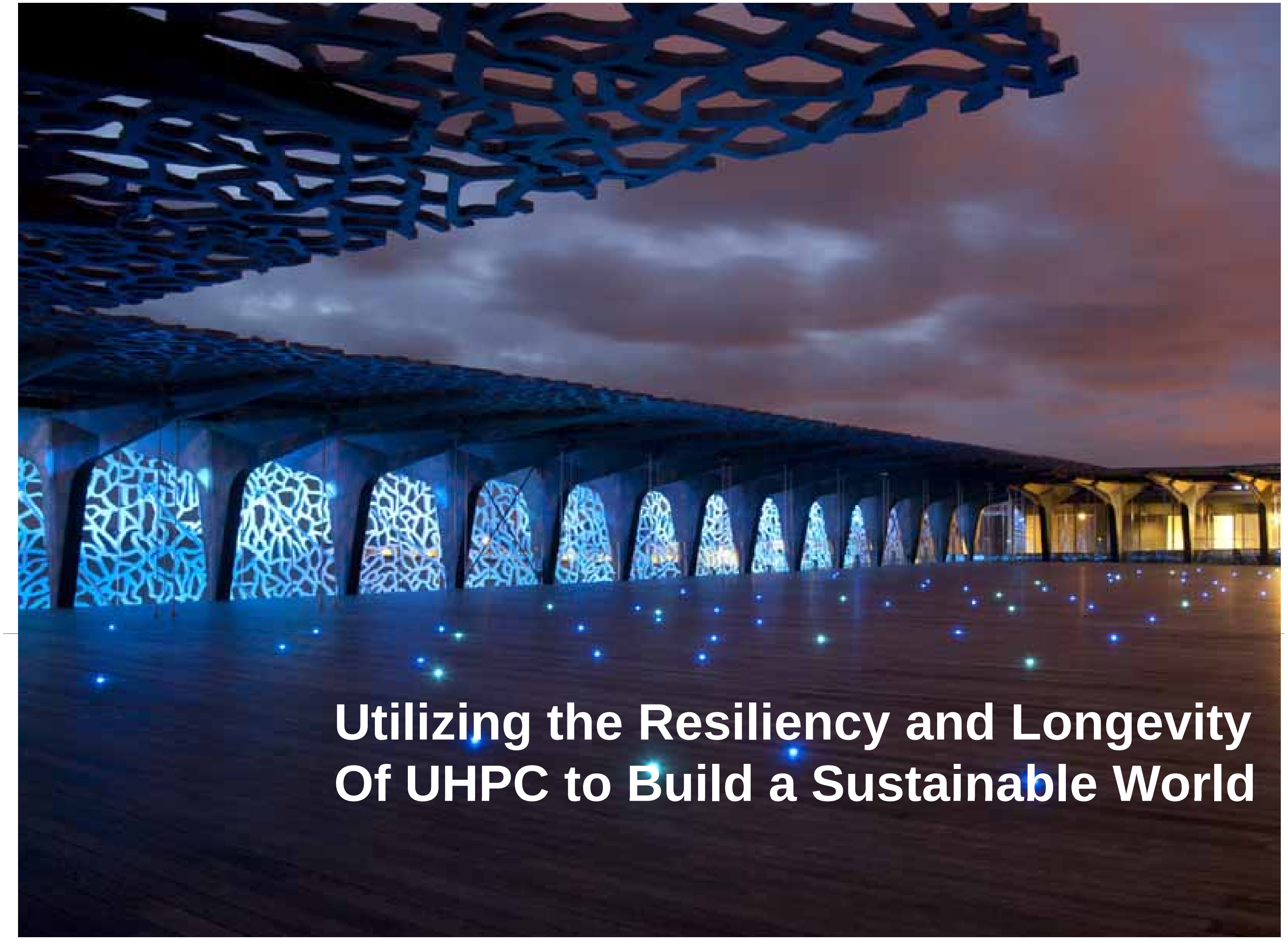

Utilizing the Resiliency and Longevity
Of UHPC to Build a Sustainable World

Outline

- **What is UHPC (Ultra High Performance Concrete)**
  - Definition / Characteristics
  - Long term Durability Testing
- **Project Review**
  - Hodder Avenue Underpass – Thunder Bay, Ontario
    - UHPC Pier Cap, Columns and Field Cast Joints
  - CN Rail Bridge – Montreal, QC
    - Column Jacketing repair
  - Perez Art Museum of Miami – Miami, Florida
    - Window Mullions
  - The Atrium– Victoria, BC
    - Curved and Flat thin panels

