Ductal® Ultra High Performance Concrete ABCIC networking II

Sao Paulo , September 25th 2018

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LafargeHolcim

Content

Part 1: Genesis of UHPC

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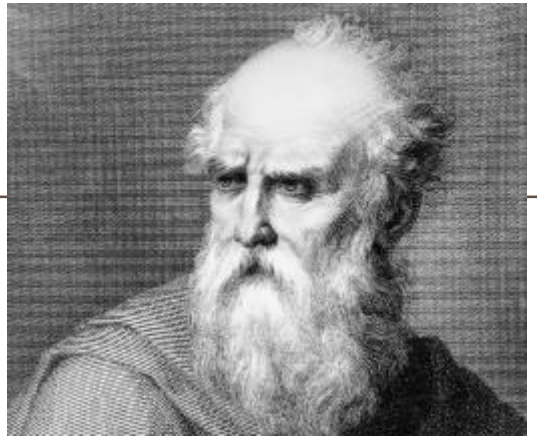
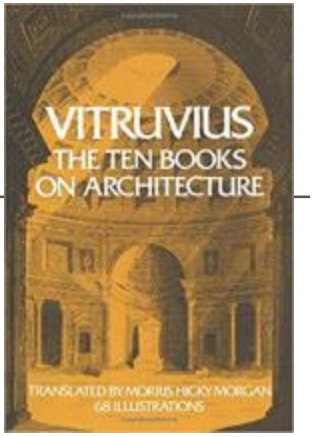
Genesis of UHPC

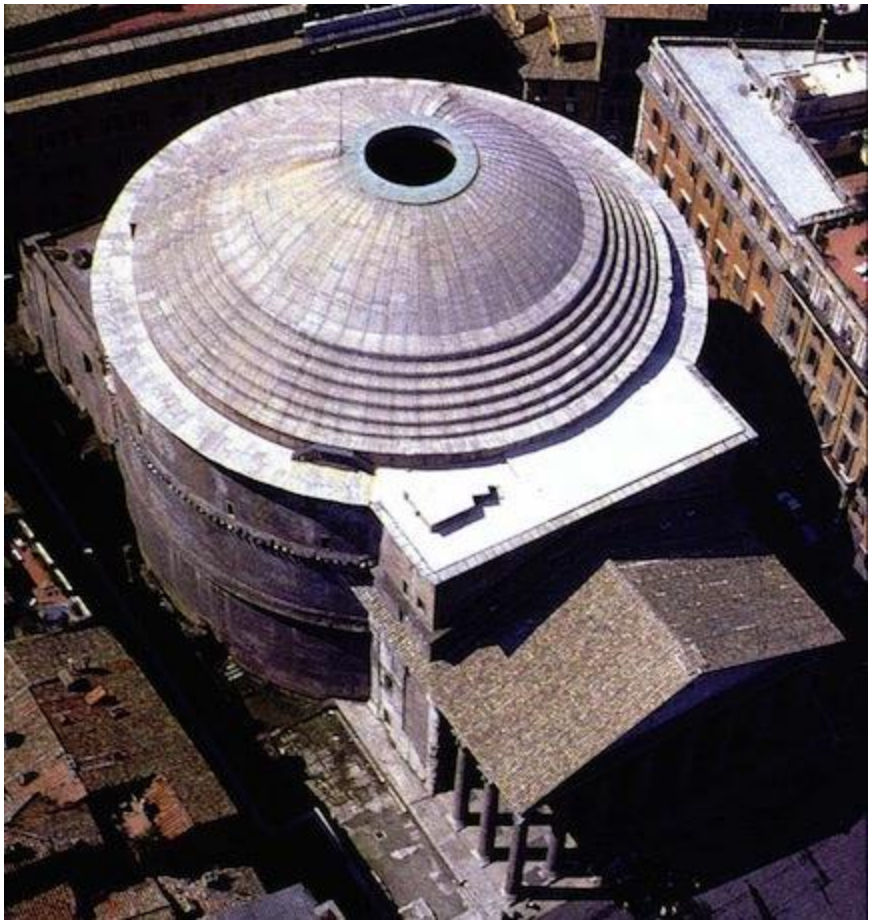




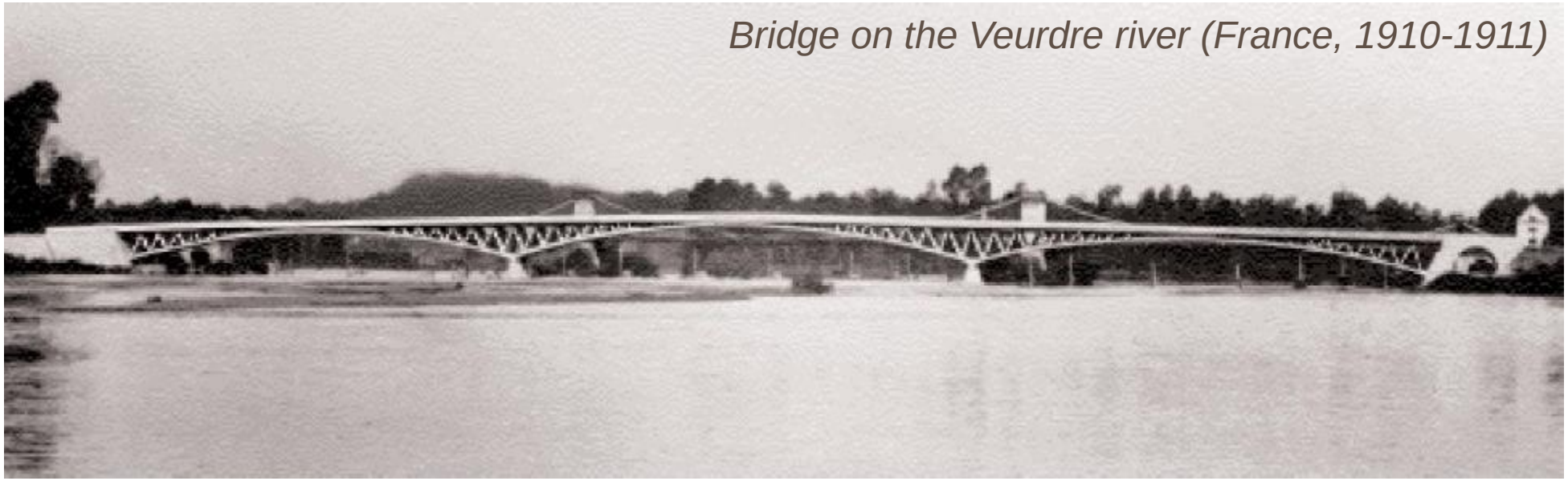
The first large-scale construction in concrete *(try-and-test)*

- **80-15 BC: Marcus Vitruvius POLLIO** is the author of *De architectura*, known today as *The Ten Books on Architecture.* Vitruvius is famous for asserting in his book that a structure must be **solid**, **useful** and **beautiful**.

- Started in 27 BC and completed in 125 AC, **the Pantheon** has the largest un-reinforced concrete (lime and natural pozzolan) dome ever built (43m in diameter).

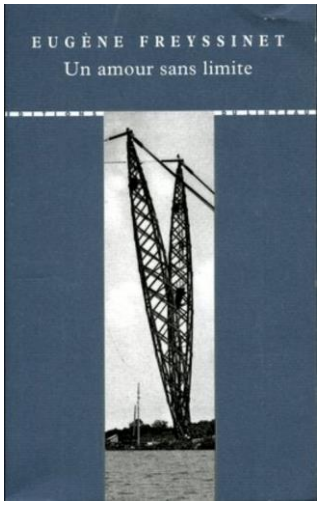


Genesis of UHPC



Bridge on the Veurdre river (France, 1910-1911)

Eugène FREYSSINET
(1879-1962)



Genesis of UHPC

Pier Luigi Nervi
(1891-1979)

The hall of the Turin Exhibition Center "is formed by the assembly of prefabricated elements in ferrocement, assembly completed by reinforced concrete ribs, cast in situ, and arranged in the hollow and the top of the wave".
Page 104, in Savoir Construire - Nervi

Genesis of UHPC

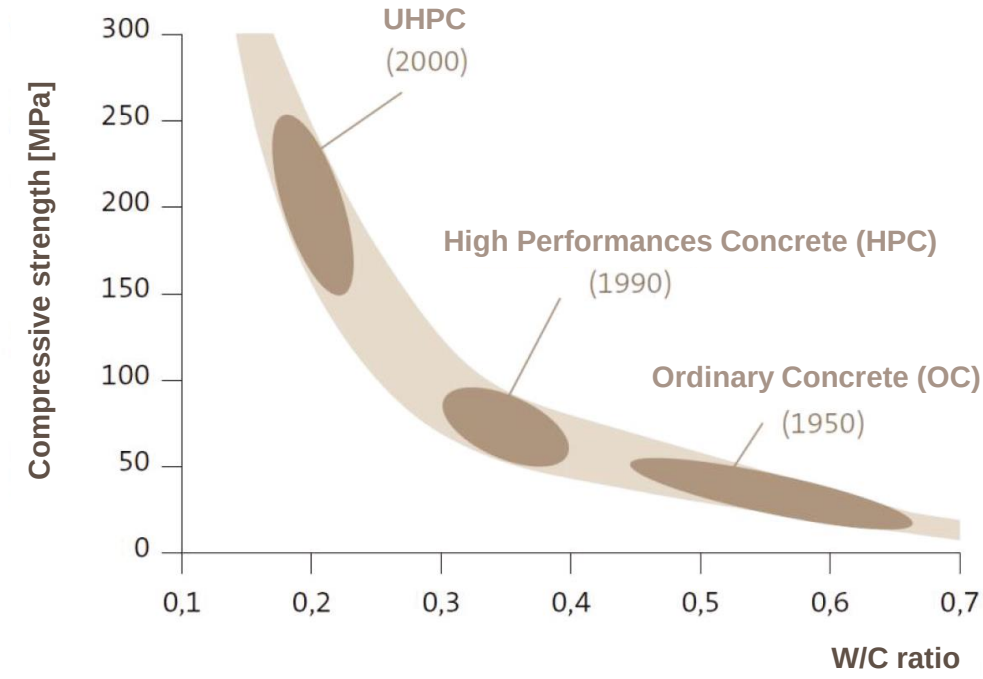
Oscar Niemeyer
(1907-2012)

Genesis of UHPC

The 20th century: the technological breakthrough

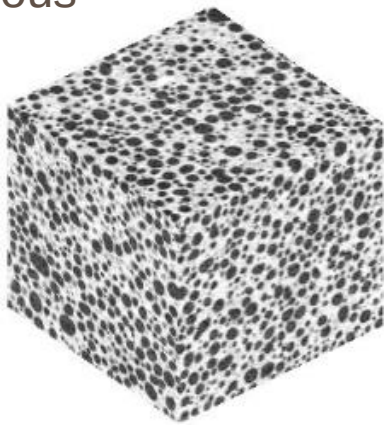
- **Advanced scientific understanding**
  - Superplasticizers
  - theory of granular packing
  - physical laws governing aging
  - predictive engineering of durability

→ **performance multiplied by 5 to 10**



Genesis of UHPC

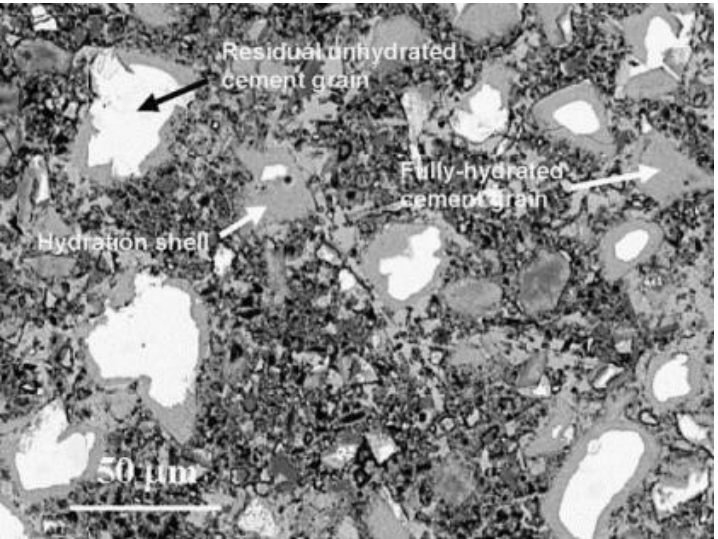
Concrete is a natural Heterogeneous material

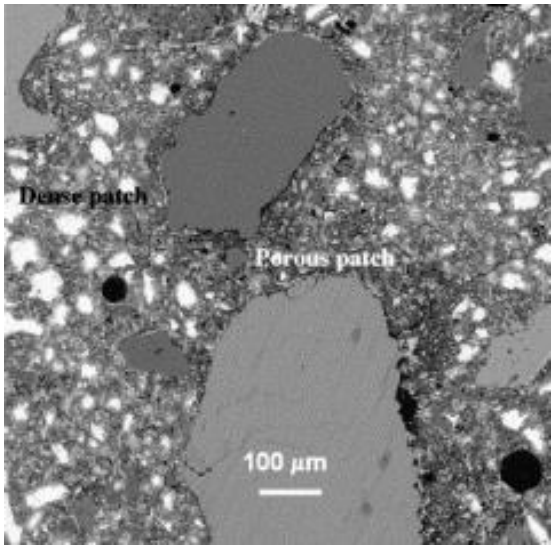


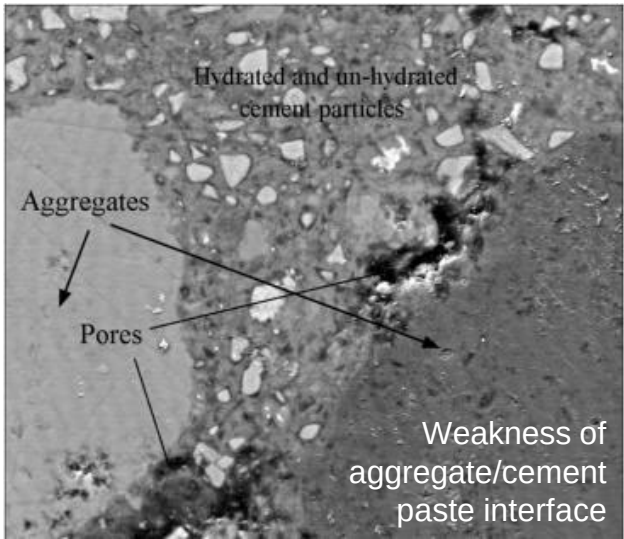
Geometrical with particles and aggregates of various sizes

Mechanical, with a different stiffness between aggregates and cement paste

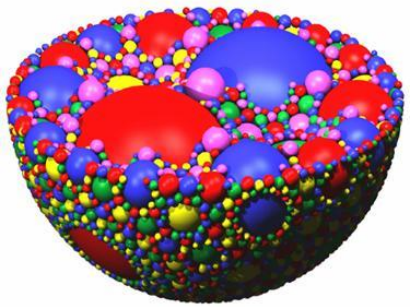
Chemical: “Chemical” shrinkage of the paste inside a rigid skeleton of aggregates => damage



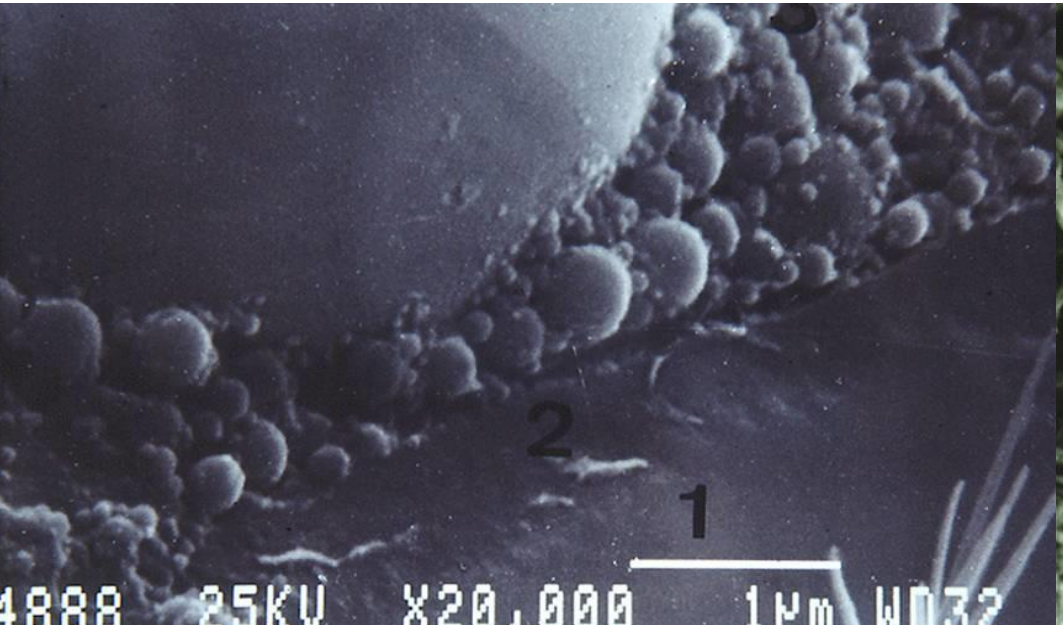


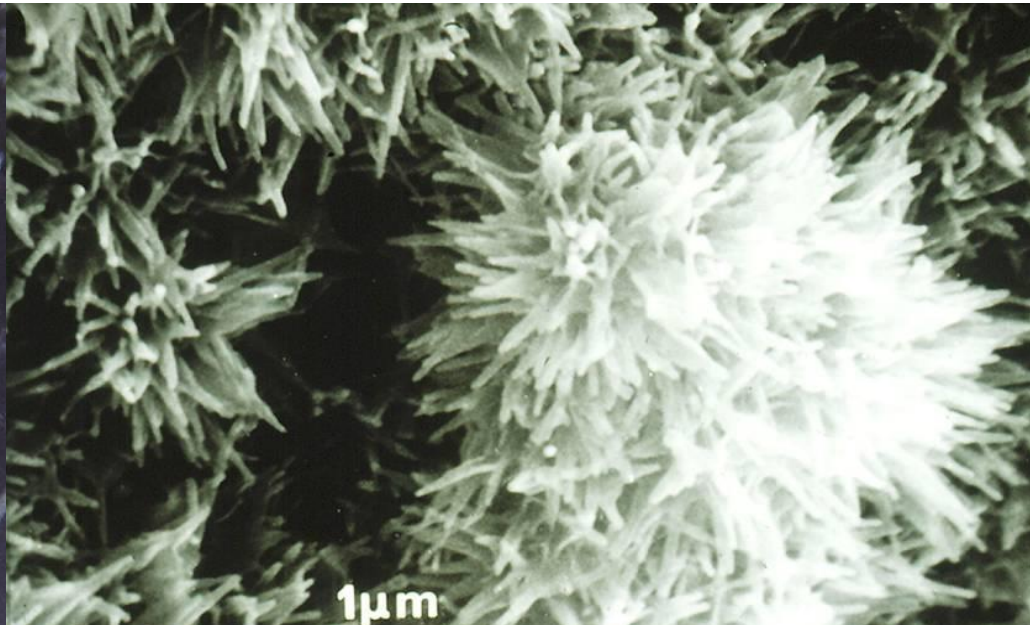


Genesis of UHPC



- Limitation of the aggregate size (<0.6 mm for Ductal®) and limitation of sand dosage
- Enhancement of paste properties with a Young modulus closer to the one corresponding to the sand skeleton
- Paste content sufficient between the aggregates to avoid rigid skeleton: Self dessication shrinkage is not blocked (less damage)





