UHPC Innovations for Durability and Resiliency

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V.H.(Vic) Perry, FEC, FEIC, FCSCE, M.A.Sc., P.E., received his Bachelor of Civil Engineering with Distinction in 1978 and his Master of Applied Science in Structural Engineering in 1984 from Dalhousie University in Nova Scotia, Canada. Mr. Perry also completed Executive Management Programs and Graduate Studies at the University of Western Ontario, the University of Toronto and Duke University. Over the past 30 years Mr. Perry has gained experience in Industry, Business, Consulting Engineering and Trade Association Affairs through various positions in George Brandy's & Associates, the Portland Cement Association, Vaughan Engineering and Lafarge throughout Canada, the USA and Europe. Mr. Perry is a Fellow of the Canadian Society of Civil Engineers, Engineers Canada and the Engineering Institute of Canada. Mr. Perry is a Past-President of the Canadian Society for Civil Engineering, a member of the US Department of Homeland Security's Advanced Material Council, a member of ACI Committee 239, UHPC, and a member of the University of Calgary's Civil Engineering Industry Advisory Board. Since 1997, Mr. Perry has been involved in the development of Ductal®, initially as Director Marketing – Ductal®/UHPC for the Lafarge Group located in Paris France and more recently as Vice-President & General Manager Ductal® Lafarge North America, located in Calgary, AB, Canada.

American Concrete Institute Always advancing WEB SESSIONS

Overview

Precast Elements

- Fabricator: Gate Precast & Coreslab.
- Designer: Herzorg & de Meuron.
- Official Opening - December 2013.
- 80,000 sq foot museum.
- Gate provided 2,861 cubic yards of precast roof trellis and floors.
- Coreslab provided 150 precast UHPC mullions.

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Ductal/UHPC Mullions

- Fabricator: Coreslab
- 12.7" deep x 16' tall tapering from 4.4" to 2.7"
- Height varies from 16' to 2' depending on location

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Material Properties for Design

Formulation: Ductal AN1000LG

Characteristic Design Values				
Stress		Test Data		
		Mean	1 S. D.	Chac. Value
Compression (MPa)		130	10	105
Flexural (MPa)		22.6	3.7	-
E-modulus (GPa)		45	2	40
Direct Tension (MPa)	f_{tj}	7	0.7	5
	$\sigma_{1\%}$	3.5	.3	3

Premix:	Light Gray
Fibers:	4% PVA
Curing:	28 days @ 20 ºC 90% r.h.

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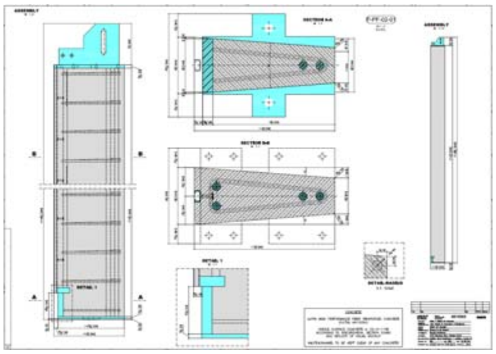
Ductal Mullions



Ductal Mullions

Design Concept
1. SLS: Deflection Analysis, elastic behaviour
- for 10 year wind (wmid < wmax)
2. ULS: Stress checks shear, compression, tension UHPC, tension reinforcement
-for 100 year wind incl. Imperfection, elastic behavior
-(σ max < fu)
3. Stability Analysis for Lateral Torsional Buckling
- for 100 year wind incl. Imperfection, plastic behaviour
max. Loadfactor (factored Loads) > 1.25

Table 7-1: Maximum allowable deformations for SLS

Level	Mullion Length	Standard Mullion	Corner Mullion
1	4.59 m 15.05 ft	25 mm 0.98 in	6.4 mm 0.25 in
2	5.26 m 17.27 ft	28 mm 1.10 in	10 mm 0.39 in
3	2.91 m 9.55 ft	18 mm 0.75 in	6.4 mm 0.25 in