Defining UHPC

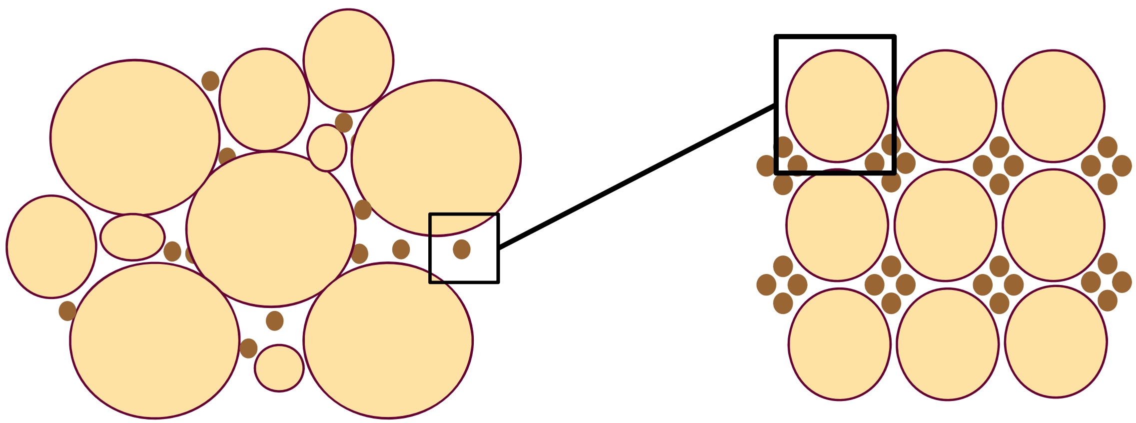
"Materials with a cement matrix & characteristic compressive strength in excess of 20,000 psi, possibly attaining 36,000 psi -- containing fibers in order to achieve ductile behavior under tension."
- SETRA (French Society of civil Engineers) (ACI is currently developing a working definition)

Typical Concrete	UHPC
Compressive Strength 2,000 to 5,000 psi	**Compressive Strength** 25,000 to 30,000 psi
Flexural Strength ~ 570 psi	**Flexural Strength** up to 6,000 psi
Direct Tension ~ 450 psi	**Direct Tension** up to 1,450 psi
Ductility None	**Ductility** Greater capacity to deform and support flexural and tensile loads, even after initial cracking.
Abrasion Resistance Weak	**Abrasion Resistance** Similar to natural rock
Impermeability Steady carbonation and penetration of chlorides.	**Impermeability** Almost no carbonation or penetration of chlorides.

