Session 2

Ultra-High-Performance Fibre Reinforced Concrete
– From Fundamentals to Applications in Bridge Engg.

By

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- Definition of UHPFRC
- Evolution of UHPFRC
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  - Shear
  - Demo of developed Spreadsheet
- Creep & Shrinkage properties of UHPFRC
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- Applications of UHPFRC

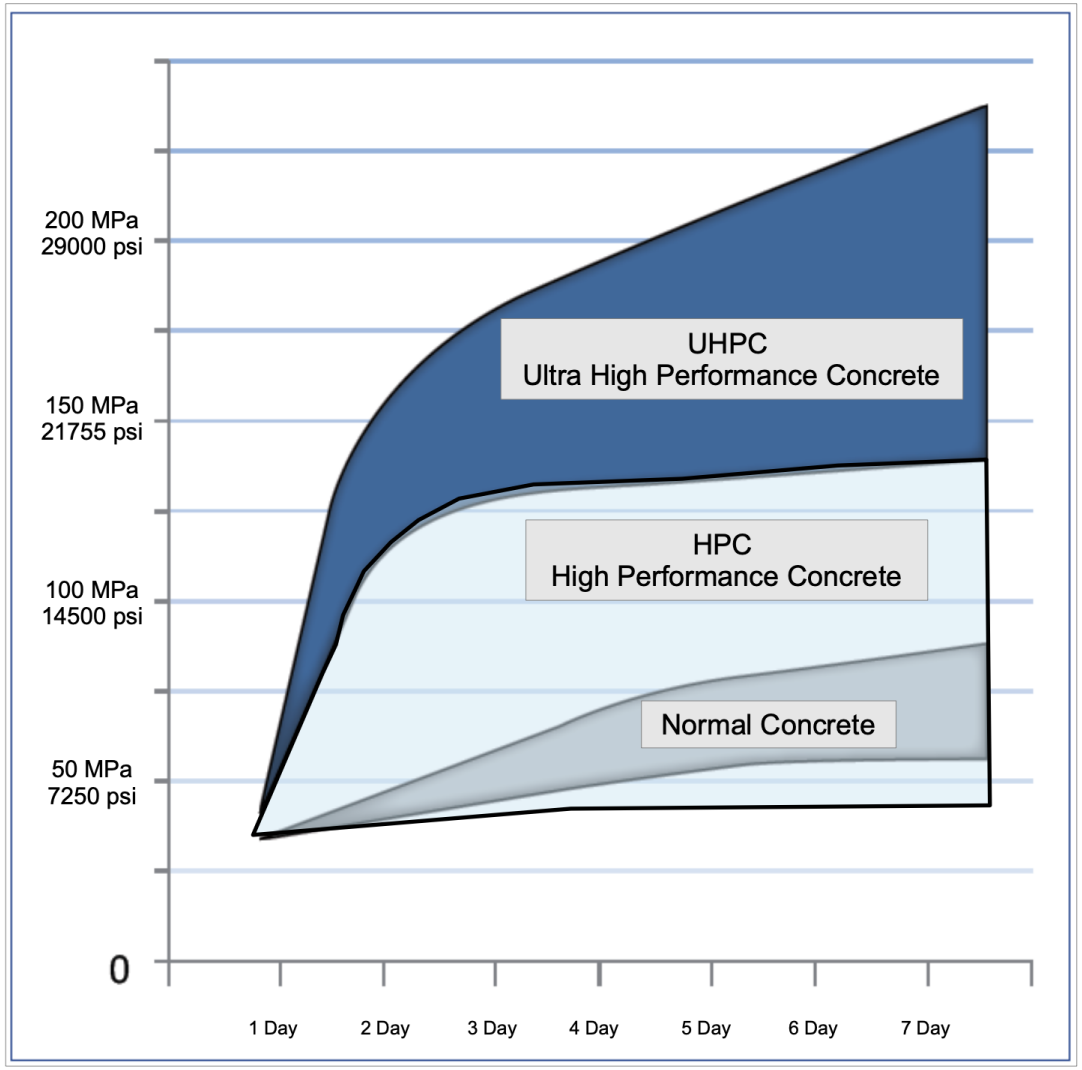
Definition of UHPFRC

IS 456 : 2000

Table 2 Grades of Concrete

(Clause 6.1, 9.2.2, 15.1.1 and 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80



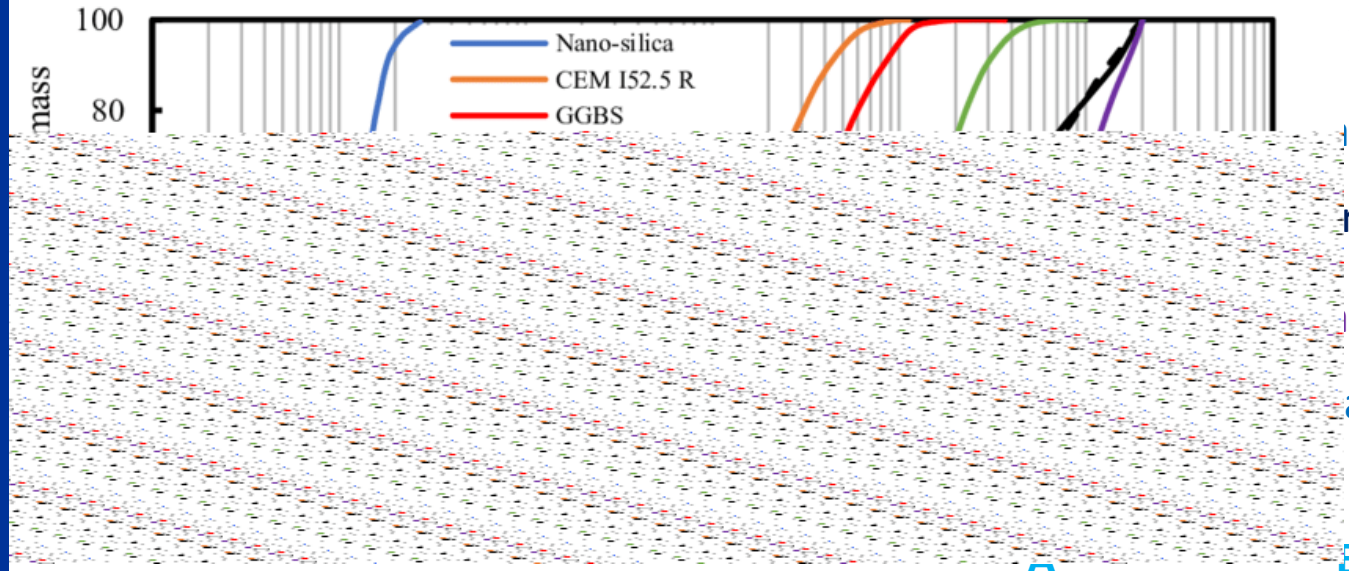
Definition of UHPFRC

U.S. Department of Transportation
Federal Highway Administration

FHWA

UHPC is a cementitious composite material composed of

- an optimized gradation of granular constituents
- a water-to-cementitious materials ratio less than 0.25
- a high percentage of discontinuous internal fiber reinforcement



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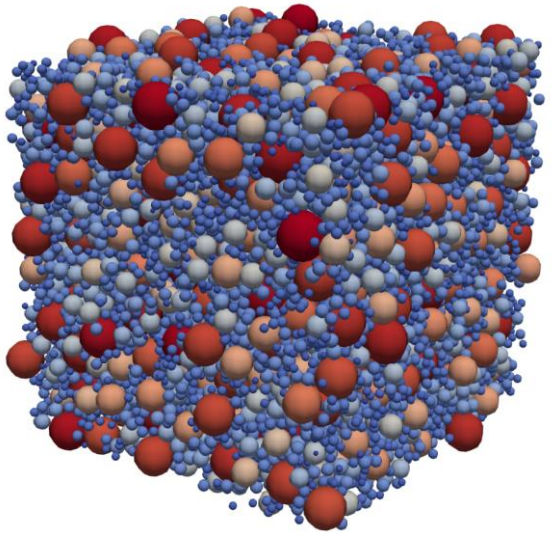

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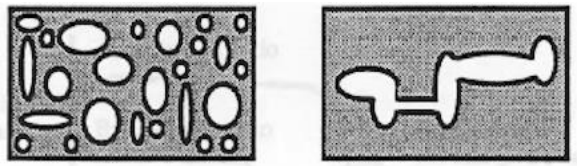
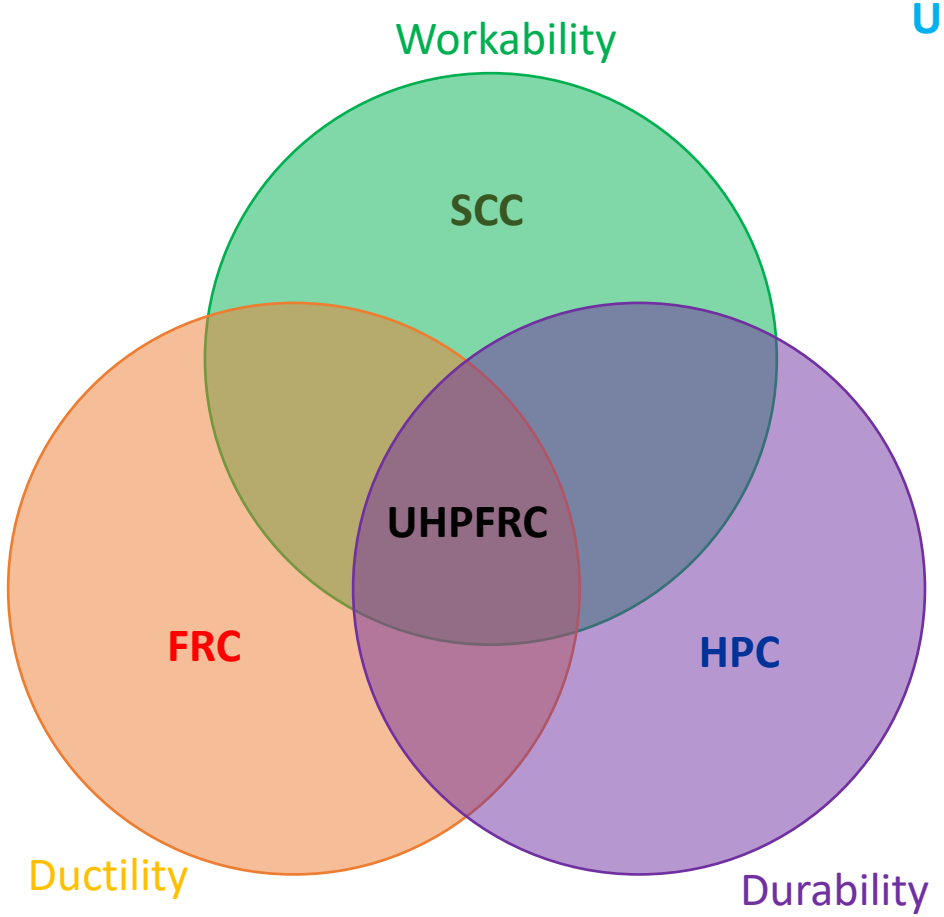