Results
SLS – max. deflection

	standard mullion	w_{mid} = 7 mm < 27 mm = w_{max} ✓ 0.24 in < 1.10 in	
	corner mullion	w_{mid} = 3 mm < 10 mm = w_{max} ✓ 0.08 in < 0.39 in	

ULS (elastic behaviour)

reinforcement	tension	f_s = 432 MPa < 435 MPa = $f_{s,d}$ ✓ 62.6 ksi < 63.1 ksi
concrete	compression	f_c = 51.6 MPa < 69 MPa = f_{cd} ✓ 7.5 ksi < 10 ksi
	shear 10year	τ_c = 1.14 MPa < 1.85 MPa = τ_{cd} ✓ 0.16 ksi < 0.27 ksi
	shear 100year	τ_c = 2.61 MPa < 1.85 MPa = τ_{cd} * 0.38 ksi < 0.27 ksi

* shear capacity of material confirmed by La Farge (Appendix 05)
use of stirrups/ ties within top and bottom part of mullion

Mullions
Manufacture, Shipping and Installation

- **Reinforcing cages fabricated in Germany and shipped to Precast**
- **Set up in trough molds and cast along either side of the center halfen chanel**
- **Post cure patching of concrete flush to halfen chanel to ensure the seal between the mullion and Glass panels was achievable**
- **Shipped in enclosed containers using the top and bottom connector plates to secure each mullion in place**

Mock-up
Assembly

Static Pressure Water Resistance

Other Testing Performed

- Dynamic Pressure Water Resistance
- Structural Performance
- Inter-storey Lateral and Vertical Differential Movement
- Impact Test
- Thermal Cycling
- Air Infiltration
- Seismic Movement

Mock-up
Hurricane Testing

TABLE #1
Uniform Load Deflection
(Deflection in inches)

Indicator Location	Positive 80.0 psf	Net Deflection	Negative 80.0 psf	Net Deflection	Allowed*
1	0.020	---	0.030	---	---
2	0.050	0.040	0.160	0.140	1.016
3	0.000	---	0.010	---	---
4	0.110	---	0.220	---	---
5	0.290	0.230	0.480	0.360	1.016
6	0.010	---	0.020	---	---
7	0.060	---	0.200	---	---
8	0.130	0.090	0.210	0.105	1.016
9	0.020	---	0.010	---	---
10	0.120	---	0.190	---	---
11	0.230	0.110	0.220	0.030	0.500
12	0.120	---	0.190	---	---
13	0.370	---	0.570	---	---
14	0.790	0.375	0.910	0.305	---
15	0.460	---	0.640	---	---

Uniform Structural Overloads

@ +60.0 psf (Preload)
@ +120 psf (Overload)
@ - 60.0 psf (Preload)
@ - 120 psf (Overload)

Passed

Missel Test

Missel – 2X4 Southern Pine
Velocity – 49.8 fps
Hit Mullion mid height center Right

Passed

Mock-up
Results

- **Final Test Results:**

  Passed All Tests with no visible damage or uncontrolled leakage of the system

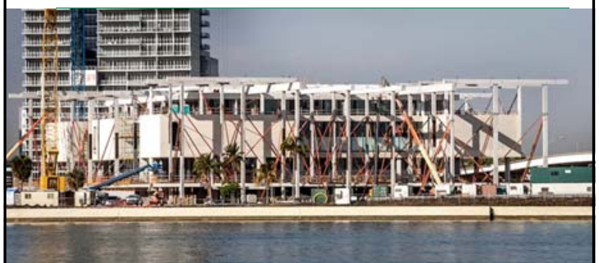
- **Tested For and met the building code requirements of the Florida Building code for the following:**

  TAS 201-94 Section 1626

  TAS 202-94 Section 1620

  TAS 203-94 Section 1626

  Cyclical wind pressure loading (Hurricane Testing)



Questions?

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