UHPC optimized grain packing

Optimum Mix:
Typical Concrete

Modified Mix:
UHPC



Aggregate ¼ to ¾ inch
Sand
Cement

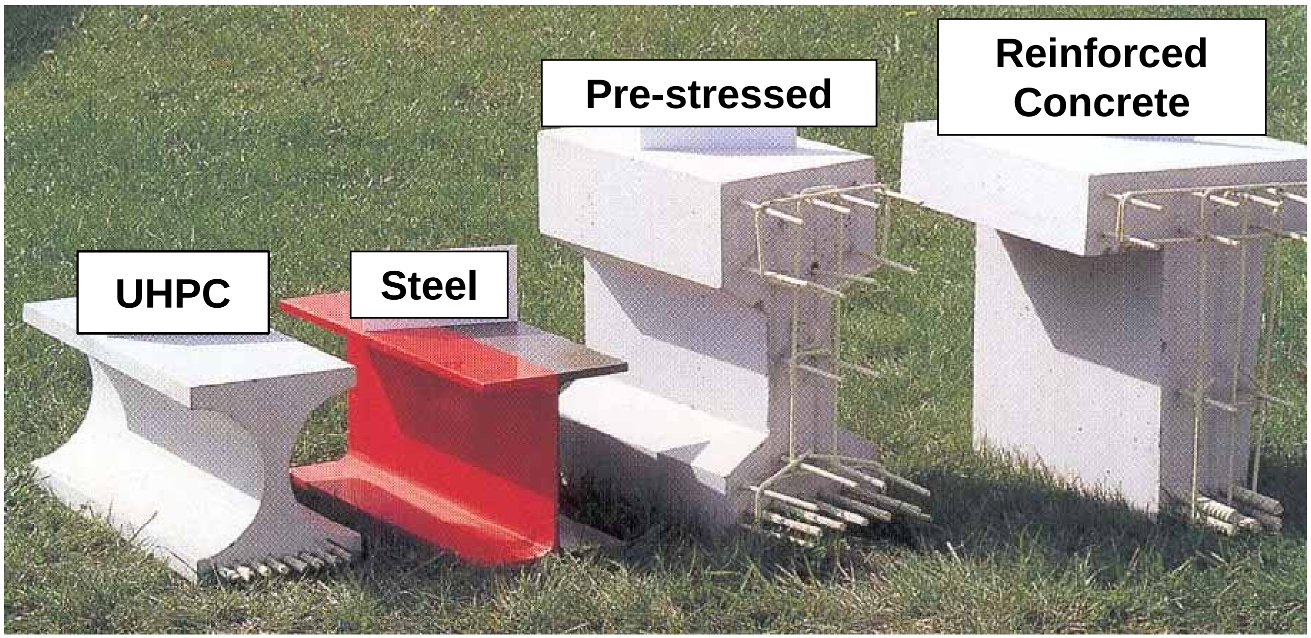
High Shear

Sand 500 microns
Cement
Quartz
Silica Fume
Fibers

Compact gradation

Ultra-High Strength

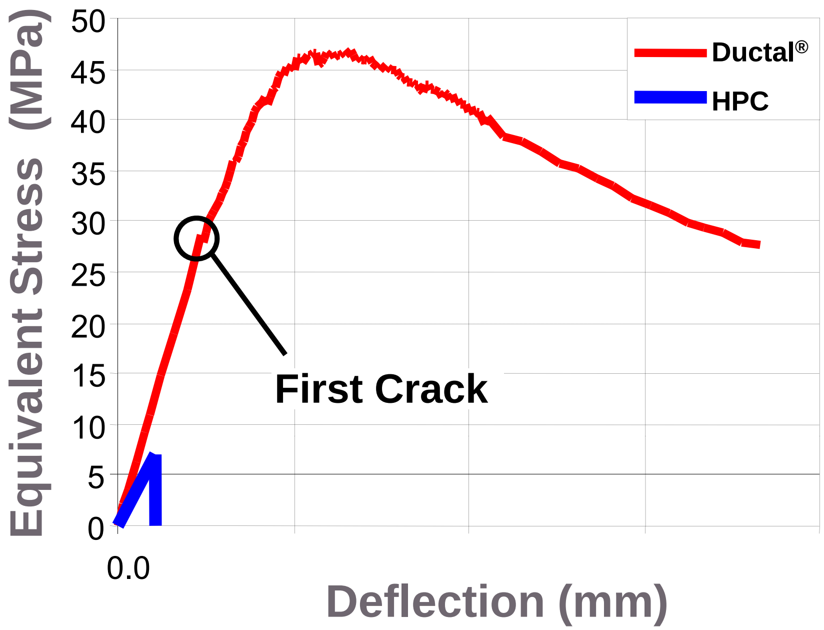
Beams of Equal Load Carrying Capacity



Mass (weight) of Beams

	UHPC	Steel	Pre-stressed	Reinforced Concrete
kg/lineal meter	**140**	**112**	**467**	**530**
lbs/lineal ft.	**94**	**75**	**313**	**355**

Ductility



2,000 lb car on a 1 ¼ -inch sheet of Ductal®

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Durability

The Goal - Long Term Serviceability and Maintenance-Free Structures

Concrete Durability depended on these physical parameters:

- Porosity,
- Permeability,
- Diffusivity

Durability performance assessments have been ongoing since 1996 and comparisons to HPC and Ordinary Concrete have been made.