What is UHPFRC



Ultra-High-Performance Fibre Reinforced Concrete (UHPFRC)

- **Higher Strength**
- **Superior Durability**
- **Greater Workability**
- **Better Ductility**

- Ultra-High Performance Concrete (**UHPC**)
- Ultra-High-Performance Fibre Reinforced Concrete (**UHPFRC**)
- Ultra-High-Performance Fibre Reinforced Composite (**UHPFRC**)
- Reactive Powder Concrete (**RPC**)

Evolution of UHPFRC

Abram's Law

Compressive strength = f(w/c)

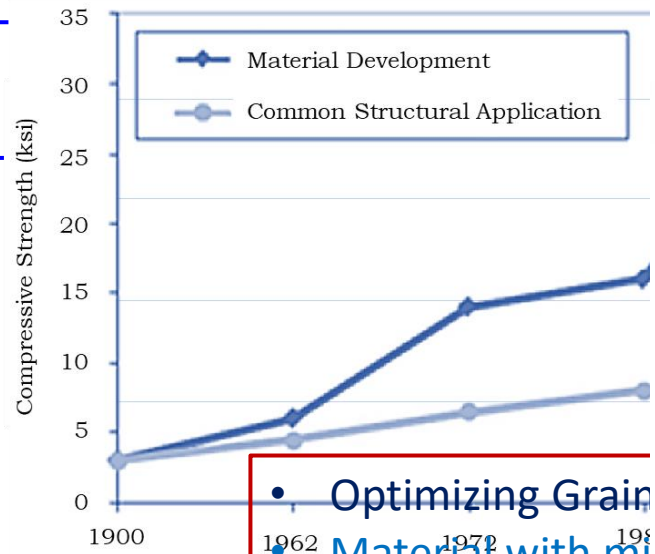
↓ w/c ↑ Strength

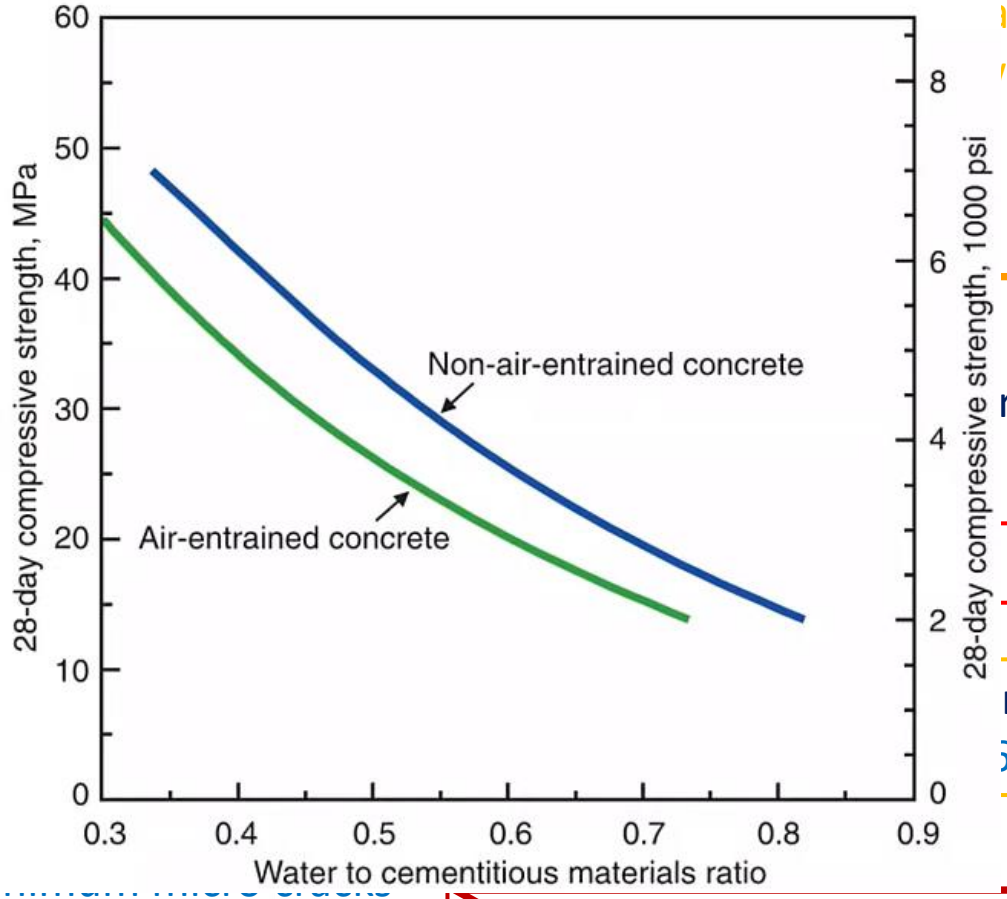
↓ Pores ↓ Workable

1918 — 1960s — Water Reducers were introduced

- No much technological advancement in existing water reducers
- Failed to reduce w/b ratio

it is realized that the high-range water ...an be used to progressively ...n to **0.30**





1990s

...rafine particle-base materials

...Superplasticizers in Concrete

Compr. Strength > 280 MPa

...me (SF)

...5

- Optimizing Grain ...
- Material with mi...
- Minimum interconnected pore spaces

Durability of UHPFRC

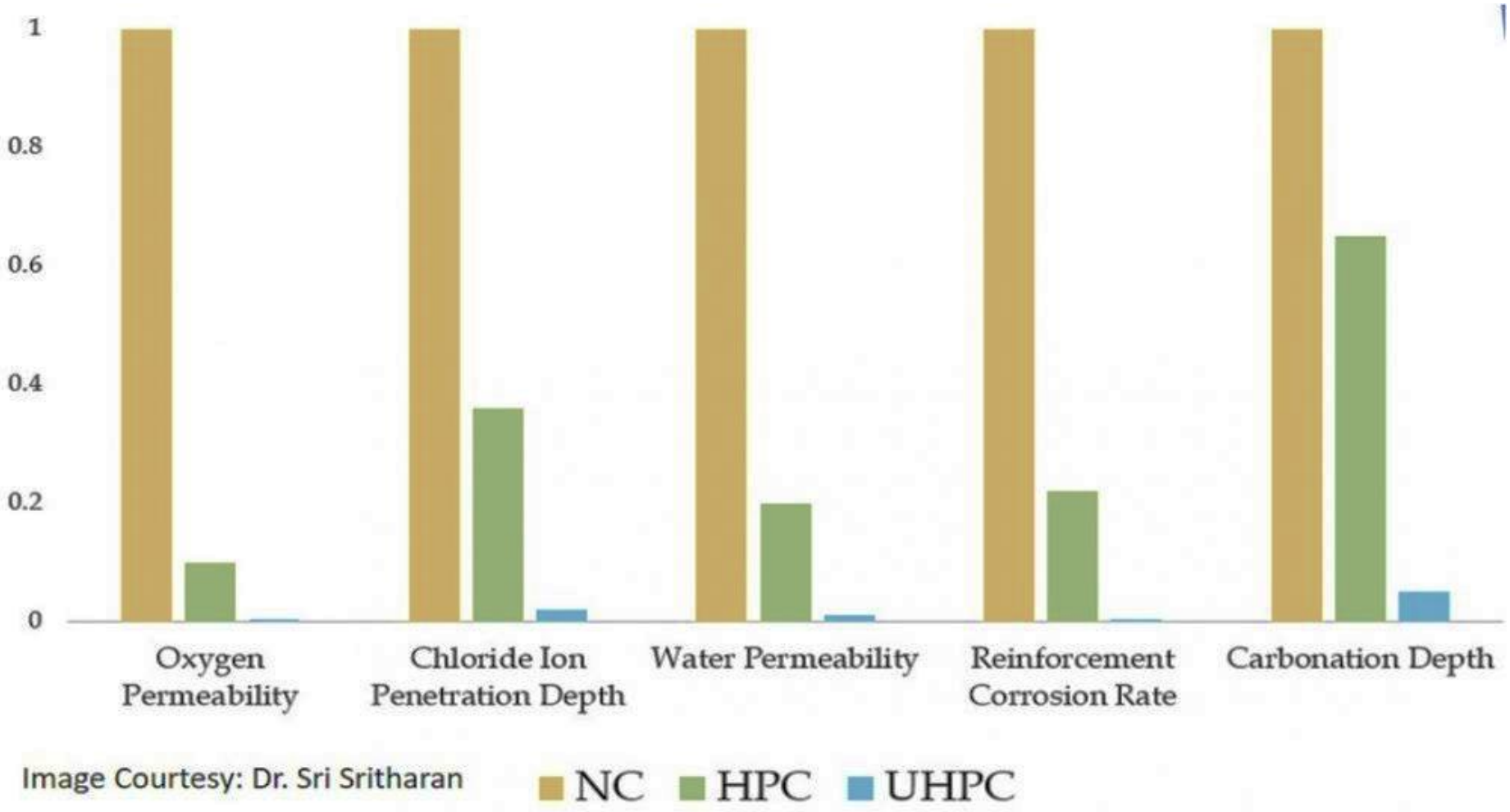
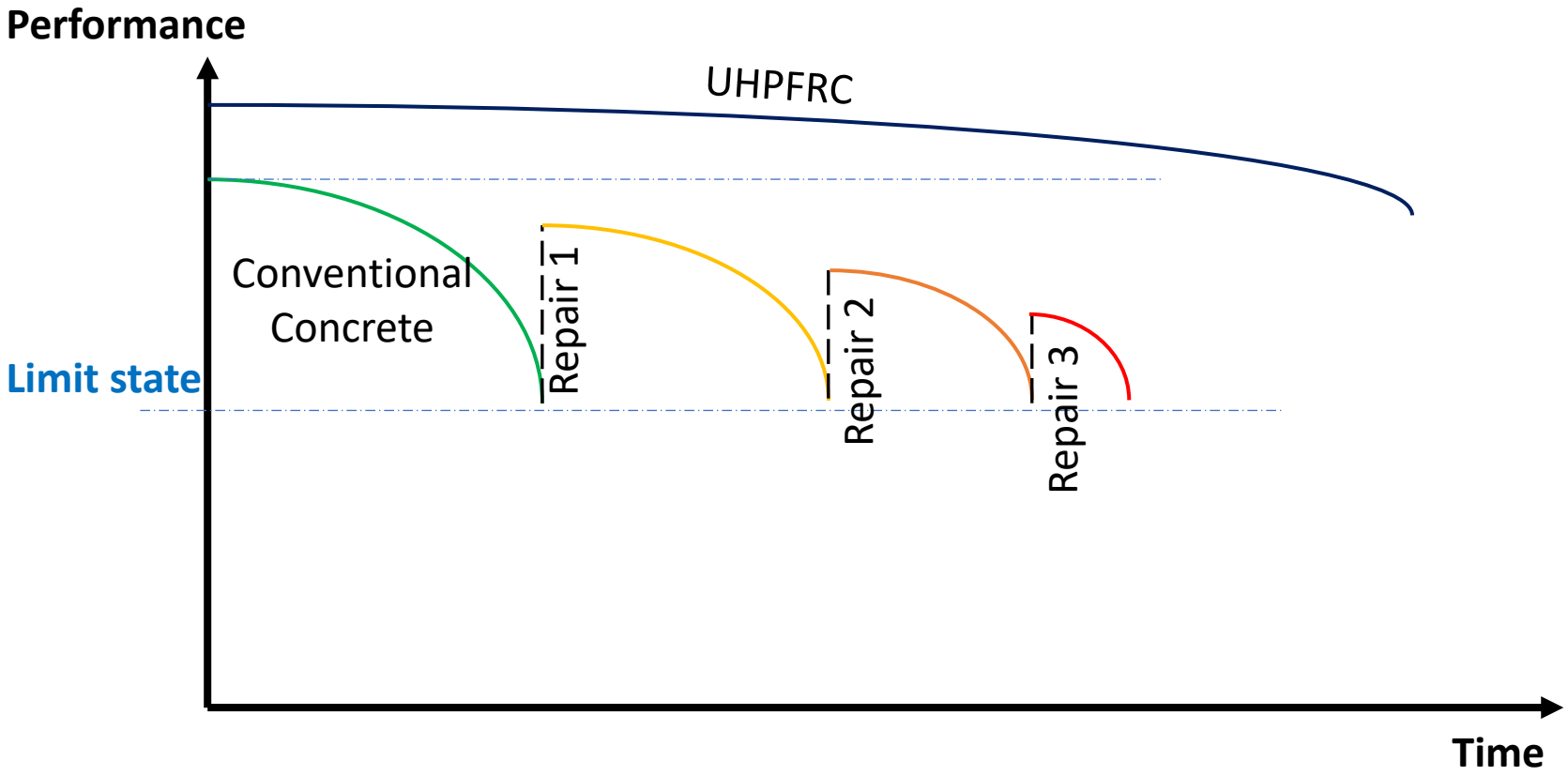