Genesis of UHPC

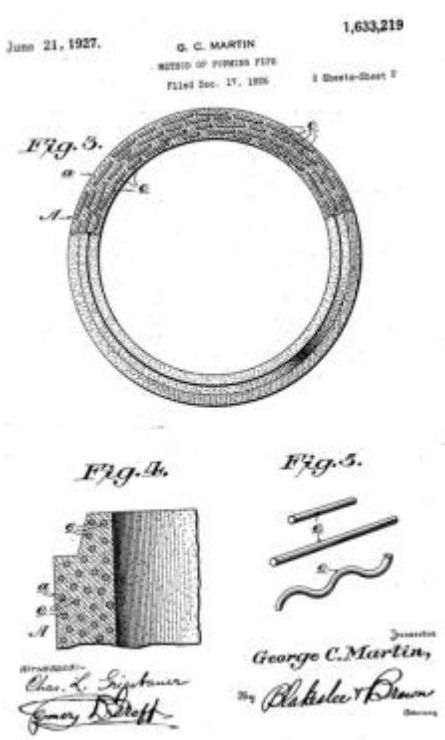
Since ancient times, fibres have been used to reinforce brittle materials

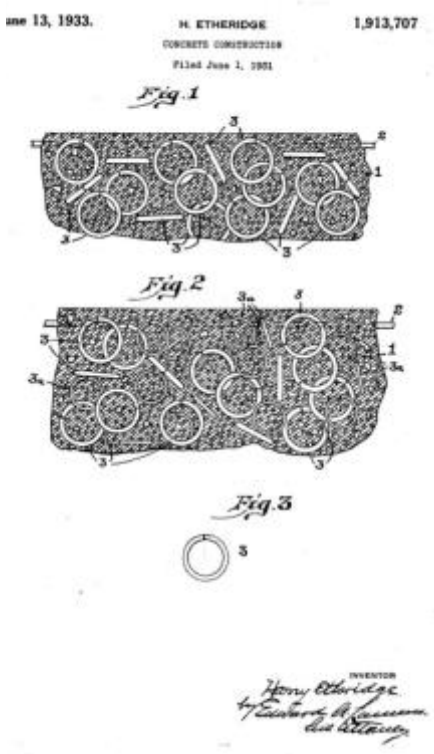
Exodus 5:6,
And Pharaoh commanded the same day the taskmasters of the people, and their officers, saying, we shall no more give the people straw to make brick, as heretofore: let them go and gather straw for themselves.

Egyptians used straw to reinforce mud bricks, but there is evidence that asbestos fibre was used to reinforce clay posts about 5000 years ago.

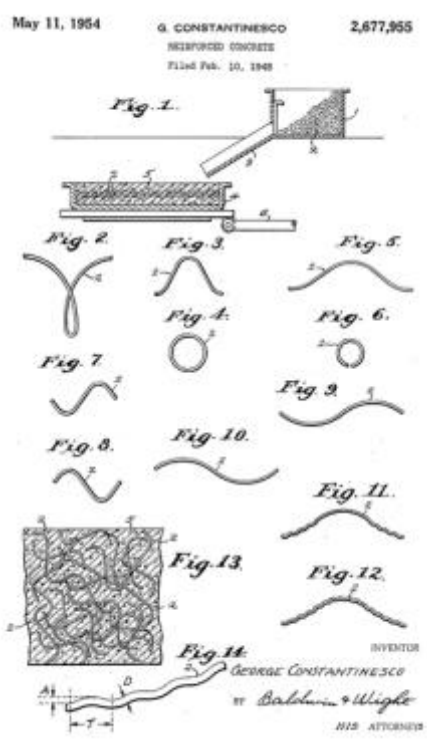
Genesis of UHPC

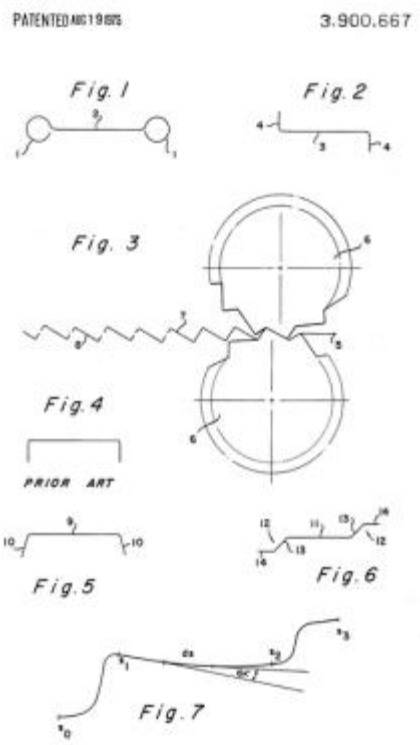
Early 19th century, patent on steel fibres as reinforcement

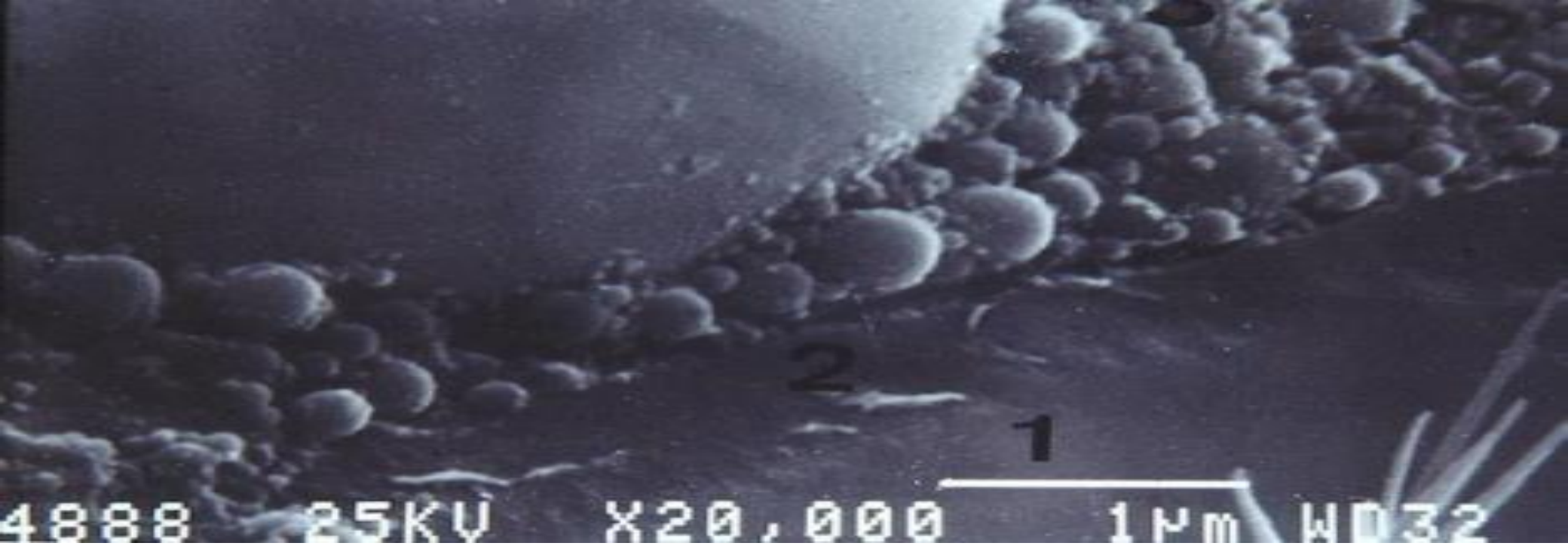




Several patents on fibre geometries







Part 2: Characteristics of UHPC

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Characteristics of UHPC

Improvement of the homogeneity

A low W/C ratio and a high cement content

- Reduction of the porosity
- High compressive strength and durability

Improvement of the packing density

UHPC does not contain any coarse particle (≤ 2 mm)

- Homogeneity
- High compressive strength

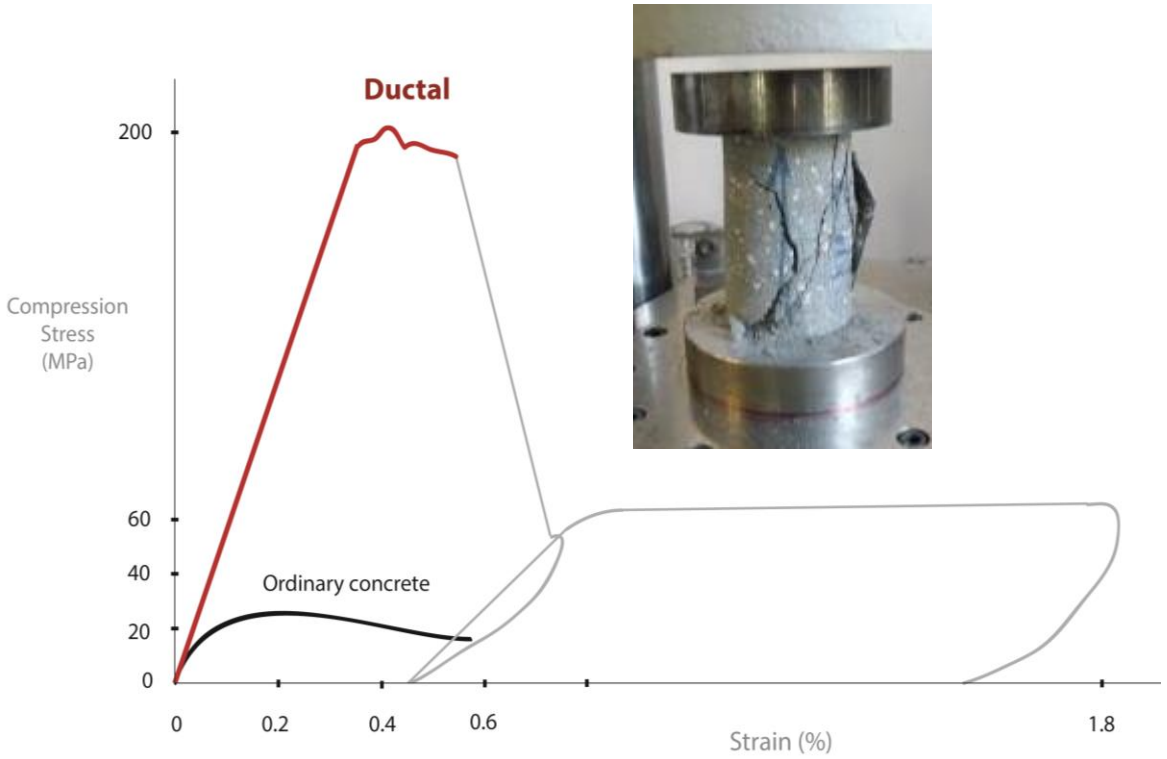
Improvement of the ductility with fibers

Use of micro-fibres

- Length 12/20mm and Ø=0.2/0.3 mm
- Tensile strength (fibre ratio depends on performance requirements)