 ®National Ready Mixed Concrete Association

Durability

Treat Island, Maine, USA

U.S Army Corp. of Engineers
Long-term Exposure Site

Samples of UHPC have been Installed at this site since 1996

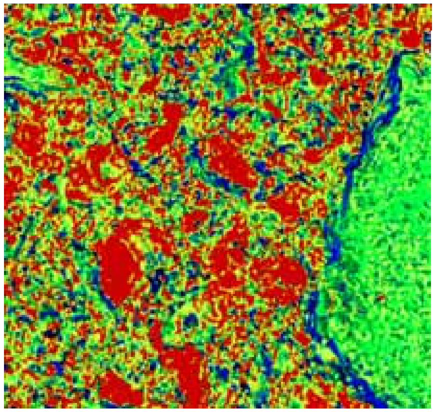
EXPOSURE data given since: 2013

- 1590 freeze/thaw cycles,
- 11950 wet/dry cycles in saturated sea water
- High abrasion from waves and ice
- No sign of corrosion on rebar with only 10mm (3/8") cover

Visual inspections are routinely done
Physical inspections are done at 5, 15 & 25 Years

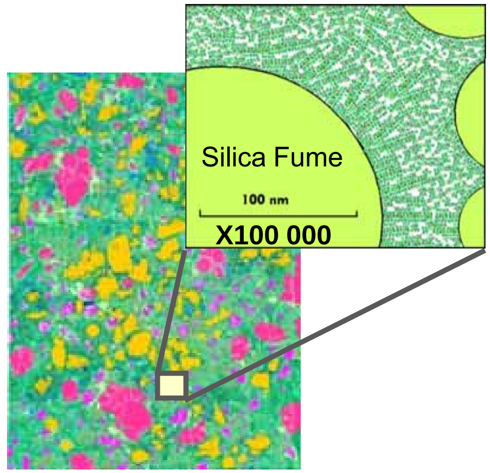
Porosity

Typical Concrete



Typical Concrete X1000

UHPC



UHPC X 1000

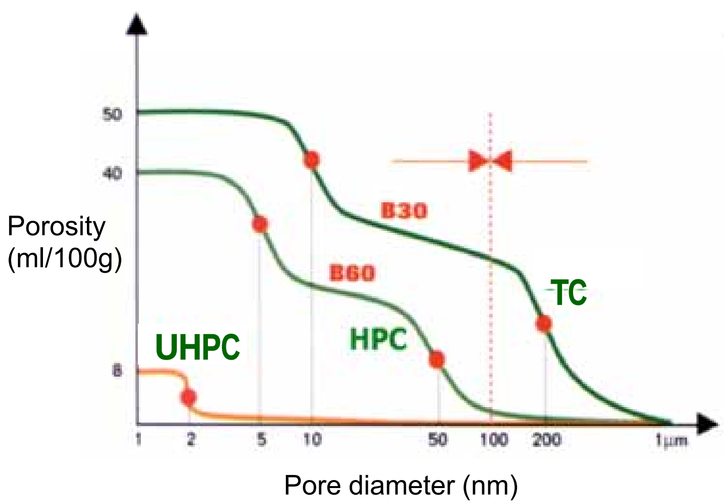
- *Connected Capillary Pores*
- *200 Nanometers*

- *No Capillary Pores*
- *Disconnected Nanopores*
- *Pore Size 2 Nanometers*

Permeability

Pore Size Determines Permeability and Diffusivity

Mercury Porometry



Nitrous Oxide Gas Permiability

Concrete :	UHPC		HPC	OC
Curing mode :	20°C	20°C (2d)	20°C	20°C
	(28d)	+90°C (2d)	(28d)	(28d)
W/C Ratio :	0.20	0.20	0.35	0.5

