Module 4: Impact of Non-Proprietary UHPC Properties on Structural Design

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UHPC In-depth web training
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Overview

> Introduction
> Influence of cost on applications of UHPC
> Potential applications
> Impact of UHPC on structural form
> Impact of UHPC on design
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Introduction

A story:

A dentist, an electronics tech and a structural engineer walked into a bar........
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Effect of Cost

- UHPC is more expensive than conventional concrete.
- Simply replacing conventional concrete with UHPC for a cast-in-place beam-and-slab bridge:
  - would definitely provide a more durable structure,
  - would definitely have a higher first-cost,
  - might prove advantageous on a life-cycle basis.
- Need to look at structural applications that play to the advantages of UHPC.
Material costs vs other costs

Material costs of UHPC
- Vary with different mixes. In range $500 - $1500/yd$^3$.
- Fibers and HRWRA are typically the most expensive items.

Other costs (about the same for all concretes)
- Labor.
- Formwork and reinforcement.
- QC (probably higher for UHPC).
- Amortization/depreciation of capital equipment.
- Overhead (administration, maintenance, supplies replacement of equipment, etc.)

Total costs
- Smaller volume of UHPC + same “other” costs.
- Ratio of total costs is lower than for material cost alone.
Proprietary vs Non-proprietary costs

**Proprietary**
- Supplier’s representative on site, takes responsibility for mixing.
- At present, many contractors choose to off-load the risk, and are willing to pay the $$ premium.
- Good for cases when the contractor or agency has little or no experience with UHPC.

**Non-proprietary**
- Perceived “entry barrier” problem.
- Contractor/precast producer needs to see enough future work to justify the investment in equipment and training for UHPC.
- Good for multiple projects (“bundling”), or large individual jobs.
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- **Potential applications**
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Potential applications

- Strength and stiffness.
- Ductility and toughness.
- Durability.
Potential applications

**Strength and stiffness - Bridges**

- Long-span precast, prestressed concrete girders.
  - Higher material compressive and tension strength → lower self weight – longer span for the same cross-section.
  - Lower shipping weight.
  - Long girders now use lightweight conc. But lower $E_c$.
  - Longest single piece girder = 223 ft. (Used high strength light weight concrete)

- But...
  - Need to consider new, cost-effective, girder shapes. Base on UHPC properties.
  - Longer spans need higher prestress, more strand. Need space for them.
  - May need 2-day casting cycle to achieve release strength.
  - Beware lateral stability problems (during handling).
Potential applications

**Strength and stiffness - Buildings**
- Columns – smaller sizes.
- Flat plate floors – punching shear around columns.
- Precast beam flexural strength where depth is limited (e.g. inverted T-beams in parking garages).
- Coupling beams in shear walls (strength and ductility).

Notes:
- These hybrid applications require planning to interface between conventional concrete and UHPC.
- Precasting can help.
Potential applications

_Ductility and toughness_

- Seismic applications
  - Columns – plastic hinge regions under cyclic load.
  - Beam-column Joints – reduce bar congestion.
  - Shear keys between bridge girders.

- Impact loads
  - Truck hits on bridge girders.
  - Marine impacts.
Potential applications

*Durability – reduced costs for future maintenance.*

- Bridges:
  - Deck overlays.
  - Complete bridge decks. Consider initial cost vs durability.
  - Link slabs.
  - Joint headers.

- Marine:
  - Precast prestressed concrete piles. Mitigate corrosion.
  - Repair of corroded structures (see Kingsley Lau presentation)

- Civil:
  - Precast prestressed concrete water pipes. (Repair is $$$)
Overview

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> Impact of UHPC on design
Impact on Structural form

Strength and stiffness → weight savings and durability

- Marine pile example

**Conventional pile:**
Prestress to approx. 1200 psi

**UHPC pile:**
Prestress to approx. 2500 psi,
- Half the weight,
- Same flexural capacity,
- Higher axial capacity,
- Better durability, better driving.