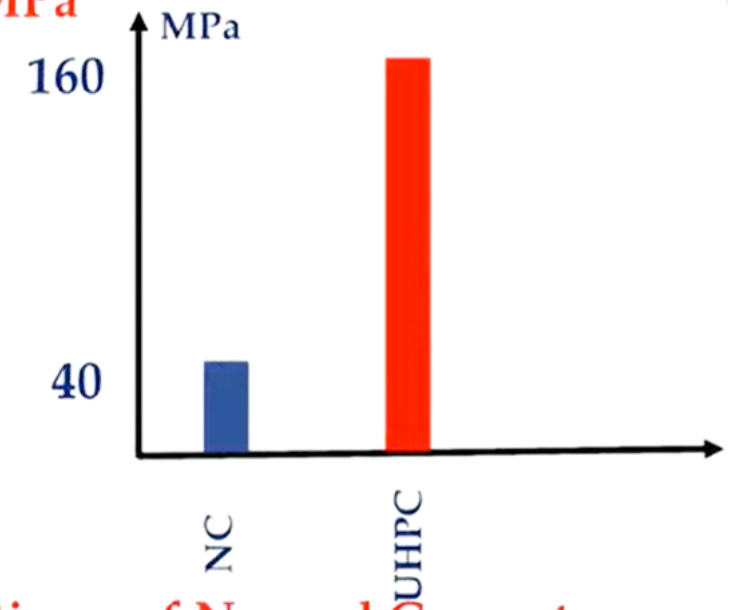
Image Courtesy: Dr. Sri Sritharan

Maintenance free Service life

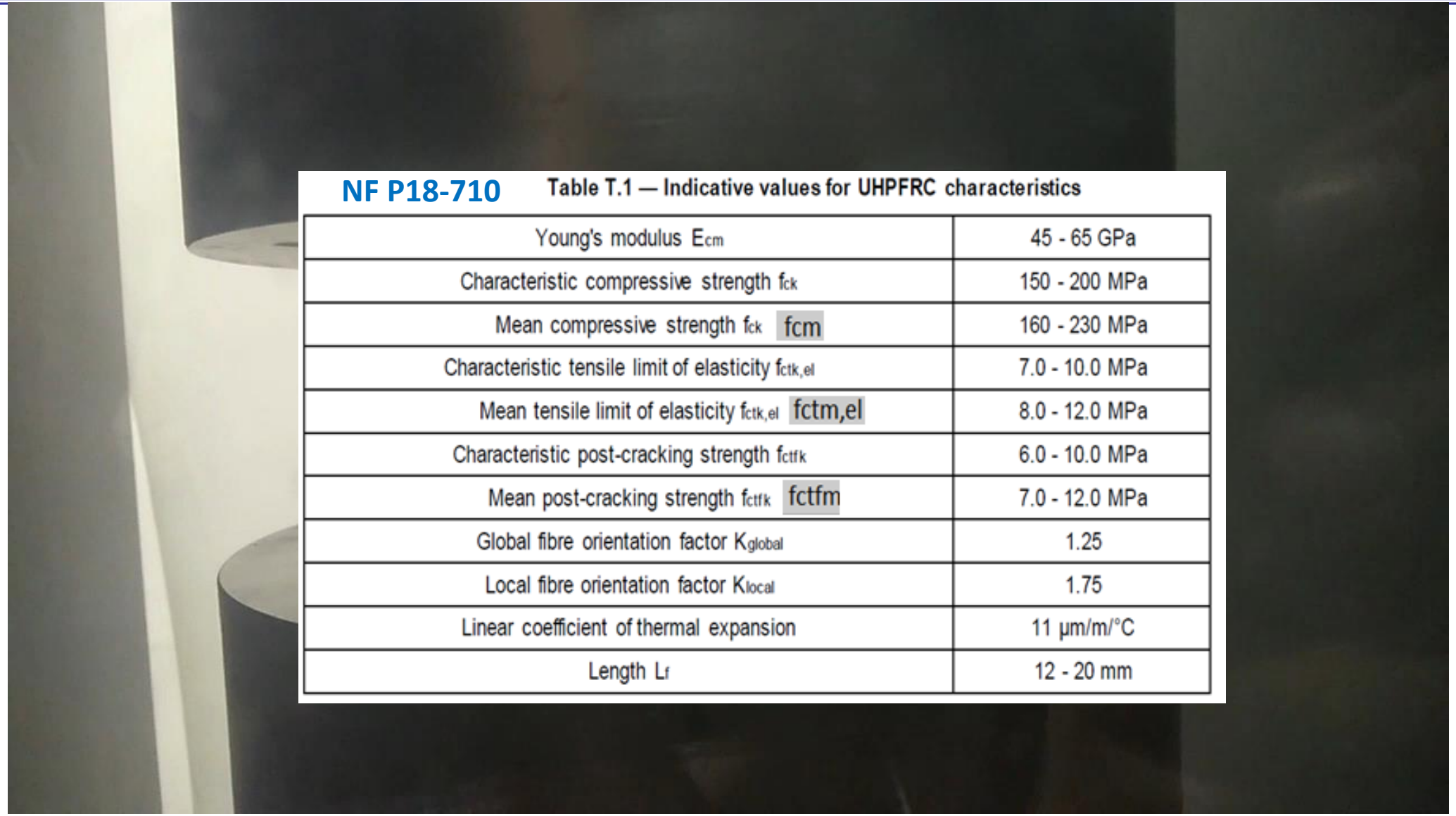


Mechanical Properties of UHPFRC

- Compressive Strength: 140 MPa to 220 MPa
- Creep Coefficient:
  - ~ 0.2 (Steam Cured)
  - ~ 1.0 (Normal Curing)
- Shrinkage: ~450 to 750 Microns
- Elastic Modulus: ~50,000 Mpa
- Abrasion Resistance (ASTM C944): > 2 times of Normal Concrete
  < 0.025 oz lost



Strength of UHPFRC



NF P18-710 Table T.1 — Indicative values for UHPFRC characteristics

Young's modulus E_{cm}	45 - 65 GPa
Characteristic compressive strength f_{ck}	150 - 200 MPa
Mean compressive strength f_{ck} fcm	160 - 230 MPa
Characteristic tensile limit of elasticity $f_{ctk,el}$	7.0 - 10.0 MPa
Mean tensile limit of elasticity $f_{ctk,el}$ fctm,el	8.0 - 12.0 MPa
Characteristic post-cracking strength f_{ctfk}	6.0 - 10.0 MPa
Mean post-cracking strength f_{ctfk} fctfm	7.0 - 12.0 MPa
Global fibre orientation factor K_{global}	1.25
Local fibre orientation factor K_{local}	1.75
Linear coefficient of thermal expansion	11 µm/m/°C
Length L_f	12 - 20 mm

Executed UHPFRC Projects

The usage of UHPC for bridges and bridge components can been seen in various countries including

- Australia
- Austria
- Canada
- China
- Czech Republic
- France
- Germany
- Italy
- Japan
- Malaysia
- Netherlands
- New Zealand
- Slovenia
- South Korea
- Switzerland

Most projects were motivated by **government agencies** as initial **demonstration projects** intended to **encourage further implementation**.

Executed UHPFRC Projects

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- Italy
- Japan
- Malaysia
- Netherlands
- New Zealand
- Slovenia
- South Korea
- Switzerland

German Research Foundation:

- A €12 million research program
- Established in 2005
- Involved 34 research projects
- > 20 local research institutes
- Aim: to expand the awareness of UHPC to make it a reliable, commonly available, economically feasible, and regularly applied material

Korean Institute of Construction Technology:

- USD$11 million
- Established in 2007
- Super 200 program
- Aim: to study the use of UHPC in cable-stayed bridges

Executed UHPFRC Projects

The usage of UHPC for bridges and bridge components can been seen in various countries including

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- Austria
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- Czech Republic
- France
- Germany
- Italy
- Japan
- Malaysia
- Netherlands
- New Zealand
- Slovenia
- South Korea
- Switzerland

Initiated by Dura Technology (DURA®)

