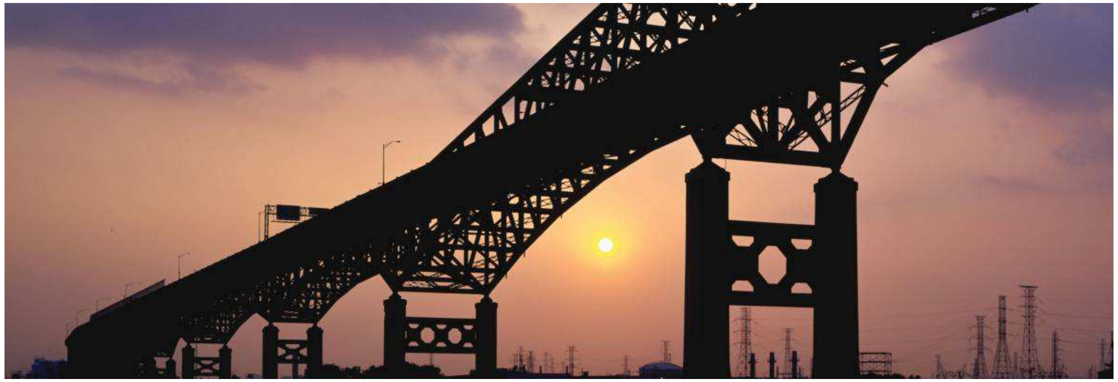

UHPFRC for strengthening or retrofitting structures. Experience and prospects

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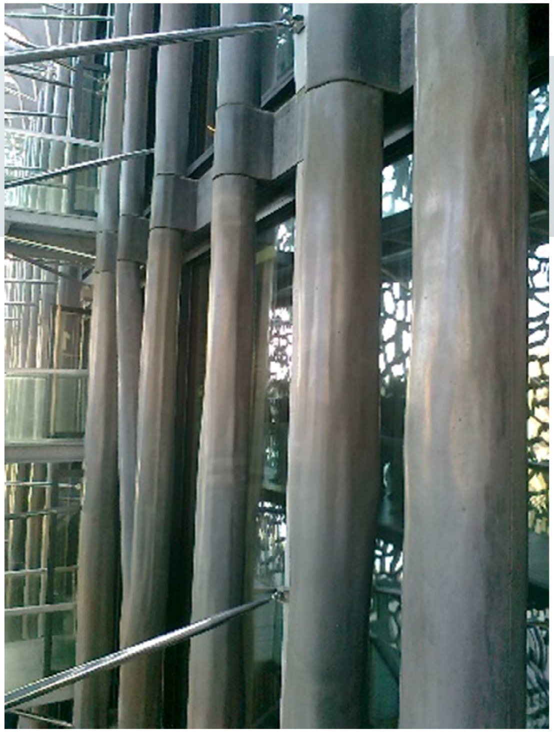
Acknowledgements to T. Thibaux, E. Brühwiler,
A. Simon, S. Bernardi, S. Jaffrelo

REMINDER: WHAT IS UHPFRC ?

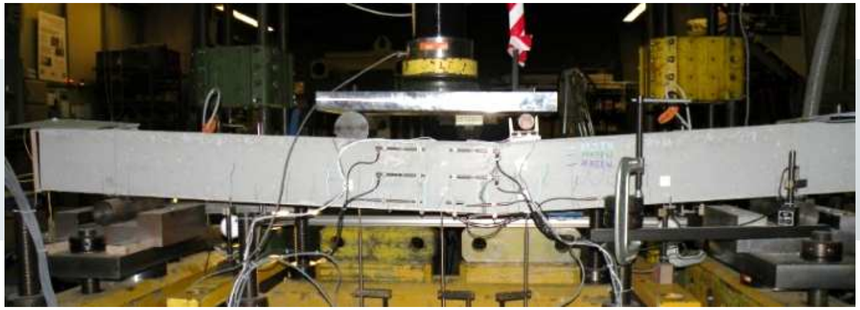


// UHPFRC result from the combination of 3 main ideas:

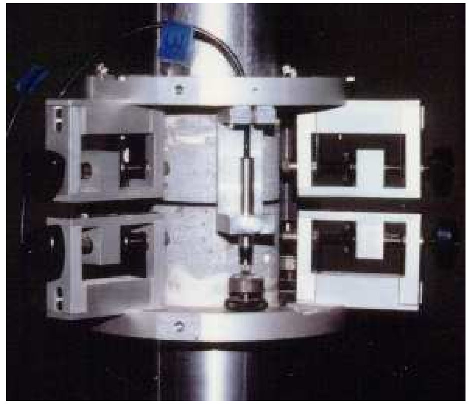
1 Strength and compactness improvement of cement materials by **intense reduction of the water to binder ratio**, which was made more and more possible and efficient with R&D advances in **superplasticizers** and mineral additions;

Macro-defects elimination : MDF, CRC (Bache)
Beyond HPC and VHPC (mid 80s)
Modification of the higher density CSH / lower density CSH balance (Ulm et al.)

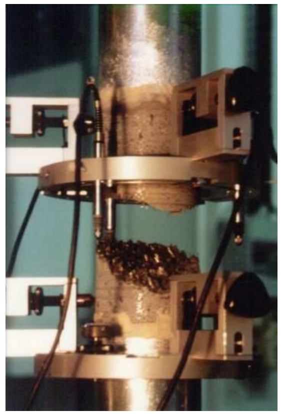
REMINDER: WHAT IS UHPFRC ?



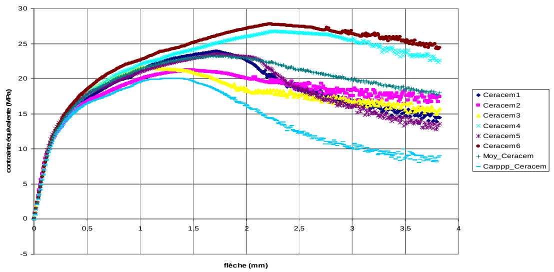
// UHPFRC result from the combination of 3 main ideas:



2 Use of **fibers to provide post-cracking tensile capacity** and pseudo-ductility, which was made possible thanks to more than two decades of conceptual and exploratory development of conventional fiber-reinforced concrete, and really **efficient** as compared to it due to the high quality of the matrix and the possibility to incorporate high amounts of fibers;



Optimized fibers aspect ratio for crack opening control (Swamy and others)
Adaptation of mix-proportioning to high fiber content
Development of tensile tests for material characterization (Rossi et al.)

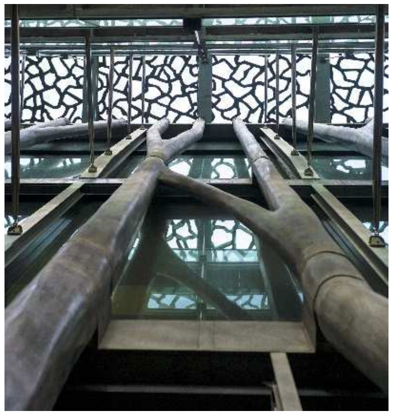


REMINDER: WHAT IS UHPFRC ?

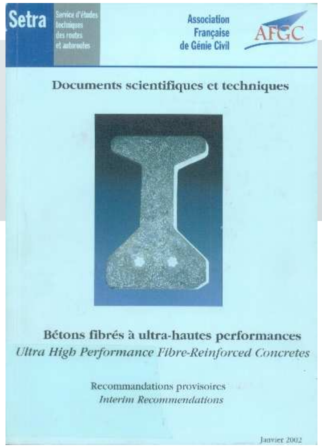
// UHPFRC result from the combination of 3 main ideas:

3 Reduction of natural imperfections due to **aggregate** in limiting their size and selecting very **high quality materials in an optimized grading**, which took benefit of aggregate packing models having being developed in the late 80s.

Use of ultrafine additions developed from the 80s
Experience of operational packing models for HPC and VHPC (de Larrard)



REMINDER: WHAT IS UHPFRC ?



