ABC-UTC 2023 In-Depth Web Training
Module 6
ABC-UTC Research Outputs Ready for Implementation – Substructures

Module 6 Description

This module features the ABC-UTC Research Outputs ready for implementation with a particular emphasis on precast substructures. The research outcome presented in this module includes (1) UHPC-shell strengthened concrete column and (2) Precast integral abutment connection to piles in ABC applications.

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Research Associate Professor, ABC-UTC
Director of Implementation - Florida International University
Principal Structural Engineer, TranTech Engineering

Module 6 Outline:

- ABC-UTC Completed Research Projects
- Guides for ABC-UTC Completed Research Projects
- Bridge Substructure Completed Research Projects and Guides
  1. UHPC-shell strengthened concrete column for seismic applications
  2. Precast integral abutment connection to piles in ABC applications
- Conclusions

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University Transportation Centers - FIU

Innovative Bridge Technologies/Accelerated Bridge Construction	
University Transportation Center **Florida International University**	
Focus Area: Improving the Durability and Extending the Life of Transportation Infrastructure	**UTC Director**
Consortia Members: 1. Florida A&M University 2. Texas A&M University 3. University of Georgia 4. University of Nevada Reno 5. University of Oklahoma 6. University of Washington	**Dr. Atorod Azizinamini** Florida International University Dept. of Civil and Environmental Engineering EC 3680, Miami, FL 33174 Phone: 305-348-3821 Email: aazizina@fiu.edu Website: https://abc-utc.fiu.edu/

Strategic Plan: Building A Better Transportation Future For All Research, Development, And Technology - Years 2022 – 2026

ABC-UTC Completed Research Projects

UTC Director: Dr. Atorod Azizinamini, Florida International University

Completed Research - All	Completed Research - Substructure
FIU (26)	FIU Completed Research Projects (4)
ISU Completed Research Projects (17)	ISU Completed Research Projects (4)
UNR Completed Research Projects (11)	UNR Completed Research Projects (7)
OU Completed Research Projects (4)	OU Completed Research Projects (0)
UW Completed Research Projects (3)	UW Completed Research Projects (2)

Completed Research Projects - Substructure

FIU Completed Projects Research

- Envisioning Connection Detail for Connecting Concrete Filled Tube (CFT) Columns to Cap Beam for High Speed Rail Application
- Innovative Foundation Alternative for High Speed Rail Application
- **Accelerated Retrofit Of Bridge Columns using UHPC Shell (Originally a sub-project of "Alternative ABC Connections Utilizing UHPC")**
- **Experimental Investigation of High Performing Protective Shell Used for Retrofitting Bridge Elements (Originally a sub-project of "Alternative ABC Connections Utilizing UHPC.")**

UW Completed Projects Research

- Economic Pier-to-Pile Connections for Permanently Cased Shaft (CFST) Piles
- New Seismic-Resisting Connections for Concrete-Filled Tube Components In High-Speed Rail Systems .

Completed Research Projects - Substructure

ISU Completed Projects Research

- Investigation of Helical Pile Foundation Implementation In Accelerated Bridge Construction Projects – Phase I
- **Integral Abutment Details for ABC Projects, Phase II**
- An Integrated Project to Enterprise-Level Decision Making Framework for Prioritization of Accelerated Bridge Construction
- **Strength, Durability, and Application of Grouted Couplers for Integral Abutments in ABC Projects**

UNR Completed Projects Research

- Application of Methacrylate Polymers for Seismic ABC Connections
- Durable UHPC Columns with High-Strength Steel
- Shake Table Studies of a Bridge System with ABC Connections
- Evaluation of Seismic Performance of Bridge Columns with Couplers
- Behavior and Design of Precast Bridge Cap Beams with Pocket Connections
- Development and Seismic Evaluation of Pier Systems with Pocket Connections and UHPC Columns

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ABC-UTC Guides – All Projects

- Complex Networks Perspectives Towards Accelerated Bridge Construction (ABC)
- Understanding Critical Impacting Factors and Trends on Bridge Design, Construction, and Maintenance for Future Planning
- Superstructure to Pier Connection in SDCL Steel Bridge Systems
- Service Life Design of Longitudinal Deck Closure Joints
- NDT Methods Applicable to Health Monitoring of ABC Closure Joints
- Full-Depth Precast Concrete Deck Panels
- Predictive Computer Program for Proactive Demolition Planning
- Multi-Span Lateral Slide Laboratory Investigation: Phase I
- Investigation of The Efficacy Of Helical Pile Foundation Implementation In Accelerated Bridge Construction Projects – Phase I

ABC-UTC Guides – All Projects – cont.

- Delivery Methods for Accelerated Bridge Construction Projects: Case Studies and Consensus Building
- Bidding of Accelerated Bridge Construction Projects: Case Studies and Consensus Building
- Accelerated Repair and Replacement Of Expansion Joints
- Development of Guidelines to Establish Effective and Efficient Timelines and Incentives for ABC
- **Integral Abutment Connections**
- Inspection and QA/QC for ABC Projects
- Repair of Reinforced and Prestressed Concrete Bridge Girders
- Innovative Foundation Alternative for High Speed Rail Application
- Rebar Hinge Pocket Connections, Hybrid Grouted Duct Connections, and SDCL Steel Girder Connections
- Assessing the Effects of Frequent, Low-Level Seismic Events

ABC-UTC Guides - Substructure

- Innovative Foundation Alternative for High Speed Rail Application
- Superstructure to Pier Connection in SDCL Steel Bridge Systems
- Investigation of Helical Pile Foundation Implementation in Accelerated Bridge Construction Projects – Phase I
- **Integral Abutment Connections**
- Rebar Hinge Pocket Connections, Hybrid Grouted Duct Connections, and SDCL Steel Girder Connections

Module 6 Selected Projects

Accelerated Retrofit of Damaged Bridge Columns using UHPC Shell

- Accelerated Retrofit Of Bridge Columns using UHPC Shell (Originally a sub- project of "Alternative ABC Connections Utilizing UHPC")
- Experimental Investigation of High Performing Protective Shell Used for Retrofitting Bridge Elements (Originally a sub-project of "Alternative ABC Connections Utilizing UHPC.")

Integral Abutment Connection Details for Accelerated Bridge Construction

- Integral Abutment Details for ABC Projects, Phase II
- Integral Abutment Connections - Guide
- Strength, Durability, and Application of Grouted Couplers for Integral Abutments in ABC Projects

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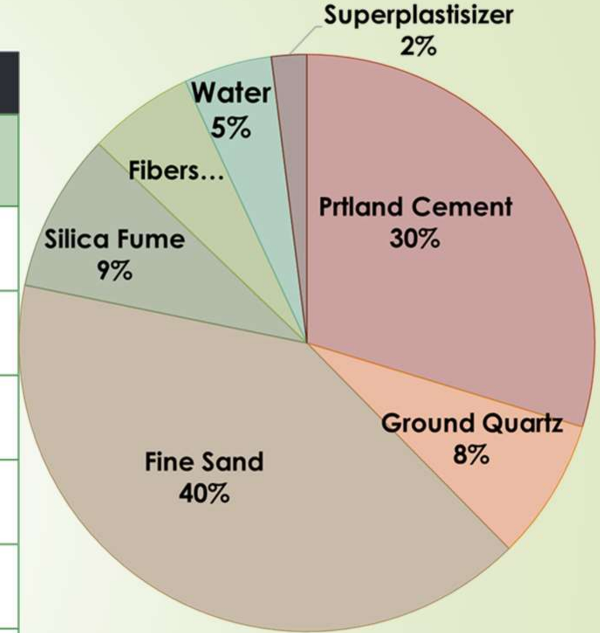
Common UHPC Ingredients and Test Methods

Table 1. Expected range of material properties of field-cast UHPC.