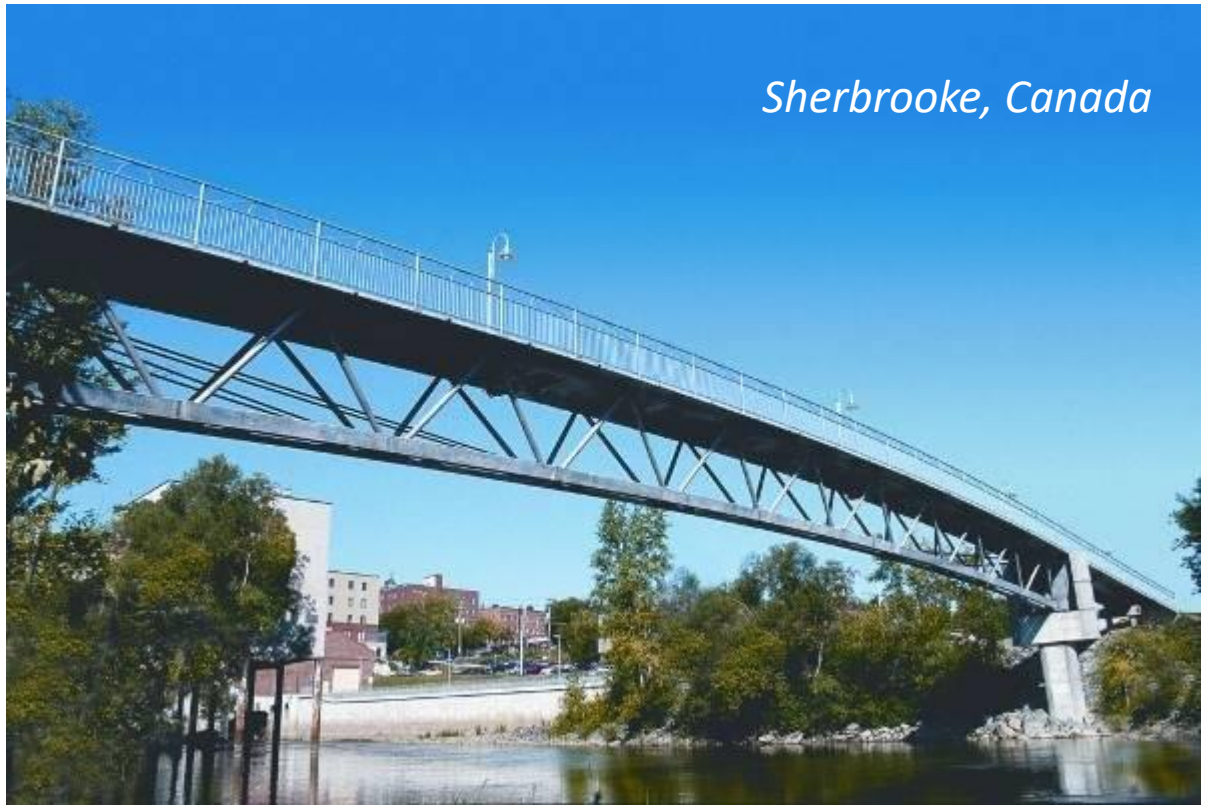
- Started in 2006
- first bridge application in 2010
- Continued several years of intensive research and development
- started its industrial-commercial penetration as a *sustainable construction material*

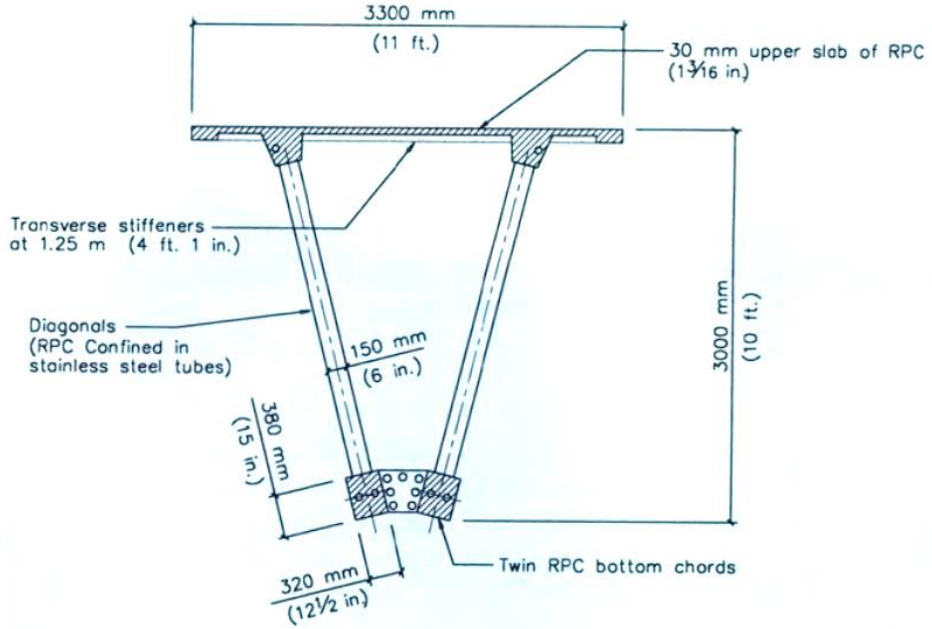
DURA® Collaborated with The Malaysia Public Work Department

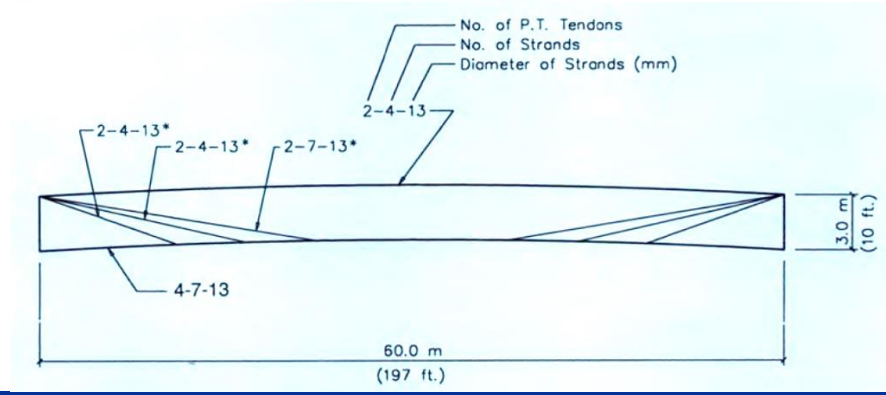
- in designing and building UHPC bridges focusing on rural area
- DURA has dominated the UHPC market in Malaysia
- Completed 113 UHPC bridges
- > 20 bridges are in construction stages

Executed UHPFRC Projects

- The first UHPC developed through RPC technology was commercialized under the name *Ductal®*
- In 1997, the **world's first RPC structure** was built for **pedestrian bridge** in *Sherbrooke, Canada*





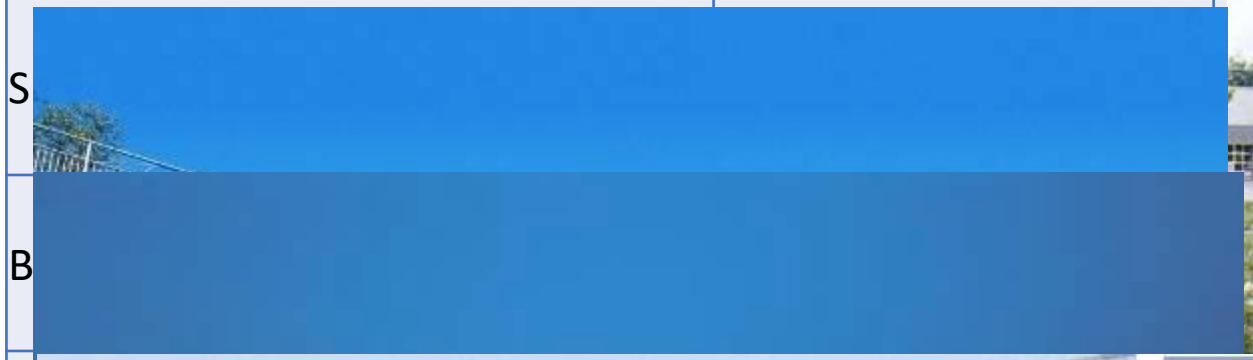


Full-length paper

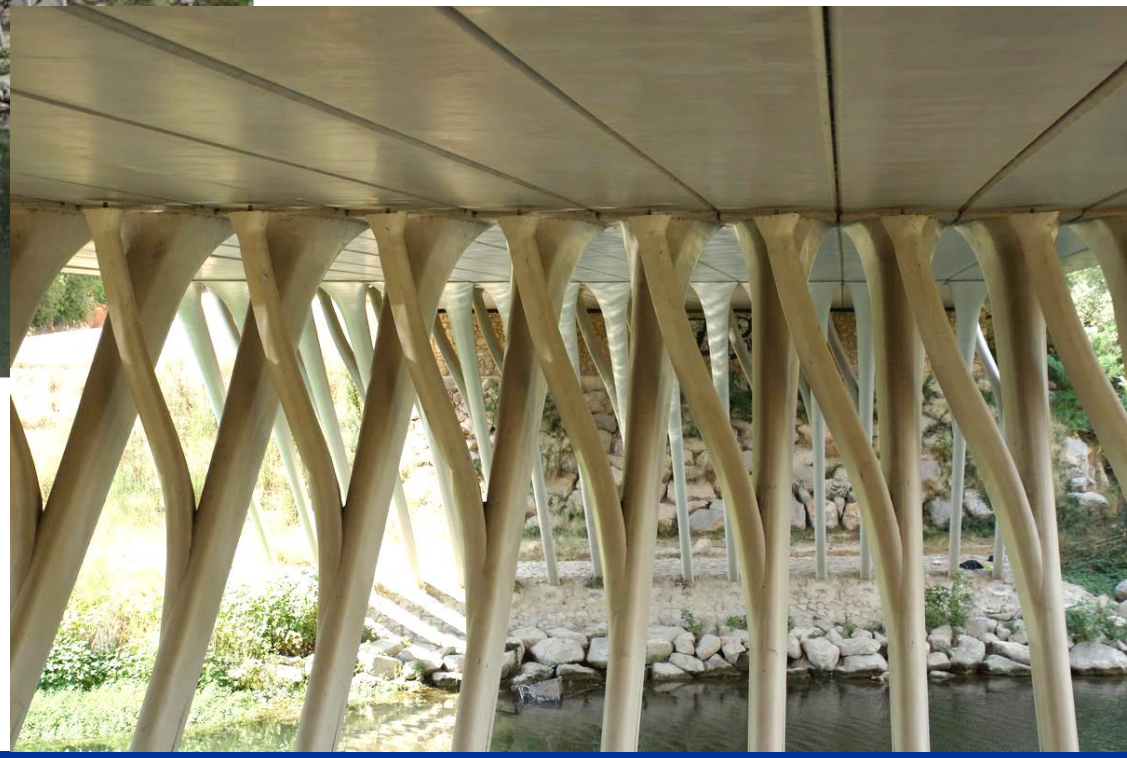
Blais, P. Y., & Couture, M. (1999). PRECAST, prestressed pedestrian BRIDGE-WORLD'S first reactive powder concrete bridge. PCI journal, 44(5).

