INNOVATIVE USE OF ULTRA HIGH PERFORMANCE CONCRETE TO ENHANCE THE PERFORMANCE OF BRIDGE INFRASTRUCTURE

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Bridge Infrastructure Overview

The numbers:
- Nation's bridge inventory: 671,000
- Average bridge age: 44 years (service life of 50 years)
- Number of structurally deficient bridges: 46,154
- Functionally obsolete bridges: 94,000
- Average daily trips over structurally deficient bridges: 178 millions


Bridge Infrastructure Overview

The problem:
- Structurally deficient bridges present higher risk for closure or weight restriction.
- Several older bridges are reaching the end of their service life and are more susceptible to extreme weather events.
- Overstressed elements from heavier truck loading
- Urgent need of rehabilitation or complete replacement of multiple bridges across the nation

Advances in Concrete Technology

UHPC as a solution to the rehabilitation and replacement of deteriorated bridges
- UHPC: class of concretes with high mechanical and durability properties
- General characteristics (Graybeal 2014)
  - $f_c \geq 21.7$ ksi
  - $w/c < 0.25$
  - Sustained post-cracking tensile strength $> 0.72$ ksi
Typical UHPC Mix Composition

- UHPC Typical Constituents
  - Binders/Supplemental Cementitious Materials (SMCs)
    - Cement
    - Slag
    - Silica fume
    - Fly ash
  - Aggregates
    - Silica sand
    - Ground quartz
  - High Range Water Reducer Admixtures (HRWRAs)
  - Fibers

Benefits of UHPC

- UHPC engineering and durability properties
  - Low porosity
  - High freeze-thaw resistance
  - Higher post-cracking tensile strength
  - No alkali-silica reaction
  - Improved control of deck cracking
  - Reduced penetration of chloride ions into the bridge deck

UHPC Durability Properties

Table 2: Durability properties of UHPC compared to HPC and NC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HPC</th>
<th>UHPC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Ion Penetration Depth</td>
<td>0.04 in.</td>
<td>0.35 lb/ft²</td>
<td>8.6 lb/ft²</td>
</tr>
<tr>
<td>Chloride Ion Permeability Time Constant</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Chloride Ion Penetration Depth (30 days)</td>
<td>0.005 in.</td>
<td>0.05 lb/ft²</td>
<td>0.05 lb/ft²</td>
</tr>
<tr>
<td>Chloride Ion Permeability Time Constant (30 days)</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Absorbed Resin</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Relative Volumetric Expansion</td>
<td>0.05 %</td>
<td>0.05 %</td>
<td>0.05 %</td>
</tr>
</tbody>
</table>

NC: Normal Concrete
HPC: High Performance Concrete
UHPC: Ultra High Performance Concrete
Applications

- UHPC has been used in various structural applications
  - Bridge deck overlays/strengthening
  - Joints between precast bridge elements
  - Pile foundations
  - Waffle slabs
- Accelerated Bridge Construction (ABC)
  - Efficient and lightweight precast modular section
  - Rapid closure pour between adjoining elements

UHPC Knowledge Gaps to Close

- Fatigue behavior of UHPC
- Punching shear strength
- Long-term durability of bond between overlay and existing deck
  - Freeze-thaw cycle effects consideration

Research Efforts at ISU

- The state of California owns and maintains over 7,000 box-girder bridges.
- Many of them have damaged decks from heavier traffic loads and harsh environmental conditions.
  - Concrete fatigue
  - Freeze-thaw damage
  - Punching failure
- Project objective: Develop a suitable methodology to rehabilitate and strengthened box-girder bridges

Material Characterization

- Evaluation includes four different UHPC overlay mixes
- Experimental program consists of:
  - Compressive strength test
  - Slope test
  - Interfacial shear strength test including freeze-thaw effects
  - Long-term properties evaluation including creep and shrinkage
- Experimental work to be implemented following appropriate standards
Material Characterization

- **Compression test**
  - Cube specimens

  ![Compression Test for UHPC Overlay Mix - Cube](image)

- **Compression test**
  - Cylinder specimens

  ![Compression Test for UHPC Overlay Mix - Cylinder](image)

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Material Characterization

- **Slope test**
  - Conducted on a 24 inch x 12 inch slab with a roughened surface and inclined at 7% slope
  - After mixing, the UHPC is placed on the slab with temporary wood forms to achieve the target overlay thickness.
  - After a few minutes of waiting time, forms are removed and displacement of the UHPC is observed.