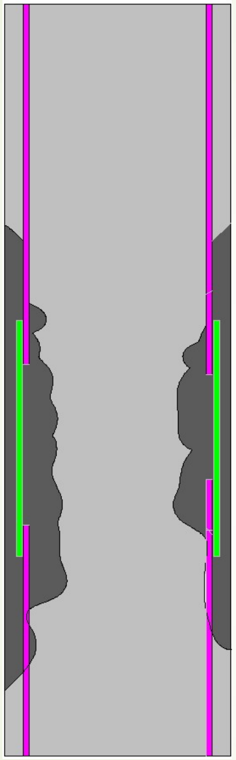
Property	Test Method and Details	Expected Range
Density	ASTM C642[8]	144–157 lb/ft^3 (2,300–2,510 kg/m^3)
7-day compressive strength	ASTM C1856[9] ASTM C39[10]	14.5–19.5 ksi (100–135 MPa)
14-day compressive strength	ASTM C1856[9] ASTM C39[10]	18–22 ksi (125–152 MPa)
Modulus of elasticity	ASTM C1856[9] ASTM C469[11]	4,250–8,000 ksi (29–55 GPa)
Poisson's ratio	ASTM C1856[9] ASTM C469[11]	0.12–0.2
Direct tension cracking strength	FHWA-developed direct tension test[12]	0.8–1.2 ksi* (5.5–8.3 MPa)
Direct tension sustained postcracking tensile strength	FHWA-developed direct tension test[12]	0.8–1.2 ksi* (5.5–8.3 MPa)
Direct tension strain capacity prior to crack localization	FHWA-developed direct tension test[12]	0.003–0.004
Direct tension bond strength (interface failure)	ASTM C1583, bonded to an exposed aggregate surface[13]	0.35–0.6 ksi (2.4–4.1 MPa)



NSC: 5 ksi

UHPC: 18-28 ksi

Accelerated Retrofit Of Bridge Columns using UHPC Shell



Typical Damage of Columns Due To Corrosion

UHPC Repair Advantage:

- Flowability
- Short tension development length
- Early gain strength and capacity improvement
- Durability
- Good bond between fresh UHPC and concrete substrate
- Low permeability
- Low amount of cast in place

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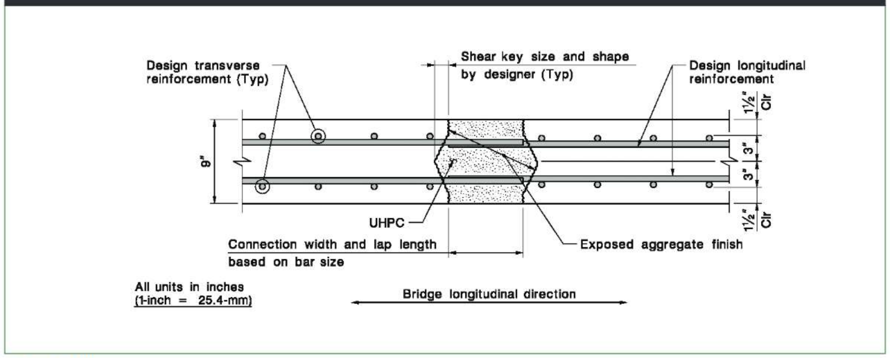
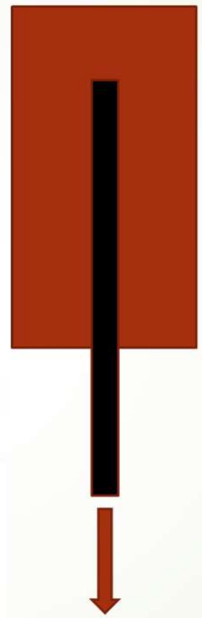
Tension Development Length

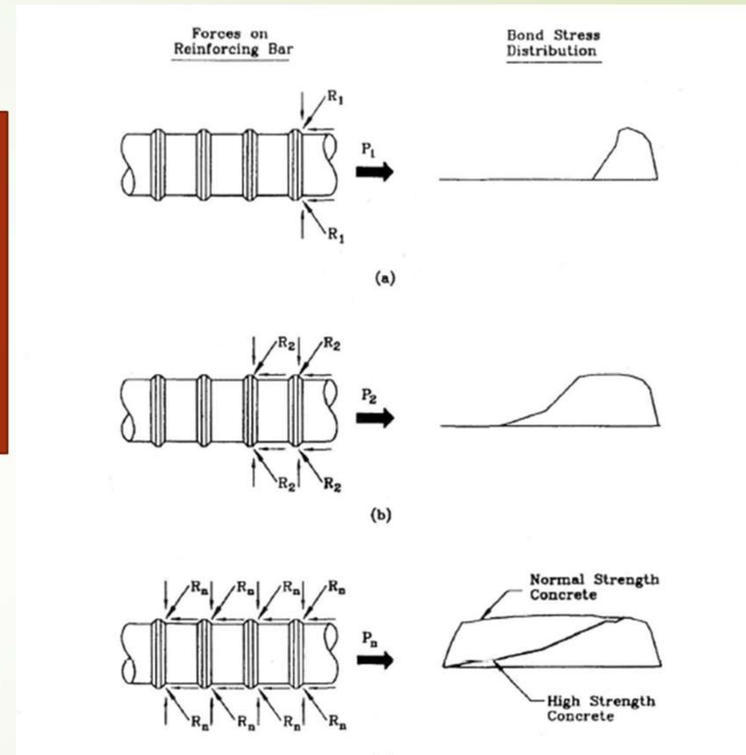
Figure 2. Illustration. Typical UHPC connection between precast deck panels.



Source: FHWA.

Figure 3. Illustration. Combined UHPC deck-level and composite connections as deployed by NYSDOT on I-81 near Syracuse, NY.





Tension development length in UHPC is very short

For minimum cover ≥ $3d_b$, the minimum ℓ_d shall be taken as the following:

$8d_b$ for reinforcing bars with yield strength $f_y \leq 75$ ksi (517 MPa).

$10d_b$ for reinforcing bars with yield strength 75 ksi (517 MPa) < $f_y \leq 100$ ksi (689 MPa).

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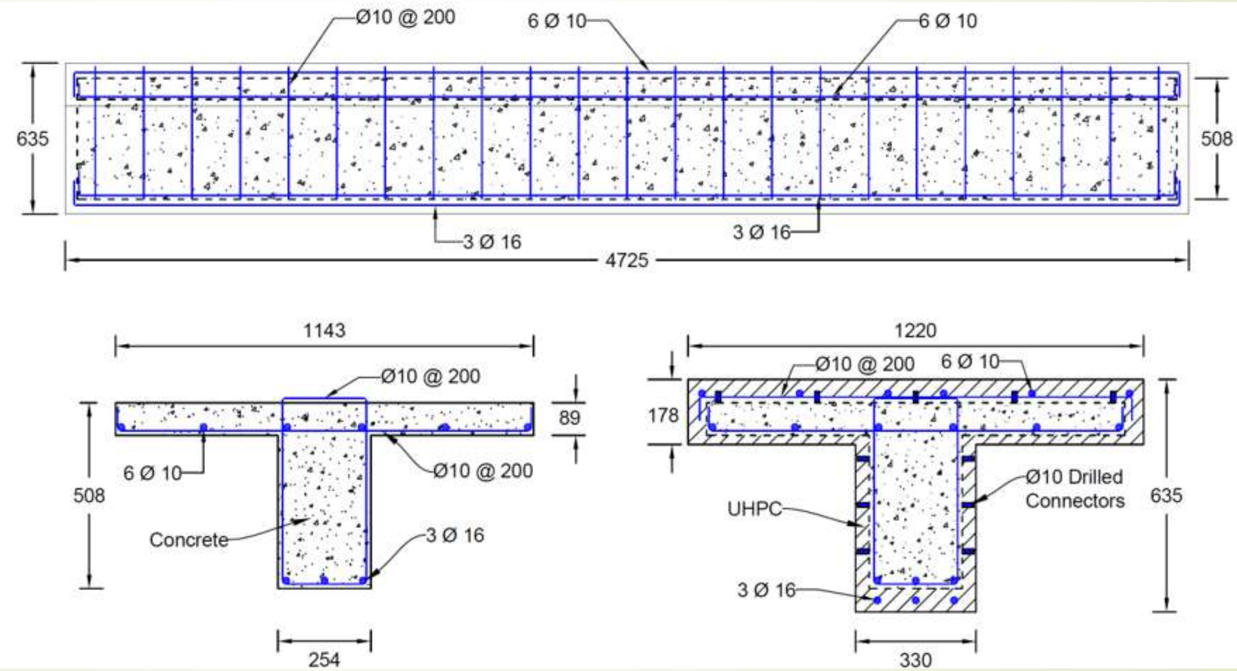
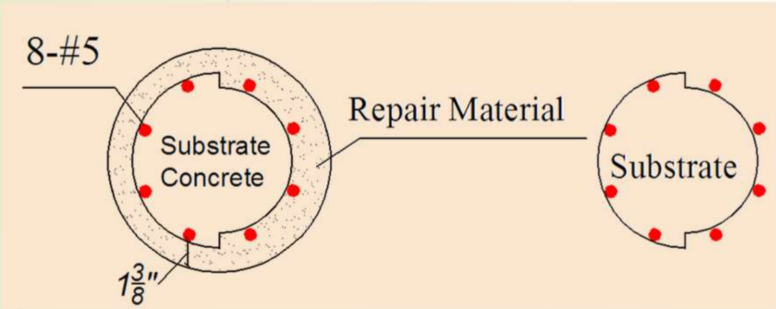
UHPC for Bridge Components Repair

