Evaluation of Hollow-Core-FRP-Concrete-Steel Column and Footing Connection

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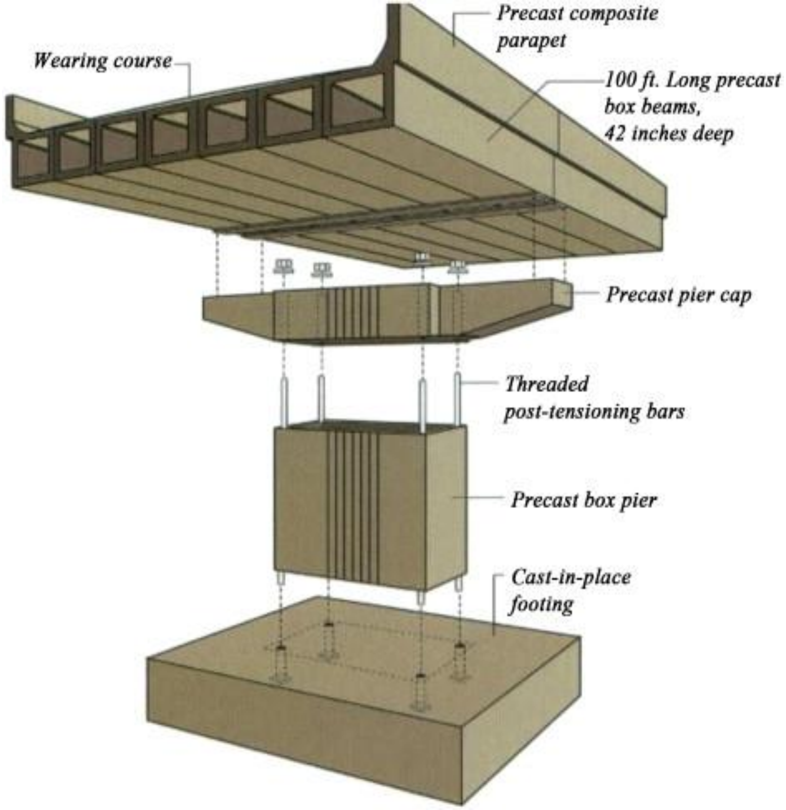
Outline

Introduction → Literature Review → Research Objectives → Approach & Methodology → Preliminary Results → Next Steps

Introduction

Accelerated Bridge Construction (ABC)

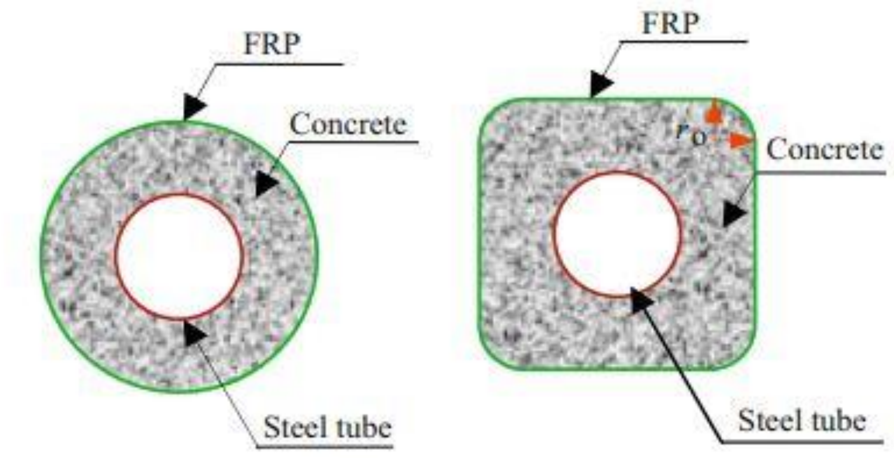
- Prefabricated elements
- Significant for rehabilitation
- Advantages:
  - Site constructability
  - Traffic flow
  - Work zone safety
  - Project delivery time



(Photo courtesy of FHWA.)

