Accelerated Repair of Existing Bridges Using UHPC

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Presentation Outline

1- Brief Introduction to UHPC as material
2- Brief overview of durability of UHPC
3- Brief overview of major UHPC work at FIU that will be presented at a later time
4- UHPC Based Solutions for Repair of Damaged Bridge Elements
   a) Bridge element subjected to predominantly axial load
   b) Bridge element subjected to predominantly moment
5- Commercialization – Mechanism is in place for field implementation of the concepts to be presented
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INTRODUCTION TO UHPC

Ultra High Performance Concrete (UHPC), is a class of concrete defined by its exceptionally high strength and durability.

- High Compressive Strength (> 22 ksi)
- High Tensile Capacity (0.8~2.5 ksi)
- Ductility
- Toughness
- High Flowability
- Self-Compacting
- Low Permeability
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MACROCELL CURRENT BETWEEN REPAIR AND SUBSTRATE CONCRETE

Onset of Ponding

NSC C/A = 5.00

UHPC C/A = 5.00

Onset of Ponding
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Will be Presented in Future Webinars

UHPC FORMWORK
Will be Presented in Future Webinars

UHPC Shell Form for Short Span Bridges
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Why Accelerated Retrofit
- We have more than 600,000 bridges, in the inventory. About 30 percent are substandard.

- Average age of bridges are 44 years. Most are designed for 50 years design life
UHPC-Based ABC Solutions for Retrofitting Bridge Element Subjected to Predominantly Axial Load
RESEARCH OBJECTIVES

Development of design and construction recommendations for repairing and upgrading damaged bridge elements and subjected to axial load, using UHPC shells
Why UHPC as Repair Material
Test Specimens and Simulating Damages in the columns

- 61 in.
- 12 in.
TEST SETUP

Parameter Investigated Experimentally

- Symmetrical damage vs un-symmetrical damage
- Fiber content (2% vs 4%)
- Inclusion or elimination of transverse reinforcement
CONSTRUCTION- Simulating Damage

Asymmetric Damaged Geometry

Symmetrical Damaged Geometry
REPAIR PROCESS

- Surface preparation
- Batching repair
LOAD SET-UP

Axial Load

Support

Support

Cyclic Load
(Max Strok 30°)
Test Results – Photos are Taken after test Conclusion
Specimens with Asymmetrical Damage

UNIT 1: Repaired no stirrup
Asymmetric repair

UNIT 2: Repaired w stirrup
Asymmetric repair

UNIT 3: Damaged
No repair –Reference
Test Results – Specimens with Asymmetrical Damage

- Repaired no stirrup Asymmetric repair
- Repaired w stirrup Asymmetric repair
- Damaged No repair
Test Results

UNIT 6: Reference – No Damage

UNIT 7: Damaged Simulated- Repaired w NSC Symmetric Damage
DISCUSSION ON EXPERIMENTS

UNIT 6: Reference – No Damage

UNIT 7: Damaged Simulated- Repaired w NSC Symmetric Damage
DISCUSSION ON EXPERIMENTS

UNIT 8: Column Repair (UHPC 2% fiber)
Symmetric repair

UNIT 9: Column Repair (UHPC 4% fiber)
Symmetric repair

UNIT 10: Column & footing repair (UHPC 2% fiber)
Symmetric repair

UNIT 11: Column & footing repair (UHPC 4% fiber)
Symmetric repair
Strengthening Process of the Base in Units 10 and 11
Test Results

UNIT 10: Column & footing repair (UHPC 2% fiber) - Symmetric repair

UNIT 11: Column & footing repair (UHPC 4% fiber) - Symmetric repair
LESSONS LEARNED FROM EXPERIMENTAL WORK

- Develop an effective ways of building formwork
- Ensure uniformity of UHPC mix
NUMERICAL WORK
SUMMARY OF FINDINGS TO DATE

- Increased load capacity
- Approach used for surface preparation is effective
- Sectional analysis to predict the failure location is recommended.
UHPC based ABC solutions for retrofitting bridge elements subjected to predominantly moment
PROPOSED METHOD
Experimental Investigation

Test Setup:
Three point loading test

Feasibility Study
✓ General and local behavior
TEST SPECIMENS – Series 1

Without Damage Specimen

Damaged Specimen

Rebar Cut length= 24”

# 3 @ 4 in.

# 4

1.5”

24”

96”