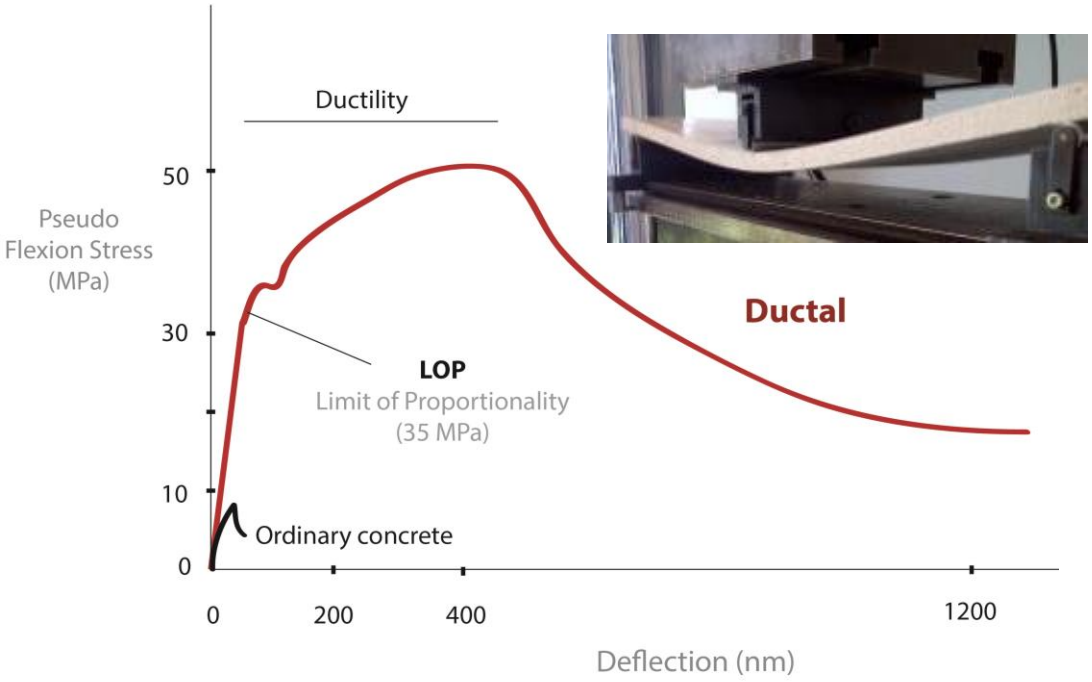
Characteristics of UHPC

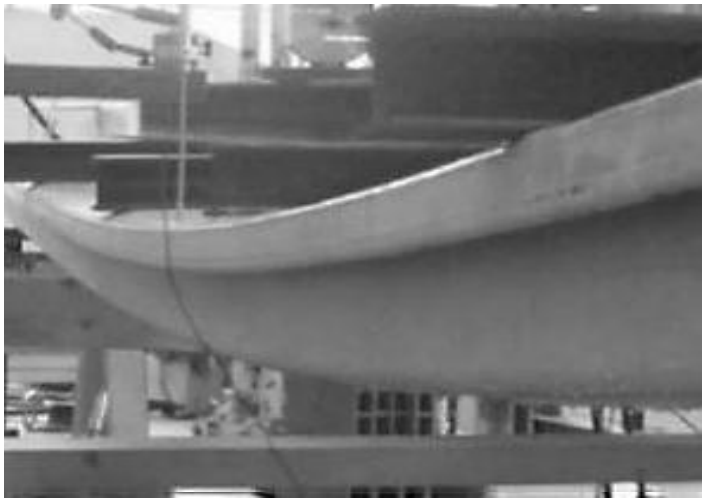
- **Very high compressive strength**



Characteristics of UHPC

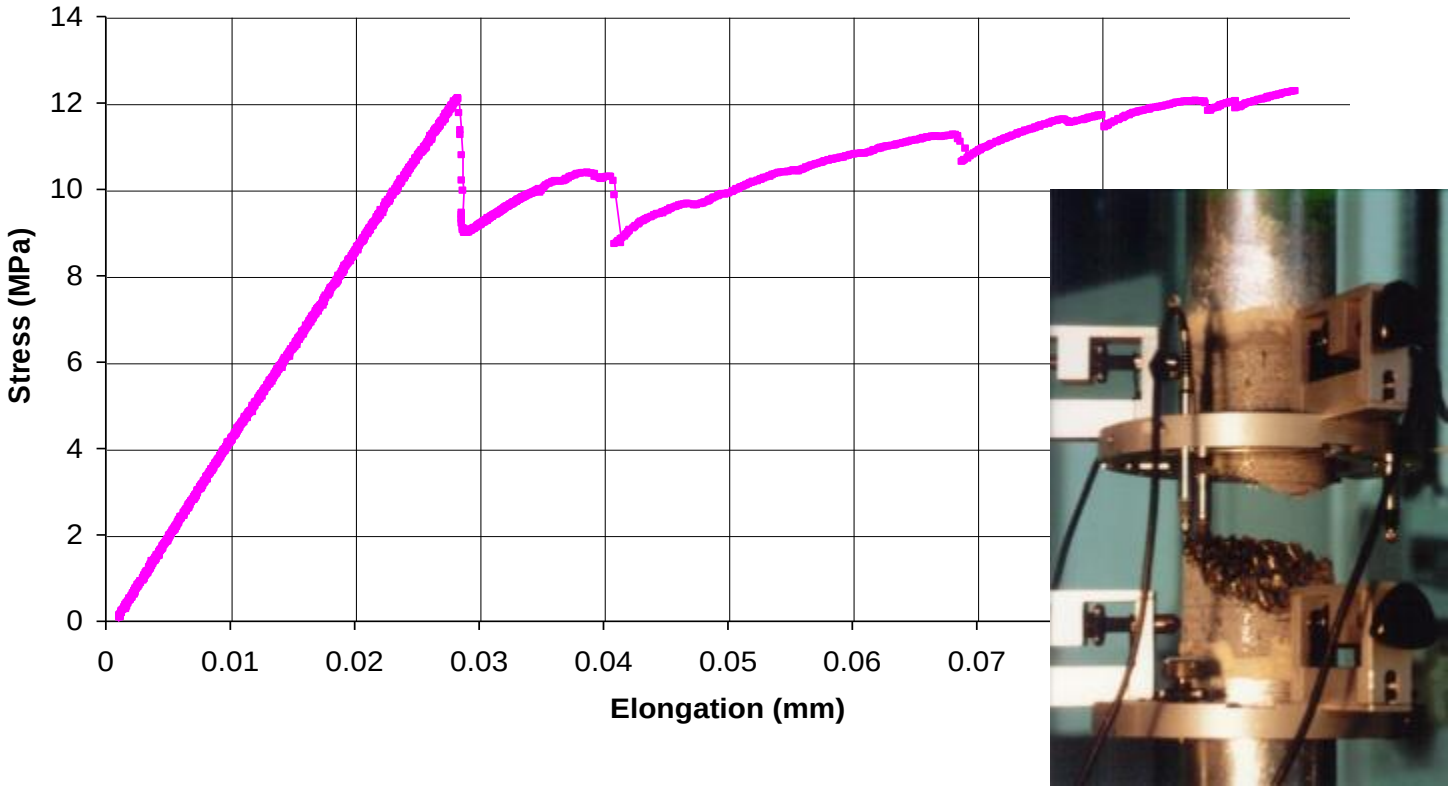
❑ Very high bending strength





Characteristics of UHPC

❑ High direct tensile strength



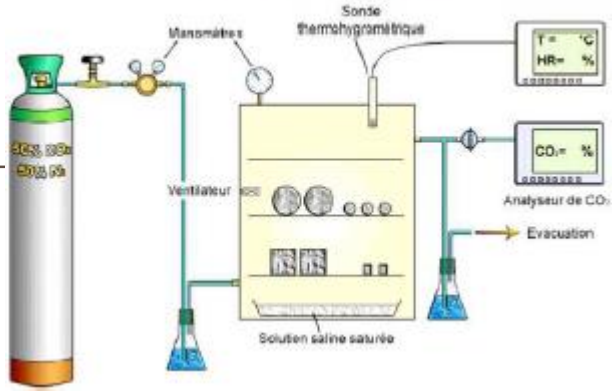
Characteristics of UHPC

❑ Very high durability

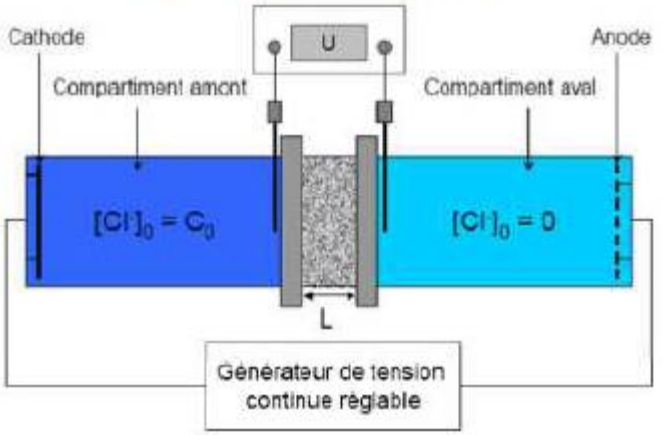
- 100 to 1000 more durable than ordinary concrete
- no depth of carbonation
- chloride resistance (diffusion and penetration)
- freeze-thaw and spalling resistance
- gas and water permeability
- water porosity / total porosity (mercury intrusion)
- high resistance to abrasion and shock

lifetime of structures > 150 years

Carbonation test



Chlorure migration test



Gaz permeability

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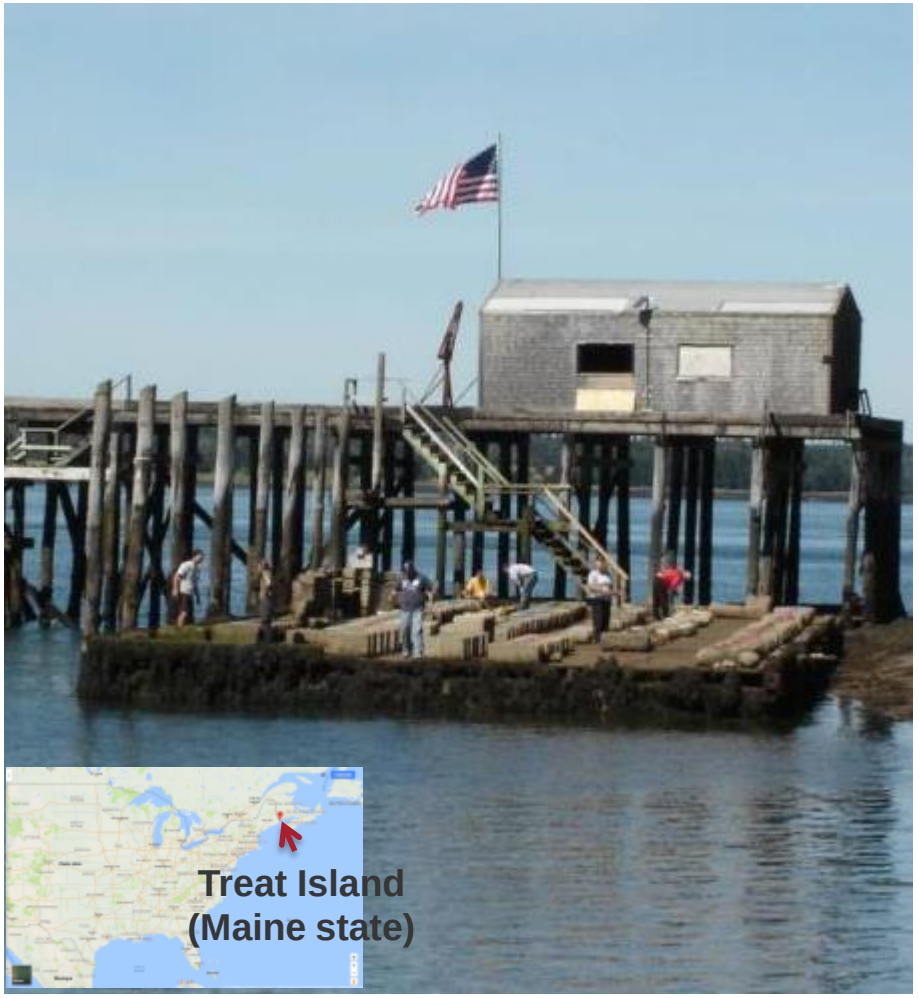
Characteristics of UHPC

❑ Very high durability

US Army Engineers Corp have placed beam sample for long term exposure resistance to sea water and tide: samples are alternatively immerge and exposed to weathering twice a day – in place for the last 20 years.

No damaged confirmed by analysis by pulse velocity measurements (ASTM C597).



Characteristics of UHPC

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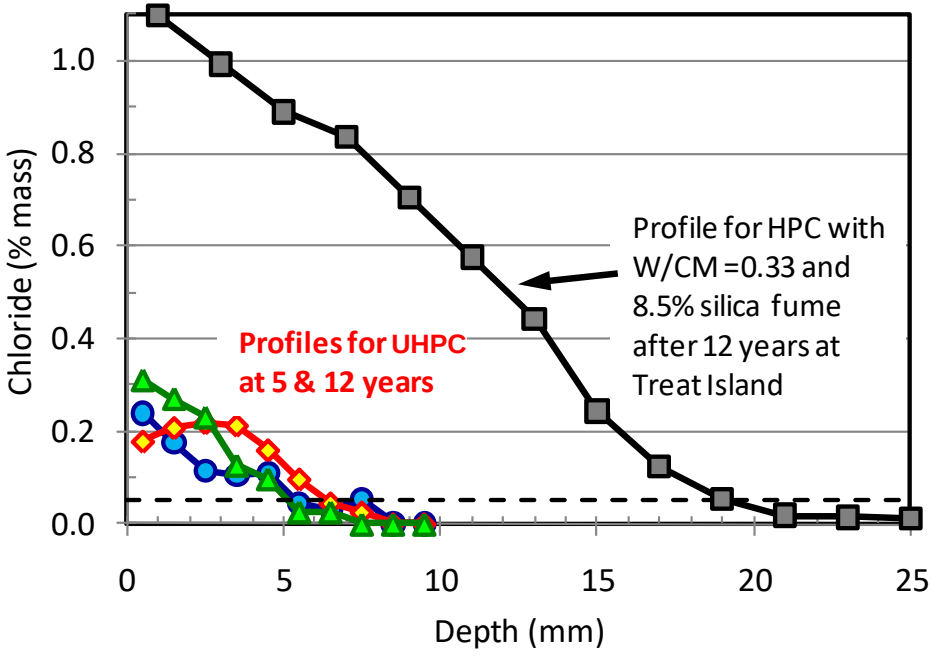
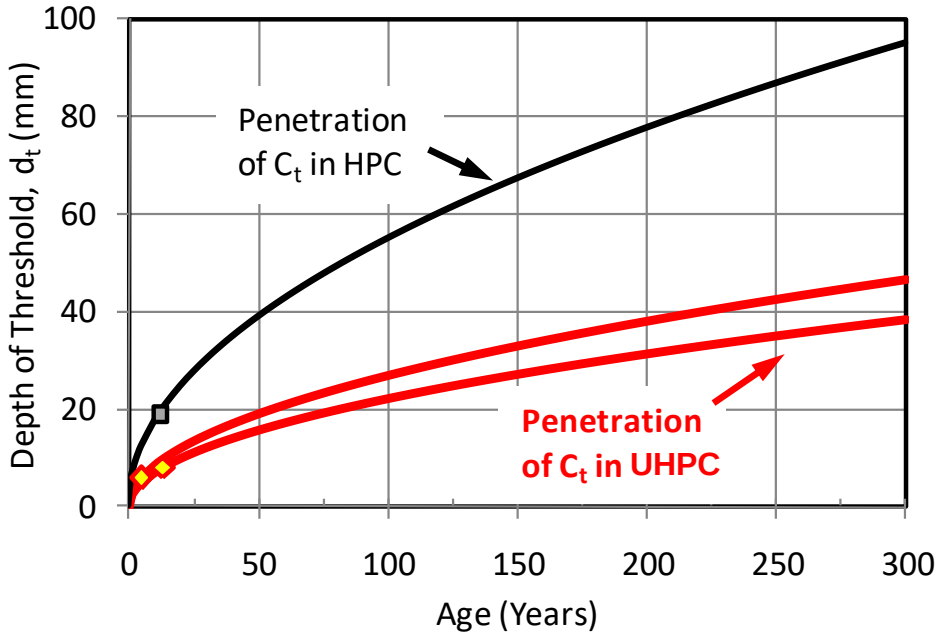


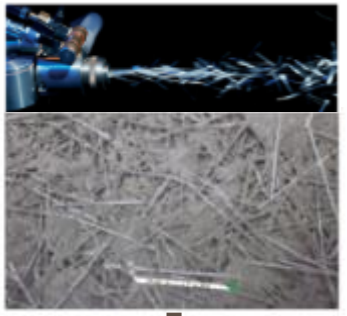
Chloride profiles: UHPC versus HPC



Predicted Rate of Penetration

Characteristics of UHPC

❑ Fine-tuning rheology



Vertical

spray, shotcrete

Slope Control

thixotropic

Self Leveling

pouring

Large range of applications by mastering the rheology

Part 3: Design & Execution

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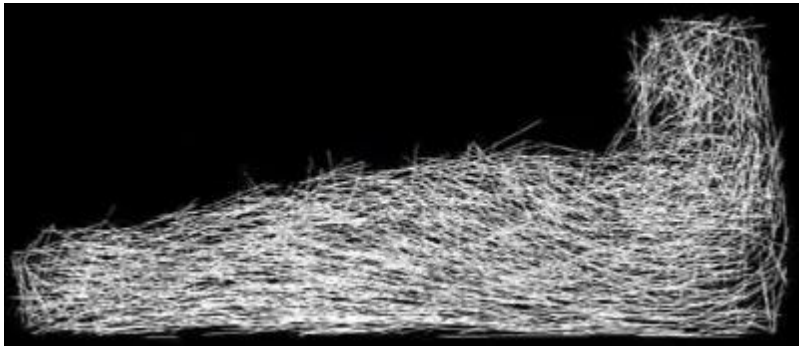
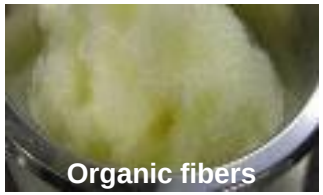
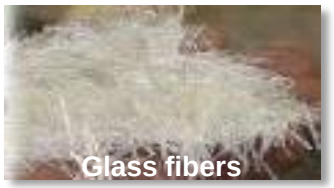
Design & Execution

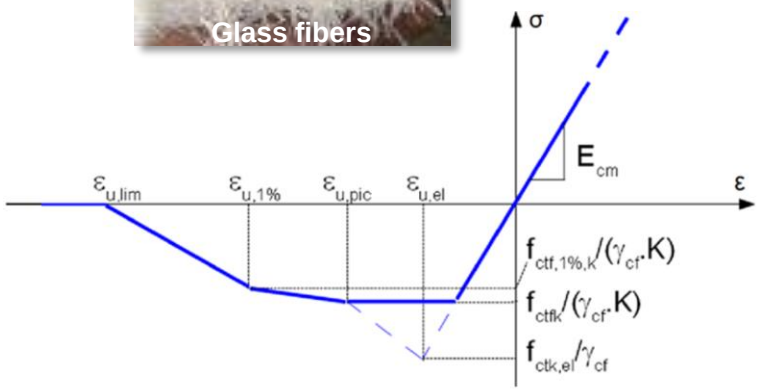
Philosophy of design

- **UHPC is an engineered concrete-like material**
- The method of design depends on:
  - **the geometry** (thin / thick members) → 2D or 3D orientation of fibres
  - **the type of fibre** (steel or non steel) → post-cracking or elastic calculation
  - **the content of fibre** → strain-softening or strain-hardening behaviour in tension









Design & Execution

Approach of design

❑ ID card concept

- declaration of all the characteristics of UHPC
- provide by the supplier of UHPC (commitments)

❑ Suitability test

- conformity of UHPC to the specifications of the project
- validation of the manufacturing method (mixing, pouring, …)
- validation of the orientation of fibres (steel only) with a control mockup

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LafargeHolcim	Identity Card of Material* Ductal® G2 FM STT		Ductal n° G2FM200STT
Date	May 2018	Written by	V. MALIK
Version	2	Validated by	S. BERNARDI

* according to the standard NF P 18-470 "Ultra High Performance Fiber-Reinforced Concrete – Specifications, performance, production and conformity".

General Characteristics	
Nominal formula and mixing process	Cf. Mix design sheet
D_{upper}	0.6 mm
Length of fibres L_f	14 mm
Class associated to the type of fibres	Type M
Designation	UHPFRC-S
Casting Method	Placement by self-weight or piston pump (according to LafargeHolcim recommendations)

Heat treatment (TT)	
Yes ☐	No ☑
Type of Heat Treatment	Not relevant
Description	Not relevant

Properties of fresh concrete	
Slump flow (ASTM cone)	245 mm ± 18.4 mm
Working time at 20°C	1 hour
Air content (entrapped air)	3.0 %
Curing conditions	Curing at 20°C (A curing product shall be sprayed on the exposed fresh surfaces. These surfaces should also be protected to limit desiccation.)

Mechanical Properties at 28 days or before/after TT	at 24 h	after TT	at 28 days
Characteristic compressive strength f_{ck} (Compressive strength class)	-	-	150 MPa (UHPFRC 150/165)
Characteristic value of limit of elasticity under tension $f_{ctk,el}$	-	-	9.5 MPa
Mean value of tensile limit of elasticity under tension $f_{ctm,el}$	-	-	10.5 MPa
Tensile behaviour class	T1		
Characteristic value of post-cracking strength f_{Ftk}	8.0 MPa		
Mean value of post-cracking strength f_{Ftm}	9.3 MPa		
Mean value of Young's modulus E_{cm}	56 GPa		

LafargeHolcim | Identity Card of Material* Ductal® G2 FM STT | Ductal n° G2FM200STT
Date | May 2018 | Written by | V. MALIK
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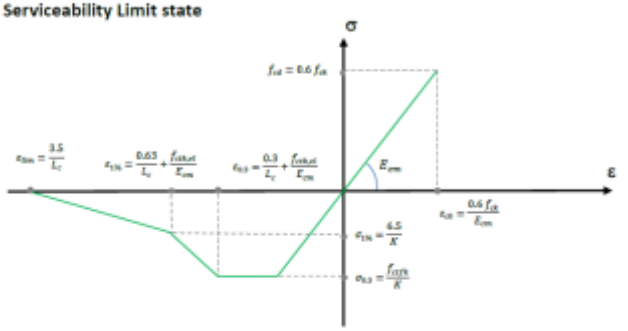
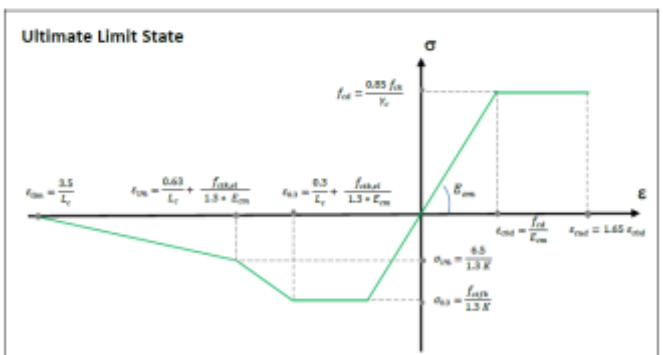
[σ-ε] Compressive/Tensile constitutive law