Column Design for Accelerating Substructure Construction

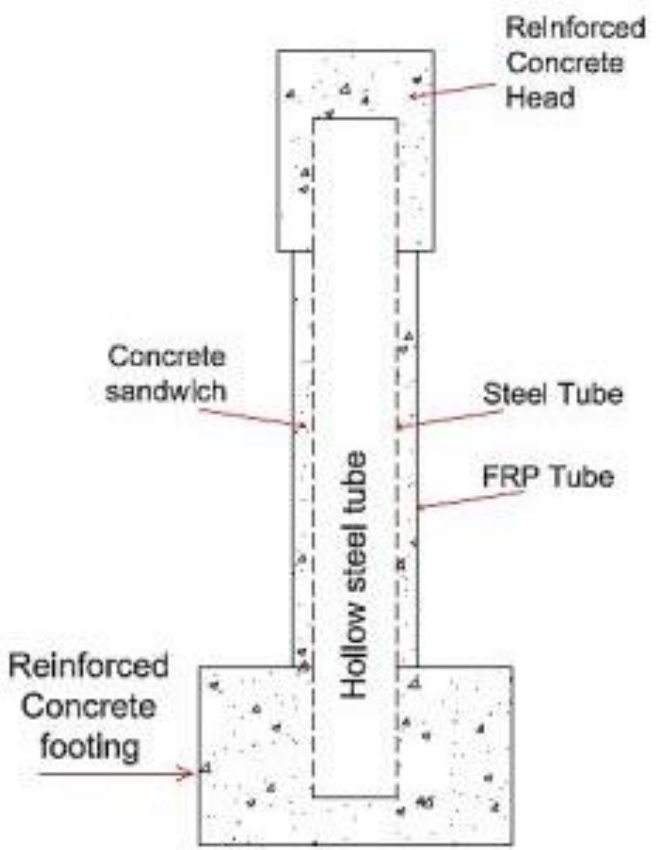
- Hollow-Core FRP-concrete-steel columns (HC-FCS)
  - 60% to 75 % less material
  - Confinement of concrete
  - Stay-in-place formwork



Cross-section view of HC-FCS (Lu Han, 2010)

HC-FCS Columns

- Composite column
  - FRP
  - Concrete shell
  - Steel pipe
- The steel pipe is used to connect to the footing



General Arrangement of HC-FCS
(El-Gawady, 2018)

Literature Review

Column Designs for ABC

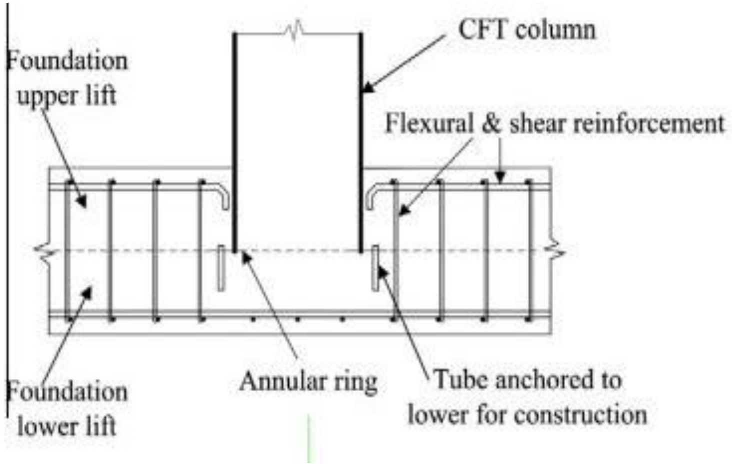
- Concrete-filled steel tubes (CFSTs)
- Concrete-filled FRP tubes (CFFTs)
- Hollow-core concrete columns
- Hollow-core FRP concrete columns (HC-FCS)

Hollow-core concrete columns (LintelTech)