Executed UHPFRC Projects

Location	Application	Year	Advantages
Sherbrooke, Canada	Pedestrian bridge	1997	•1st UHPC structure
Seonyu, Seoul, South Korea	Footbridge	2	egments
S			
B			
M			
M			
Je			
Fe			



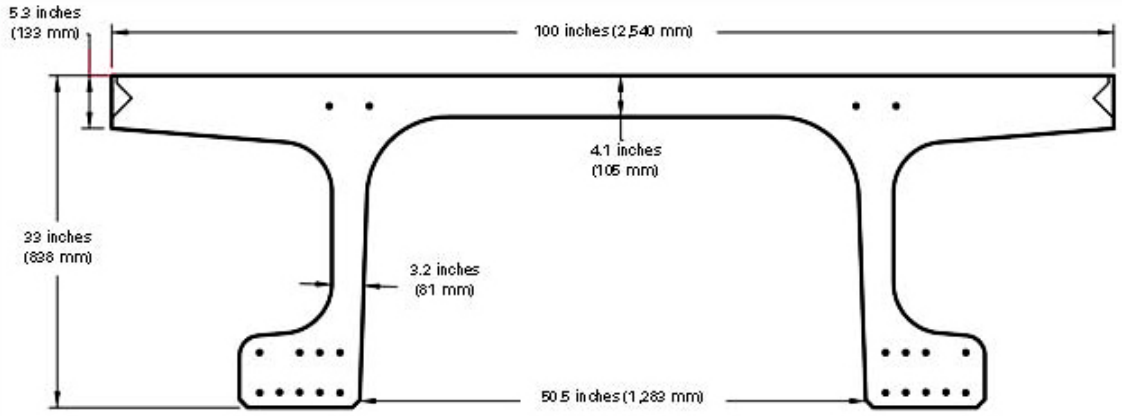
Executed UHPFRC Projects

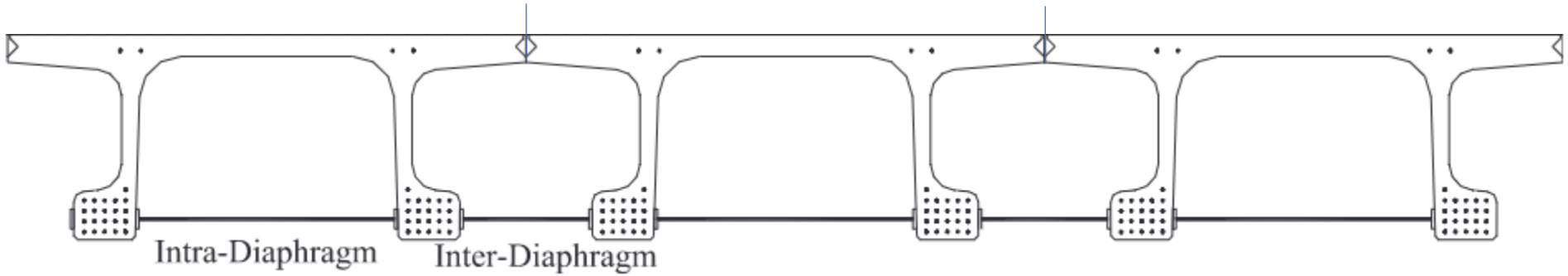


Pont de la République in Montpellier, France

Executed UHPFRC Projects

2nd Generation UHPC Pi-Girder, FHWA





First UHPFRC Bridge in India

Project: Construction of Major Bridge across Sole Nalla on Latur – Nitur - Nilanga – Balki – Road NH752K

Structure

Superstru

Substruct

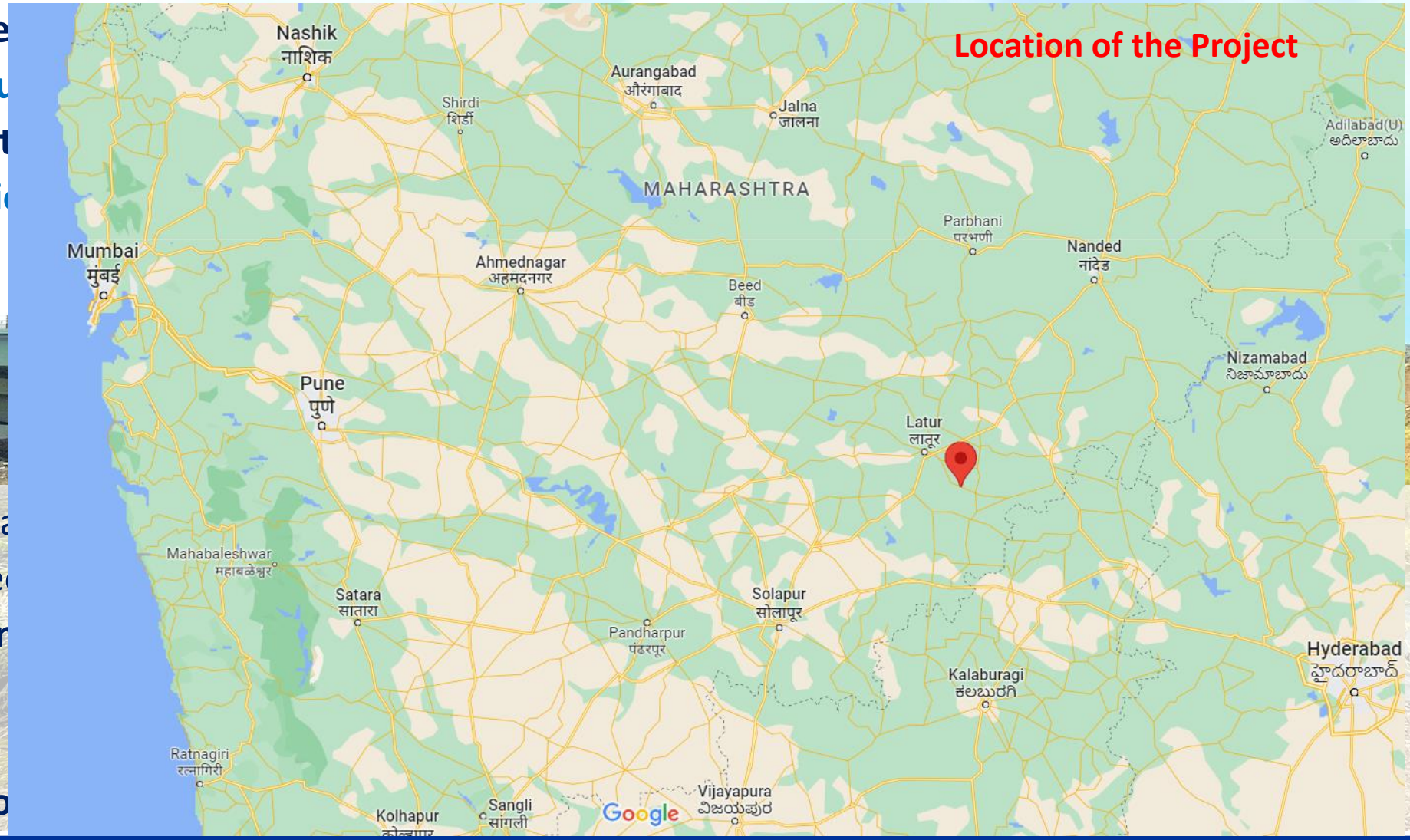
Foundati

Client: Ma

S.O.: Vale

Consultar

Contracto



MoRTH Circular on the use of UHPFRC in Bridges

File No.RW/NH-33049/01/2020-S&R (B) Pt.
Government of India
Ministry of Road Transport & Highways
(S&R (P&B/New Technology) Zone)
Transport Bhawan, 1, Parliament Street, New Delhi-110001

Dated: 22th February, 2022

CIRCULAR

To,

1. The Chief Secretaries of all the State Governments/ UTs.
2. The Principal Secretaries/ Secretaries of all States/ UTs Public Works Department/ Road Construction Department/ Highways Department (dealing with National Highways and other centrally sponsored schemes).
3. The Chairman, National Highways Authority of India, G-5 & 6, Sector-10, Dwarka, New Delhi-110 075.
4. The Managing Director, NHIDCL, PTI Building, New Delhi-110001.
5. The Director General (Border Roads), Seema Sadak Bhawan, Ring Road, New Delhi- 110 010.
6. All Engineers-in-Chief and Chief Engineers of Public Works Department of States/ UTs/ Road Construction Department/ Highways Departments (dealing with National Highways and other centrally sponsored schemes).
7. All CE-ROs, ROs and ELOs of the Ministry.

Subject: - Use of Ultra High Performance Fiber Reinforced Concrete (UHPFRC) in Design & Construction of Structures/Bridges of National Highways - Regarding

Madam/Sir,

Advanced structural design guidelines IRC: 112-2020 "Code of Practice for Concrete Road Bridges" and analysis software are presently being used in India. These are in tune with the International codes. However, its full exploitation to design the durable cost-effective slender sections are being made in a very limited manner. Therefore, need is felt for adoption of State-of-Art advanced level of bridge technologies for use in National Highway projects so that widespread usages of more cost effective sustainable design solutions and implementation methodologies are encouraged.

2. Concrete up to M50 grade is generally being used for bridges and structures on National Highways in India. Indian Roads Congress (IRC) has published IRC: SP: 70-2016 "Guidelines for the Use of High Performance Concrete in Bridges" which provides for use of High Performance Concrete/Self-Compacted Concrete up to M90 grade. It is, however, observed that use of High Performance Concrete/Self-Compacted Concrete (M60 to M90 grade) is limited to a few long span extra dose/cable stayed bridges only.

Bidur Kant Jha

3. Properly designed Ultra-high-performance fiber reinforced concrete (UHPFRC) which have following superior characteristics are being used in some developed countries:

- Available up to Grade M150MPa
- Available up to ultimate tensile strength 8MPa and ultimate flexural strength 30MPa.
- At least 4-6 times stronger than normal concrete (in compressive strength)
- Much more durable than conventional concrete
- Longer service life
- Reduced deck height
- Lower carbon footprint

4. Recently UHPFRC girders have been used in Sole River Bridge at Km 42+050 of NH -752K near Latur (2x56m span). Few more bridges/viaducts of span varying from 50-72m have been approved for construction. A bridge over Ganga River parallel to JP Setu in Patna is under planning that envisages use of UHPFRC girders for 100m span.

5. On careful consideration of the advantages of UHPFRC, it is found that UHPFRC girders may be preferred in long span bridges i.e. span length ranging from 50m to 100m in India. In the urban viaduct structures, where generally 30m standard span is used, span length can be increased to 60m with use of UHPFRC. It can also be used for smaller span.

6. To promote use of UHPFRC girders in bridges and structures in India, following has been decided:

6.1. While preparing detailed project report, Consultants shall evaluate both traditional PSC girders and UHPFRC girders for elevated corridors/ viaduct sections and bridges having length 500 m and above and consider the preferred alternative in cost estimate and analysis. Similar exercise shall also be done if aggregate length of bridges having span length greater than 30m and viaduct sections is greater than 2000m in a single project.

6.2. The French design standard and material specification to be referred are NF P18-710- " National addition to Euro code 2 – Design of concrete structures: specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC) & NF P18-470- "Concrete - Ultra-High Performance Fiber-Reinforced Concrete - Specifications, Performance, Production and Conformity".

6.3. Concessionaire/Contractor is free to use UHPFRC girders in its design. IE/AE shall review and approve the design without any prejudice.

6.4. Although usage of UHPFRC is expected to result in significant cost savings and reduction in life cycle costs, it is decided at this stage that the cost implications of

Bidur Kant Jha

using the technology may be fully absorbed within the Agreement cost of the project until further orders and the Authority (i.e. executing agency) shall neither demand for any share of cost reduction benefits nor pay/compensate for additional expenses incurred by the Concessionaire / EPC Contractors as per the Ministry's policy circulated vide letter No. RW/NH-33044/18/2020-S&R (P&B) dated 14.12.2020 even if the changes are accompanied by reduction in number of foundations and piers.

