Repair and retrofit of bridges using UHPC

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Project Manager, LafargeHolcim

UHPC in North America

UHPC has been used on bridges projects for over 10 years in NA. Precast deck panels connected with field cast UHPC joints has been the most popular application. Approximately 200 projects completed in more than 25 states and provinces to date.

UHPC has also been used for:
- Structural overlays
- Headers and link slabs to replace traditional expansion joints
- Jackets for columns/piers
- Pier cap to column connections
- UHPC precast elements to widen and strengthen existing bridges

UHPC projects in North America
UHPC matrix

30 MPa (4 ksi) normal

70 MPa (10 ksi) high performance

150 MPa (22 ksi) UHPC

UHPC vs Normal Concrete

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Normal Concrete</th>
<th>Ratio</th>
<th>UHPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression – MPa (psi)</td>
<td>20 – 40 (3,000 – 6,000)</td>
<td>6 x</td>
<td>140 – 160 (20,000 – 25,000)</td>
</tr>
<tr>
<td>Flexure – MPa (psi)</td>
<td>30 (4,000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic Tensile Strength – MPa (psi)</td>
<td>8 (1,200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water / Cement ratio</td>
<td>0.40 – 0.70</td>
<td>&lt; 2</td>
<td>&lt; 0.25</td>
</tr>
<tr>
<td>Chloride ions diffusion (coulombs)</td>
<td>&gt; 2000</td>
<td>20 x</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Freeze / thaw cycles scaling (g/m²)</td>
<td>&gt; 1000</td>
<td>100 x</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Abrasion (kg/m²)</td>
<td>1</td>
<td>100 x</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Steel fibers

Fibers = Ductility

UHPC in Flexure

Fibers = Stain hardening (1st crack at 4,000 psi)
Chlorides penetration test

US Army Corps test site in Maine

Design Guides - FHWA

FHWA has published over 40 reports, TechNotes and Guidelines

Design Standard – SIA 2052 - 2016

Swiss Society of Engineers and Architects

Design Standard - NF P 18-470 - 2016

AFNOR (Association française de normalisation)
Design Guidelines US/Canada

Committee work in progress

- American Concrete Institute (ACI)
  239 - Ultra-High Performance Concrete
  239-A Emerging Technology Report
  239-B Report on UHPC
  239-C Structural Design on UHPC
  239-D Materials & Methods of Construction with UHPC

Batching equipment

A size for every job

On site batching is the preferred option for most projects. We have a fleet of portable mixers which can be rented by contractors.

<table>
<thead>
<tr>
<th>Batching Size</th>
<th>Capacity</th>
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<tbody>
<tr>
<td>0.15 m³ batches</td>
<td>0.5 m³ / hour (0.5 yd³)</td>
</tr>
<tr>
<td>0.5 m³ batches</td>
<td>2 m³ / hour (2.6 yd³)</td>
</tr>
<tr>
<td>1.0 m³ batches</td>
<td>4 m³ / hour (4.8 yd³)</td>
</tr>
<tr>
<td>4.5 m³ per truck</td>
<td>4.5 m³ (16 yd³)</td>
</tr>
</tbody>
</table>

Applications

UHPC has been used to joint precast elements together and also used to secure the deck to the supporting beams by filling the haunches and shear keys pockets.

DOT’s elaborate their own specifications and designs.

Main issue: UHPC joints are now the stronger elements and not affected by live loads, freeze-thaw or deicing salts.

Solution: UHPC joints allows for faster construction because no need to form decks on site and wait for deck curing. Also, ideal for remote areas where the contractor is not dependant on the availability of ready mix.
Pulaski Skyway, NJ 2014/17

5.5 km (3.5 miles) - 4 lanes

Nipigon Bridge, east of Thunder Bay

Grouting precast deck panels with UHPC

Pulaski Skyway, NJ

Traffic maintained on 2 lanes during construction

Peoria Street Bridge, Chicago, IL

Photos by David Liu
UHPC overlay

Application of dense layer of strain-hardening UHPC with 25 to 60 mm (1 in to 2.5 in) thickness applied on the superstructure in zones of severe environmental and mechanical loads.

UHPC

<table>
<thead>
<tr>
<th>h ≥ 25 mm</th>
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</thead>
<tbody>
<tr>
<td>reinforced concrete</td>
</tr>
<tr>
<td>protection</td>
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</table>

Reinforced UHPC

<table>
<thead>
<tr>
<th>h ≥ 35 to 60 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>reinforced concrete</td>
</tr>
<tr>
<td>protection + strengthening</td>
</tr>
</tbody>
</table>

UUPC overlay formulation

Self leveling mix to thixotropic mix

UHPC overlay – large project

Batching 60 to 75 m³ (75 to 100 yd³) capacity per day

Motorized buggies to bring materials in front of the power

Portable batching plant; one site for sand, one site for the premix; 2 high shear mixers 2 m³ (1.5 yd³) batches

UHPC overlay

Placing – industrialized system

1. spread in front of machine
2. vibration
3. finished surface
**Chillon Viaducts, Switzerland 2014-15**

