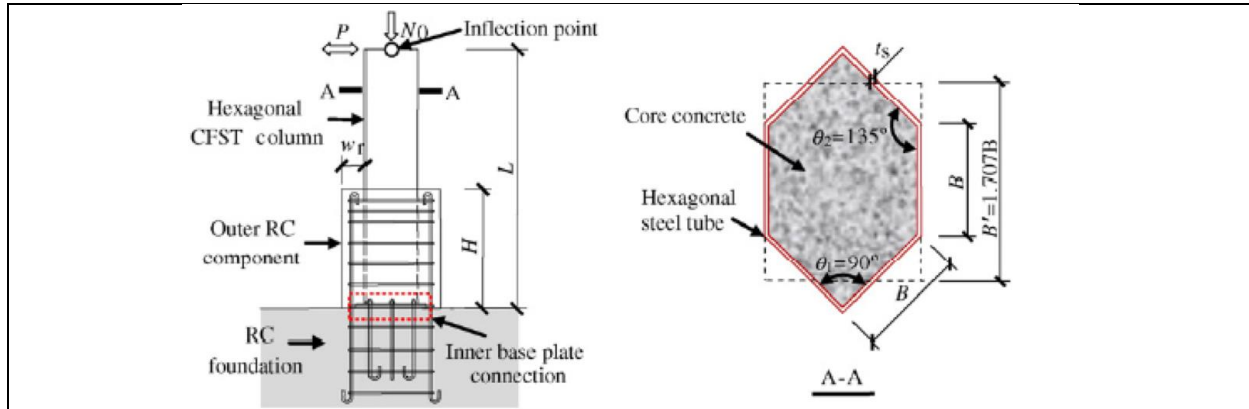
(a) Specimen Geometry and Reinforcment Layout
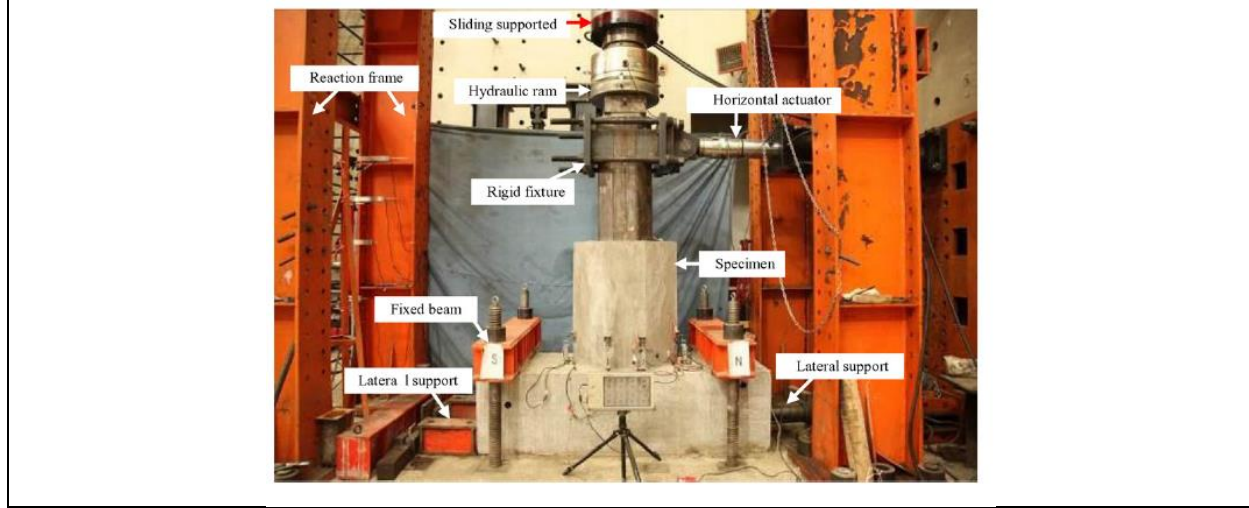
(b) Test Set Up

(c) Predicted Response

Figure 4. Test Specimen and Simulation for Han et al.

Task 4 – Final Report.
A Final Report will be written that summarizes the methods used and the findings reached during the project. This work has not been initiated.

5. Expected Results and Specific Deliverables

Tentative ABC-UTC Guidelines for Design and Behavior of Column-to-Pile Connections.
Initial guidelines will be developed for the connection designs. These designs are conceptual and expected to be followed by experimental testing; this testing is critical to investigate the salient design methods and parameters as well as to validate the modeling approaches. To the extent possible will take into account the conditions in which the HSR is to be built (e.g. seismic vs. non-seismic, soil-structure interaction for different soil conditions, etc.) Seismic conditions will be a primary design constraint given the focus on the California HSR route.

6. Schedule

The following is a revised schedule with Task 4 removed.

Task Number and Description		Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4
Task 1	Literature Review	███			
Task 2	Meeting with CA HSR		███		
Task 3	Parametric Study		███	███	███
Task 4	Removed				
Task 5	Report				███