Permeability				
N_2, O_2 (no drying)	**1.0 E^{-22}**	**1.0 E^{-22}**	1.0 E^{-19}	2.0 E^{-18}
N_2, O_2 (severe drying)	**< 1 E^{-20}**	**< 1 E^{-20}**	5.0 E^{-18}	3.5 E^{-17}

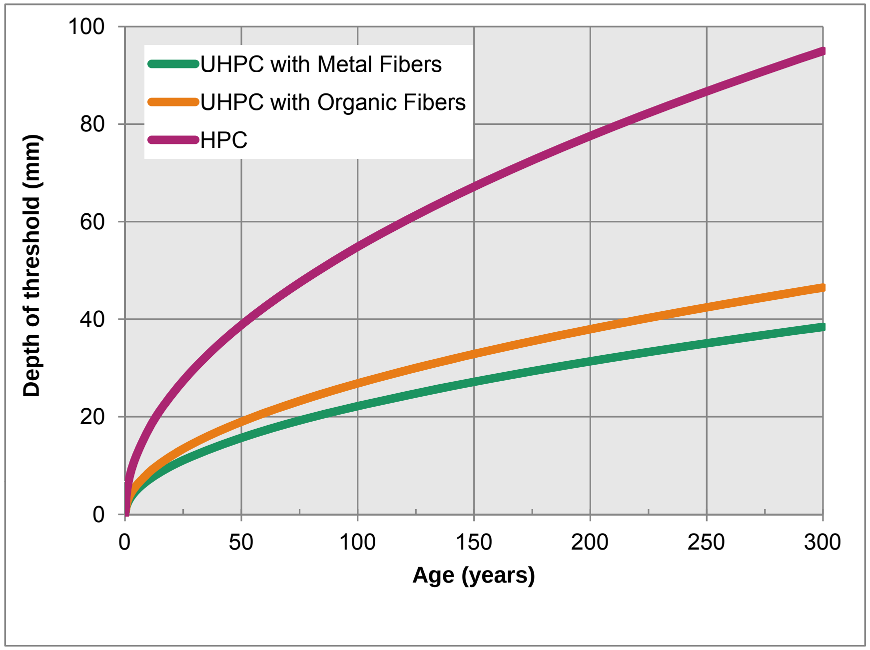
UHPC is not permeable to fluids or Oxygen Molecules because of disconnected* nanopores that also have sharp bottle-neck geometries