Best use of UHPC perhaps is in retrofit and upgrading existing deficient structural members

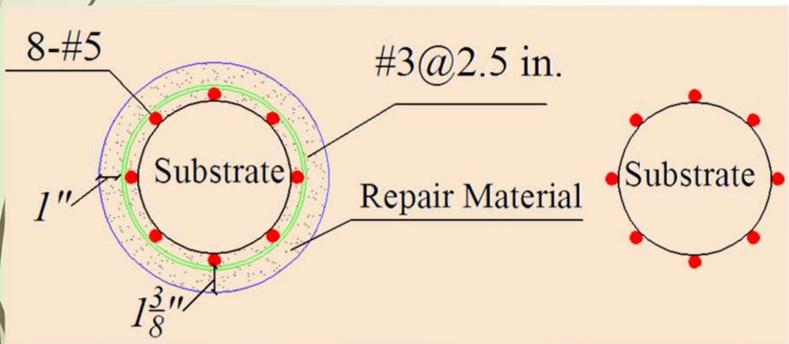


Laboratory Testing of Retrofitted Columns

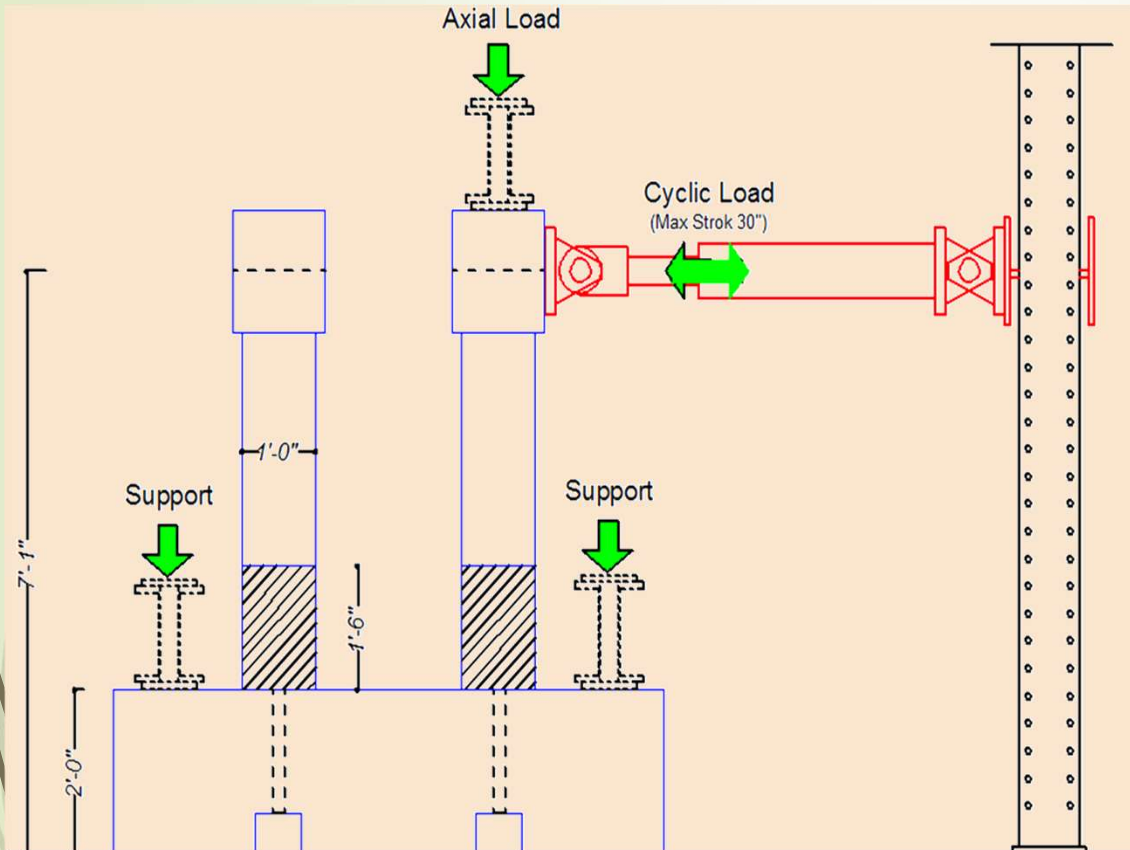
Asymmetric Repair



Symmetric Repair



Load Test Setup



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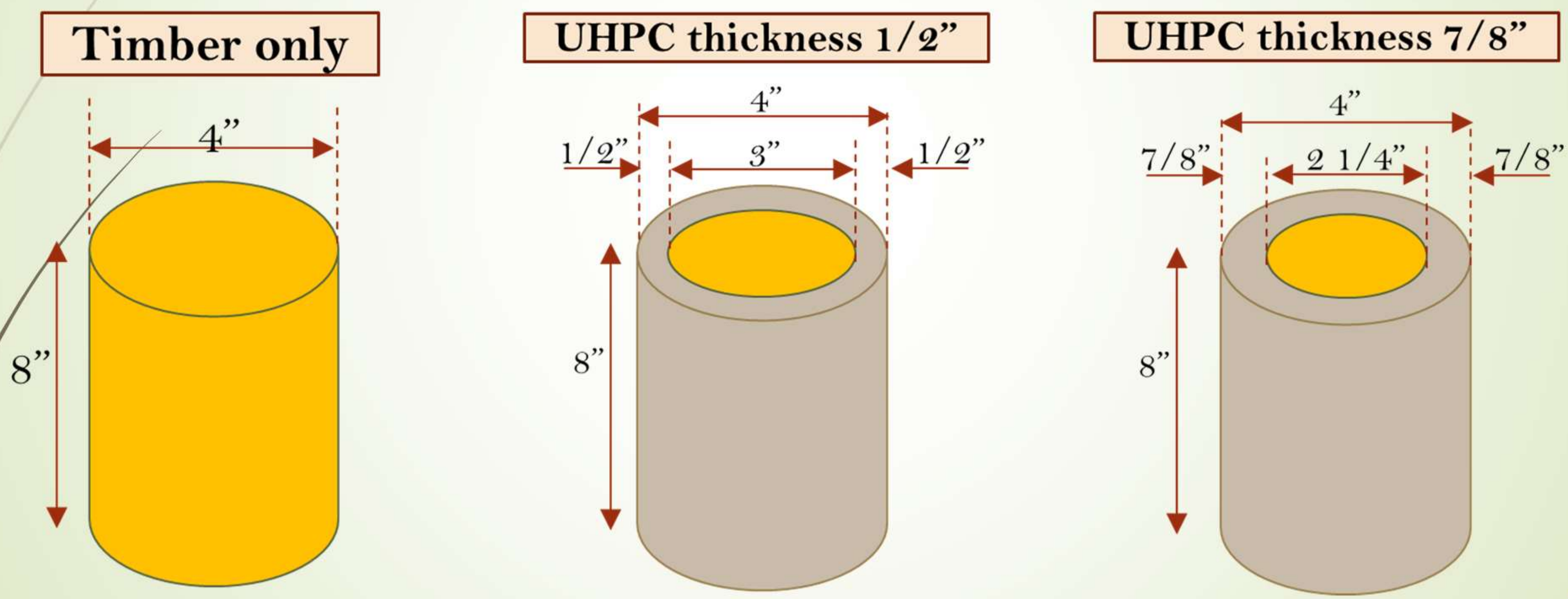
UHPC Shell for Timber Pile Repair