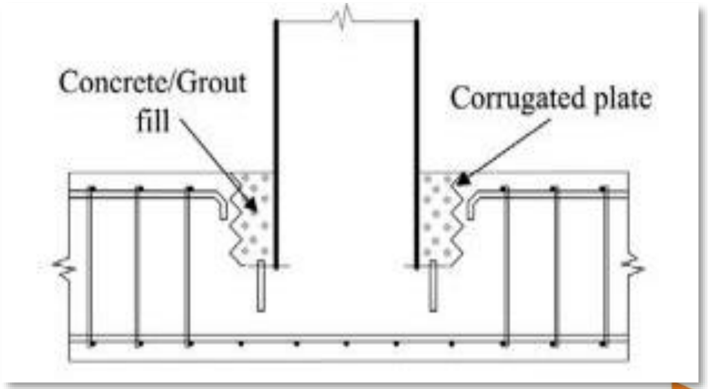
CFST columns (Khaleghi, Bijan)

Column-Footing Connection Designs

- Lehman & Moon, 2013
  - CFT columns
- Monolithic & socket connections
- Connection design
  - Develop ultimate strength
  - Provide ultimate ductility in seismic regions
  - No significant slip
  - Simple and economical for ABC



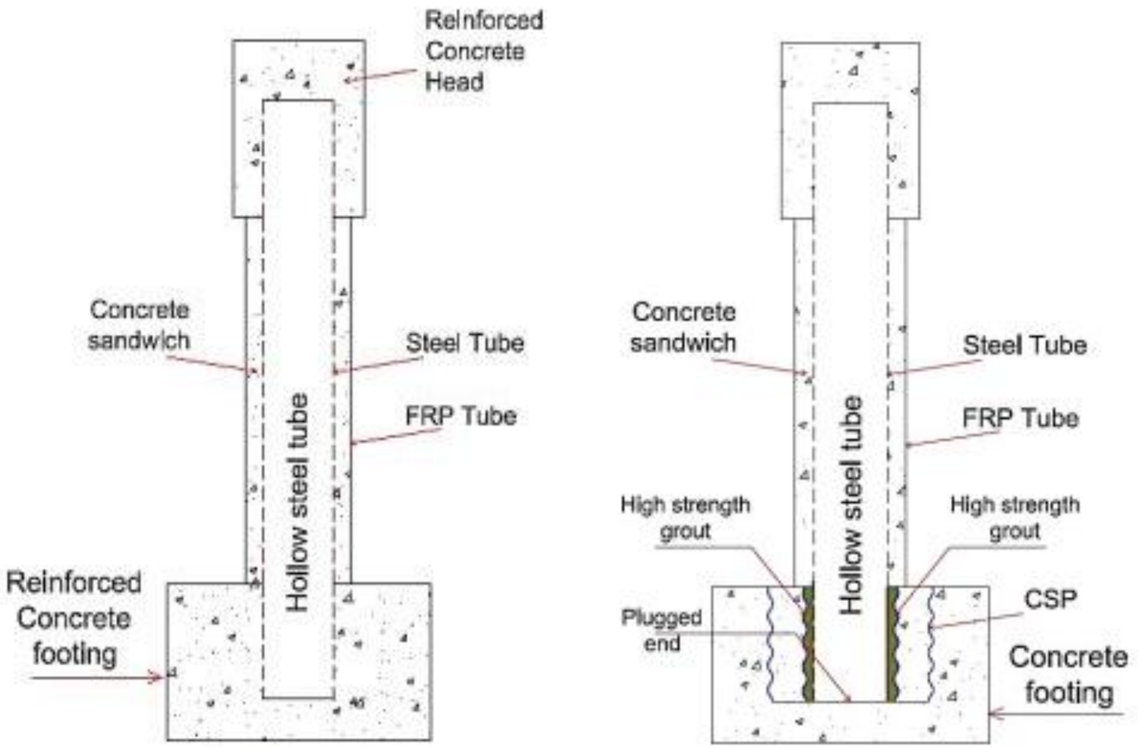
Monolithic connection (Moon, 2013)



Socket connection (Moon, 2013)

ElGawady, 2015 and 2018

- HC-FCS columns
- Monolithic vs socket connections
- Socket
  - Developed the column's plastic flexural capacity
  - Better ductility and energy dissipation than monolithic



HC-FCS column connection types
(El-Gawady, 2018)

Research Objectives

Research Objectives

Evaluate the effect of inner steel tube thicknesses and embedment lengths on the column-footing connection

Identify the required embedment length to achieve the ultimate flexural capacity and shear capacity of the HC-FCS column.