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Mix Performance: Slope Test
Mix Performance: Flow Test

Finite Element Modelling

- Investigate the effects of full and partial deck thickness removal and replacement on local/global structural behavior of box-girders
- Evaluate various demolition/reconstruction sequences depending on bridge type
- Predict short- and long-term performance of rehabilitated decks

Prototype Bridges

- A simply supported bridge
  - 120-feet span
- A two-span continuous straight bridge
  - Span lengths of 207.5 ft and 210.5 ft
- A three-span curved bridge
  - Span lengths of 125, 180, and 155 ft and radius of 1165 ft
- A three-span skewed bridge
  - Span lengths of 51, 132, and 51 ft and skew of 59.41°
Task 4: Finite Element Modelling

- CSiBridge
  - Shell elements for box-girder and diaphragms
  - Tendon elements for posttensioning steel
  - Frames elements for columns
  - Link elements for support bearings and foundations
- Time-dependent properties: CEB-FIP Model Code 1990

Simply Supported Bridge Model

- 26th Street Undercrossing located in Sacramento, CA
- Northern structure includes 3 westbound lanes and 2 merging lanes and southern structure consists of 4 eastbound lanes.
- Transverse replacement sequence only

Simply Supported Bridge Model

- Deck replacement sequence

Simply Supported Bridge Model

- Deck replacement sequence
Simply Supported Bridge Model

- $f'_c = 4600$ psi
- Post-tensioning force parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tensioning Force (kips)</th>
<th>Tensioning Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensioning Force (kips)</td>
<td>1200</td>
<td>1.1</td>
</tr>
<tr>
<td>Tensioning Stress (ksi)</td>
<td>1100</td>
<td>0.9</td>
</tr>
</tbody>
</table>

- Full-depth deck replacement analysis results
- Deflections increased by as much as $400\%$ and $550\%$ immediately and 50 years after rehabilitation, respectively.

- Partial deck thickness removal/reconstruction as a solution to excessive deflections and stresses
- Implementation of partial deck removal using superposed slabs connected rigidly connected with links
- Evaluate effects of different removal thicknesses on bridge condition
Simply Supported Bridge Model

- Removal of 0.25 inch with replacement thickness of 1.5 inches
  - 25 to 29% increase in deck top stresses
  - 41 to 48% increase in deflections
- Removal of 1.25 inch with replacement thickness of 1.5 inch
  - 27 to 32% increase in deck top stresses
  - 42 to 49% increase in deflections

Two-span Continuous Straight Bridge Model

- Route 113/5 Separation Structure located in Woodland, CA and constructed in 1973

Two-span Continuous Straight Bridge Model

- Transverse replacement sequence

Two-span Continuous Straight Bridge Model

- Longitudinal replacement sequence
Transverse deck replacement sequence

Step 1 & 2

Step 3 & 4

Full-depth deck replacement analysis results

Deflections increased by as much as 116% and 240% immediately and 50 years after rehabilitation, respectively.
Ongoing Tasks

- Experimental testing under preparation
  - Creep and shrinkage
  - Freeze-thaw
  - Tensile and compression strength

- Experimental testing
  - Half scale unit anticipated to include 3 cells
  - Positive and negative bending moments to be considered
    - Fatigue load cycles
    - Punching failure
    - Ultimate strength

Questions/Comments