Dimensions (scaled test)

UHPC compressive strength= 25 ksi
Timber compressive strength= 283 psi



Accelerated Retrofit of Bridge Columns using UHPC Shell

Accelerated retrofit of bridge columns using UHPC shell – Phase I: Feasibility Study

Quarterly Progress Report

For the period ending June 30, 2018

Submitted by

Atorod Azizinamini

Graduate students

Mahsa Farzad

Affiliation: Civil & Environmental Engineering Department

Florida International University

ACCELERATED BRIDGE CONSTRUCTION

UNIVERSITY TRANSPORTATION CENTER

Submitted to:

ABC-UTC

Florida International University

Miami, FL

EXPERIMENTAL INVESTIGATION OF HIGH PERFORMING PROTECTIVE SHELL USED FOR RETROFITTING BRIDGE ELEMENTS

Submitted by

Alireza Valikhani

FINAL REPORT

Department of Civil and Environmental Engineering

Florida International University

Miami, Florida

Submitted to

Atorod Azizinamini

Director, ABC-UTC

June 2018

ABC-UTC

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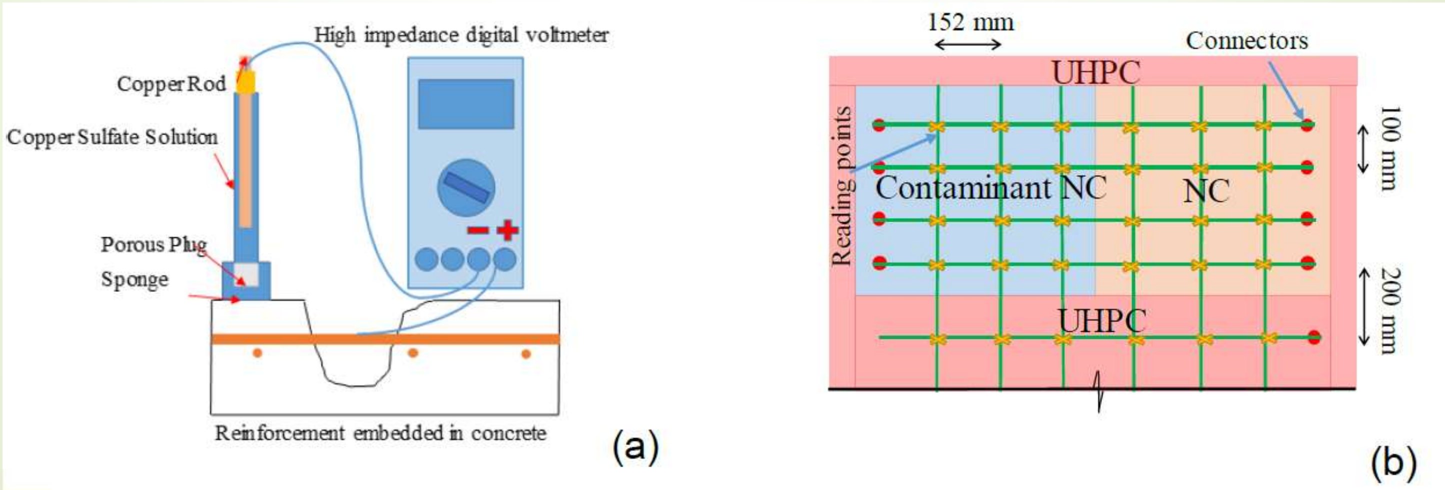
Accelerated Retrofit of Bridge Columns using UHPC Shell

Instrumentation of Accelerated Repair Using UHPC Shell:

The main objective of this project was to select an existing in-service bridge with damaged column element, retrofit it using cast in place UHPC shell, instrument and monitor to identify deterioration of the repair and substrate material as well as development of corrosion of steel within the column.



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Accelerated Retrofit of Bridge Columns using UHPC Shell

Research Approach:

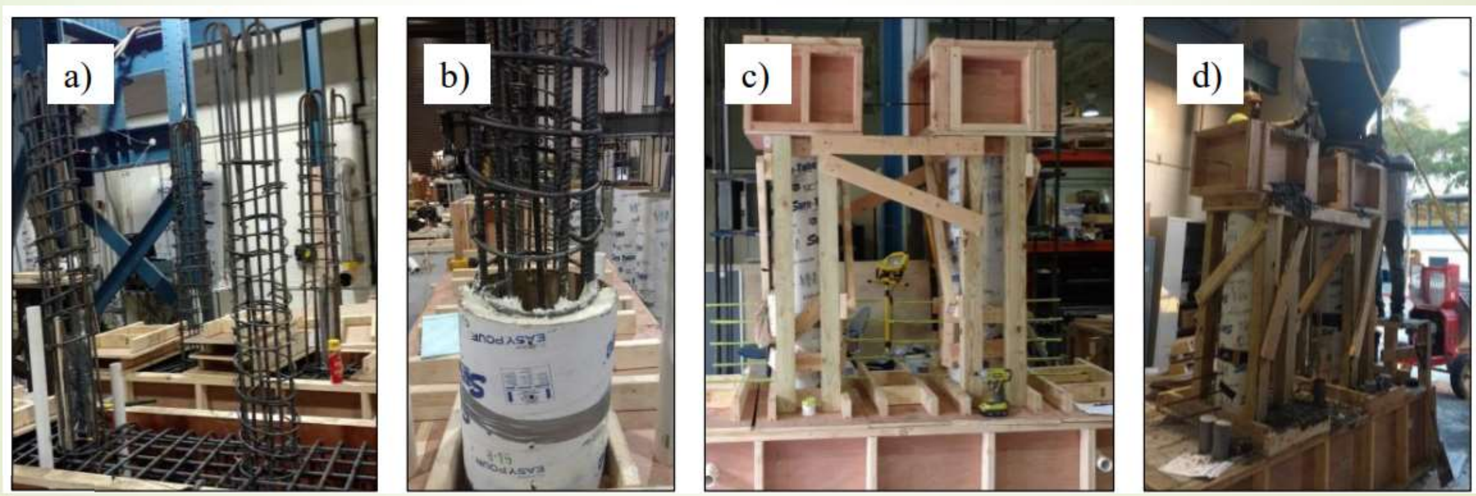
- In this research, three Reinforced Concrete (RC) columns were cast and artificially damaged with spalling cover.
- Two of the Columns were artificially damaged, and one column, with no repair, was used as the test baseline.
- One of the repaired columns included confining reinforcement and the other one was strengthened using only UHPC
- Damaged concrete cover were removed and cleaned to exposed aggregate to have a good bond between UHPC and existing concrete in repaired areas.

Accelerated Retrofit of Bridge Columns using UHPC Shell

Test Specimen Construction

- The columns were longitudinally reinforced with eight Grade 60, #5 bars, resulting in 2.2% longitudinal steel reinforcement ratios (ρ=2.2%), with 0.375 in. diam. hoops at 4 in.

The construction process of a typical specimen formwork, caging and casting is shown in the Figure: a) formwork and caging, b) simulating the damage, c) erecting the columns, and d) casting the concrete substrate.



Accelerated Retrofit of Bridge Columns using UHPC Shell

Repair Procedure

The areas of the test specimens including damage were sandblasted to expose the aggregate and clean the substrate from residue particles. The cleaned surface was sprayed with water and allowed to dry to reach dry-surface condition. The damaged area was cast with UHPC.

Figure - Repair Procedure: a) damaged part before repair, b) damaged part after sandblasting treatment, c) formwork for the repair plastering, d) casting UHPC, and e) damaged part after repair.