Evaluate the effect of the footing compressive strength concrete and the use of socket connection with Ultra-High-Performance-Concrete (UHPC) to develop full fixity of the HC-FCS column

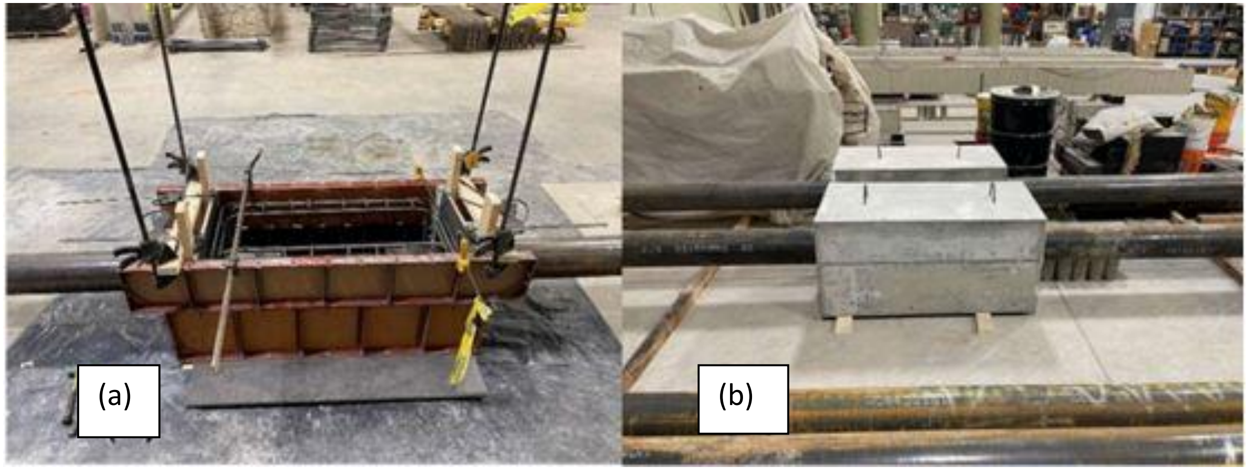
Approach & Methodology

Design Approach

- Column capacity calculations
  - Based on a current project
  - Methods from Moon, 2013 and ElGawady, 2015
- Footing design
  - Support nominal capacities of HC-FCS
  - Failure in the column or connection
- Trial specimen
  - Smaller representation of the test specimens

Small-Scale Column Connection Specimens

- Steel pipe and footing
- Dimensions
  - 2-ft by 2-ft by 4-ft
  - 7-ft-4-in. extension of steel pipes
- Tested as a simply supported beam
- Potential failures investigated
  - Steel pipe flexure
  - Pullout failure
  - Footing failure