Serviceability Limit state



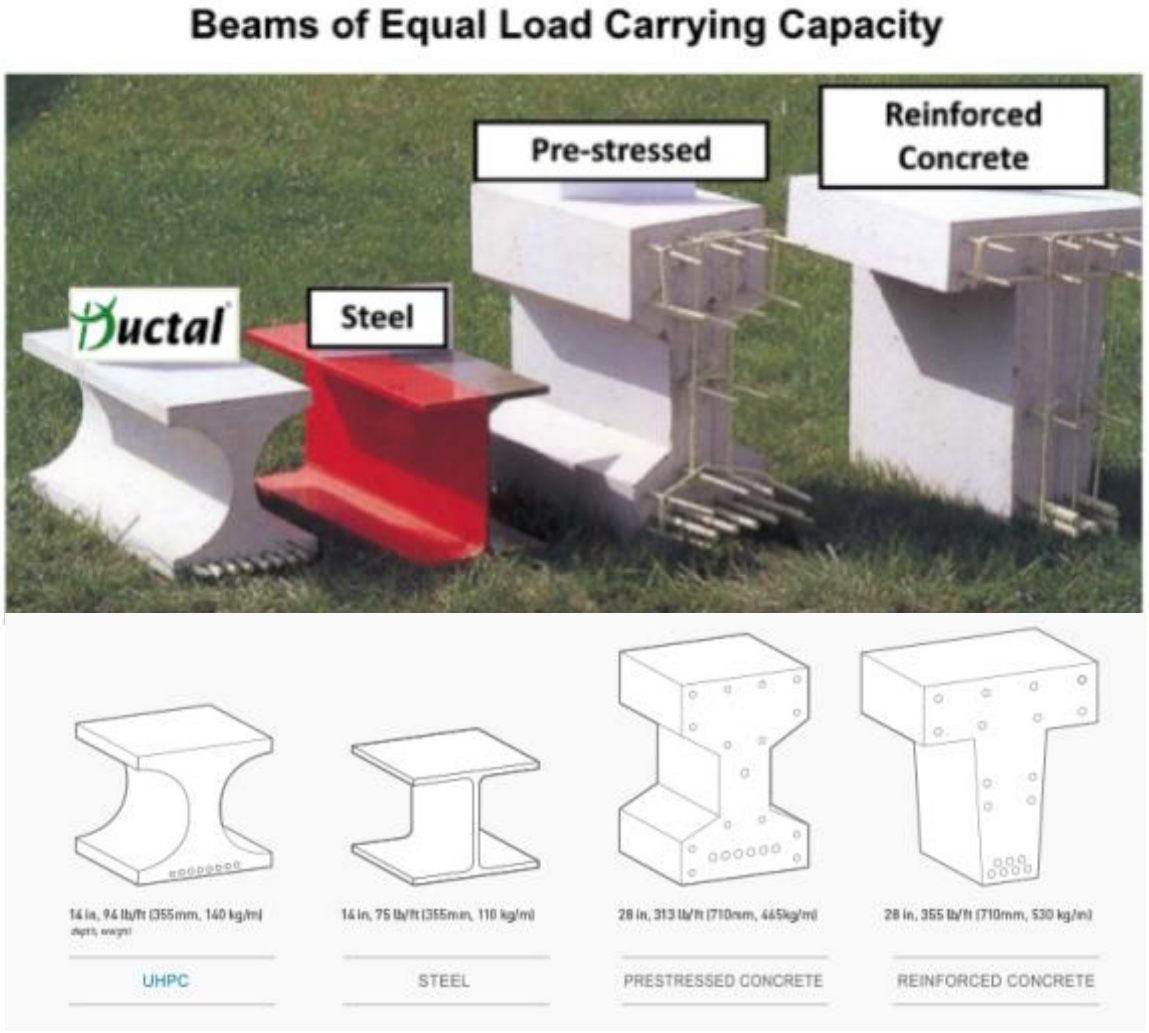
Ultimate Limit State



K_{global}	1.35 (to be validated with the project suitability test)
K_{local}	1.80 (to be validated with the project suitability test)
L_c	2h/3 (h is the height of the section)
γ_c	1.30 (the Ductal® premix is subjected to internal quality control)

Design & Execution

Case study



Design & Execution

Guidelines & Standards

French Recommendations on UHPC:

- version 1: January 2002
- version 2: June 2013

FRANCE		
Standards	**Commission**	**Publication**
NF P 18-470: Material	AFNOR – P18B	July 2016
NF P 18-710: Design	BNTRA – CN EC2	April 2016
NF P 18-451: Execution	AFNOR – P18E	Q4 2018


French standard

NF P 18-470
29 July 2016

Concrete — Ultra-high performance fibre-reinforced concrete — Specifications, performance, production and conformity

French standard approved

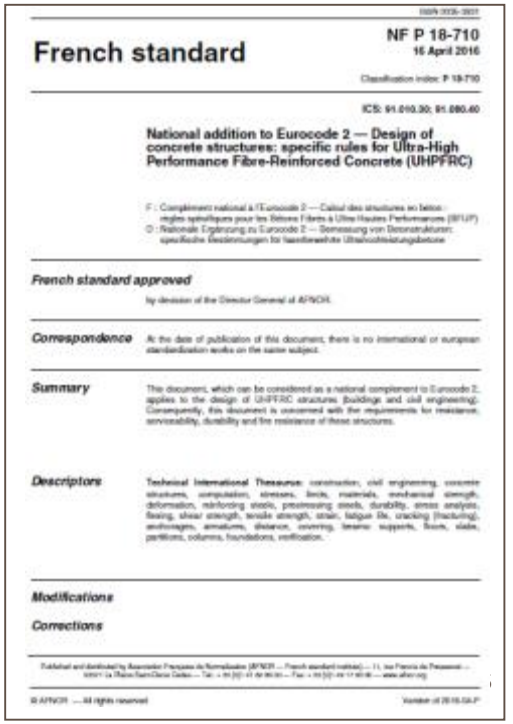
Correspondence

Summary

Descriptors

Modifications

Corrections


French standard

NF P 18-710
16 April 2016

National addition to Eurocode 2 — Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC)

French standard approved

Correspondence

Summary

Descriptors

Modifications

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Design & Execution

Guidelines & Standards

Countries	Committee / WG	Reference / Title	Publication
Japan	JSCE (Japan Society of Civil Engineers)	CES 82 Recommendations for design and consruction of high performance fibre reinforced cement composites with multiples fine cracks	March 2008
Switzerland	SIA Commission 262	Technical leaflet n° 2052 UHPFRC – Construction material, dimensioning and application"	Sept. 2015
China	GB (National standardization technical committee on Concrete)	GB/T 31387-2015 Reactive Powder Concrete	Nov. 2015
Canada	CSA A23.1	A23.1 – A23.2 Annex U (Informative) Ultra-high performance concrete (UHPC)	Q3 2018
China	CBMF (China Building Materials Association)	CBMF XX-201X Standard for Ultra-high Performance Concrete: General Performance and Test Methods	2019
Germany	DAfStb (Deutscher Ausschuss für Stahlbeton)	EN 206:2013 "Beton - Festlegung, Eigenschaften, Herstellung und Konformität" The UHPC-Guideline is designed as a complementary document to the norms (DIN 1045-part 1-3) for which DIN EN 206 is the basis document.	2019
USA	ACI Committee 239	ACI 239-D Materials & Methods of Construction with UHPC	Q3 2019

Examples of projects over the past 20 years

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Applications for civil engineering

- *Joint fill for bridges*
- *Overlays*
- *Bridges*
- *Dams*
- *Ground slabs*
- *Nuclear plant*
- *…*

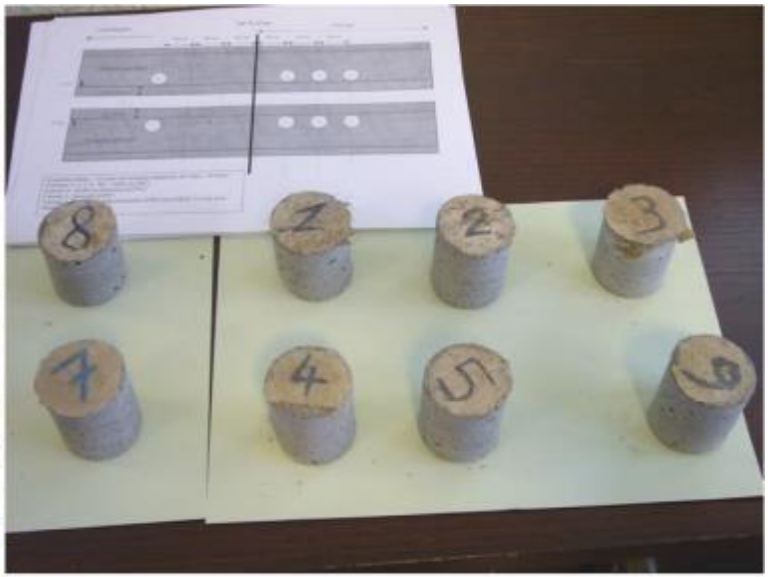
Nuclear power plant, France

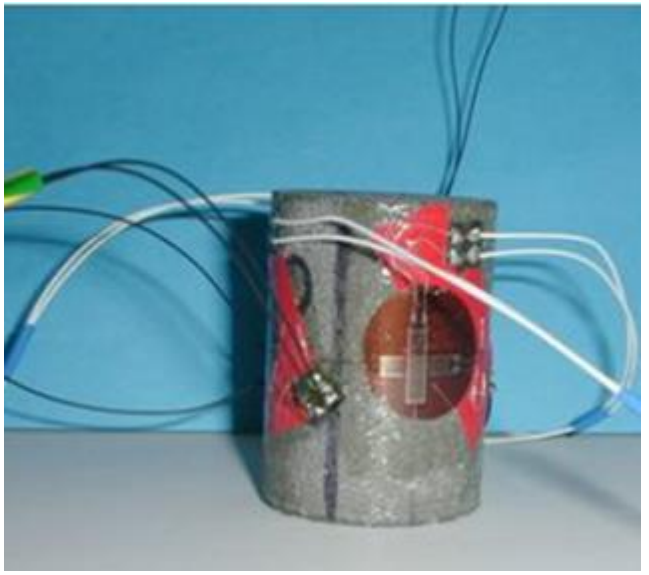
UHPC solution was selected to upgrade the Cattenom power station cooling towers. Specifications were clear; they required a building **material that could withstand physicochemical aggressions** (run-off water, sulfates, thermal gradient & freeze/thaw cycles) for the beams and girders providing the support structure of the heat exchange building.

A total of 2400 prestressed girders made of UHPC were produced at a rate of **twenty per day**. Its lightness also enabled the weight of the **structure** on the foundations to be reduced **to a third** of its conventional weight, with the added bonus of a **vastly extended lifetime** for the structure.

Test samples taken in 2008, (after ten years of being subjected to a stream of pure water at 35°C) showed that the UHPC material had no degradation of mechanical properties when compared to the initial measurements taken.

Nuclear power plant, France: 10 years later

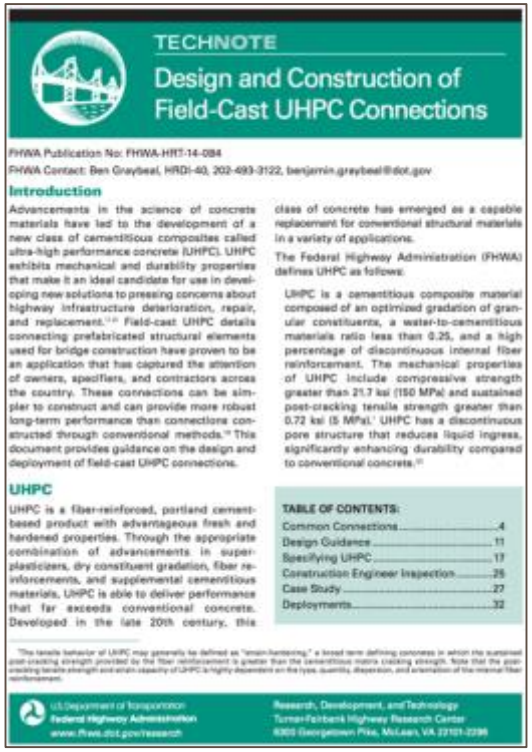




- Mean compressive strength = 240 MPa
- Young's modulus = 55 Pa
- Poisson coefficient = 0.19
- pH = 12.35
- carbonation depth = 0
- water absorption = 0.03 g/cm² (10 times less than HPC)

Next sampling and testing in February 2019

Joint fill solution, USA & Canada



TECHNOTE

Design and Construction of Field-Cast UHPC Connections

FHWA Publication No: FHWA-HRT-14-084

FHWA Contact: Ben Graybeal, HRDI-40, 202-493-3122, benjamin.graybeal@dot.gov

Introduction

Advancements in the science of concrete materials have led to the development of a new class of cementitious composites called ultra-high performance concrete (UHPC). UHPC exhibits mechanical and durability properties that make it an ideal candidate for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement.[1,2] Field-cast UHPC details connecting prefabricated structural elements used for bridge construction have proven to be an application that has captured the attention of owners, specifiers, and contractors across the country. These connections can be simpler to construct and can provide more robust long-term performance than connections constructed through conventional methods.[3] This document provides guidance on the design and deployment of field-cast UHPC connections.

UHPC

UHPC is a fiber-reinforced, portland cement-based product with advantageous fresh and hardened properties. Through the appropriate combination of advancements in superplasticizers, dry constituent gradation, fiber reinforcements, and supplemental cementitious materials, UHPC is able to deliver performance that far exceeds conventional concrete. Developed in the late 20th century, this class of concrete has emerged as a capable replacement for conventional structural materials in a variety of applications.

The Federal Highway Administration (FHWA) defines UHPC as follows:

> UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 ksi (150 MPa) and sustained post-cracking tensile strength greater than 0.72 ksi (5 MPa).[1] UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.[2]

TABLE OF CONTENTS:

"The tensile behavior of UHPC may generally be defined as "strain-hardening," a broad term defining concretes in which the sustained post-cracking strength provided by the fiber reinforcement is greater than the cementitious matrix cracking strength. Note that the post-cracking tensile strength and strain capacity of UHPC is highly dependent on the type, quantity, dispersion, and orientation of the internal fiber reinforcement.

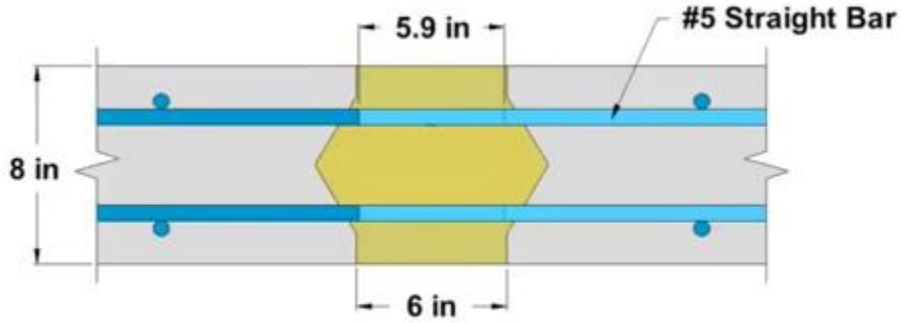
U.S. Department of Transportation
Federal Highway Administration
www.fhwa.dot.gov/research

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, McLean, VA 22101-2296

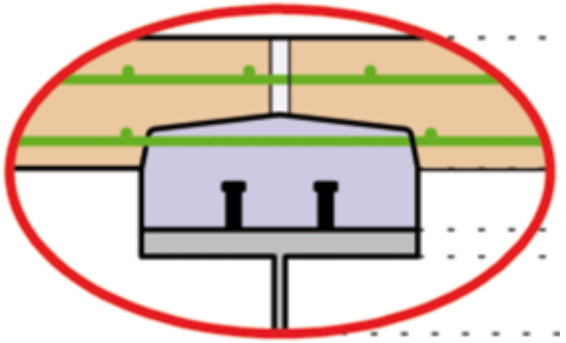
Joint fill solution, USA & Canada

Benefits

- **Accelerated Construction.** UHPC offers durable and simplified details that facilitate the fabrication and construction efforts needed to connect prefabricated bridge elements.
- **Simplified Connection Details.** UHPC allows for significant simplification to the design of the component connections. Its properties allow for the redesign of common connection details in ways that promote both ease and speed of construction.
- **Improved Long-Term Performance.** Field casting of UHPC connections between prefabricated components results in a strong connection that provides better long-term performance.



Straight Bar Connection w/ UHPC



Girder Haunch w/ UHPC

Pulaski Skyway

3.5 miles, 4 lanes
NJDOT Mega-project

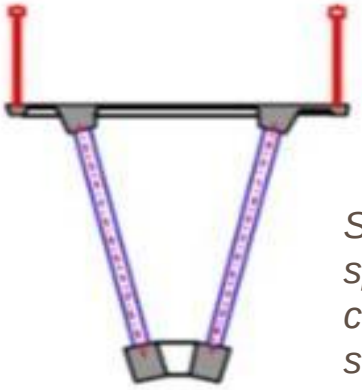
Renovation of Chillon viaducts, Switzerland

- 53,000 m² redecking
- 6,000 m³ cast in 6 + 4 weeks (two summer periods) in a 40 mm-layer
- 7% slope

Precast Applications

- *Cladding*
- *Sunshades*
- *Facade pannels*
- *Perforated panels*
- *Roof*
- *Perforated roofs*
- *Stairs*
- *Balcony*
- *Beams*
- *Columns*
- *Segments for footbridges, bridges*
- *…*

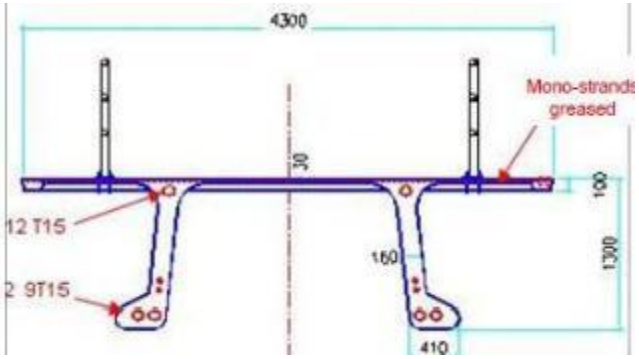
First UHPC footbridge, Canada

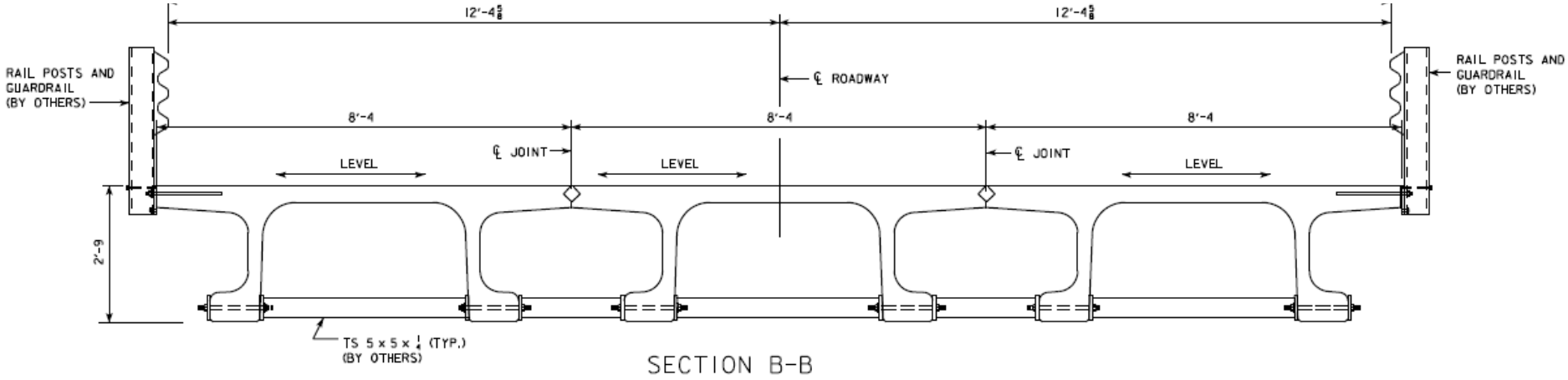


Single 60 meter long span with an only 3 cm thick deck with stiffening ribs.