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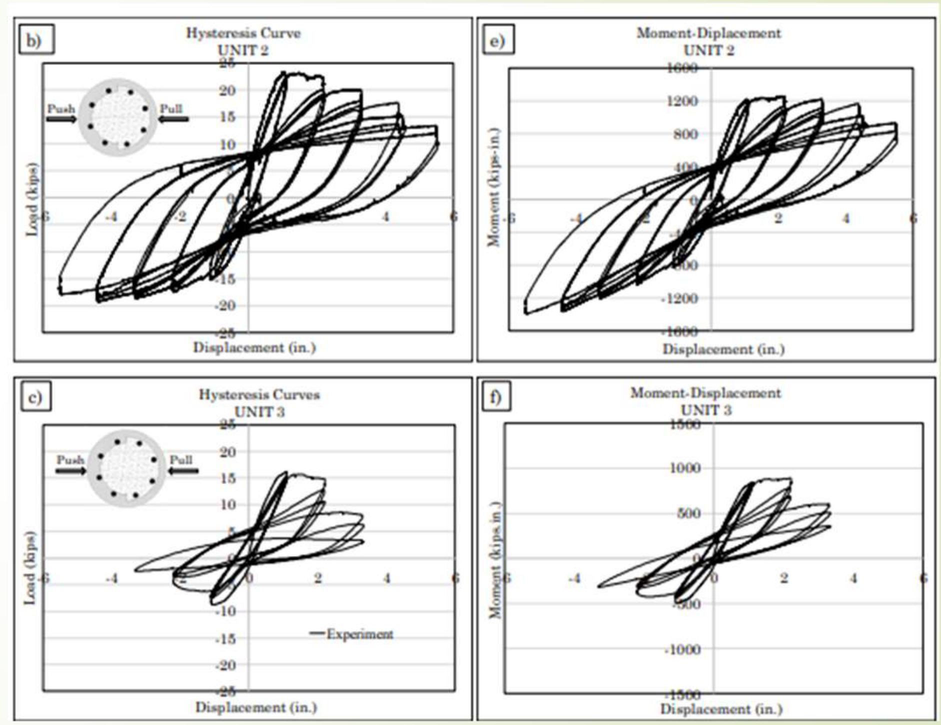
Accelerated Retrofit of Bridge Columns using UHPC Shell

Experimental Results

- The specimens were able to sustain 80% of the maximum horizontal force corresponding to a peak displacement at 5.5% drift.



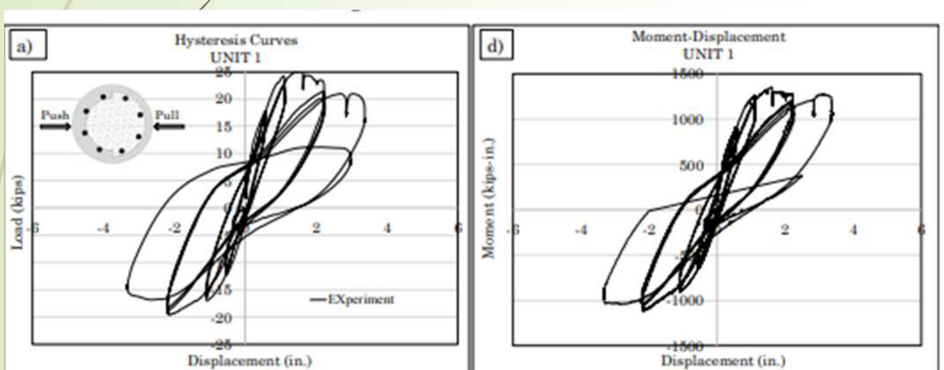


Figure shows the Load-displacement hysteretic responses and Moment-displacement hysteretic responses

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Accelerated Column Retrofit using UHPC Shell - Conclusions

Using thin UHPC shell provides an alternative method to repair damaged portions of bridge components.

A total of three reduced scale columns are cast and artificial damages were created. The damaged areas were repaired with thin UHPC shell.

The performance of repaired columns was compared with the baseline column. Based on the results of these tests, the following conclusions can be made:

- The UHPC shell concept to repair damaged bridge element is a promising concept.
- The repair using the UHPC is efficient regarding lateral strength, deformation, energy dissipation capacity, and stiffness degradation.
- The experimental results reveal that the UHPC shell increases the strength of the damaged elements, without increasing its size.

Accelerated Column Retrofit using UHPC Shell – Conclusions – cont.

- UHPC shell transforms the sudden cover spalling to a gradual mechanism. However, it does not prevent bar buckling. This is due to the ability of the fibers to limit the progression of cracks in the concrete, thereby resulting in greater material integrity at large strains.
- Sand blasting produced an acceptable bonding between the regular concrete and UHPC.
- Having 1.5 inches UHPC cover provides a good bonding between regular concrete and UHPC shell.
- Experimental findings indicate that a slight increase of lateral reinforcement significantly improves the cyclic behavior, energy dissipation capacity, deformability, and ductility.
- Combination of adding rebar and using 2 inches UHPC could give the best results based on increasing the strength.
- The method of casting can have a significant influence on fiber distribution, fiber orientation, and the overall UHPC resistance.
- The flowability of UHPC makes it possible to fill different cavity shapes, and its low permeability acts as a barrier to moisture and other intrusions.
- The early strength gain of UHPC accelerated the repair and reduces the traffic interr

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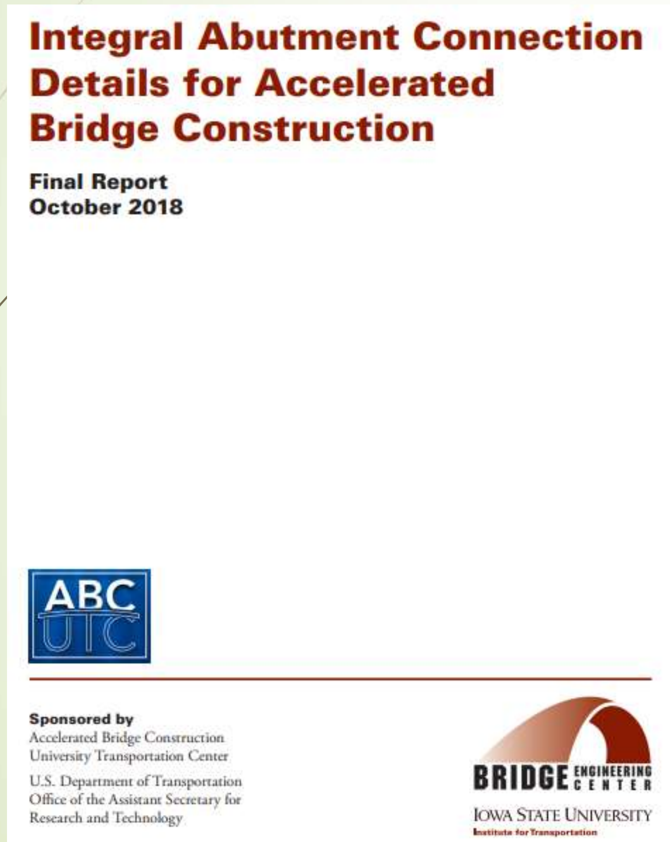
Integral Abutment Connection Details for Accelerated Bridge Construction



Integral Abutment Connection Details for Accelerated Bridge Construction

Final Report
October 2018

ABC UTC

Sponsored by
Accelerated Bridge Construction University Transportation Center
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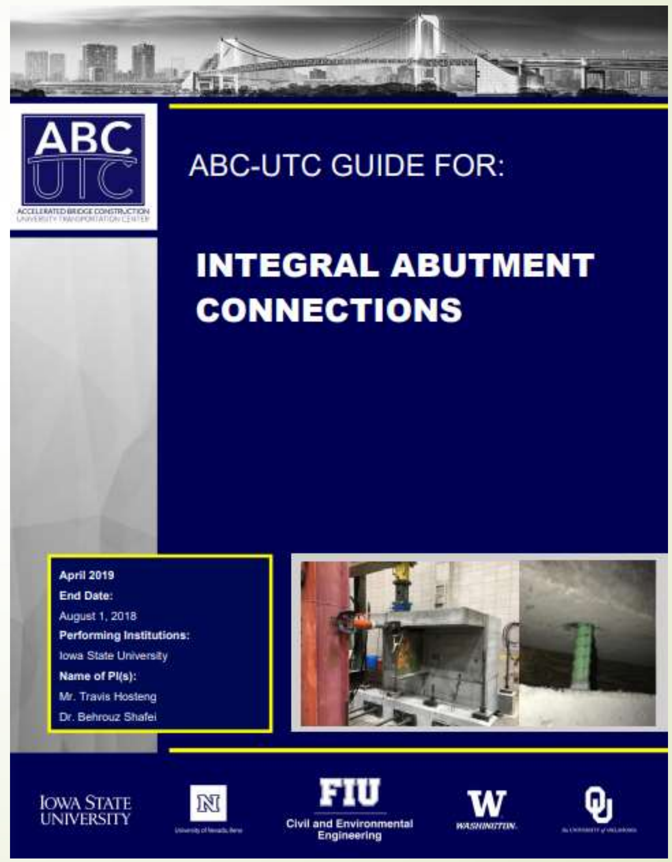
BRIDGE ENGINEERING CENTER
IOWA STATE UNIVERSITY
Institute for Transportation