6.5. Defect liability period of such bridges/structures will be 10 years irrespective of whether defect liability period of the project is 5 years.

6.6 Concessionaire/contractor shall submit a detailed bridge inspection plan on completion of the construction works to the Ministry for approval. Concessionaire/contractor, IE/AE, Authority shall jointly conduct periodic inspection of the structure and will prepare a condition monitoring report. This report shall be prepared and submitted to the Ministry on half-yearly basis till completion of the defect liability period unless otherwise decided by the Ministry.

7. It is requested that the contents of the letter may be brought into the notice of all concerned for needful compliance.

8. This issues with the approval of Competent Authority.

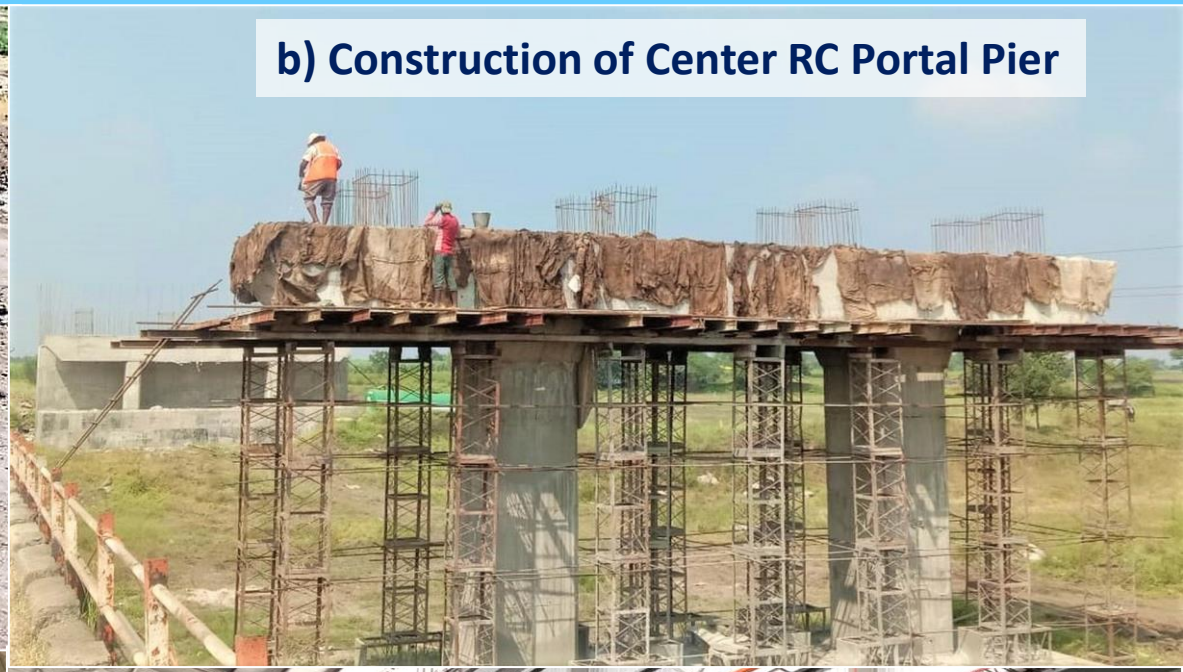
विदुर कान्त झा / Bidur Kant Jha
निदेशक / Director
सड़क परिवहन एवं राजमार्ग मंत्रालय
Ministry of Road Transport & Highways
भारत सरकार / Government of India
नई दिल्ली / New Delhi-110001

Yours faithfully,
Bidur Kant Jha
22-02-2022
(Bidur Kant Jha)
Director
(New Technology for Highway development)
For DG (RD) & SS

Copy to:
1. All CEs in the Ministry of Road Transport & Highways
2. All ROs of the Ministry of Road Transport & Highways
3. The Secretary General, Indian Roads Congress
4. Technical circular file of S&R (P&B) Section
5. NIC-for uploading on Ministry's website under "What's new"

Copy for information and necessary action to:
1. Sr. PPS to Secretary (RT&H)
2. PPS to DG (RD) & SS
3. Sr. PPS/ PPS to Addl. Secretary (Road Safety)/ Addl. Secretary (RT&H & LA)
4. Sr. PPS/ PPS to AS&FA
5. Sr. PPS/ PPS to ADG (SKN) / ADG (RP)/ ADG(DS)
6. Sr. PPS/ PPS to JS (RT&MVL)/ JS (EIC) / JS (Logistics)/ JS (NHIDCL)

First UHPFRC Bridge in India



First UHPFRC Bridge in India

e) Sending beam segments to Penang port, MY

f) Loading segments onto the ship.

g) Arranging beam segments in Ship

h) Unloaded beam segments to truck at Mumbai port

First UHPFRC Bridge in India

i) Transportation of UHPC box girder segments to job site
(540 km from Mumbai Port)

j) Placing the UHPC box segment onto the steel temporary staging support

k) Assembly of box segment using mobile crane

l) One full beam fully post-tensioned
(6 Segments)

First UHPFRC Bridge in India

m) Sealing the segmental joints with epoxy

n) Soffit views of two beams together

o) Beams positioned for stitching

p) In-situu UHPC stitching work

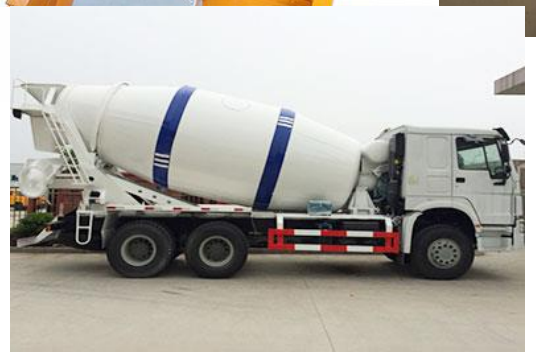
First UHPFRC Bridge in India

q) Completed Latur Bridge

Advantages of UHPFRC

Accelerated Construction, Ease of Mixing and Placement

- Accelerated Construction
  - 24 hr compressive strength > 50 MPa (Typ. 60 MPa)
  - 3 day compressive strength > 90 MPa (Typ. 100 MPa)
- Self Consolidating Concrete – Ease of Placement
- Longer Workability
  - Initial Setting time ≈ 4 hrs
  - Final Setting time ≈ 14 hrs
- It can be Mixed in a
  - Plastic Bucket
  - Drum Mixer
  - Pan Mixer
  - Twin shaft mixer
  - RMC
- It can be Sprayed and Pumped



Constituents of UHPFRC

Supplementary Cementitious Material (SCM)

(Silica Fume, Ground Quartz, GGBS, Fly Ash, RHA, etc..)

Fibers

Superplasticizers (SP)

ICE

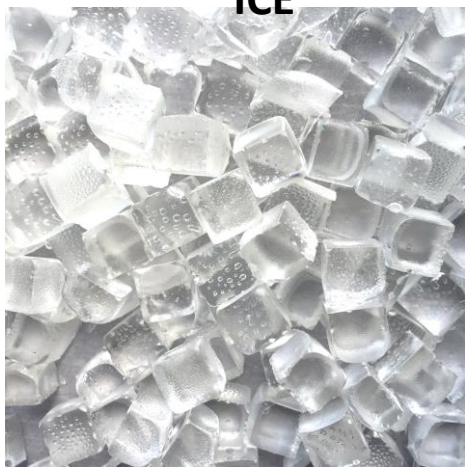
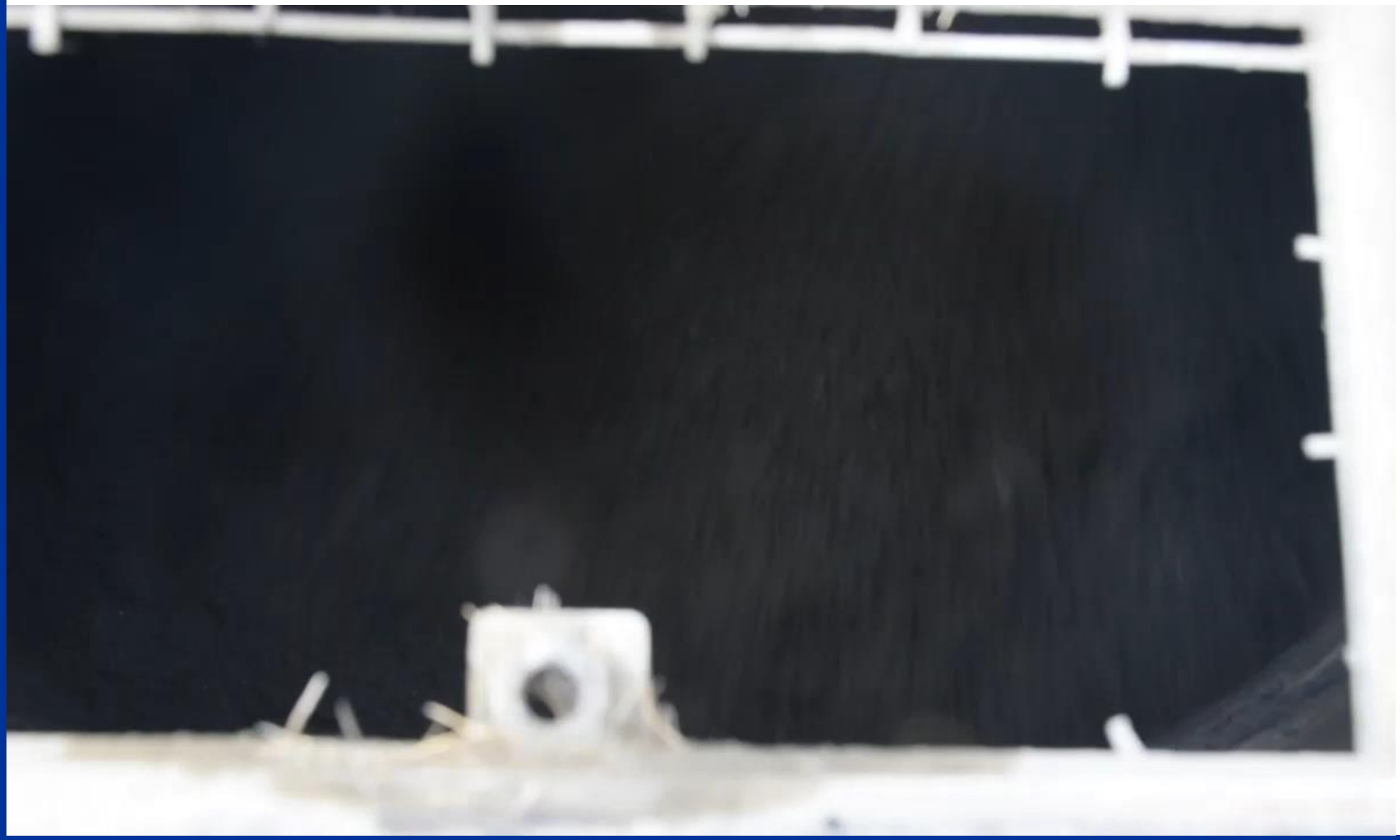