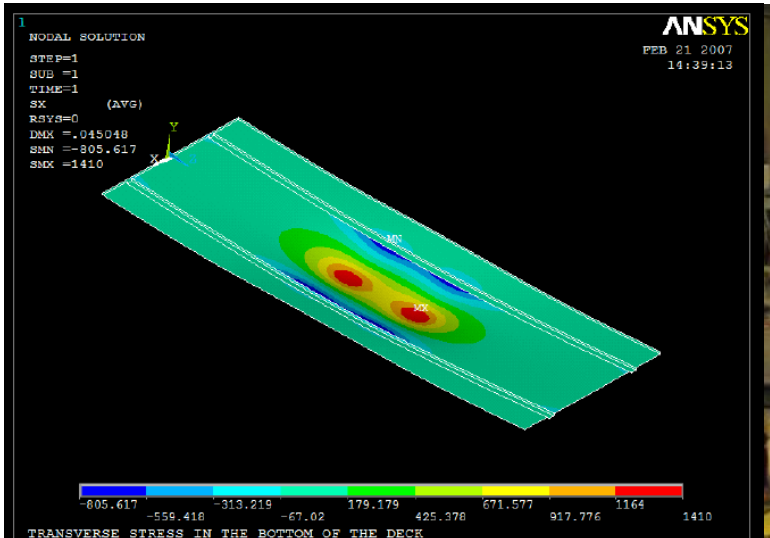
Arch UHPC footbridge, South Korea

UHPC arch bridge for pedestrians spanning 120m. It consists of 6 precast prestressed segments shaped as double-T beams that are 4.3m wide and 1.3m deep. The deck is 30mm deep and has transverse ribs every 1.225m.

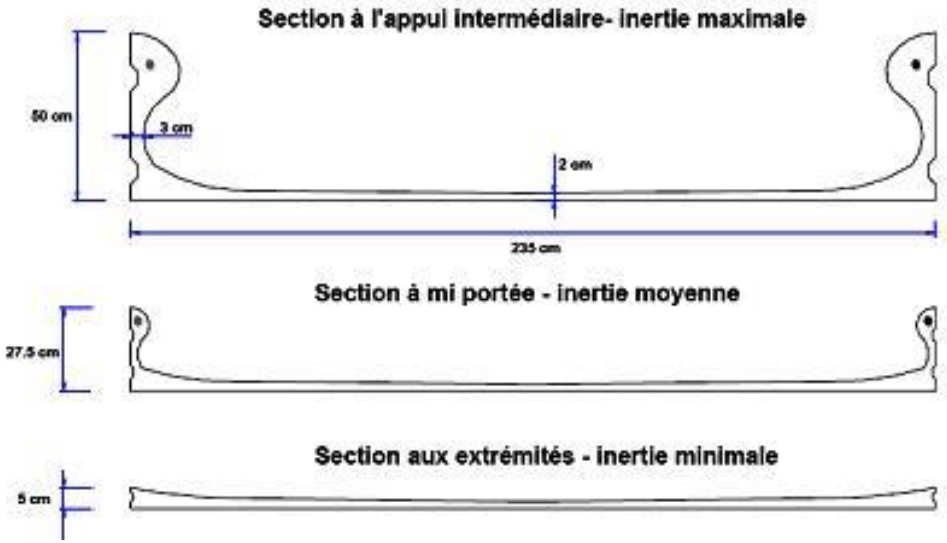



12'-4 5/8
12'-4 5/8
RAIL POSTS AND GUARDRAIL (BY OTHERS)
℄ ROADWAY
RAIL POSTS AND GUARDRAIL (BY OTHERS)
8'-4
8'-4
8'-4
℄ JOINT
℄ JOINT
LEVEL
LEVEL
LEVEL
2'-9
TS 5 x 5 x ¼ (TYP.) (BY OTHERS)

SECTION B-B


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SX (AVG)
RSYS=0
DMX =.045048
SMN =-805.617
SMX =1410
ANSYS
FEB 21 2007
14:39:13
-805.617
-559.418
-313.219
-67.02
179.179
425.378
671.577
917.776
1164
1410
TRANSVERSE STRESS IN THE BOTTOM OF THE DECK


FHWA
STRUCTURES LAB



- New constructive pardigms
- New Tectonics, between continuous and discontinouous
- “Liquid Stone” ductile – Cold cast iron

Villa Navarra – R. Ricciotti

LafargeHolcim

Haneda Airport extension, Japan

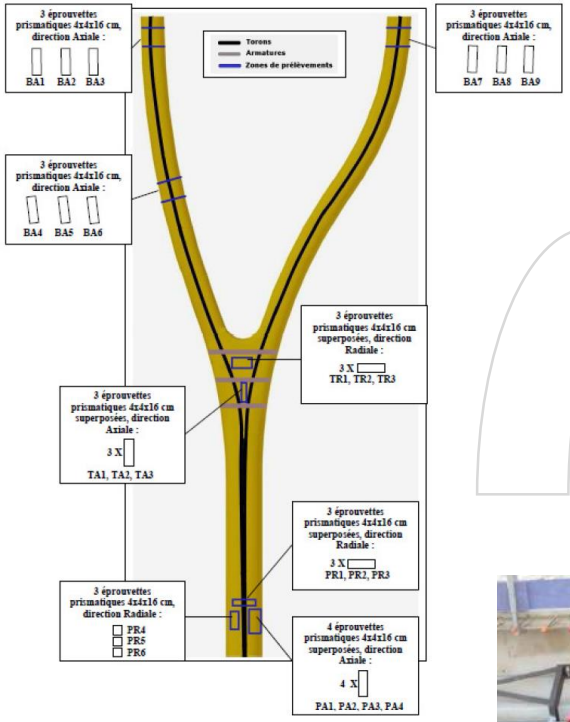
7000 prestressed slabs assembled by post-tensioning to make the runaway of airport extension over the sea (50 000 m²)

MUCEM museum, France

MUCEM museum, France

Highlights

- 380 net panels
- 2000 m² thin deck slabs
- 330 tree-shaped columns
- 2 footbridges 75 m-span
- 35 hangers for external decks

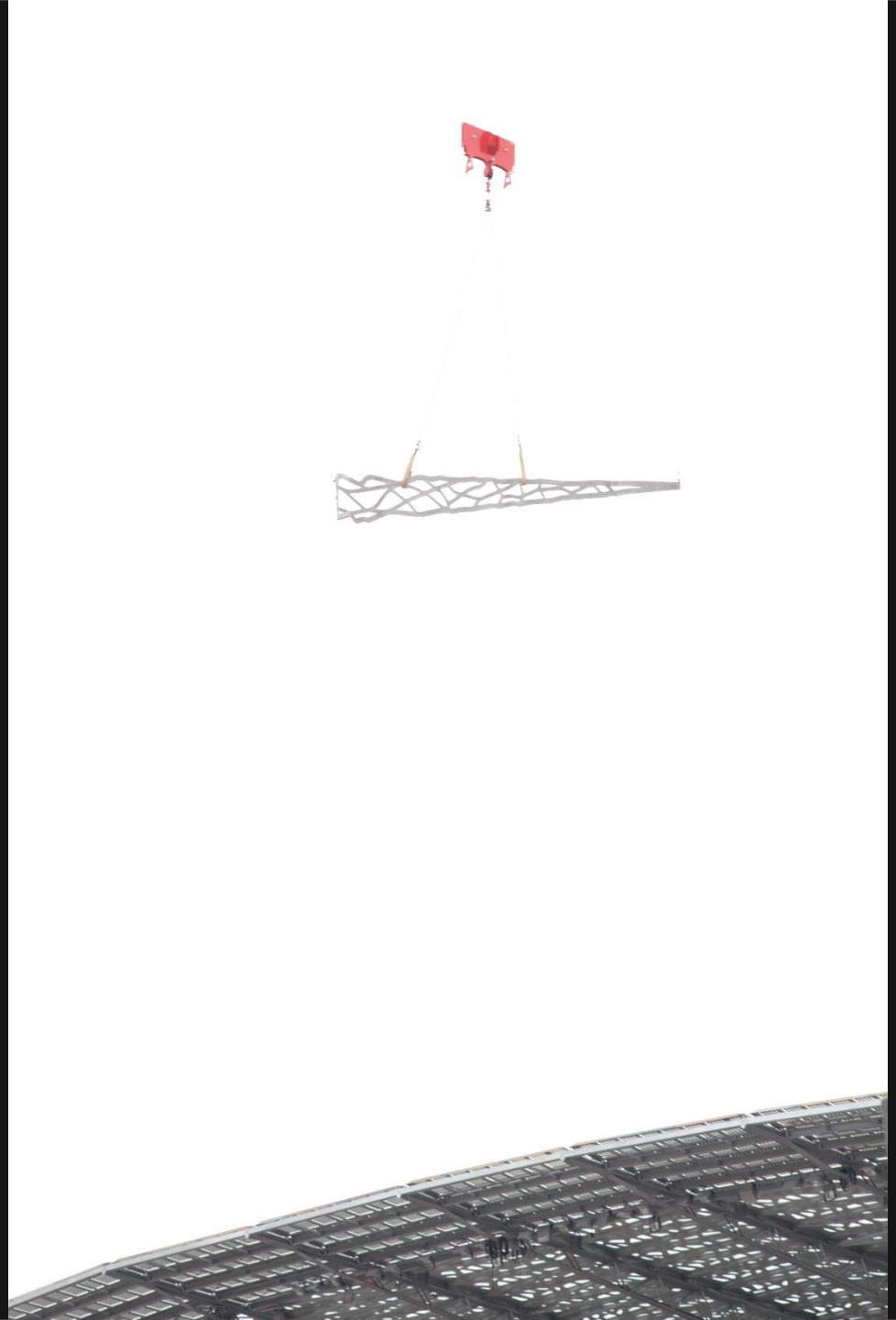

3 éprouvettes prismatiques 4x4x16 cm, direction Axiale :
BA1 BA2 BA3
3 éprouvettes prismatiques 4x4x16 cm, direction Axiale :
BA4 BA5 BA6
3 éprouvettes prismatiques 4x4x16 cm, direction Axiale :
BA7 BA8 BA9
Torons
Armatures
Zones de prélèvements
3 éprouvettes prismatiques 4x4x16 cm superposées, direction Radiale :
3 X
TR1, TR2, TR3
3 éprouvettes prismatiques 4x4x16 cm superposées, direction Axiale :
3 X
TA1, TA2, TA3
3 éprouvettes prismatiques 4x4x16 cm superposées, direction Radiale :
3 X
PR1, PR2, PR3
3 éprouvettes prismatiques 4x4x16 cm, direction Radiale :
PR4
PR5
PR6
4 éprouvettes prismatiques 4x4x16 cm superposées, direction Axiale :
4 X
PA1, PA2, PA3, PA4

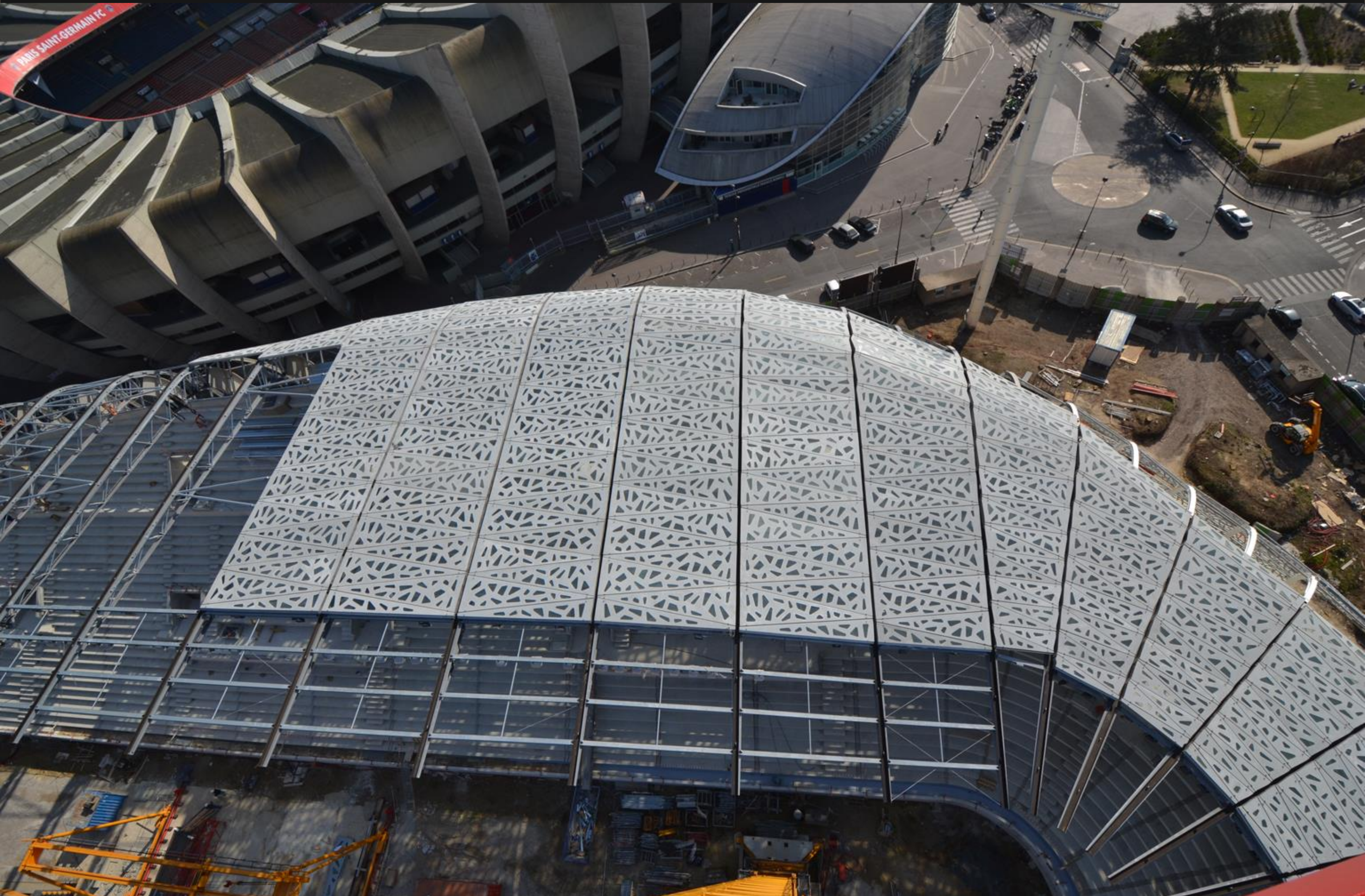
Jean Bouin Stadium, France

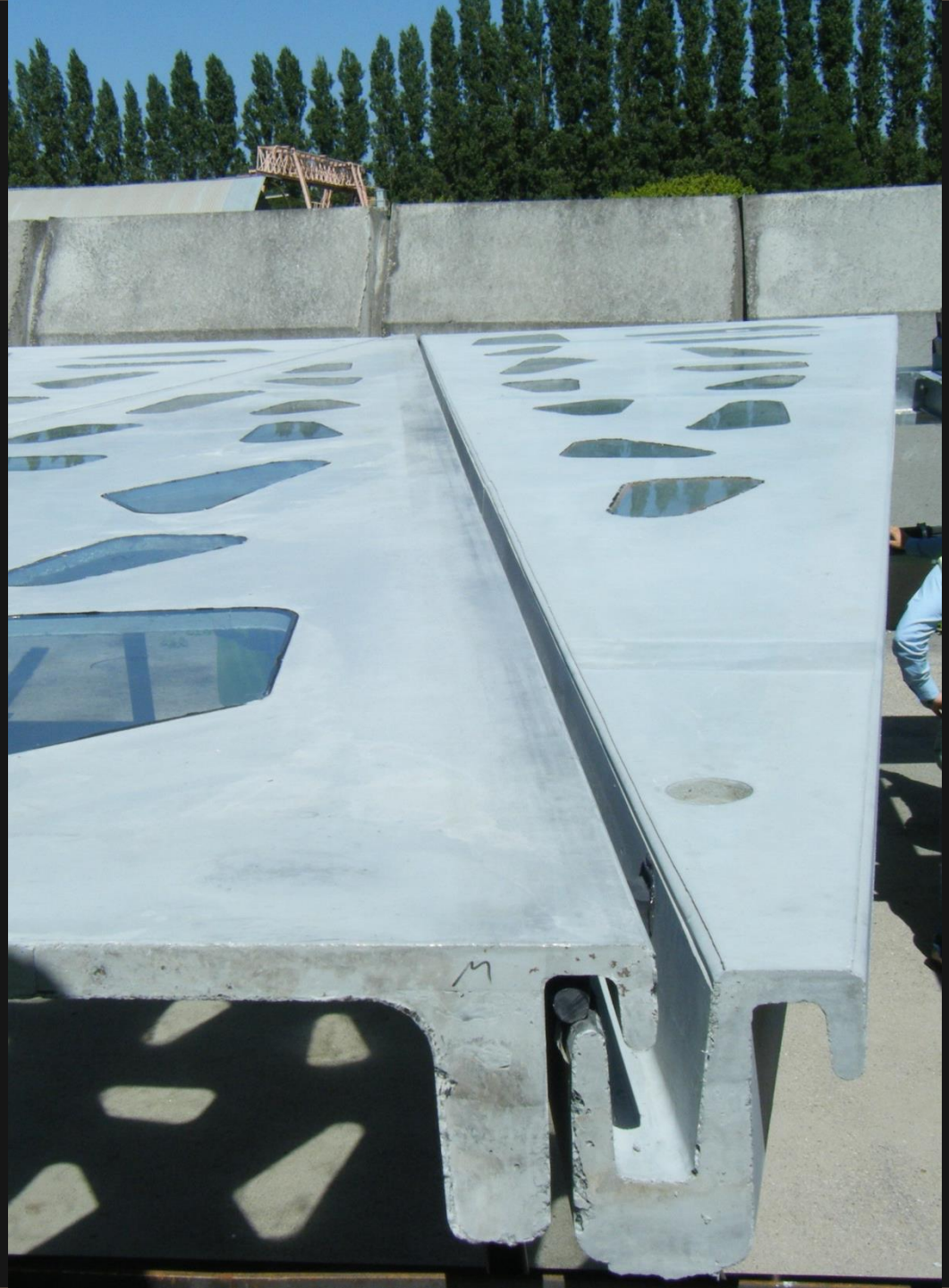
Highlights

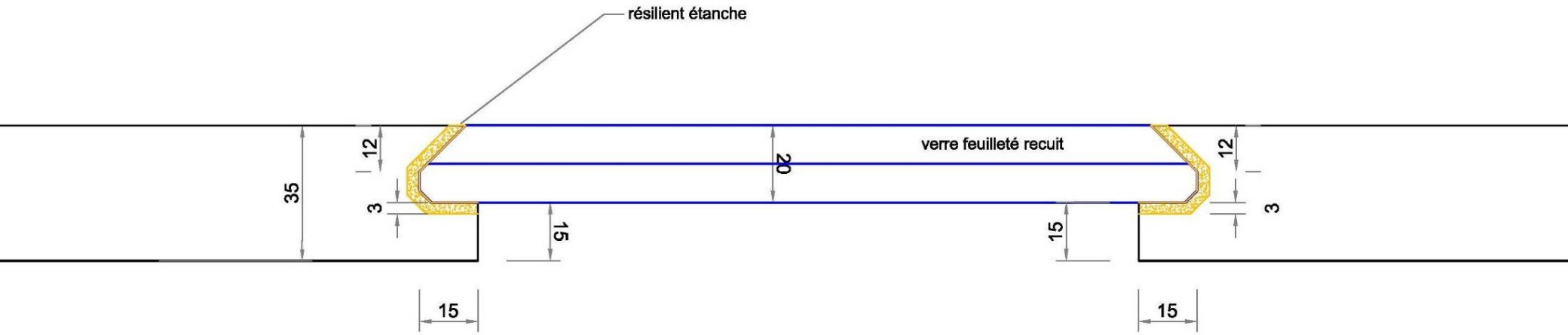
- Facade: triangle perforated panels, up to 8m x 2.4m
- Roof: waterproof panels + glass inclusions, same dimensions. Ribs devices used for drainage of water
- Isostatic panels support, specific designed hinges