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ACCELERATED BRIDGE CONSTRUCTION UNIVERSITY TRANSPORTATION CENTER

ABC-UTC GUIDE FOR:

INTEGRAL ABUTMENT CONNECTIONS

April 2019
End Date:
August 1, 2018
Performing Institutions:
Iowa State University
Name of PI(s):
Mr. Travis Hosteng
Dr. Behrouz Shafei

IOWA STATE UNIVERSITY
FIU Civil and Environmental Engineering
W WASHINGTON

IOWA STATE UNIVERSITY
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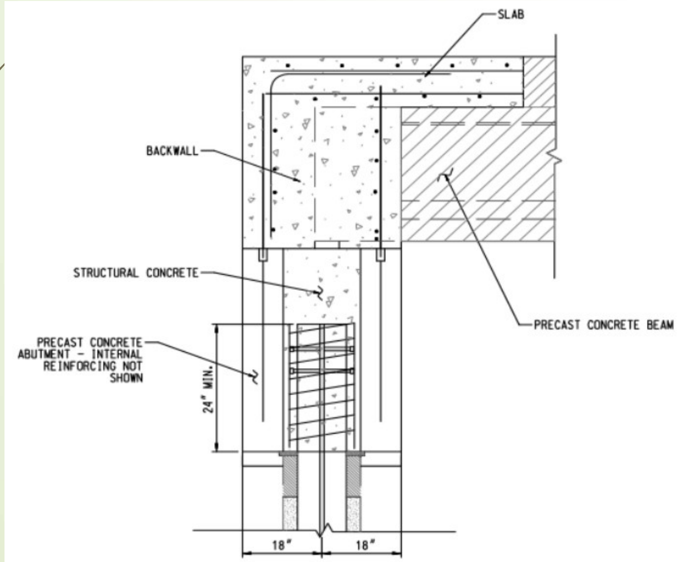
Integral Abutment Connection Details for ABC

The ABC Manual defines an integral abutment as follows:

"A bridge abutment type that is made integral with the bridge superstructure through a combined shear and moment connection. They are often constructed with a single row of piles that allow for thermal movement and girder rotation. Soil forces behind the abutments are resisted through the strut action of the superstructure."



SECTION THROUGH PRECAST CONCRETE INTEGRAL ABUTMENT

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Integral Abutment - Structural Analysis

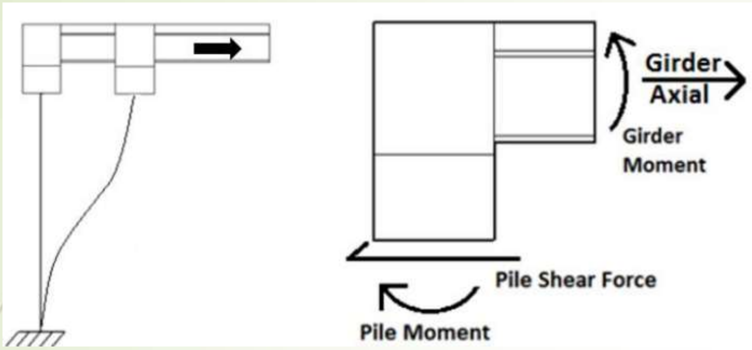

Figure. Structural analysis for thermal contraction of bridge

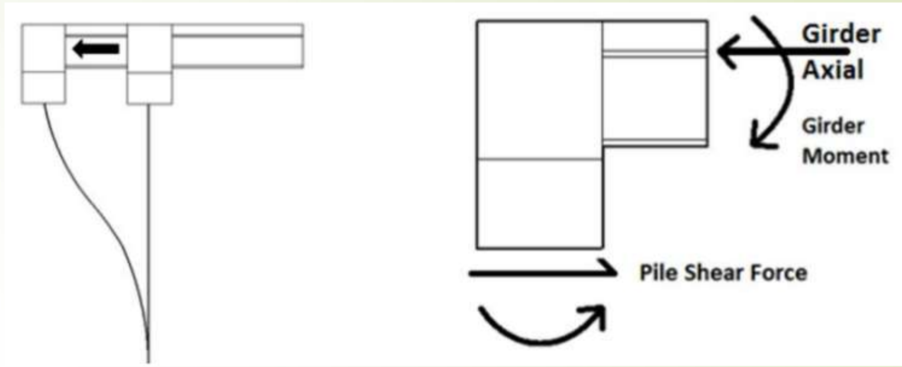

Figure. Structural analysis for thermal expansion of bridge

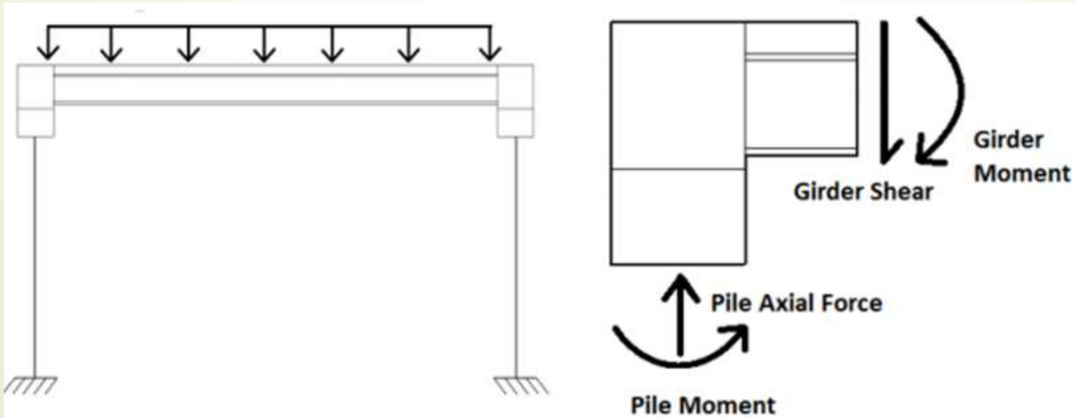

Figure. Structural analysis for live loading of bridge

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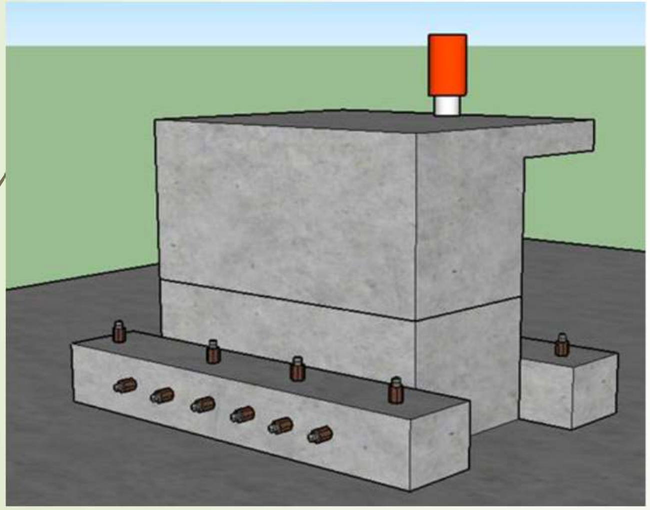
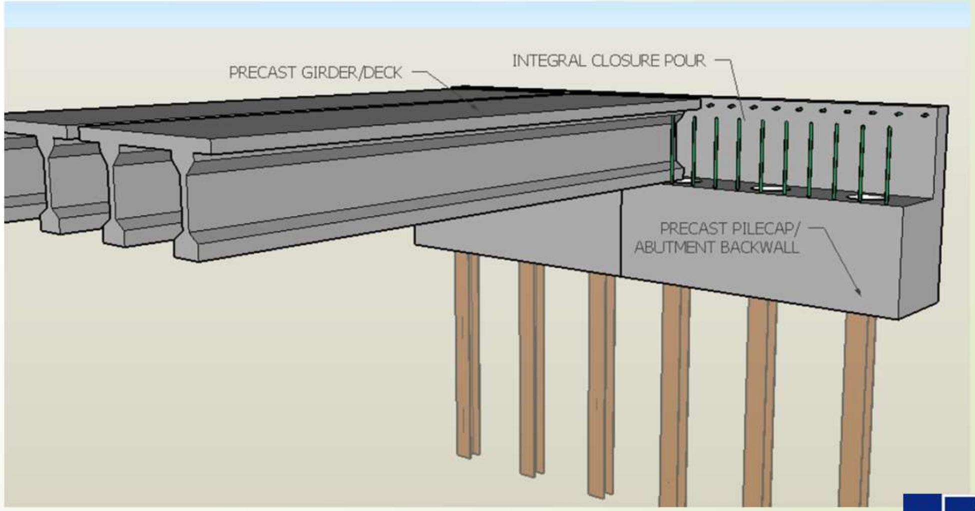
Integral Abutment Connection Details for ABC