UHPC is less permeable than Granite

* Electrical Conductivity Test have been conducted to verify pour disconnection

Diffusitvity

Chloride Ion Penetration Depth following Frick's Law



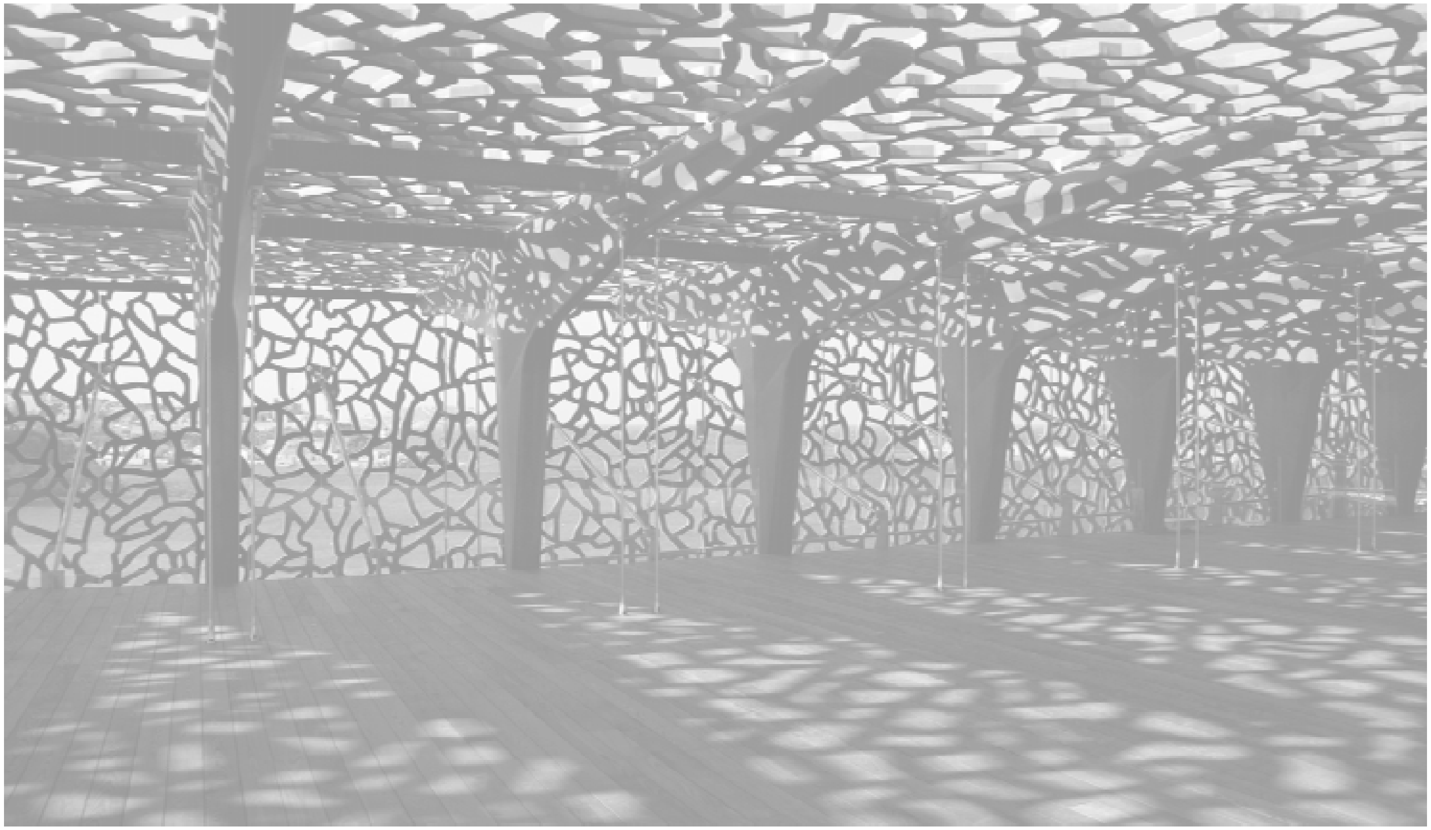
Resistance to chemical aggression and leaching are the result of the diffusivity Value for UHPC.

UHPC Diffusivity is 100 X better than HPC (D = 2.E^{-12} m2/s)

3 years are required for a tritium ion to pass through a 3 mm thick UHPC slice. From the diffusivity coefficient value, we can estimate a duration of 800 years for an ion to pass through a 50 mm thick UHPC layer !

Only 18 years is given as the estimate for the tritium ion to progress to the same distance (50 mm) in HPC

Project Review



Hodder Avenue Underpass

Thunderbay, Ontario
Built: 2012
UHPC Use: Pier Cap, Shell around Columns and Field Cast Joints (New Construction)

Further Information:
Construction Canada (January 2013 Vol. 55 No. 1)
Building a Better Bridge with UHPC Concrete Solutions in Nothern Ontario
By Raymond Krisciunas, Peter Seibert, Philip D. Murray

Hodder Avenue Underpass

Field Cast Joints

• Reduction of joint width due to development length of UHPC
• Durability and Strength characteristics make it the strongest part of the bridge
• Can be ground smooth, no need for asphalt over lay

http://www.iowadot.gov/bridge/abc_ppt_2014.htm
Papers and related Research

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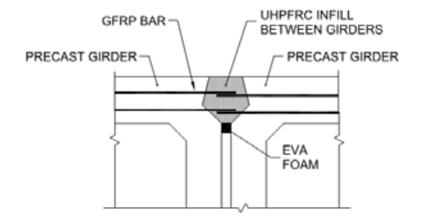
Table 1. Examples of UHPFRC joints in Hodder Avenue Underpass