Specimen 1 (a) formwork setup and (b) at 7-days of age

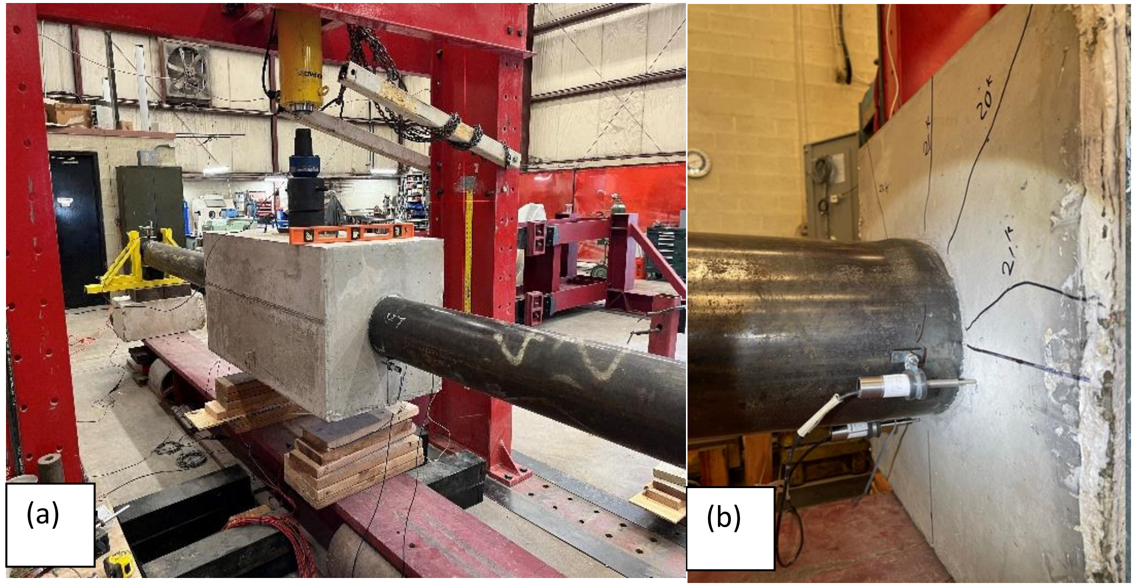
Parameter Matrix

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen1	1.6D	8.625/.219	10000	Monolithic
Column-Footing Specimen2	1.8D	8.625/.219	10000	Monolithic
Column-Footing Specimen3	1.6D	8.625/.219	5000	Monolithic
Column-Footing Specimen4	1.8D	8.625/.219	5000	Monolithic
Column-Footing Specimen5	Eq.	8.625/.219	5000	Monolithic
Column-Footing Specimen6	1.6D	8.625/.219	5000	Monolthic with Shear Lugs
Column-Footing Specimen7	1.6D	6.625/.25	5000	Monolithic
Column-Footing Specimen8	1.6D	8.625/.219	5000	Socket
Column-Footing Specimen9	1.6D	8.625/.219	5000	Socket

Preliminary Results

Column-Footing Specimen 1

- Failure Load of 21,054 lb
- Steel pipe local buckling
  - No damage in the footing
- No Significant Separation

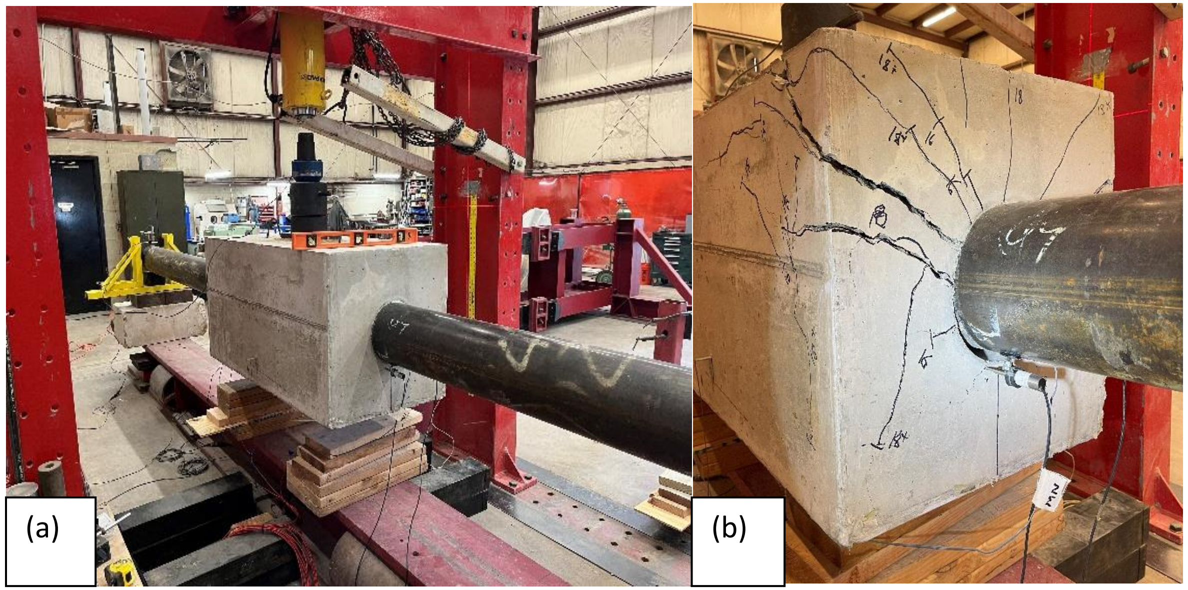


Specimen 1 (a) loading set up and (b) local buckling failure of the steel pipe

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen1	1.6D	8.625/.219	10000	Monolithic