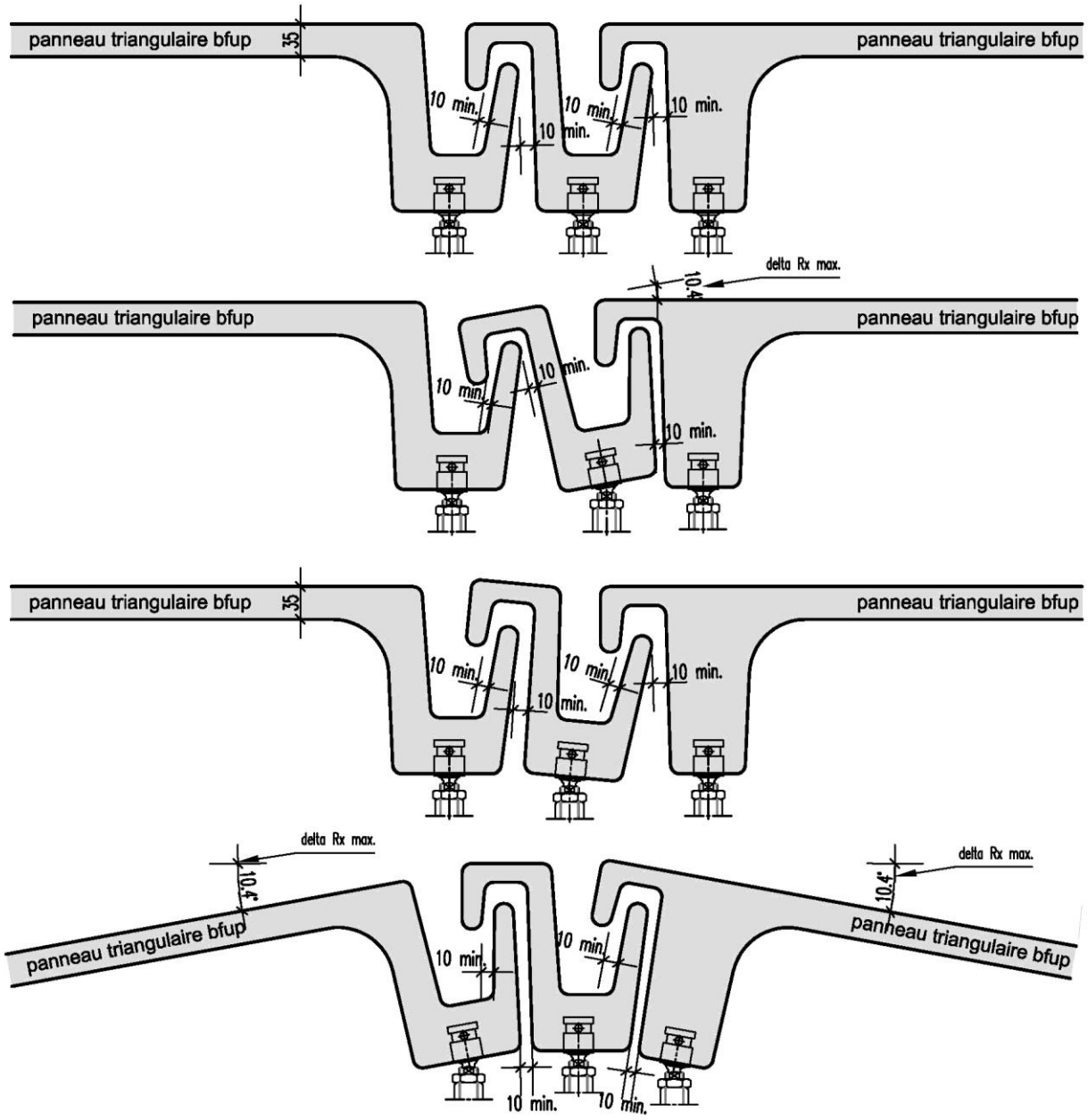

JLG ULTRA BOO
Gunco

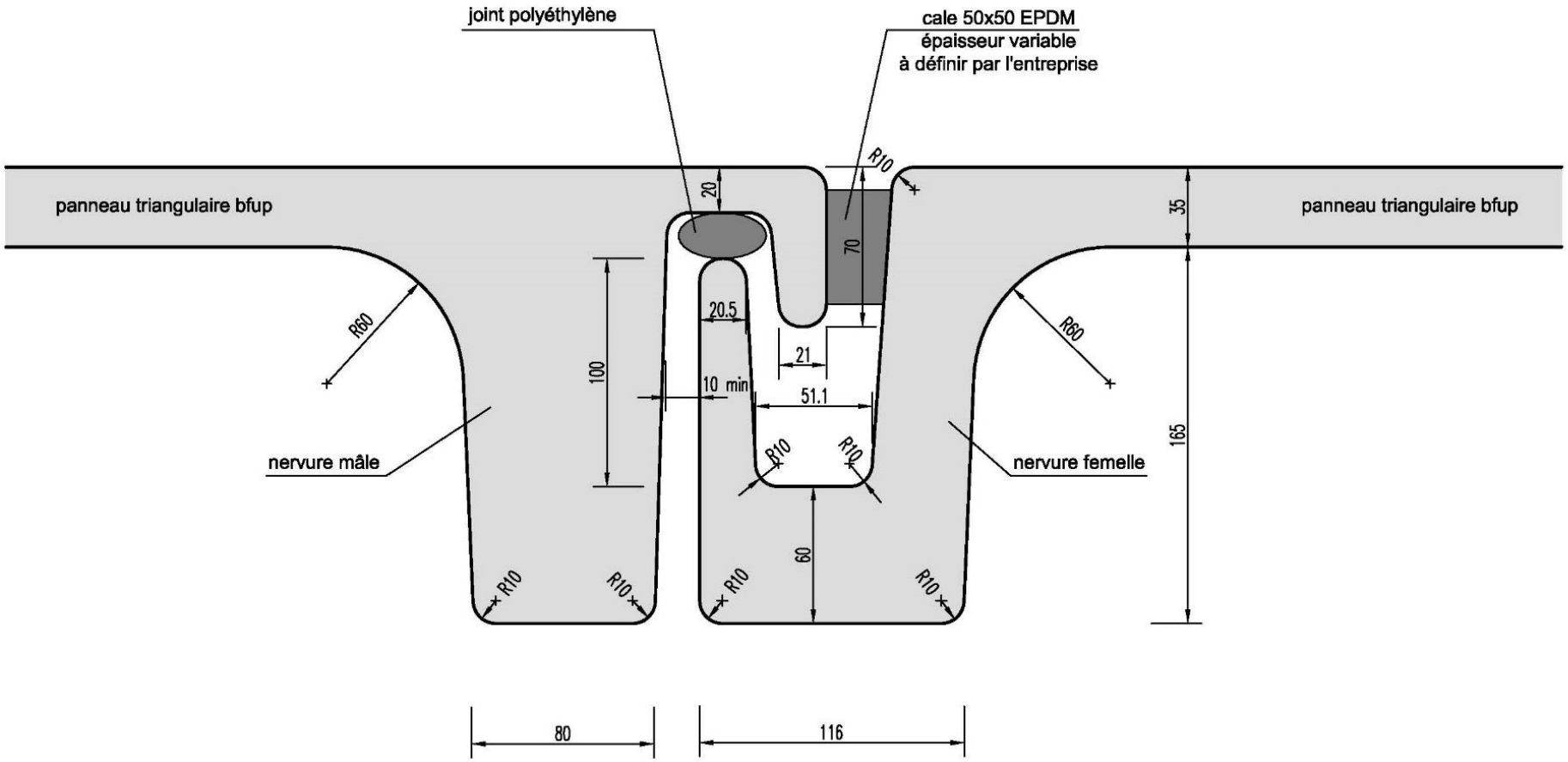



PARIS SAINT-GERMAIN FC





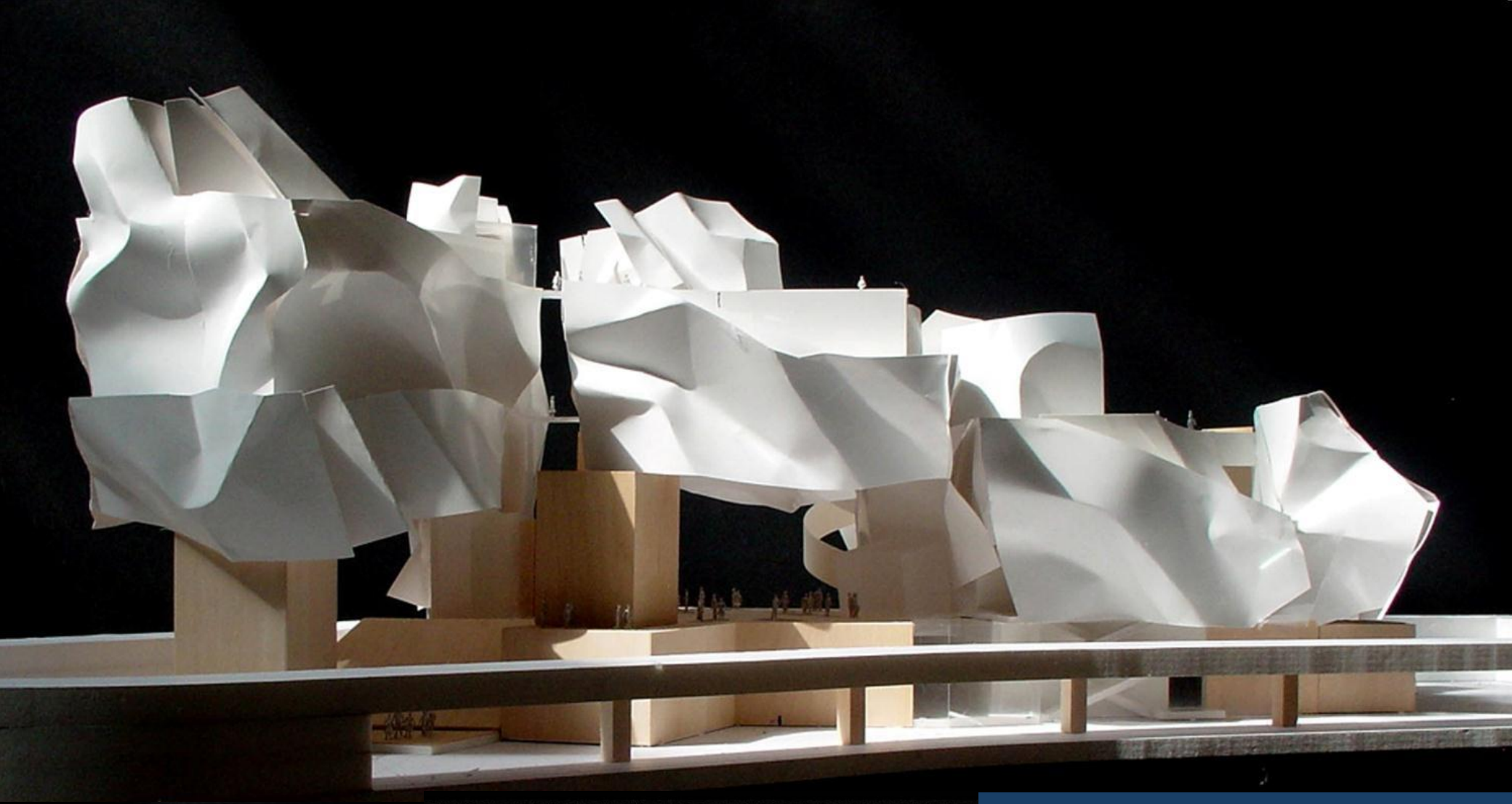


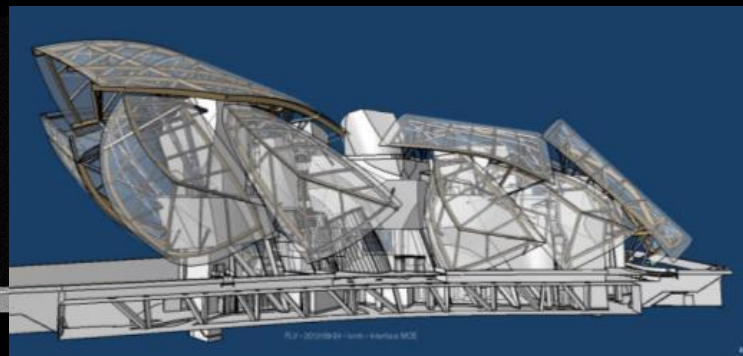


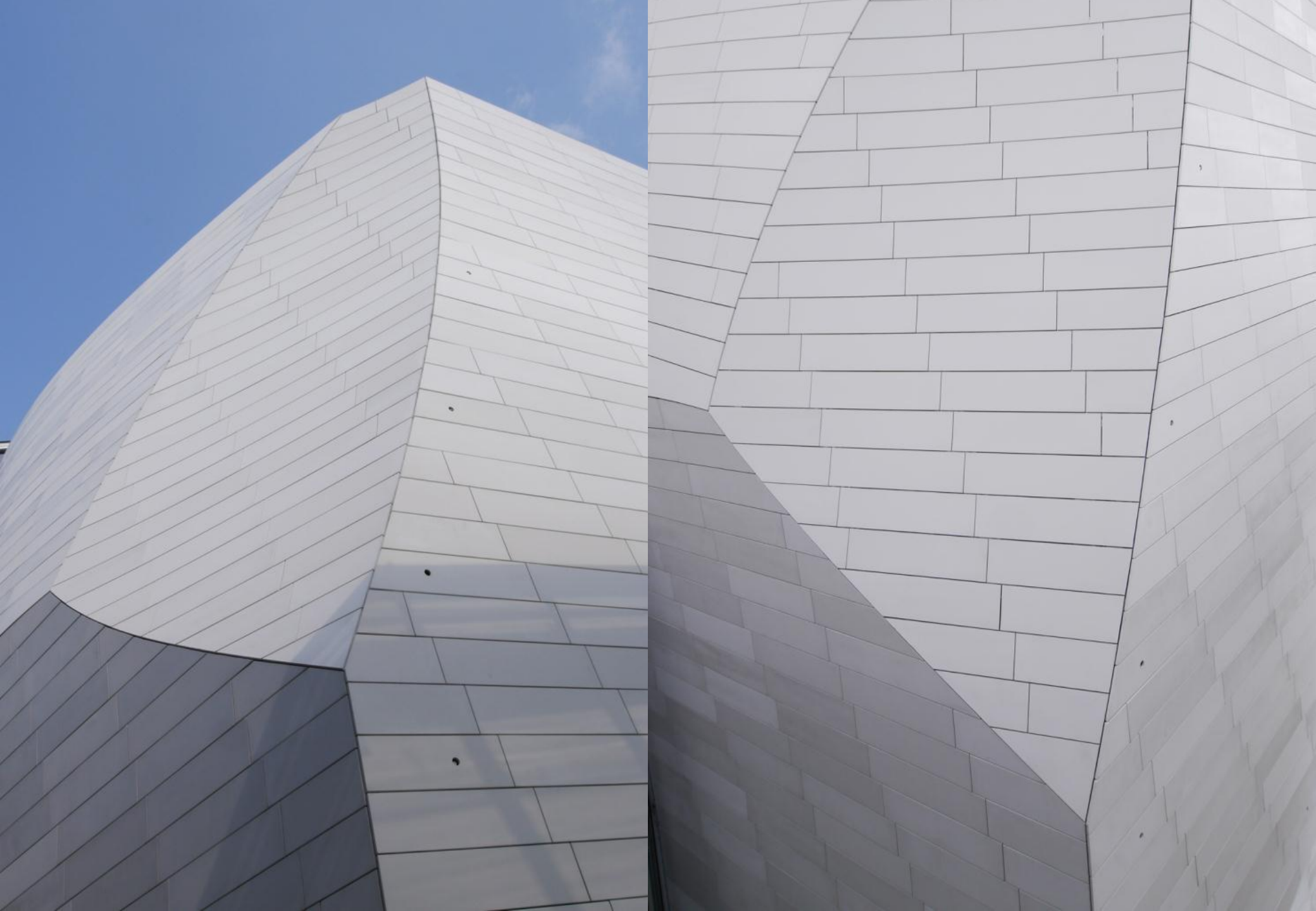

PARIS SAINT-GERMAIN FC
RÊVONS PLUS GRAND
ICI C'EST PARIS

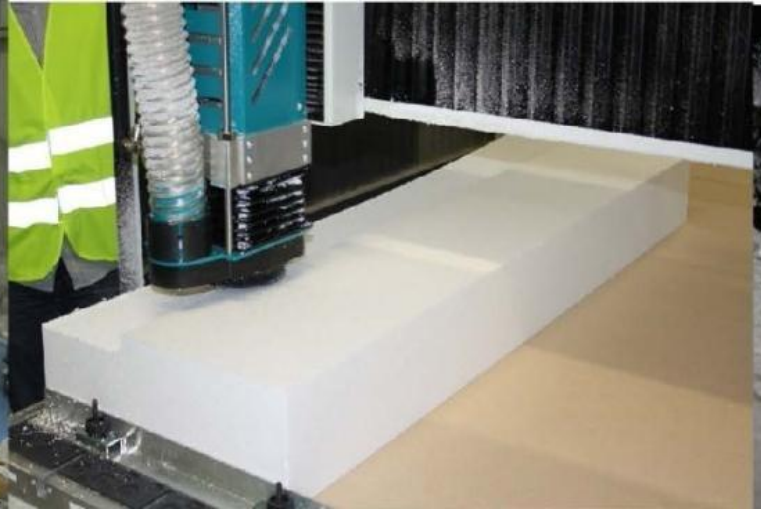

Plaza de Toros MADRID
GRANDIOSA CORRIDA DE TOROS
EULALIO LOPEZ "EL ZOTOLUCO"
JUAN JOSE PADILLA
GOMEZ ESCORIAL
BRASIL
10

Fondation Louis Vuitton, France

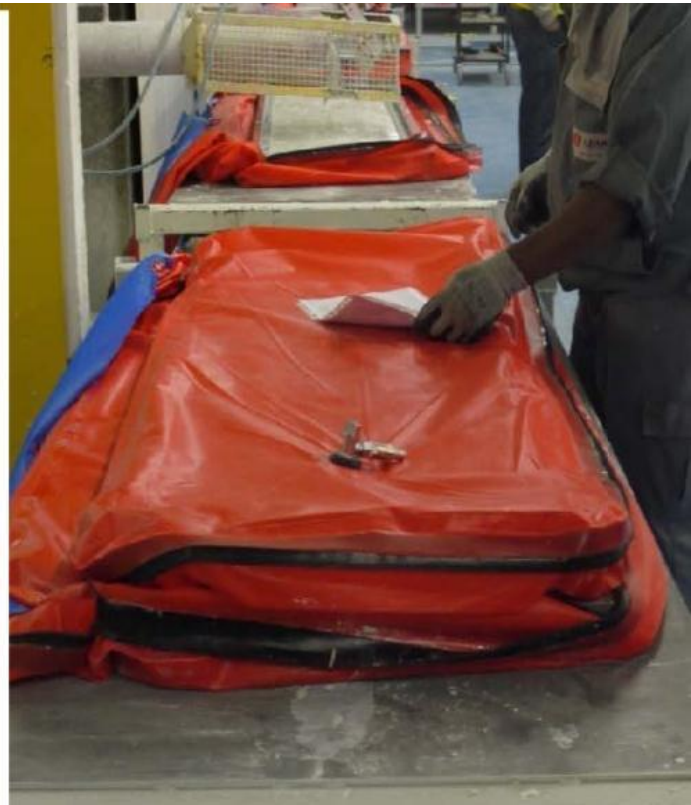






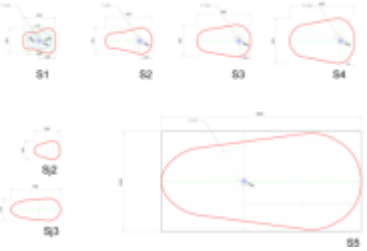




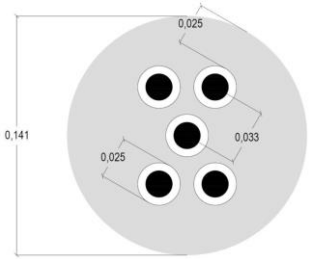
Tour La Marseillaise, France

- 135m high
- facade: 3500 UHPC precast pieces, fire resistant