Fig: Kosmatka, S. H., Panarese, W. C., & Kerkhoff, B. (2002). Design and control of concrete mixtures

Mixing of UHPFRC : Turning from Dry to Wet Mix



Mixing can be done by

Demo of UHPFRC Flowability

flow dia. 180 mm to 250 mm

UHPFRC – An SCC

Constituents of UHPFRC

Fine Sand

Silica Sand

Abrasion resistance

Basalt Sand

Fire resistance

Crushed Quartz sand

Aesthetic requirement
More Abrasion resistance

- Well Graded Clean Fine Sand
- Shall be **Washed** to avoid Silt content
- 1mm passing
- Maximum aggregate size ≈ 600 µm

Constituents of UHPFRC

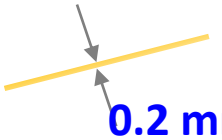
Fibers

- Fiber Aspect Ratio (60 to 70)
- Brass (or) Copper coated fibers
- Consistency in the fiber aspect ratio & diameter
- Dosage **2% by Volume** for Typ. application

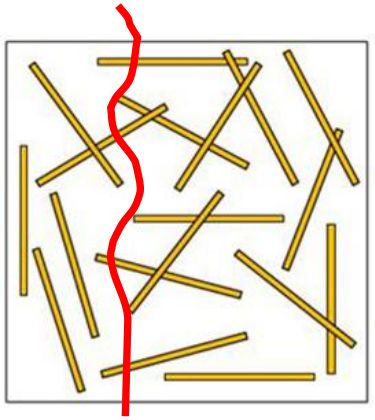
156 kg/m^3

INR 180/kg - PRC

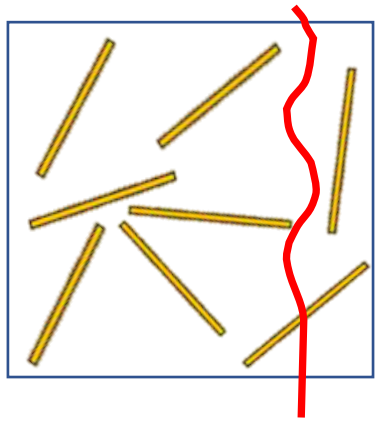
Length



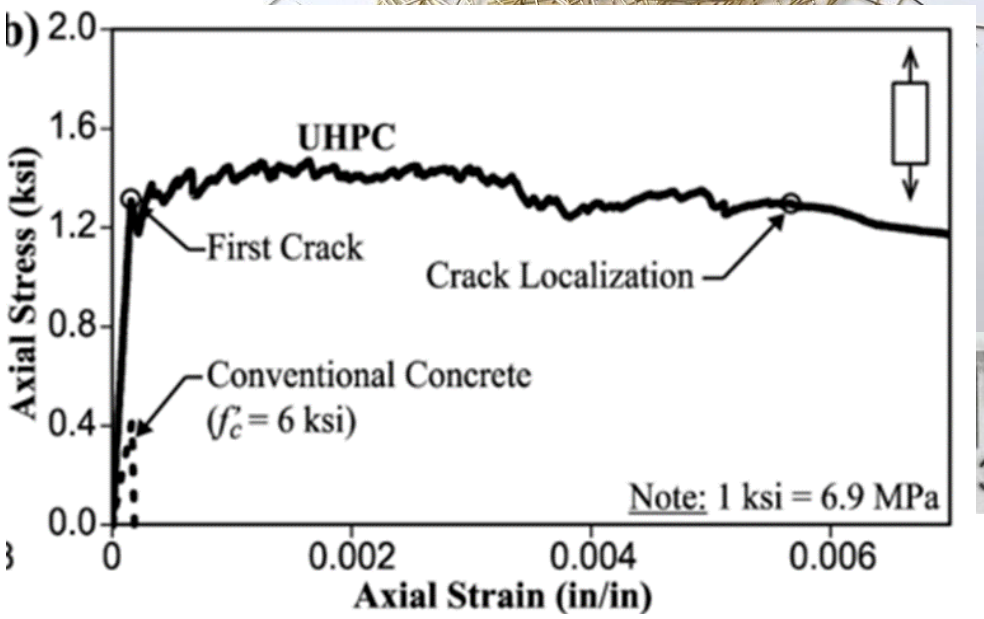
Diameter



0.2 mm dia



0.4 mm dia



Worldwide commercial manufacturers of UHPFRC

Compositions of Commercial UHPFRC

Materials (kg/m^3)	BCV®	BSI®	Cemtec®	Ductal®	DURA® LIKE CONCRETE • LIKE STEEL
Portland cement	2115	1114	1050	712	911
Fine sand (150–600 μm)	(Premix)	1072	514	1020	911
SF (Silica fume)		169	268	231	225
Ground quartz (d_{50} = 10 μm)		–	–	211	–
Accelerator	–	–	–	30	–
Steel fibers	156	234	858	156	173
SP	21.5	40	44	30.7	38
Water	159	211	180	109	200

Azmee, N. M., & Shafiq, N. (2018). Ultra-high performance concrete: From fundamental to applications. Case Studies in Construction Materials, 9, e00197.

Codal Provisions

- French national standards for UHPC
  - NF P18-470
  - NF P18-710
- Swiss Recommendations : MCS-EPFL
- German Recommendations
- Japanese Recommendations

ISSN 0335-3931

French standard

NF P 18-710
16 April 2016

Classification index: **P 18-710**

ICS: 91.010.30; 91.080.40

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

F : Complément national à l'Eurocode 2 — Calcul des structures en béton : règles spécifiques pour les Bétons Fibrés à Ultra-Hautes Performances (BFUP)
D : Nationale Ergänzung zu Eurocode 2 — Bemessung von Betonstrukturen: spezifische Bestimmungen für faserbewehrte Ultrahochleistungsbetone

French standard approved

by decision of the Director General of AFNOR.

Correspondence

At the date of publication of this document, there is no international or european standardization works on the same subject.

Summary

This document, which can be considered as a national complement to Eurocode 2, applies to the design of UHPFRC structures (buildings and civil engineering). Consequently, this document is concerned with the requirements for resistance, serviceability, durability and fire resistance of these structures.

Descriptors

Technical International Thesaurus: construction, civil engineering, concrete structures, computation, stresses, limits, materials, mechanical strength, deformation, reinforcing steels, prestressing steels, durability, stress analysis, flexing, shear strength, tensile strength, strain, fatigue life, cracking (fracturing), anchorages, armatures, distance, covering, beams: supports, floors, slabs, partitions, columns, foundations, verification.

Modifications

Corrections

Published and distributed by Association Française de Normalisation (AFNOR — French standard institute) — 11, rue Francis de Pressensé — 93571 La Plaine Saint-Denis Cedex — Tel.: + 33 (0)1 41 62 80 00 — Fax: + 33 (0)1 49 17 90 00 — www.afnor.org

MCS MAINTENANCE CONSTRUCTION SÉCURITÉ
INSTITUT D'INGÉNIERIE CIVILE

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Recommendation:

Ultra-High Performance Fibre Reinforced Cement-based composites (UHPFRC)

Construction material, dimensioning und application

English translation of the Technical Leaflet SIA 2052 with adaptations

For internal use

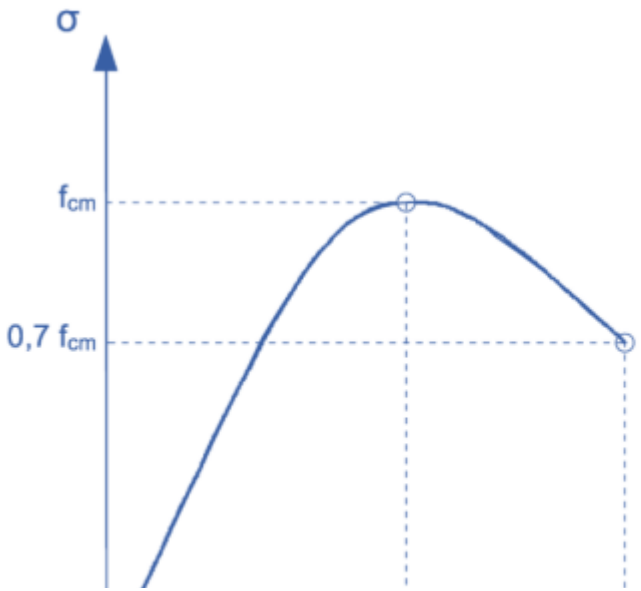
MCS-EPFL Lausanne, Switzerland, 17 April 2016

Adress:
EPFL-Swiss Federal Institute of Technology
MCS-Maintenance, construction and safety of structures
Station 18
CH-1015 Lausanne, Switzerland

NF P18-710

- Standard has been drafted by adapting **Eurocode 2**

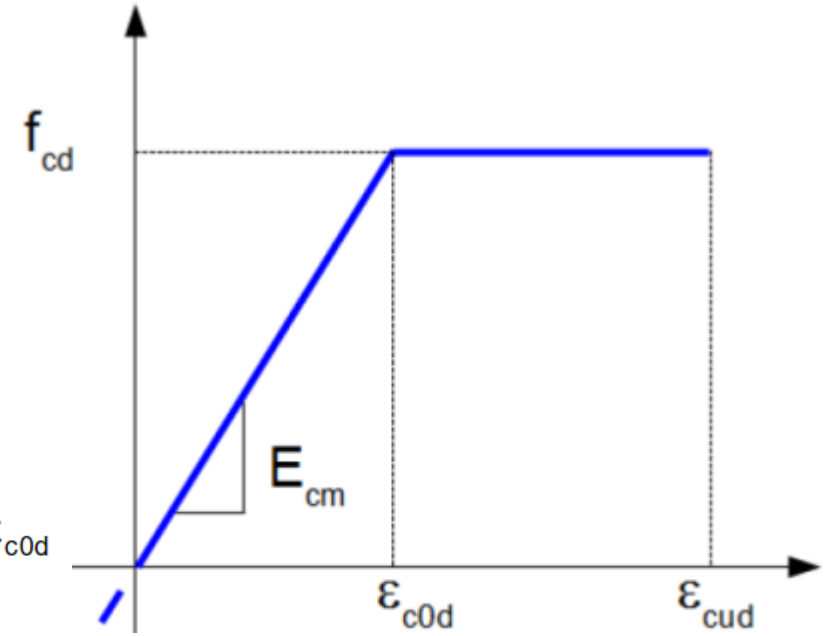
Compression



$$f_{cd} = \alpha_{cc} f_{ck} / \gamma_C$$

$$\alpha_{cc} = 0.85.$$

$$\varepsilon_{cud} = (1 + 14 \frac{f_{ctm}}{K_{global}.f_{cm}}).\varepsilon_{c0d}$$



(2) K_{local} is dedicated to local effects corresponding to resistant mechanisms which require fibre contribution in very localised areas (for example the diffusion of prestressing forces).

R

K_{global} deal areas and a slab).