Column-Footing Specimen 3

- Failure Load of 18,984 lb
- Pullout failure
  - Separation of more than 2 in.
  - Significant damage in the footing

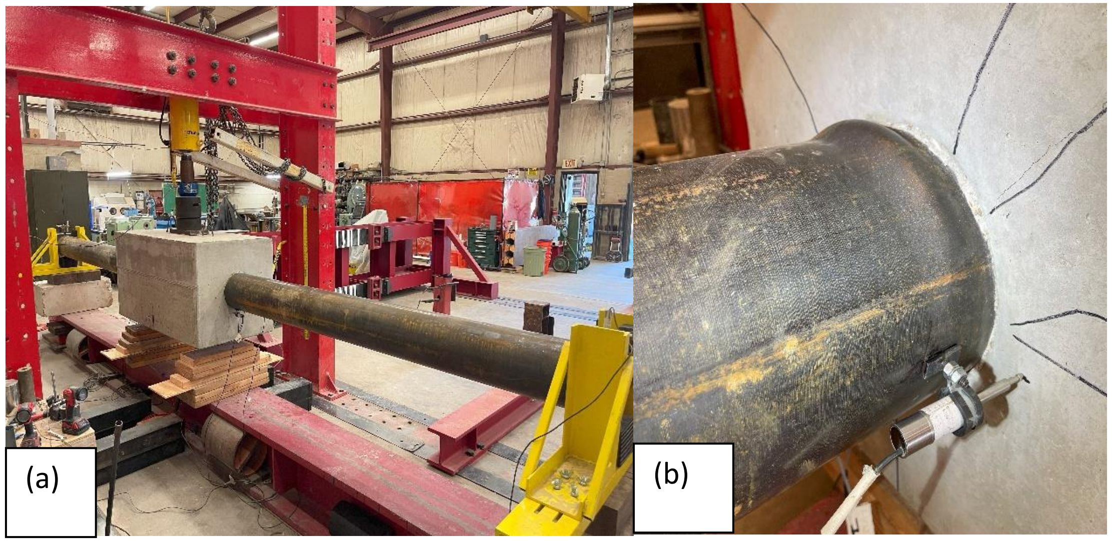


Specimen 3 (a) loading set up and (b) pullout failure

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen3	1.6D	8.625/.219	5000	Monolithic

Column-Footing Specimen 4

- Failure Load of 20,740 lb
- Steel pipe local buckling
  - Some damage in the footing
- Separation approximately 0.25 in.