- 26 shades with blue, white and orange as dominant colors

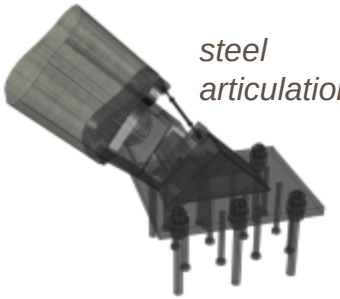
Pont de la Republique, France



Variable section of the piers



Post-tensioning zone of the piers (5 T15S tendons)



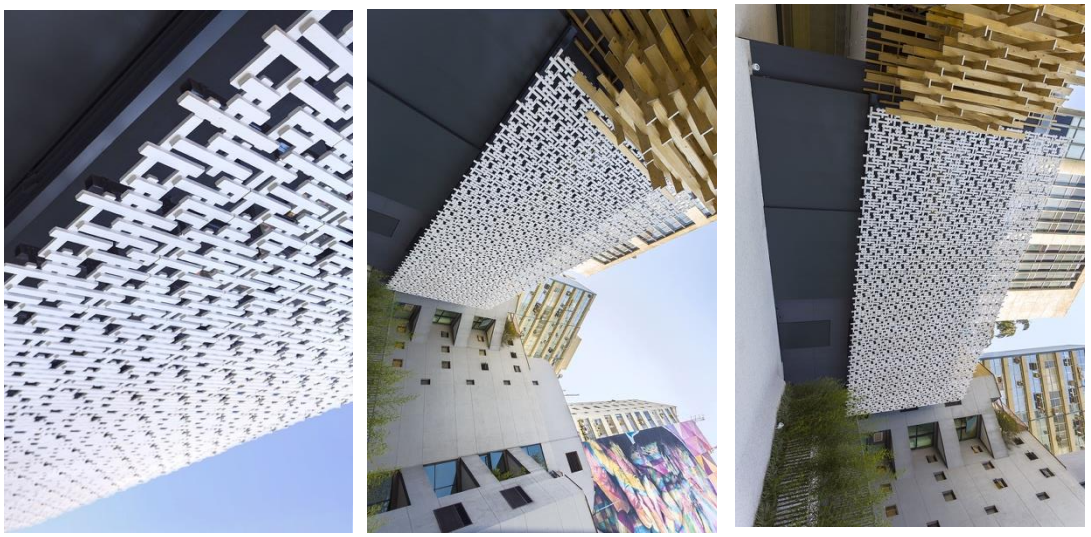
steel articulation

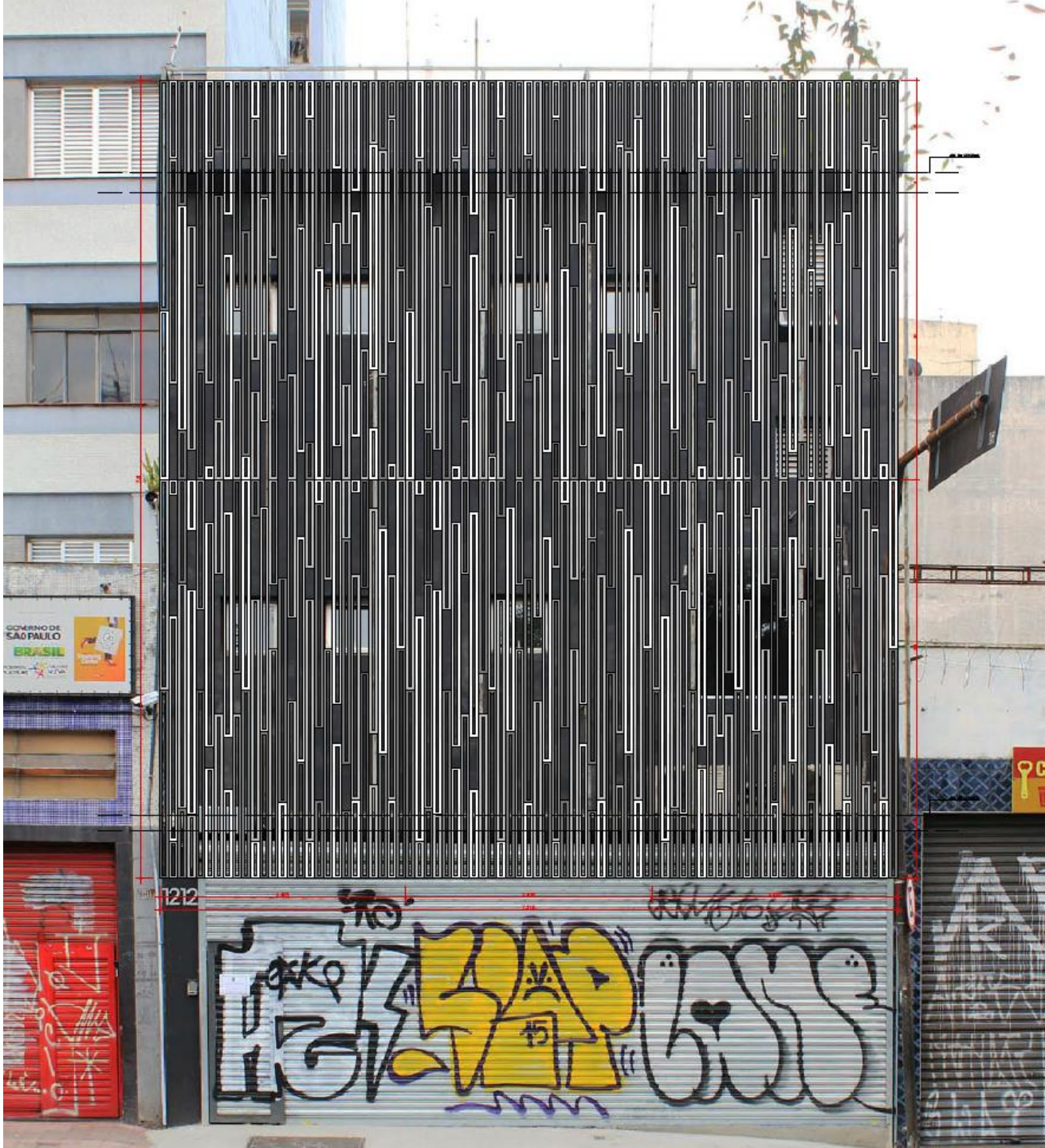

PEDESTRIAN
WALKWAY

Ministry of Foreign Affairs Office (São Paulo)

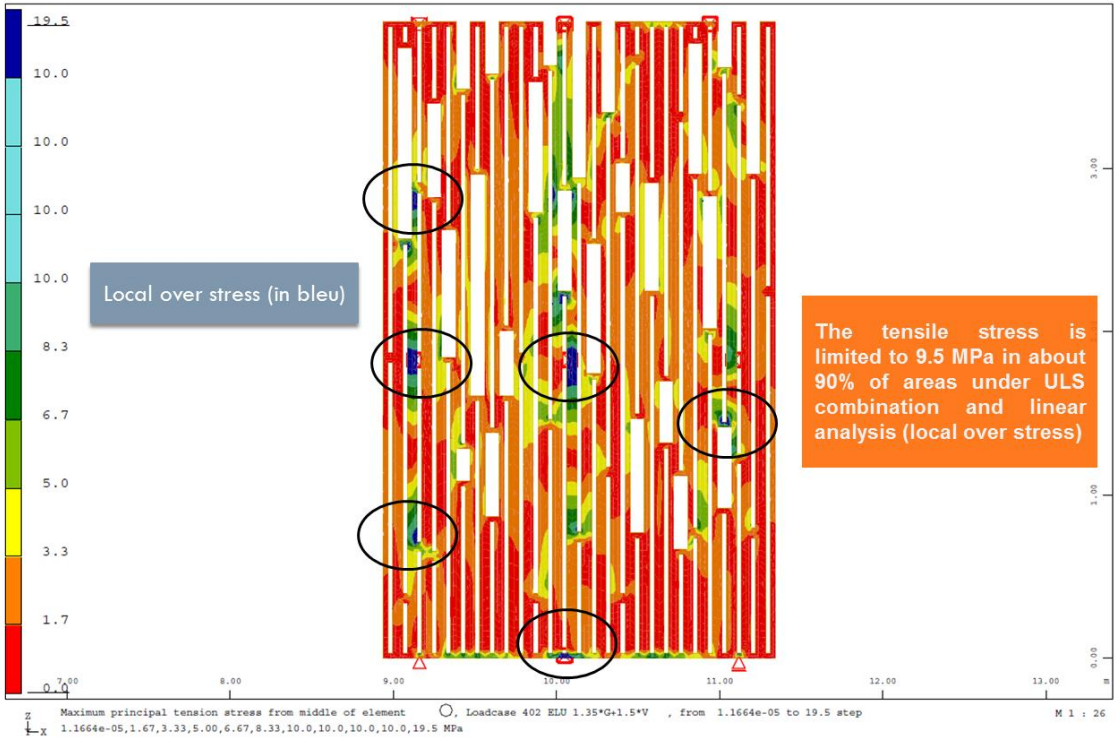
L’Oreal – R&D LATAN (Rio de Janeiro)

Japanese House (São Paulo)



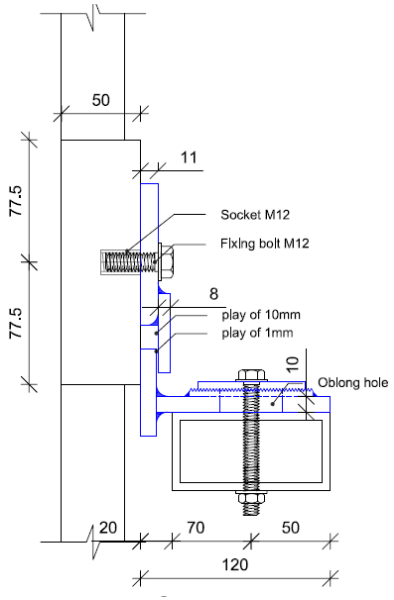


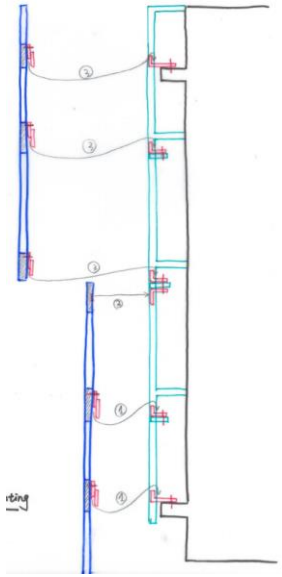
LafargeHolcim

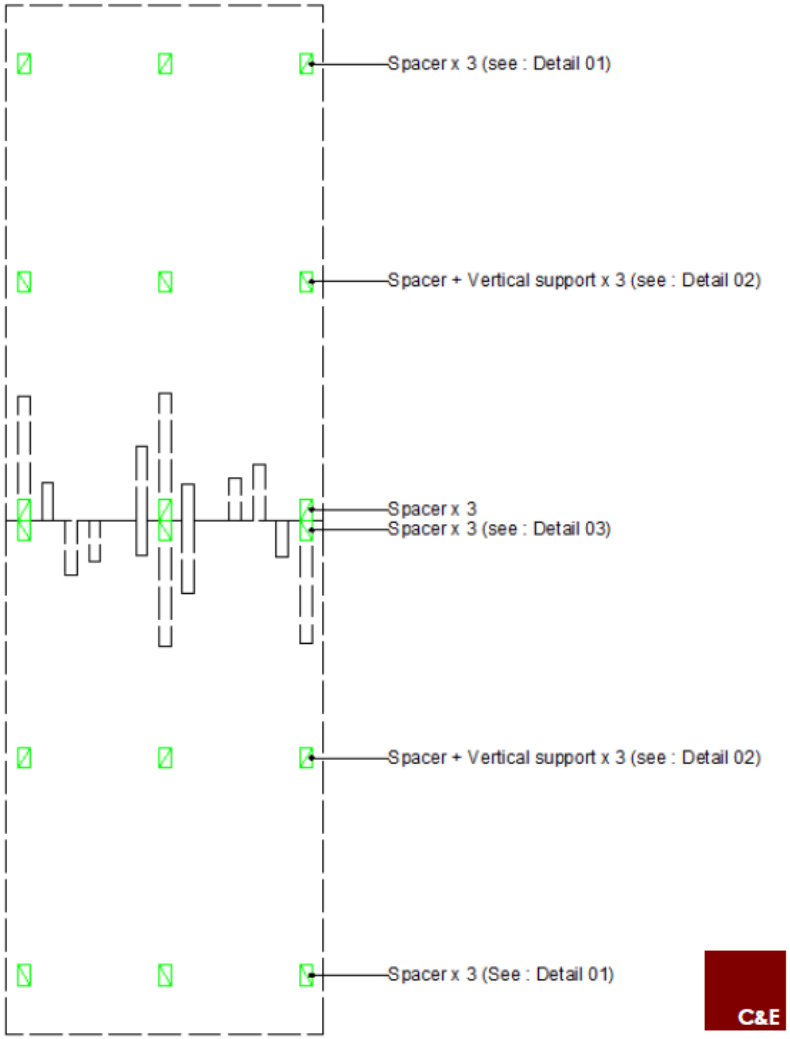


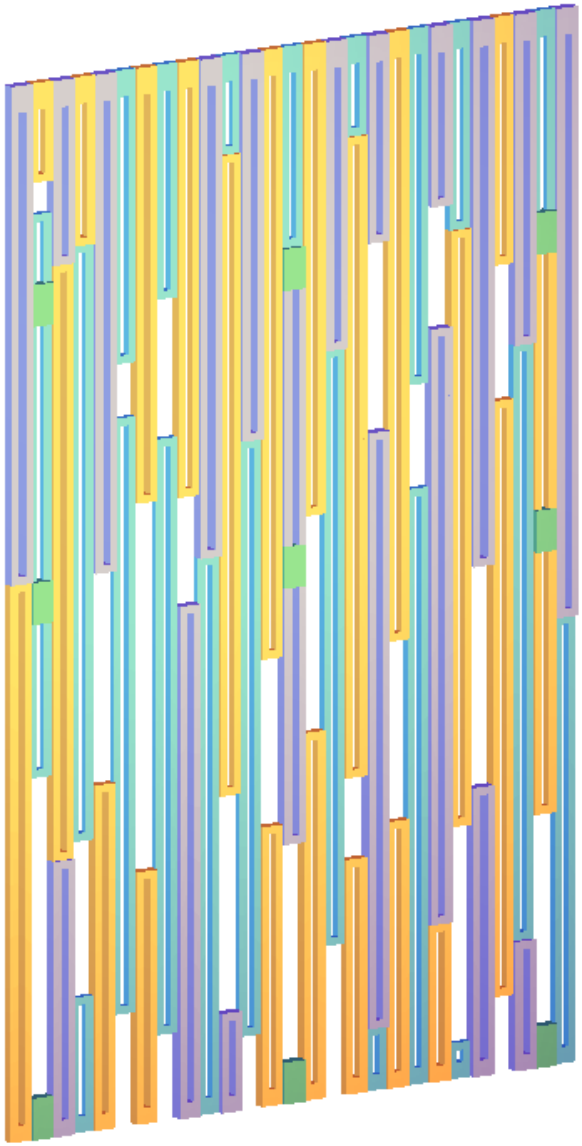
Local over stress (in bleu)