Images: courtesy e.construct
**Impact on Structural form**

**Strength and stiffness** → **weight savings and durability**

- Bridge girders – Iowa State “Pi girders”, 2011

*Figure 1.4-Second Generation Pi-Section-(Keierleber, et al. 2008)*

Span = 50 ft
18 bottom strands

*Image: Rouse et al. Iowa State University (2011)*
Impact on Structural form

**Strength and stiffness** → *weight savings and durability*
- Bridge girders – lower shipping weight, longer spans

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Image: courtesy e.construct

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**Thin, ribbed, deck.**

**Thin web.**

**Big bottom flange to accommodate strands, needed for long spans.**

Decked I-Beam
Impact on Structural form

Weight savings and durability

- Precast ribbed bridge deck elements

Image: courtesy D Rogers

**Composite deck element**
- Steel “tub” beam
- Stay-in-place metal deck form (3” on 3”) with UHPC deck
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Impact on Design

Design the mix for the needs of the application:
- High axial compressive strength (columns, ps products).
- High shear strength (girder webs).
- Good bond strength (joints between pc deck panels).
- Durability (bridge deck applications, marine piles, column retrofit jackets).

Cementitious materials influence:
- Compressive strength, first cracking stress, durability.
- Little effect on ductility.

Fibers influence:
- Tensile, shear and bond properties (especially ductility).
- Little effect on compression strength.
**Impact on Design**

**Flexure - Example:** Plastic hinge zone of a seismic column

- Ductility is important $\rightarrow$ use UHPC in plastic hinge region.
- *But...* the high overall strength of UHPC risks pushing the inelastic behavior into the body of the column.
- *Thus...* reduce the dimensions of the UHPC region to capacity protect the body.
**Impact on Design**

Shear - Example: Girder web.

- Will depressed strands be used?
  - Need space for strands in web.
- Are ties needed?
  - If yes, minimum thickness controlled by cover.
  - If no, minimum thickness controlled by shear strength of UHPC.

*Image: courtesy e.construct*
**Impact on Design**

**Bond - Example:** Closure pour strip between precast deck elements.
- High bond strength $\rightarrow$ short splice length $\rightarrow$ narrow pour strip.
- Also, UHPC toughness resists deterioration under traffic loads.
- But.....
  - Fresh UHPC is flowable, so need leakproof forms.
  - May need top forms if deck is inclined.
Impact on Design

Bond – Example. Tests on panel joints.

UW tests on UHPC joints (2017).
Here: 6” joint, #5 bars, 4” overlap.
Impact on Design

**Bond - Example:** TEST SETUP

- UHPC joint
- Precast deck panel
Impact on Design

Bond – Example – after yield of bars.

Lateral confinement system

Damage concentrated at the interface, or in precast element

5” UHPC joint
Impact on Design

Design for durability - example

Mostetler Bridge, Clare Co., MI.

Image: DeWayne Rogers
Impact on Design

7.0” joint
3.5” overlap

Image: DeWayne Rogers
Impact on Design

Precast bridge deck elements – for durability

Image: DeWayne Rogers

Composite deck element
Steel “tub” beam
Stay-in-place metal deck form (3” on 3”) with UHPC deck
Impact on Design

Precast bridge deck elements – for durability.

Image: DeWayne Rogers
Impact on Design

Precast bridge deck elements – for durability

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Impact on Design

Precast bridge deck elements – for durability

**Durability vs cost**
- Clare Co. report a total cost premium of $10,000 due to the use of UHPC vs conventional concrete. (premium ≈ $600/yd$^3$).
- They expect to recoup that $10,000 cost quickly through lower maintenance costs.

**Notes**
- With only 3.5” nominal overlap, great care is needed in placement of units. Might be better to use a slightly wider joint.

*Image: DeWayne Rogers*
Questions?