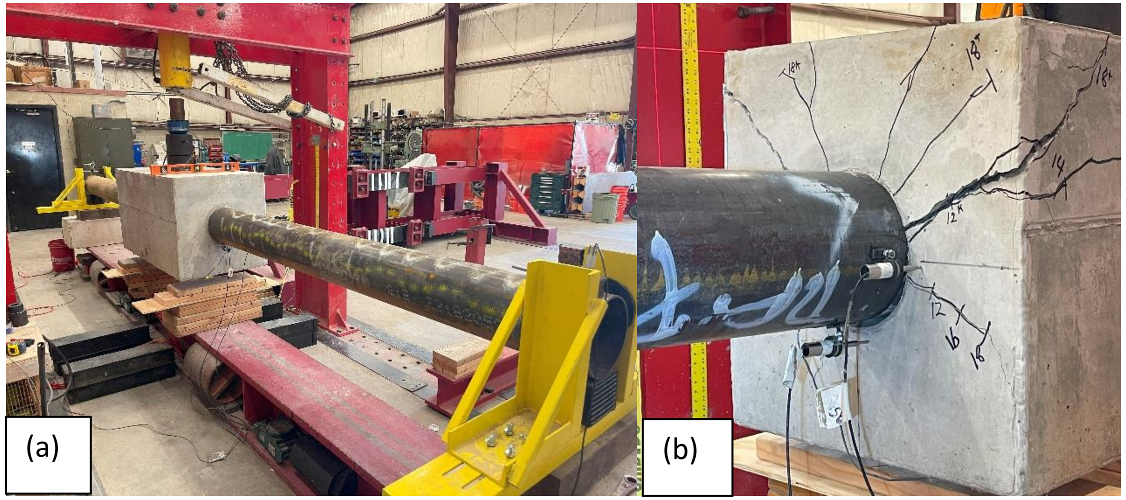


Specimen 4 (a) loading set up and (b) local buckling failure of the steel pipe

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen4	1.8D	8.625/.219	5000	Monolithic

Column-Footing Specimen 5

- Failure Load of 18,109 lb
- Pullout failure
  - Separation more than 2 in.
  - Significant damage in the footing



Specimen 5 (a) loading set up and (b) pullout failure

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen5	Eq.	8.625/.219	5000	Monolithic

Embedment length equation derived from Moon, 2013

Column-Footing Specimen 6

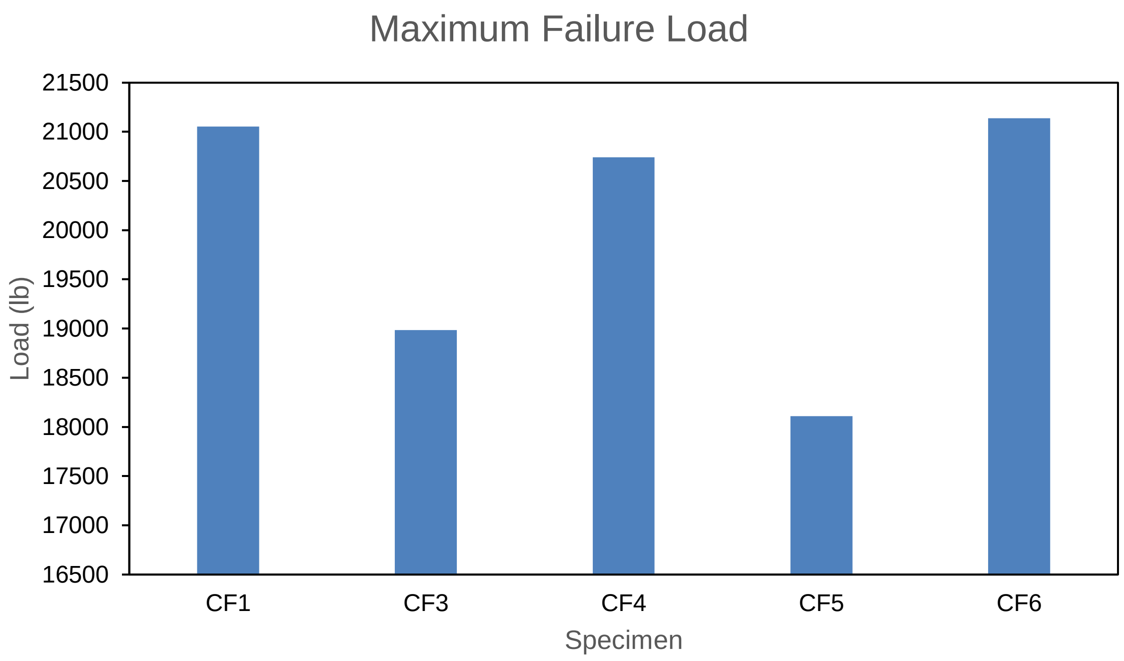
- Failure Load of 21,136 lb
- Footing failure
  - Pullout failure occurred
  - Separation more than 3 in.