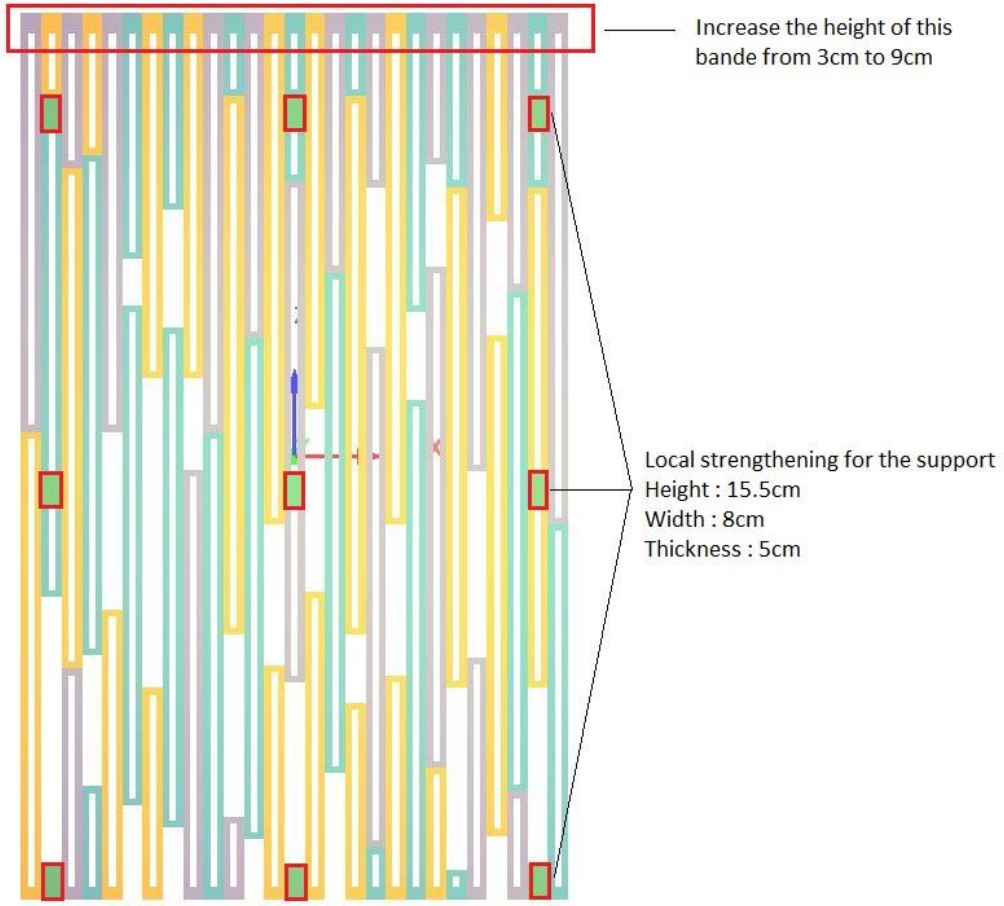
The tensile stress is limited to 9.5 MPa in about 90% of areas under ULS combination and linear analysis (local over stress)





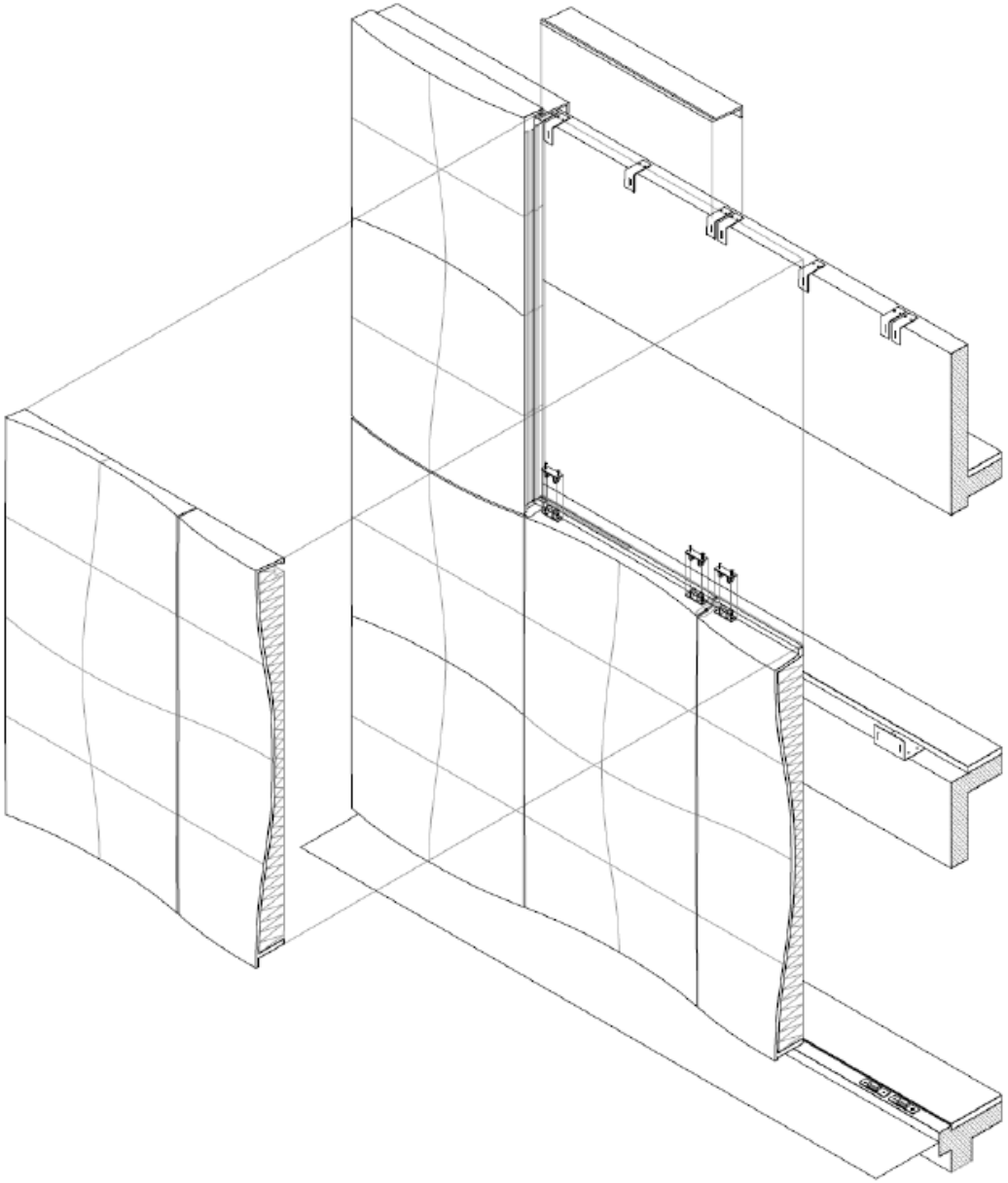







MORE THAN 30 DAILY FLIGHTS
TO THE CARIBBEAN, MEXICO
CENTRAL AND SOUTH AMERICA
PRIVATE EYES
GENTLEMEN'S CLUB
HYC

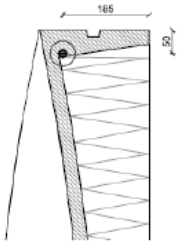
Budin Nursery, France

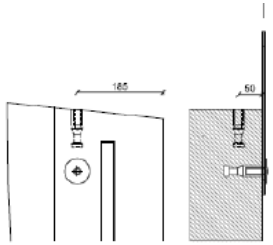


Comment 1 : The principle allows to create periodical geometry

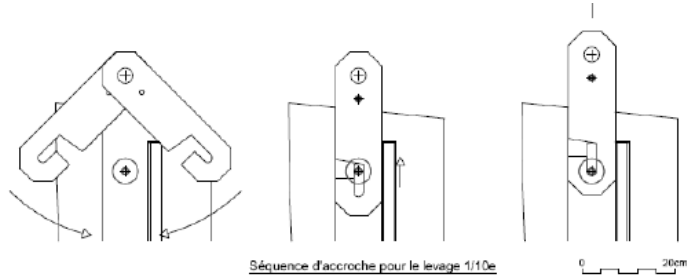
Comment 2 : The principle consists of applying a polystyrene mold when Ductal is still liquid in order to evacuate the material along the reinforced edges of the panel.

Comment 3: in the center the thickness of the panel(sign) is 30 mm against 235 mm along the edges. The joins between two panels is about 10 mm.

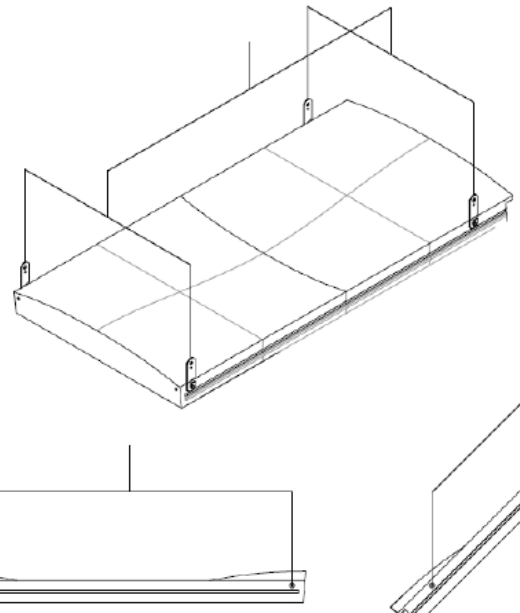




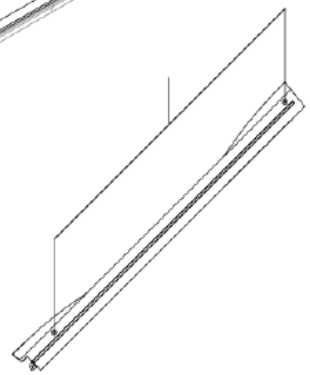
Dispositif de levage 1/10e
Douille de Fixation HALFEN DEHA-6380 M16



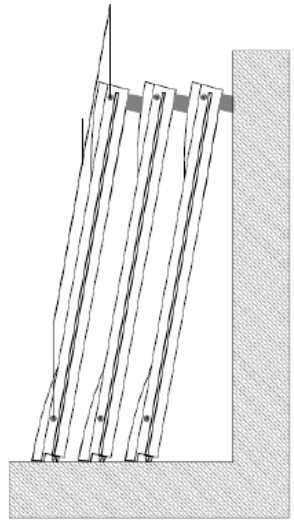
Séquence d'accroche pour le levage 1/10e



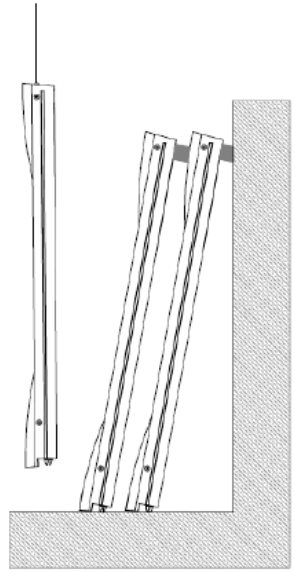
Levage à l'horizontal 1/50e



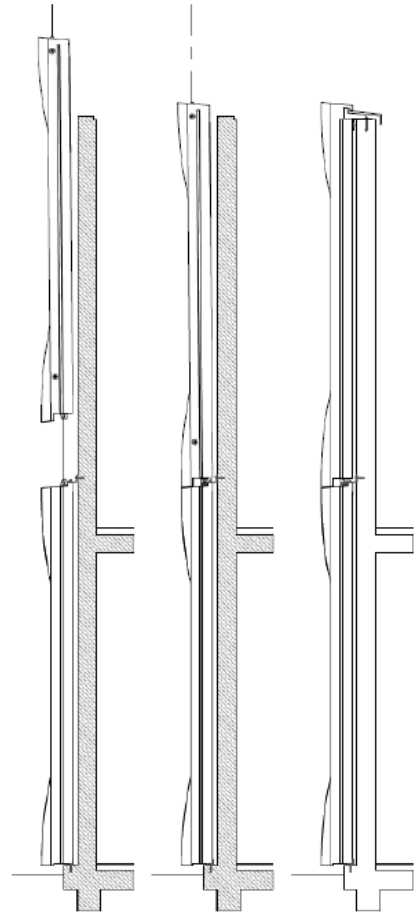
Basculement 1/50e



Stockage des panneaux 1/50e



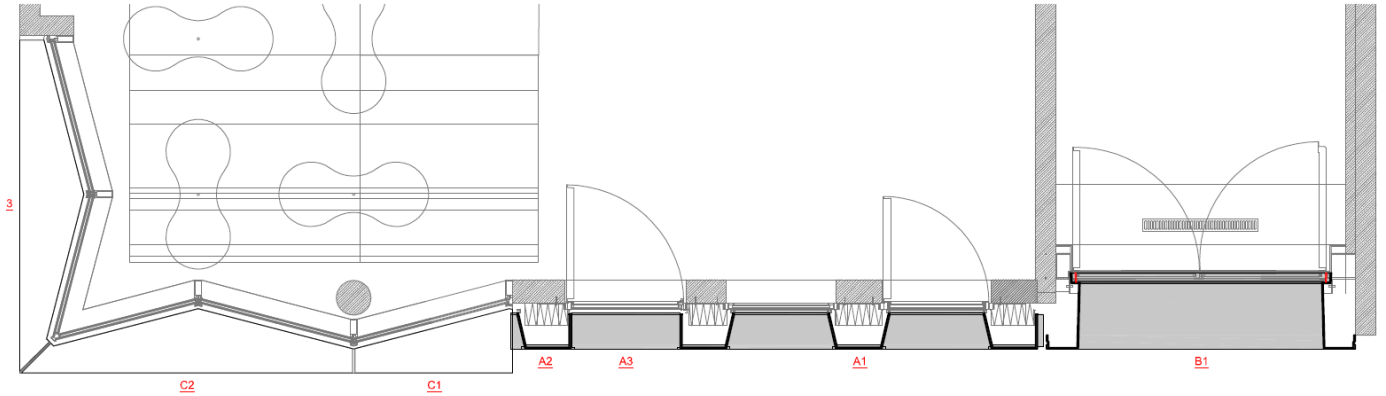
Levage à la verticale des panneaux 1/50e



Mise en oeuvre des panneaux 1/50e

Campus EDF, France

LafargeHolcim



LafargeHolcim

Part 5: Wide trends with UHPC

LafargeHolcim

Wide trends with UHPC

UHPC worldwide market in 2018

- The current global UHPC market is estimated to **USD 250 million**
  - 50% in civil engineering → **existing structures** are significantly and economically improved providing them a next service life cycle while responding to the requirements of modern use
  - 50% in architectural → **new lightweight structures** with enhanced durability and original aesthetics will complement and replace step by step traditional construction in concrete and steel

- The global UHPC market is expected to reach **USD 1.9 billion by 2025** (x8 in six years), and will become worldwide (5 continents)

- The most active regions are:
  - West of Europe (France, UK, Italy, Switzerland, Germany, Czech Republic)
  - North America (USA, Canada)
  - Asia (China, Japan, Korea) and Middle East (UAE)
  - And now Latin America with Brazil

Wide trends with UHPC

Windmills

UHPC cast in place connection

Application of the technology for bridges to windmills

High strength and superior bond properties

Compensation of shrinkage technology

Self levelling

Durability

Wide trends with UHPC

Windmills

Why 140HH Tower?

- To find better Wind – more constant, high speeds, more wind stability;
- Every 1m high more 0,5% to 1% more energy production (10% more yield, shorter investment payback than 120m towers);
- To increase a WEG competitive in the Brazilian Turbine Market.

Why Ductal for post tensioned segments?

- 50% lighter, or more, for the higher section (possibility to use in T5 and T6 section);
- Avoids to use a 750tons crane which is very expensive and very scarce in Brazil (only 5);
- Replacement of steel adapter for Ductal;
- Reduce the cost with infrastructure (access roads for the crane)

Wide trends with UHPC

Repair & Retrofitting

- Faster erection and shorter traffic disruption
- Simplified connection details (joint, watertightness) and quicker installation
- Suitable for seismic environments and remote locations
- Improves bridge long term performance (allows “100 years” lifespan) with light maintenance

New durable infrastructures

Huge extension of public transportation network (elevated viaduct, tunnel):

- Longer span with UHPC (minimal disturbance during construction, reduced network diversions)
- Light, sustainable structure (reduced deck weight, precast construction, better durability)
- Designed for the environment (part of the urban fabric, emblem of the city)

Wide trends with UHPC

Impact & Blast (security)

High energy absorption capacity (efficiency of high fibres content):

- thinner structures with a better integration in their environment (population acceptance)
- reduction of spalling, scabbing
- high level of protection

3D printing

Printing submodules or complete UHPC structures before assembly and internal work could transform the industry with respect to design, cost, and time. However, 3D printing is still in the early stages of its development and cannot yet be deployed at the scale and speed required for large projects.

Wide trends with UHPC

Conditions of further UHPC development

- **Consolidation of engineering and industrial know-how**

- **Education and dissemination of knowledge**
  - symposium, congress
  - journal, bulletin
  - international recognition

- **Research and development efforts**