Hodder Avenue Underpass

<table>
<tr><th>Joint example</th><th>Detail</th><th>Photo</th></tr>
<tr><td>(a) Shear key between girders</td><td>
</td><td>
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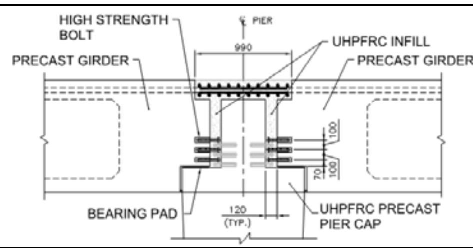
<tr><td>(b) Continuity joint over pier</td><td>
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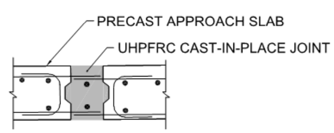
<tr><td>(c) Approach slab panel joint</td><td>
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Hodder Avenue Underpass

Pier Column Shells

- 8.35 M (27 ft)
- Leave in place mold
- Protective exterior to salt and ice

CN Rail Bridge

Montreal, QC
Built: Oct 2013
UHPC Use: Column Jacketing (Repair / Rehabilitation)

20 Year Maintenance Cycle Increased to an estimated 40 Years

Further Information:
Rehabilitation of Bridge Piers Utilizing UHPC – by Gaston Doiron and Vic Perry
Presented at the 9th International Conference on Short and medium Span Bridges

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CN Rail Bridge

3 Types of Repair method

- Spray UHPC (Naperville Example)
- Precast UHPC barriers (Japan Example)
- Cast in place “Jacketing” CN Rail example shown above

CN Rail Bridge

This column impedes into an access ramp with already narrow lanes. UHPC was utilized because of the ability to have a thin jacketing application with the greatest resistance to salt, de-icing compounds and freeze thaw.

- 100 mm thickness
- Done in two pours
- UHPC slurry mix was used to plug the attachment point holes.

Perez Art Museum of Miami

Miami, US
Designer: Herzorg & de Meuron
Built: Under Construction (2013)
Dimensions: mullions 12.7″ deep x 16′ tall tapering from 4.4″ to 2.7″
Fabricator: Coreslab

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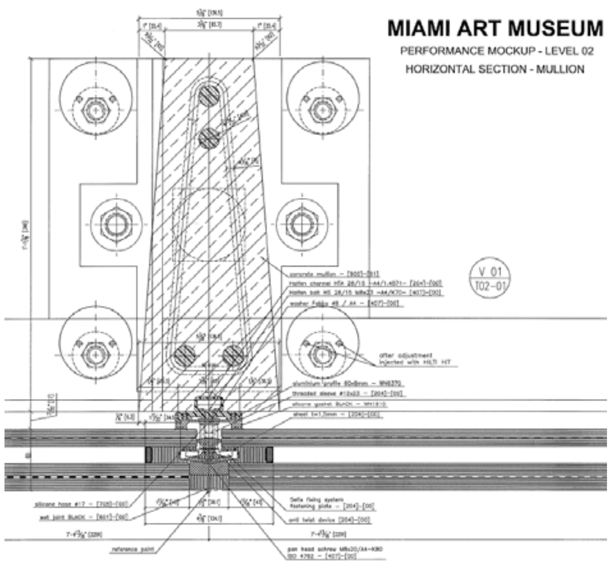
Perez Art Museum of Miami



Full Mock up testing at ATI

- Water Leakage
- Air Leakage
- Impact Test

Expected to Perform well in the High Salt Environment of Biscayne Bay

The Atrium

Victoria, Canada
Designer: Franc D'Ambrosio
Built: 2010
Dimensions: panels 1.3m x 1.3m x 1.7cm
Fabricator: Lafarge Precast