Specimen 6 (a) loading set up and (b) pullout failure

Specimen	Embedment Length (in)	Diameter/ Thickness	f'c (psi)	Connection
Column-Footing Specimen6	1.6D	8.625/.219	5000	Monolthic with Shear Lugs

Preliminary Findings

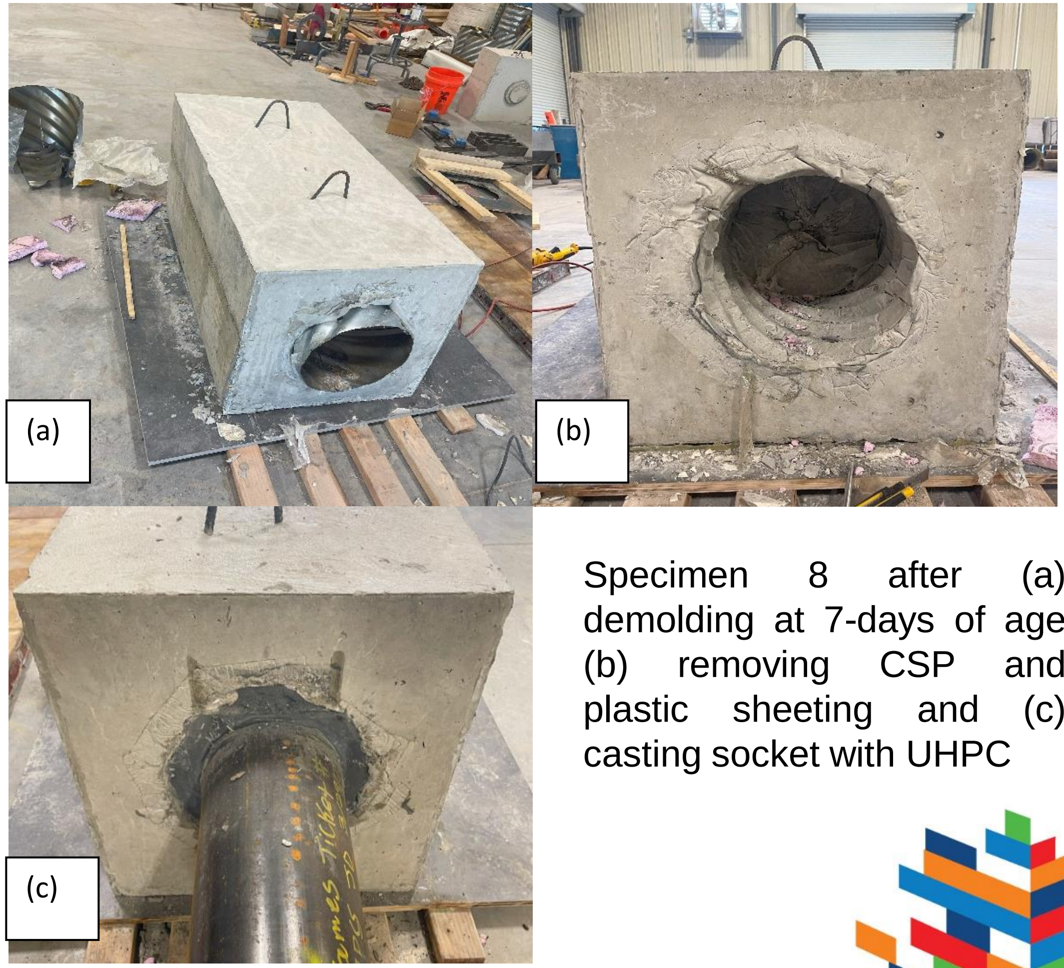
- CF1, CF4, and CF6
  - Failure load exceeded 20,000 lb
  - Steel pipe local buckling for CF1 and CF4
  - Footing failure for CF6
- CF3 and CF5
  - Not sufficient embedment length
  - Pullout failure



Next Steps

Socket Connection Specimens

- Two trial specimens
  - Corrugated Steel Pipe (CSP) and plastic sheeting
  - Sand blasted surface
  - Socket thickness is 1.5-2 in. filled with UHPC



Specimen 8 after (a) demolding at 7-days of age (b) removing CSP and plastic sheeting and (c) casting socket with UHPC

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Thank you!

Questions?