UHPFRC first applications date back 1997 (Sherbrooke – Cattenom)

// Main properties of UHPFRC detailed in AFGC Recommandations

- **Compressive strength**: **180** – 200 MPa (2002) extended to **150** – 200 MPa (2013)
- **Direct tensile strength:** 7 to 12 MPa
- **Post cracking stress** (for 0,3 mm crack opening) : 7 to 12 MPa (hard/soft-ening)
- Young's modulus : 45 to 65 GPa
- Total shrinkage: 550 to 800 µm/m
- Consistency at the fresh state: **from self-levelling to viscous with threshold**

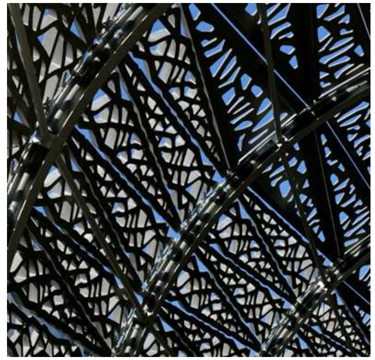
// Other notable features

- Favorable structural behaviour of **thin plates**
- High dependency of the tensile behaviour on fiber orientation
- Experience gained in the **orientation factors K** effectively obtained in structures
- High shock strength and energy absorption capacity
- Very high **durability** / low transfer coefficients (related to low w/b)
- Documented fire resistant capacity of several UHPFRC mixes
- Possibly very high resistance to abrasion

Reference for UHPFRC designation

Compressive strength fck
and pseudo-ductile post-cracking tensile capacity
(flexure-hardening behaviour)
are the 2 independent criteria used for considering the material as UHPFRC

fck (MPa)	**non-brittle metallic fibres**	**non-brittle other fibers**	**possibly brittle**
150 to 250	UHPFRC – *BFUP* **type S**	UHPFRC – *BFUP* **type A**	UHPC
130 to less than 150	UHPFRC – *BFUP* **type Z**		
less than 130	VHPFRC - *BTHP* ***FM***	VHPFRC - *BTHP* ***FO***	VHPC



This proposed designation is not universal for the moment...

... It is proposed for **common understanding**

At least the designations in white are agreed from NF P 18-470 in France

- Type M / Type A fiber-reinforcement is related to clear physical differences
- Non-brittleness threshold is considered a key issue for possibly dispensing with reinforcement
- 130 and 150 MPa somehow conventional thresholds, related to present accepted experience
- These thresholds determine accepted design methods, changing them requires background
- **Warning: this technical designation may differ from the commercial (ranges) designation**

Architecture of French standards for UHPFRC

Compatible with European Standards for Concrete

Published 2016

NF P 18-710 national addition to Eurocode 2

Design Standard: Design of UHPFRC structures (UHPFRC with steel fibres) (related to EN 1992)

Case by case technical approvals

Design of non structural UHPFRC elements

Note: Design of UHPFRC structures made of UHPFRC with non-metallic fibres shall be dealt with as non-traditional

New in 2018

Revision of NF EN 13369

Common rules for precast products

NF P 18-470 self-supporting standard substitute to EN 206 (similar outline)

Product Standard: UHPFRC

(specification, performance, production and conformity)

Type S: UHPFRC for structures

Type A or Z: UHPFRC for non structural or architectonic elements

Premix	*On-site prefabrication*	*Mixed on site*
No Premix	*Prefabrication in a precasting plant*	*Ready-mix*

T E S T S

Annexes to NF P 18-470

Published 2016

Revision of specific standards

Special rules for precast products

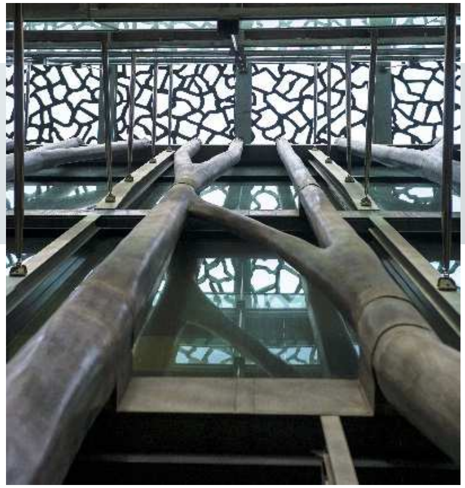
NF P 18-451 national addition to NF EN 13670/CN

New in 2018

Execution Standard:

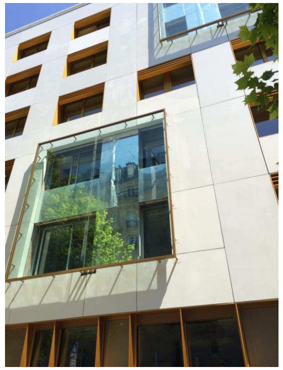
applicable to execution of UHPFRC structures and non-structural or architectonic UHPFRC elements

SOME ICONIC REFERENCES OF UHPFRC IMPLEMENTATION



// Large buildings and building components

- MuCEM, Marseille (2013)
- Jean Bouin Stadium, Paris (2013)
- Montpellier new railway station (2017)
- Biostyr building of Achères water treatment plant (2012)
- Façade components of La Marseillaise high rise building (2019)



// Bridges and civil engineering facilities

- Seonyu footbridge, Seoul (2002)
- La République Bridge, Montpellier (2014)
- Haneda airport extension (landing tracks - terminal D) (2007-2010)
- Notre-Dame de Lorette Ring of Memory (2014)
- passerelle des Anges, MuCEM footbridges (2008-2013)

UHPFRC is not a simple concrete extension

- **The UHPFRC offer may be complex** : the list of required properties to be specified is not only f_{ck} and slump (cf. NF P18-470 section 6)
  - useful **identity cards** (time savings)
  - beware of variants in the offers
  - some sensitive aspects: shrinkage, fiber type, post-cracking behaviour, Young's modulus...
  - **material / design interaction** is critical due to incidence on cost-efficiency, methods and contracting aspects
- **UHPFRC is not only a premix nor a receipe**
  - the **suitability test** is critical to validate the concreting program / finishing treatments / reaching the required K-factors
  - **combined responsabilities** of the user and the supplier
- **« Skills in UHPFRC » concern:**
  - the premix supplier, if any; the supplier of fresh UHPFRC (not a conventional RMC producer)
  - **the user** of fresh UHPFRC (precaster / contractor), the one who assembles UHPFRC precast elements, where relevant
  - the designer, checker, laboratories, prescriber and supervisor

  Various organisation/contract situations – for a generally high quality demand...
- **When UHPFRC is used for strengthening / retrofitting** the interaction between material / execution / assessment is even more critical

  → **examples** follow, to stimulate implementation

References in UHPFRC application for buildings repair

- Renovation of beams in Cattenom power plant cooling towers (1997)
  - Durability, lightness (dead loads not increased)
- Replacement of thinner and wider spaced columns: museum in Albi, building rue Volney in Paris (2003)
  - Capacity in compression
- Columns jacketing to increase the bearing capacity: parking in Perpignan (2008)
  - Capacity in compression, fluidity, bond to existing concrete
- Renovation of industrial slabs, retrofitting of bending capacity – Switzerland (2007)
  - Composite RC / UHPFRC behaviour, capacity in compression, selflevelling
- Self supporting columns for external thermal insulation, residence rue Blanche in Paris (2011)
  - Light self-supporting structure, architectural versatility
- Composite timber-UHPFRC floors for old building renovation, Germany (2014)
  - Lightness, fire stability

A winning strategy

- Low intrusiveness
- Lightness (no incidence on supports and gravity loads flow)
- Simultaneous optimization of materials and methods
- Bearing capacity of the UHPFRC material itself
- Material cost less critical than methods and logistics
- Integrated solution, supposes special contracting procedures?

In repair / retrofitting of bridges and civil works, additional advantages are:

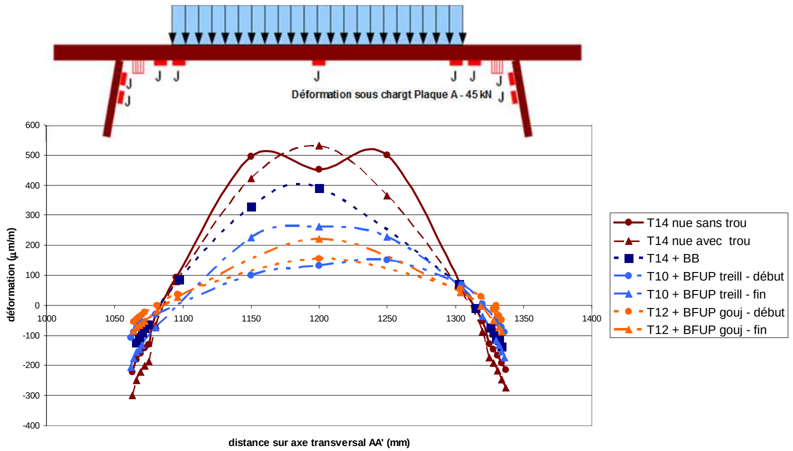
- *durability*
- *resistance to abrasion*
- *compatibility with existing support (concrete / steel)*