Scope: The proposed research aims to develop ABC compatible integral abutment connections to marry the two technologies together and continue to advance the quality, performance, economics and constructability of bridges to meet the demands of today's growing infrastructure.





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Strength, Durability, and Application of Grouted Couplers for Integral Abutments in ABC Projects:

- The scope of this research is to provide information for the construction of connection detail, and laboratory test results to aid planning, design, and construction of the integral abutment used in ABC projects.
- This research focused on the development of integral abutment details utilizing grouted couplers and conduct laboratory testing.
- The Bridge Engineering Center (BEC) at Iowa State University (ISU) has tested three possible full-scale laboratory connection details, for integral abutments for ABC applications.
- The laboratory specimens were evaluated on three criteria:
  - constructability,
  - strength, and
  - durability.

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Integral Abutment Connection Details for ABC- Objectives, and Tasks

The following five tasks were completed to meet the objectives of the project:

1. Conduct a detailed literature review of ABC procedures with respect to integral abutments.
2. Develop and design connection details for an integral abutment using ABC methods.
3. Investigate and evaluate the constructability aspects of the connection details and adjust designs accordingly.
4. Test the flowability of UHPC through the designed cross-section of the joint connection detail.
5. Construct and test full-scale specimens of the connection details in the laboratory, measuring the performance of the detail in terms of durability and strength.
6. Summarize the results for the future use of integral abutments in ABC

Strength, Durability, and Application of Grouted Couplers for Integral Abutments in ABC

Specimens were tested to determine the strength, durability, and constructability of two proposed connections compared to a cast-in-place control specimen.

The two proposed connections were: grouted reinforcing bar coupler (GRBC) and pile couplers

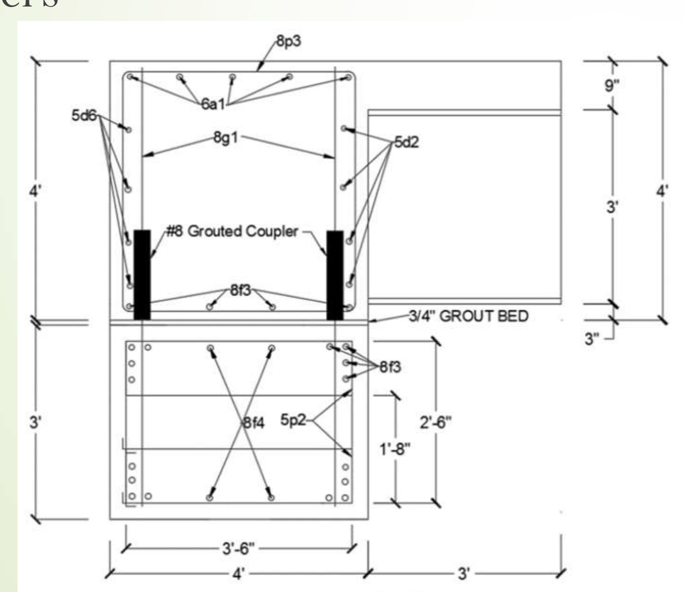

Figure . Grouted reinforcing bar coupler

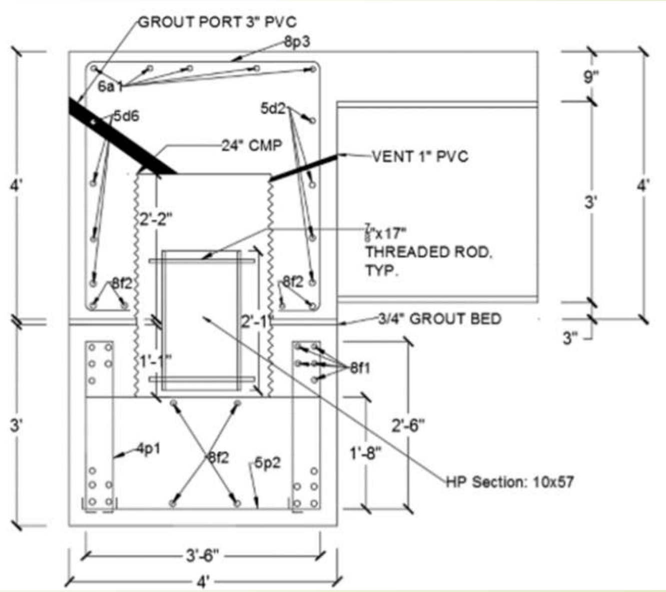

Figure . Pile coupler

Grouted Reinforcing Bar Coupler (GRBC) and Pile Couplers

Figure. Bridge cap with pile couplers

Figure. Pile coupler integral diaphragm completed

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Integral Abutment - Laboratory Testing

The setup for testing the strength and durability of integral abutment connection details required the construction of two reaction blocks to attach the specimens to the strong floor of the structural laboratory with post-tensioning, causing the specimens to have a fully-fixed boundary condition.

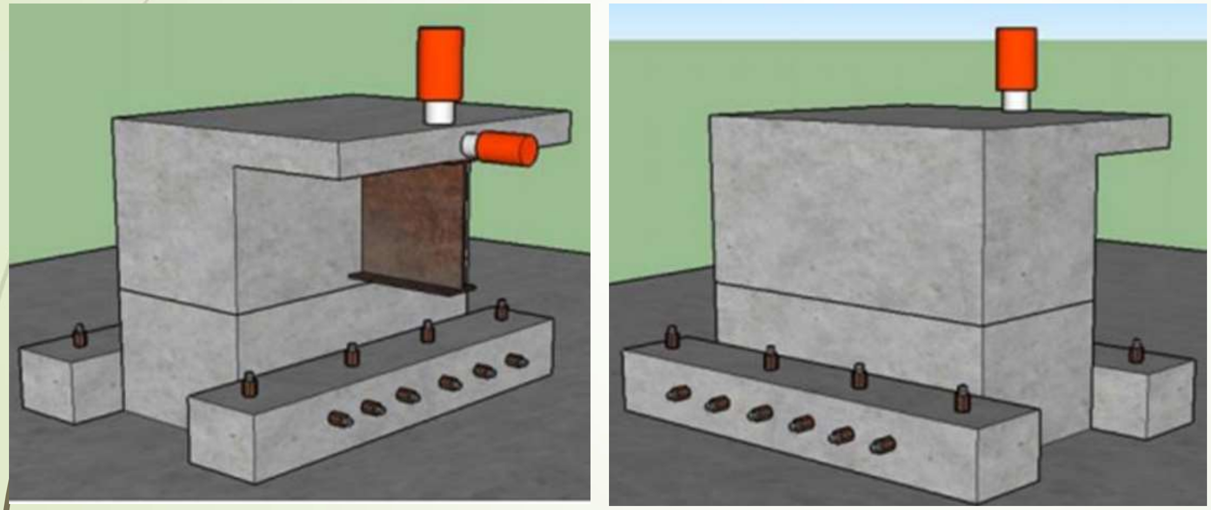

Figure. Model of testing setup – Front and Rear views

Figure. Laboratory testing setup

Integral Connection: Grouted Reinforcing Bar Coupler

The initial design of the grouted reinforcing bar specimen coupler (GRBC) specimen (Phase I) started with a typical cast-in-place integral abutment design and inserted a grouted reinforcing bar coupler at each reinforcing bar that provided continuity between the abutment pile cap and the abutment diaphragm.