# 3
TEST SPECIMENS Series 1 - Repaired
CONSTRUCTION PROCEDURE
CONSTRUCTION PROCEDURE

With out Damage

With Damage

Retrofitted
TEST RESULTS – Series 1
LESSONS LEARNED FROM FIRST SERIES OF TEST

- Adding the UHPC shell can increase flexural capacity of the element
- Surface preparation is important

- Parameters investigated in the second test series:
  - UHPC thickness
  - Better bond between UHPC shell and existing concrete through
    - Sand blasting or Mechanical devices
Test Specimens – Series 2 – Control Specimen – No Repair

Rebar Cut length = 24”
Test Specimens – Series 2 – 0.75 Inch Shell
Shell 0.75+ Mechanical Device - wide spacing

Shell 0.75+ Mechanical devices – small spacing
Test Specimens – Series 2 – 1.5 & 2 Inch Shell

Rebar Cut length = 24”
Surface Condition - Before Preparation — Series 2 Test Specimen

With damage (Control 2)  
Shell 0.75  
Shell 0.75-MD-wide space  
Shell 0.75-MD-small space  
Shell 1.5  
Shell 2
Test Specimens – Surface Condition after Surface Preparation

Shell 0.75

Shell 0.75-MD-wide space

Shell 0.75-MD-small space

Shell 1.5

Shell 2

With damage (Control 2)
TEST RESULTS – Series 2 Test Specimens

With damage
Shell 0.75
Shell 0.75-MD-wide space
Shell 0.75-MD-small space
Shell 1.5
Shell 2
TEST RESULTS

Control Test Specimen

Shell 2

Shell 0.75

Load (Kips)

Displacement (in)

Shell 0.75
Shell 2
With damage
TEST RESULTS

Shell 0.75

Shell 0.75-MD-small space

Shell 0.75-MD-wide space

Graph showing load (Kips) vs. displacement (in) with data points for Shell 0.75, Shell 0.75-Mechanical Devices-wide space, and Shell 0.75-Mechanical Devices-small space.
LESSONS LEARNED FROM SECOND SERIES OF TEST

• Sand blasting can result in adequate surface condition to produce good bond between regular concrete and UHPC

• Applying UHPC shell with minimum 0.75 inch thickness could transfer the failure outside of the retrofitted section

• Use of mechanical devices to give composite action between normal strength concrete and UHPC, is effective and can increase the ductility.

• Higher UHPC shell thicknesses result in higher sectional capacity
We have tested additional test specimens to study the effect of adding additional reinforcement in the repaired area.

- Added Rebar with length of 23”
- Rebar Cut length = 18”
Investigation includes significant non-linear finite element analysis to accompany the experimental work to better comprehend the performance.
SUMMARY OF RESULTS

• The UHPC shell concept to repair damaged bridge element is an effective way of repairing damaged bridge elements.

• Repairing damaged bridge element can be achieved using small shell thickness and mechanical devices or thicker UHPC shell and no mechanical devices.

• Sand blasting is effective way to expose aggregate and develop good surface condition, capable of providing good bond between existing concrete and UHPC shell.
Upcoming Tests for Upgrading Substandard Bridges
Wrapping the Damaged Elements with UHPC Shell
M Before Retrofit = 1580 Kips-in
M after Retrofit = 4680 Kips – In

M Retrofit / M Damaged = 2.96
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At ABC-UTC we are interested to work closely with various sectors of bridge industry to implement the UHPC based solutions that we have developed.

Several State and Federal opportunities are available that can be taken advantage of to implement UHPC based solutions we are developing.

Please send me an email at aazizina@fiu.edu if you are interested or would like to have more information.
5. Protection against chemical attack and aggressive wastewater in two containers, Switzerland, 2015

- extremely compact material structure of UHPFRC: high resistance against acid attack
- relatively thin layer to limit the reduction of storage volume
Numerical Analysis

Experimental test specimens by Eligehausen et al. (1983)

Schematic representation of Eligehausen’s tests
Numerical Analysis

Finite Element Model
Numerical Analysis

Comparison with experimental results by Eligehausen et al. (1983)
The bond resistance at given slip value was approximately proportional to $\sqrt{f'_c}$. 

$$y = 0.66x^{0.5193}$$
ABC-UTC is Developing Non Proprietary UHPC Mix that will be available in about a year.

The cost of material is between $400 to $600 per cubic yard

All five partner Universities are involved in this development