Steel decks strengthening

- Stiffening to reduce vulnerability to fatigue
- Demonstrated efficiency provided the connection is effective (PN Orthoplus)
- Application with cast in place UHPFRC: prototypes in the Netherlands, in Japan and France (Rance mouth crossing)
- Application with precast slabs: ®Orthodalle - Illzach (2011)

Potential market of large sensitive bridges (France, Japan, USA and Europe – especially Germany and the Netherlands)

Optimization of methods and logistics?



Stiffening of concrete decks

- Renovation of the upper deck part polluted by chlorides
- Reconstitution of an upper part able to sustain compressive forces
- low permeable or even tight layer (depending on joints treatment)
- Use as paving layer if (e.g. formed) texture or grooving
- Cast-on site on a roughened surface (logistics / methods)
- References since 2004 especially in Switzerland (Samaris, Arches projects - Chillon viaducts – ACI award, 53,000 m^2 redecking – 6,000 m^3 cast in 6 + 4 weeks (two summer periods) in a 40 mm-layer - and more than 50 bridges)

Important potential market in zones of intense use of deicing salts

Cost-efficiency in a preventive maintenance approach? Only in Switzerland?

Renovation of the concrete deck of composite bridges, widening

- Research and prototype qualification carried out but not implemented (MIKTI)
- Waffle slab implemented in the USA over concrete beams
- Lightness, durability
- Quick launching in case of an independent structure (e.g.. Pont Pinel)

Future market of composite bridges retrofitting?

Widening of urban bridges / under heavy traffic?

Joint fills (keying joints in bridge renovation)

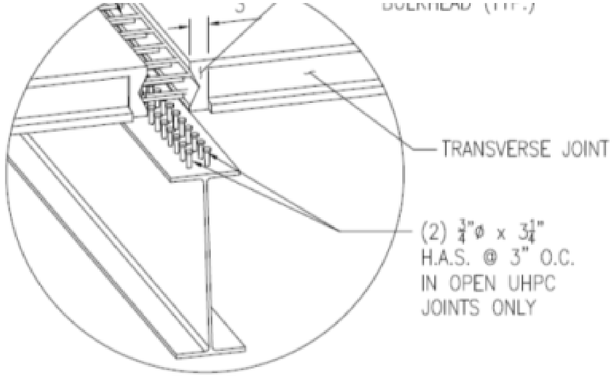
- For partial or total bridge decks renewal (ABC)
- applied to more than 200 bridges in the USA and Canada
- Reduction of cast in place material quantity (higher bond strength of UHPFRC to rebars)
- Increased durability at the joint location
- Rapid hardening: re-opening to traffic within 24 h
- Recent application in France for a steel bridge: Thouaré s/Loire

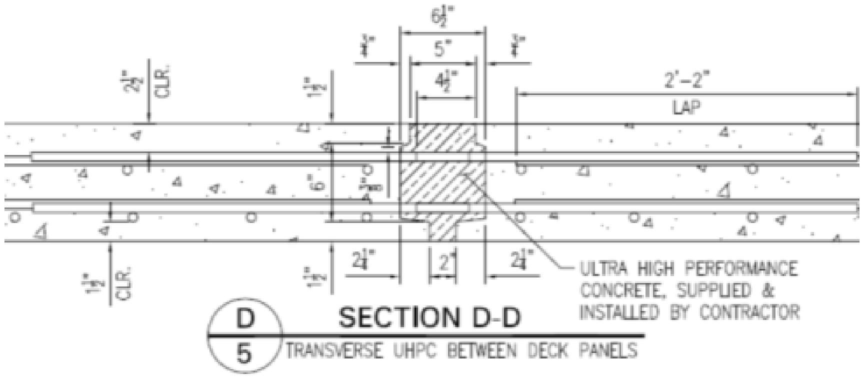
Market presently optimized for beam bridges without waterproofing / pavement layer or keying between precast slabs of composite bridges