However, subsequent testing (Phase II) indicated that adequate strength and serviceability could be achieved by reducing the number of couplers by half.

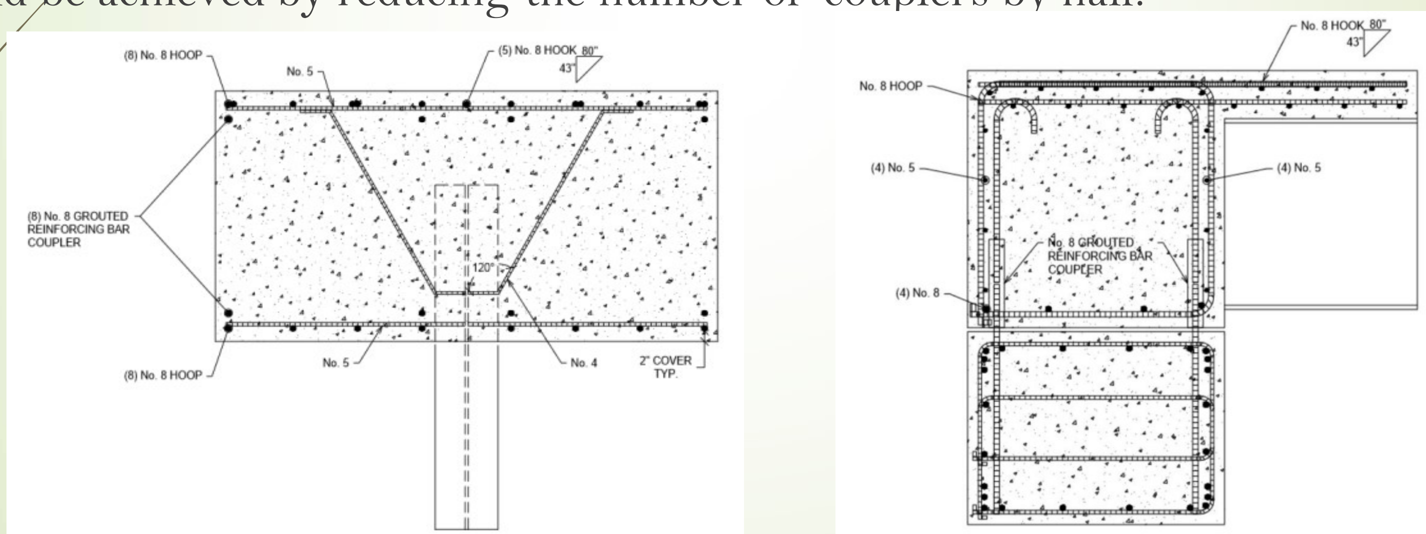

Figure. Plan view of GRBC specimen showing locations of couplers.

Integral Abutment Connection : UHPC Joint

- UHPC was used to fill the void between the two precast elements with protruding reinforcing bars from the integral diaphragm and pile cap. UHPC was chosen in lieu of concrete or a grouting material due to the increased flowability characteristic of UHPC, as well as its impermeability and high strength.
- The UHPC joint design utilized a “notched” cross section formed into the integral diaphragm performed well.

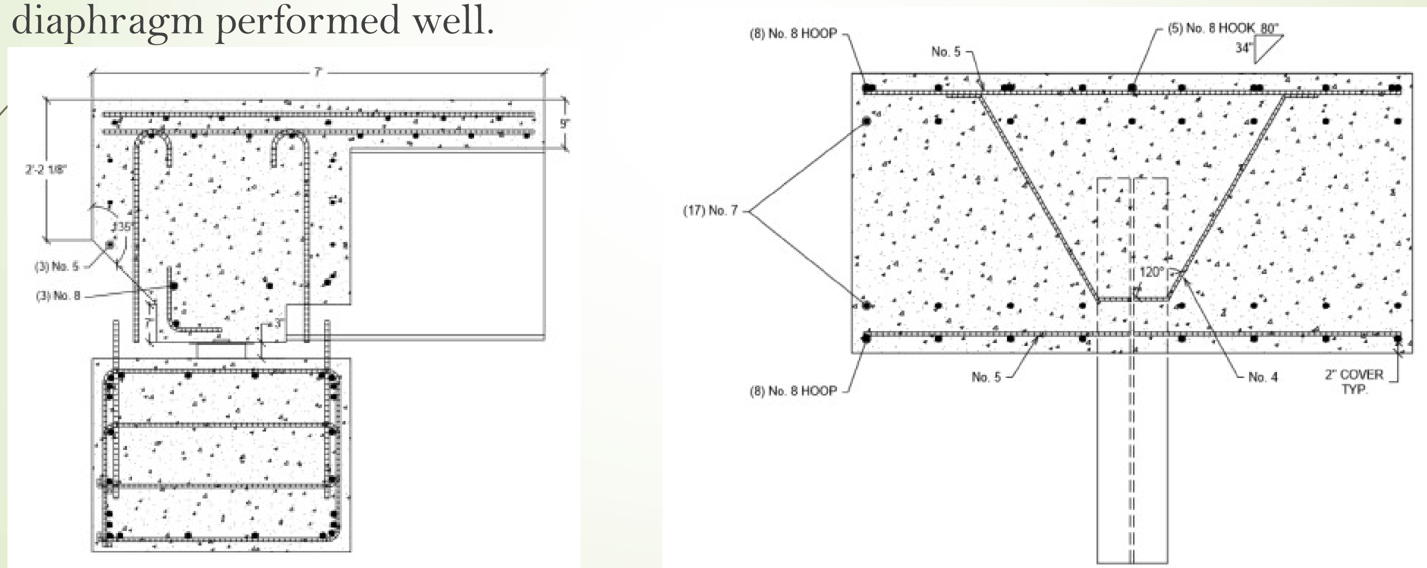

Figure - Plan view of UHPC-Joint specimen showing locations of connection bars

Integral Abutment Connection Details for ABC - Conclusions

The integral abutment removes the need for the expansion joint by having the superstructure being rigidly connected to the foundation to cause the structure to act together in response to traffic loads and thermal expansions and contractions.

Based on the test results the following conclusions can be made:

- Integral abutments have limited use in ABC because they are often large and heavy and have complex reinforcing details.
- The construction of the precast elements was not difficult and should be achievable for experienced fabricators.
- Connections of Integral Abutments when attempting to apply ABC methods often need to be heavily reinforced, resulting in congestion issues and tight construction tolerances, and weight of integral abutments cause some problems for ABC projects.

Integral Abutment Connection Details for ABC – Conclusions – cont.

- Three connection details were tested to investigate the use of mechanical couplers to splice the foundation elements to the superstructure elements of bridges while applying ABC techniques.
- Integral abutments constructed for ABC projects have typically relied on cast-in-place closure pours. However, there are certain benefits to precasting the abutment, as material closure pours add significant cost to the project and add curing time to the project schedule.
- The Phase I investigation consisted of a cast-in-place integral abutment connection, which was the control specimen, and two ABC connections utilizing mechanical couplers.
- The grouted reinforcing bar coupler design was revised to use only 8 splices rather than the 17 used in Phase I. This revision helped to alleviate the tight construction tolerances present, and it was designed to maintain allowable structural behavior throughout the cold joint connection.

Integral Abutment Connection Details for ABC – Conclusions – cont.

- Results from the full-scale testing showed the revised connection had adequate strength and proper development of connecting materials while having reasonable cracking behavior compared to the Phase I results.
- The template used to "match cast" the grouting sleeves of the integral diaphragm to the protruding bars from the pile cap and was proven successful through a "dry fit" done prior to the installation of the connection.
- The strength and durability of the mechanical coupler connection details were evaluated through full-scale laboratory testing that applied simulated thermal loads and live loads.
- The results from the testing were very promising for the advancement of the connection, since the size of the precast joint opening and development of connecting materials was comparable to the control specimen from Phase I.
- The connections discussed in this guideline are intended to be considered and implemented by bridge engineers and contractors for design and construction of integral abutment bridges using ABC methodologies.

Thank You

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