- 45 mm (1.75 in) cast-in-place overlay with rebar reinforcement
- Thixotropic mix used to cast on 7% slope
- 2 parallel structures each 12 m (40 ft) wide 2 km (1.2 mile) long
- 51,000 m² (560,000 yd²) total deck area
- Original segmental box system built 1969

Main issue: ASR (alkali silica reaction) and lost of concrete performance

Solution: Thin structural UHPC overlay provides waterproofing to halt ASR progression and increase substantially the strength of the deck

UHPC cheaper alternative

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**Iowa DOT, Buchanan Country, 2016**

- 38 mm (1.5 in) cast-in-place overlay
- Thixotropic mix used to cast on 5% slope
- 30 m (100 ft) long, 3-span deck
- 8.5 m (28 ft) wide
- 260 m² (310 yd²) total deck area

Main issue: Pilot project to evaluate the constructability and performance of a UHPC overlay

Solution: Current low lump concrete overlays are not performing optimally. A more durable UHPC product would provide added durability. This pilot project done in conjunction with Iowa DOT, Buchanan County, FHWA, local contractors and Lafarge will be monitored for long term durability.

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**Cudrex Viaduct, Switzerland, 2016**

- 30 mm (1.25 in) waterproofing overlay
- 45 mm (1.75 in) used on curbs and sidewalk for deicing protection

Main issue: Waterproofing at end of its life, supporting structure in good shape

Solution: Thin structural UHPC overlay provides waterproofing. Option with minimal traffic interruption.

UHPC cost comparable but more durable than other options.
Cudrex Viaduct, Switzerland, 2016

443 m (1,450 ft) x 9.5 m (31 ft) wide deck

Kanderal Bridge, Switzerland, 2017

230 mm (9 in) thick UHPC jacket used on a height of 3.5 m (11.5 ft) along with additional dowels and a rebar cage to confine the area.

Main issue: Final stage to complete the retrofit of the bridge. One pier on the south shore required additional work because of poor soil conditions.

Solution: Using a UHPC jacket allowed for a thin layer that does not obstruct the view or significantly alter the original appearance.

UHPC cheaper than using soil consolidation techniques.

Mission Bridge, Abbotsford, BC, 2014
Mission Bridge, Abbotsford, BC, 2014

Completed project Delivery to the site (total of 4 trips)

Hoisting and casting from the top of the formwork

Loading and batching in ready-mix truck at Lafarge plant

CN Rail Bridge, Montreal, Quebec, 2013

115 mm (4.5 in) thick UHPC jacket cast around an existing pier which is 600 mm (2 ft) thick x 3.5 m (11.5 ft) in height.

Main issue: Deteriorated surface due to rebar corrosion and chloride spray because of the very narrow lanes.

Solution: Owner wanted to minimize maintenance and required a material with very low porosity and that could last at least twice as long compared to normal concrete.

Casting - traffic maintained on adjacent lane

Completed repair

Grafstal Bridge, Switzerland, 2016

CN Rail Bridge, Montreal, Quebec

UHPC jacket - change in past history under the CN rail track

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**Grafstal Bridge, Switzerland, 2016**

**Hooper Road Bridge, Union, NY, 2014**

UHPC used to connect new precast pier cap elements to existing columns. Part of a 21-day structure replacement.

Main issue: Original detail called for ducts and drilling of a total of 84 holes in the existing columns and grouting of each individual hole. Difficult to implement on site and potential for many delays and issues.

Solution: UHPC connection; initiated by the Contractor who was looking for an alternative solution. Saved 2 days on the schedule. Very short development length of 280 mm (11 in) required for the joint because using UHPC.

**Hooper Road Bridge, Union, NY, 2014**

Female coupler (right) cast in Male coupler shipped loose

Existing rebar to remain

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Hooper Road Bridge, Union, NY, 2014

Francis Lewis Blvd., Queens, NY, 2015

Removed existing steel angles and associated deteriorated concrete. Add new rebar and use 125 mm (5 in) x 300 mm (12 in) wide UHPC headers.

Main issue: Steel angle and rebar corrosion damage concrete, affect supporting beams and require maintenance.

Solution: Remove the original problem in header joint, the steel angle and rebar that can corrode. By using UHPC, the corners/edges of the slabs will no longer be affected by chlorides and water penetration.

Pont de la Tine, Switzerland, 2011

Precast 200 mm (8 in) thick UHPC slabs added to extend the bridge by 1.5 m (5 ft).

cantilevered slabs are anchored to the existing structure with mechanical anchors.

Main issue: Narrow structure needed to be retrofitted to accommodate larger vehicles and provide a proper protected sidewalk.

Solution: Taking advantage of the flexural capacity and durability. Underside is exposed to elements. Low cost option in this case.

Link Slabs, Binghamton NY, 2014

Eliminating joints on bridge decks extends the life of the structure.

Main issue: Expansion joints deteriorate over time and water/chloride penetrate and damage the slabs edges and the supporting girders.

Solution: By providing a continuous link on top of the piers (approx. 100 mm thick), water/chlorides can no longer deteriorate the structure. The UHPC slab can flex and the strain-hardening provided by the steel fibers limit the width of micro cracks while maintaining the integrity of the link slab.
Link Slabs details, NY, 2016

Contact

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