covered by a technical file issued by FHWA

Implementation on
Pulaski Skyway, NJ
5 kms, 4 lanes

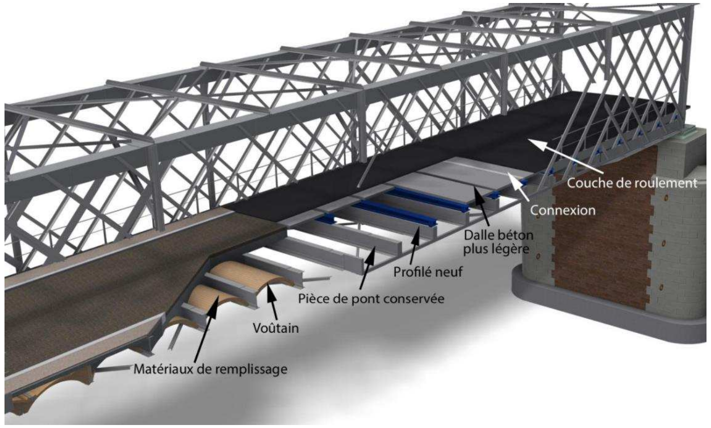
Example of « ABC Joint-fill » in North America



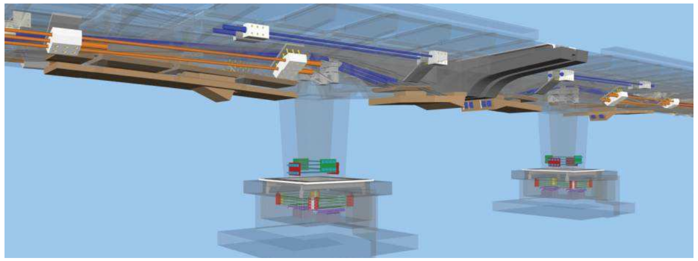


Bridge renovation at Thouaré-sur-Loire (deck reconstitution)

Possibly relevant for several old steel bridges in Europe



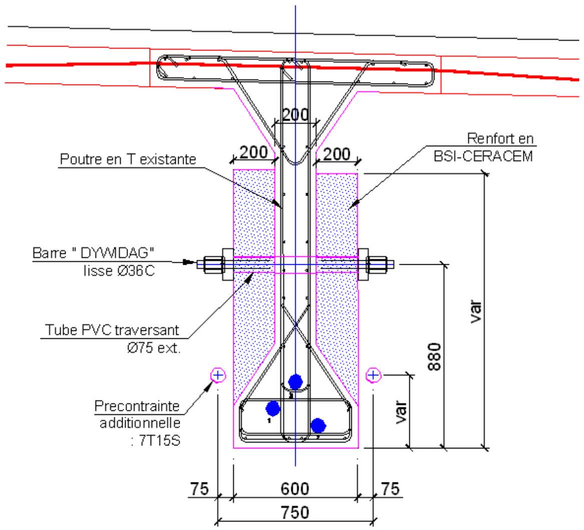
Additional post-tensioning



- Optimized size of anchor blocks to be fixed
- Possible thin reinforcement layer added for taking additional compressive forces
- Application: concrete post-tensioned beam bridge over the Huisne river at Le Mans (2006) for adaptation to a tram line
- Application to retrofitting of the Hammersmith Flyover in London (2013-2015)

Different options for methods and logistics (prefabrication or on-site casting)