Global fibre orientation factor K_{global}	1.25
Local fibre orientation factor K_{local}	1.75

to act over wider ing resistance of

NF P18-710

Tension

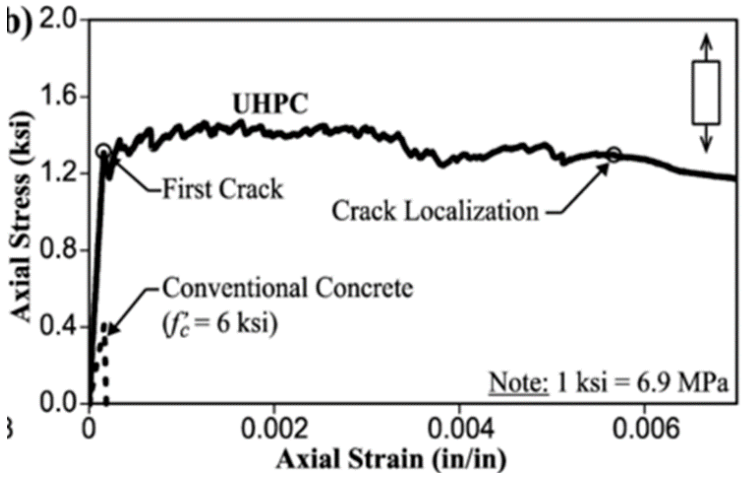
A thin member is a member whose thickness e is such that

$e \leq 3\ L_f$ where L_f = length of the longest fibres contributing to ensuring non-brittleness.

- class T1* (softening under direct tension) when $f_{ctf}/K < f_{ct,el}$ both for the mean curve and for the characteristic curve, i.e. $f_{ctfm}/K < f_{ctm,el}$ and $f_{ctfk}/K < f_{ctk,el}$

- class T2* (exhibiting limited strain hardening) when $f_{ctf}/K \geq f_{ct,el}$ for the mean curve and $f_{ctf}/K < f_{ct,el}$ for the characteristic curve, i.e. $f_{ctfm}/K \geq f_{ctm,el}$ and $f_{ctfk}/K < f_{ctk,el}$

- class T3* (exhibiting significant strain hardening) when $f_{ctf}/K \geq f_{ct,el}$ both for the mean curve and the characteristic curve, i.e. $f_{ctfm}/K \geq f_{ctm,el}$ and $f_{ctfk}/K \geq f_{ctk,el}$



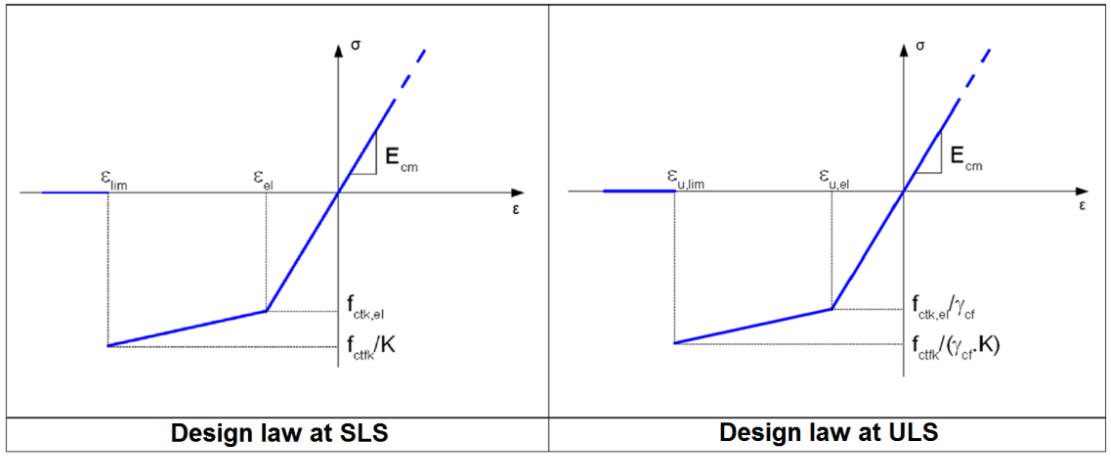


Figure 3.206 — Law for UHPFRCs of class T3* (obtained directly in σ(ε))

- T3
- Thick Member

NF P18-710

- V_{Rd} is the superposition of the three resistance terms $V_{Rd,c} + V_{Rd,s} + V_{Rd,f}$
- $V_{Rd,c}$ is the UHPFRC contribution term
- $V_{Rd,s}$ is the contribution term for the transverse reinforcement in the truss diagram
- $V_{Rd,f}$ if the fibre contribution term

$$V_{Rd,f} = A_{fv}\sigma_{Rd,f}\cot\theta$$

In the case of UHPFRCs of class T3*, the expression for $\sigma_{Rd,f}$ becomes:

$$\sigma_{Rd,f} = \frac{1}{K.\gamma_{cf}} \times \frac{1}{\varepsilon^* - \varepsilon_{el}} \int_{\varepsilon_{el}}^{\varepsilon^*} \sigma_f(\varepsilon)\, d\varepsilon$$

NF P18-710

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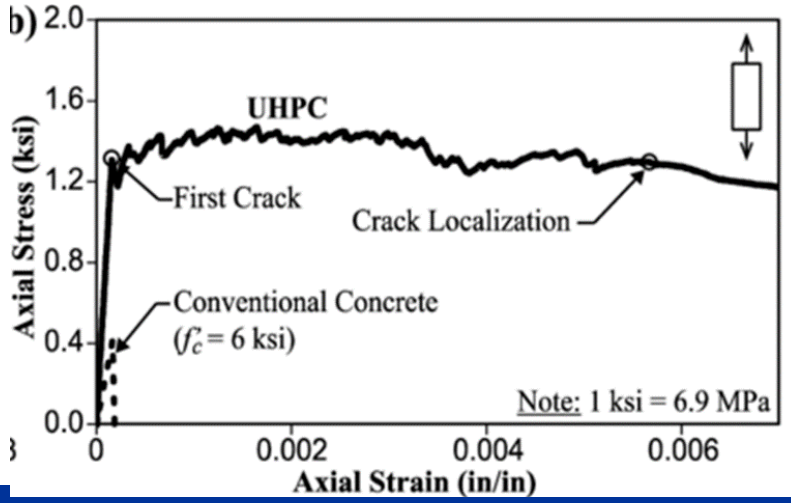


$$\sigma_{Rd,f} = \frac{1}{K.\gamma_{cf}} \times \frac{1}{\varepsilon^* - \varepsilon_{el}} \int_{\varepsilon_{el}}^{\varepsilon^*} \sigma_f(\varepsilon)\, d\varepsilon$$

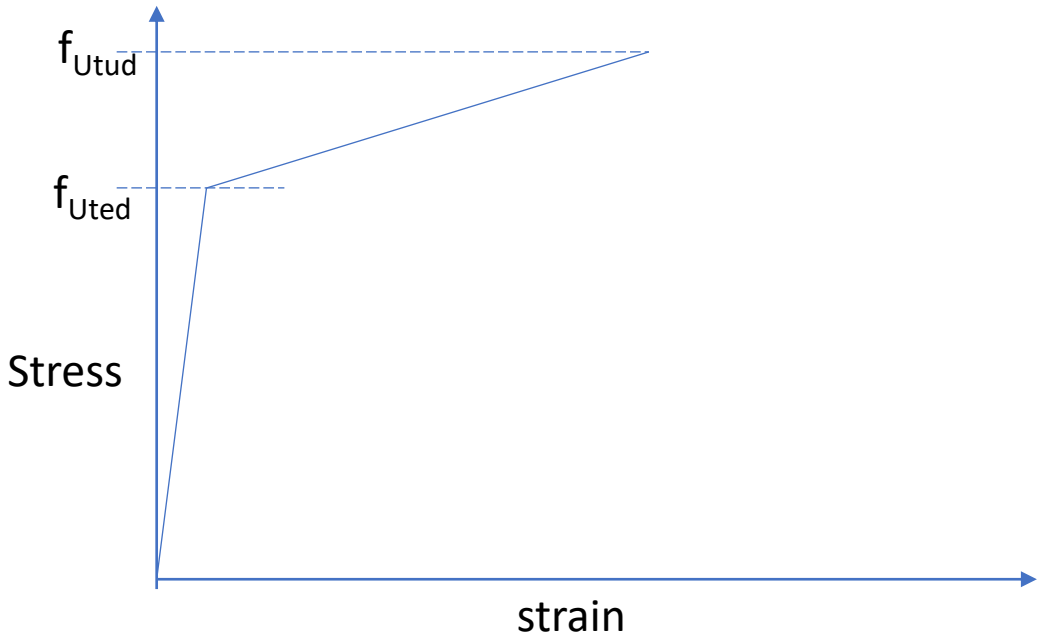
Swiss Recommendations : MCS-EPFL

$$V_{Rd} = V_{Rd,U} + V_{Rd,s}$$

with :

$$V_{Rd,U} = \frac{b_w \cdot z \cdot 0{,}5(f_{Uted} + f_{Utud})}{\tan\alpha}$$

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{sd} \cdot (\cot\alpha + \cot\beta)\sin\beta$$

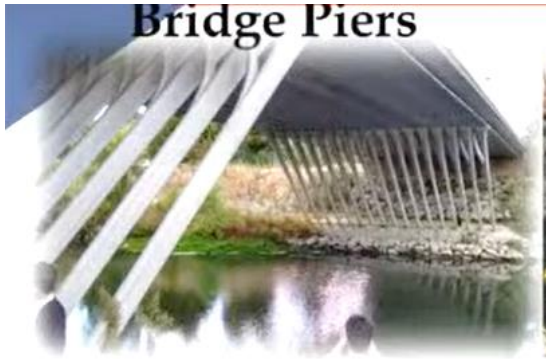


Design of UHPFRC structural member

- Design Spreadsheet
- Creep & Shrinkage of UHPFRC – A comparison with Conventional Concrete
- Comparison of Codal Provision

Applications of UHPFRC

Bridge Piers



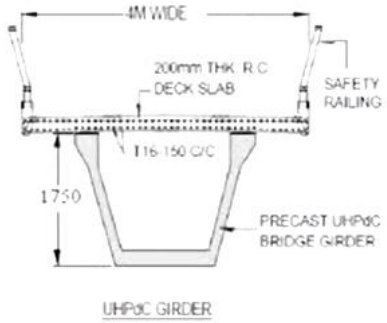
Precast Joints

Rehabilitation

Overlay

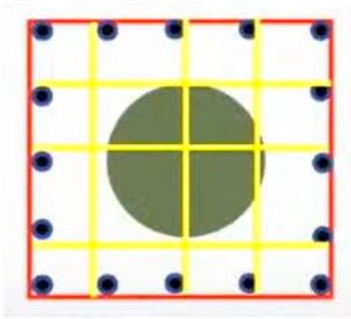
Jacketing

Girders



Long-Span Beams

RC-UHPC Composite Cols



Architectural/Façade

Buildings

Industrial Slabs

Machine Beds

UHPC India

Thank you….

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