2011 PCI Design Award

The Atrium

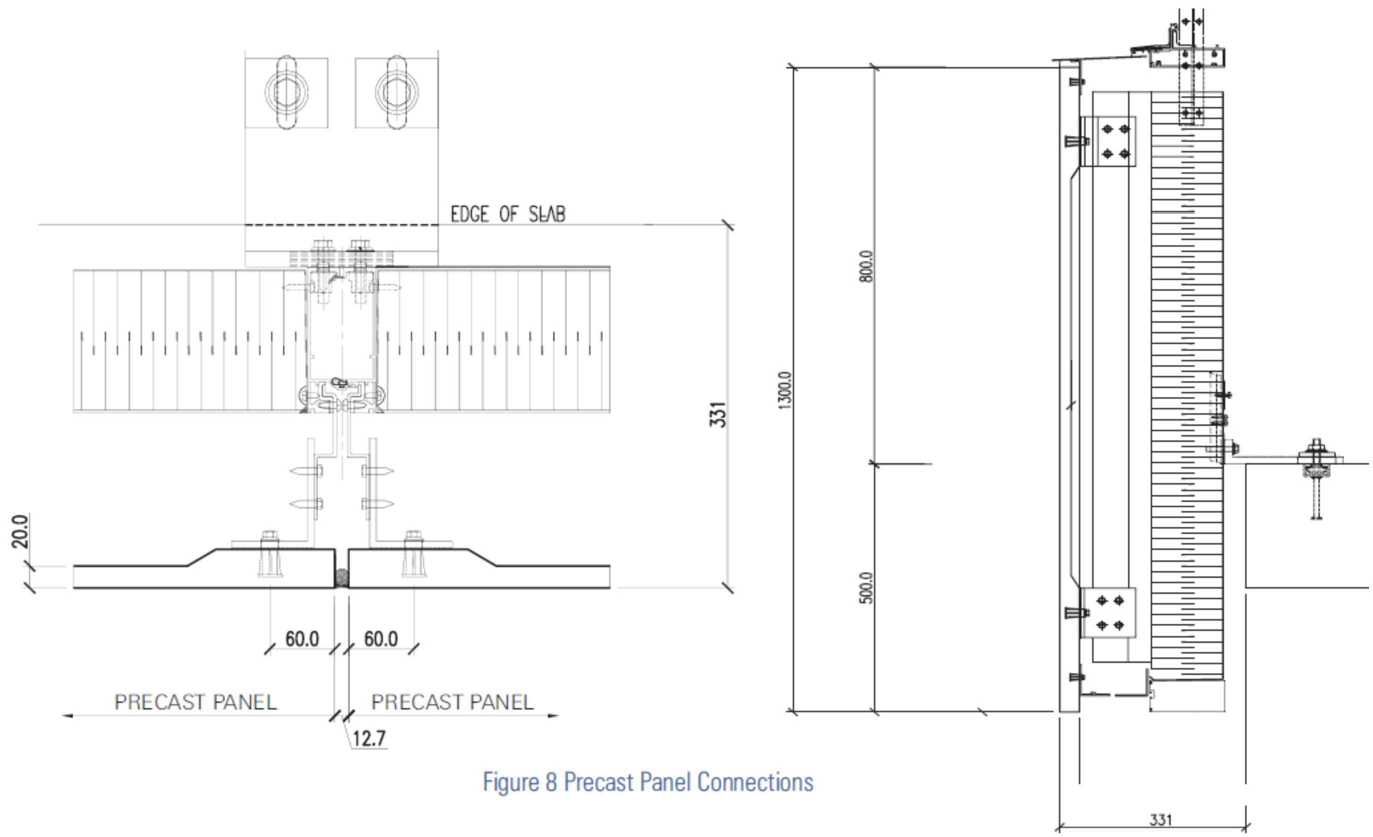


Figure 8 Precast Panel Connections

- High seismic loading
- Salt air environment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Thank You, Any Questions?