Performance of "surgery" operations



Jacketing, protective layers / shells

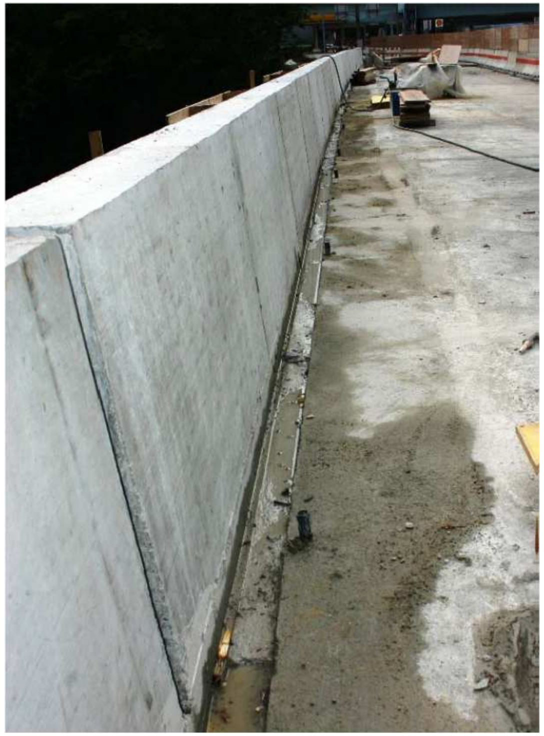
- Protection against chlorides / chemical attacks
- Resistance to shocks and abrasion
- Precast shells or cast-in place wearing layer
- Application to severely exposed facilities, bridge piers in rivers or off-shore, hydraulic structures (dams), marine signal equipments
- Execution, methods and logistics require special care

Potential growing market?

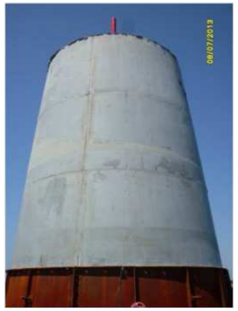
Applications under study or validation

- Internal jacketing of steel culverts (sprayed UHPFRC)
- Columns jacketing for seismic retrofitting
- Additional / renewed equipments (sound barriers, parapets…)

Promising markets? Optimised cost-efficiency?



Concluding remarks (1)



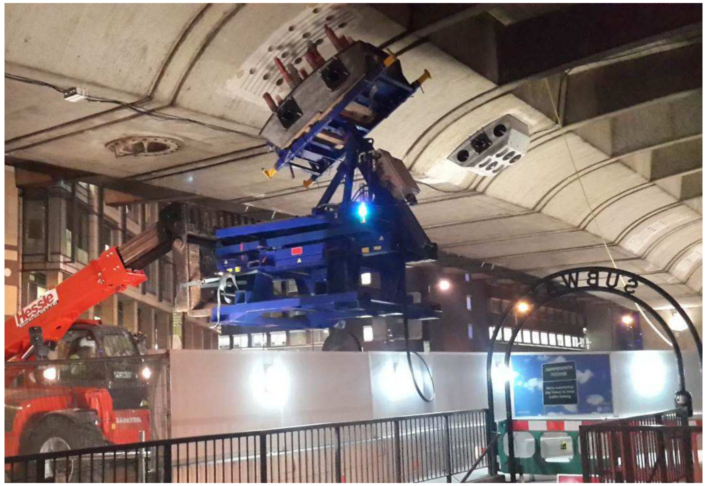
Advantages to be searched

- Optimization of added dead weight (performance)
- Reduction of jobsite duration (prefabrication, optimized rheology for cast-in-place UHPFRC, rapid hardening)
- Durability (quality of execution - watertightness)
- Rigidity (high Young's modulus and low creep)

Promising fields, studies and demonstrators to be followed up?

- Orthotropic steel deck bridges
- Steel culverts
- Off-shore signals, marine structures
- Old steel bridges with degraded stone/bricks/steel beam decks
- External thermally-insulating façade / cladding elements?
- Seismic strengthening (confinment, diaphragms...) ?

Concluding remarks (2)



Special issues to be carefully handled: methods of execution

- Connection of light precast elements / fixations / geometrical tolerance % with respect to existing structures
- On-site placement: gravity-driven casting, injection, shotcreting, spreading with a finisher... effect on fiber orientation and coping with restrained shrinkage
- Provisions for UHPFRC specification, suitability testing and production control to be adapted
- How to qualify watertightness ability?

Conditions for correct implementation

- Technical relevance in comparison to possible alternative methods (fire resistance, feasibility of complex shapes, rigidity and compressive usable strength, possible underwater concreting)
- Integrated material / design / methods engineering
- Material cost less critical than execution costs and duration
- Contracting procedures and risk management ?