# ULTRA-HIGH-PERFORMANCE FIBER REINFORCED CEMENTIOUS COMPOSITE (UHPFRC) – APPLICATIONS IN SWITZERLAND

# CÔNG NGHỆ BÊ TÔNG SỢI SIÊU TÍNH NĂNG – ỨNG DỤNG TẠI THỤY SĨ

Dr. TRỊNH Ngọc Thành, *Deputy head of Leman Engineering Structure Department, Gruner Stucky Ltd, Switzerland*

*ngoc-thanh.trinh@gruner.ch / 25.06.2022*

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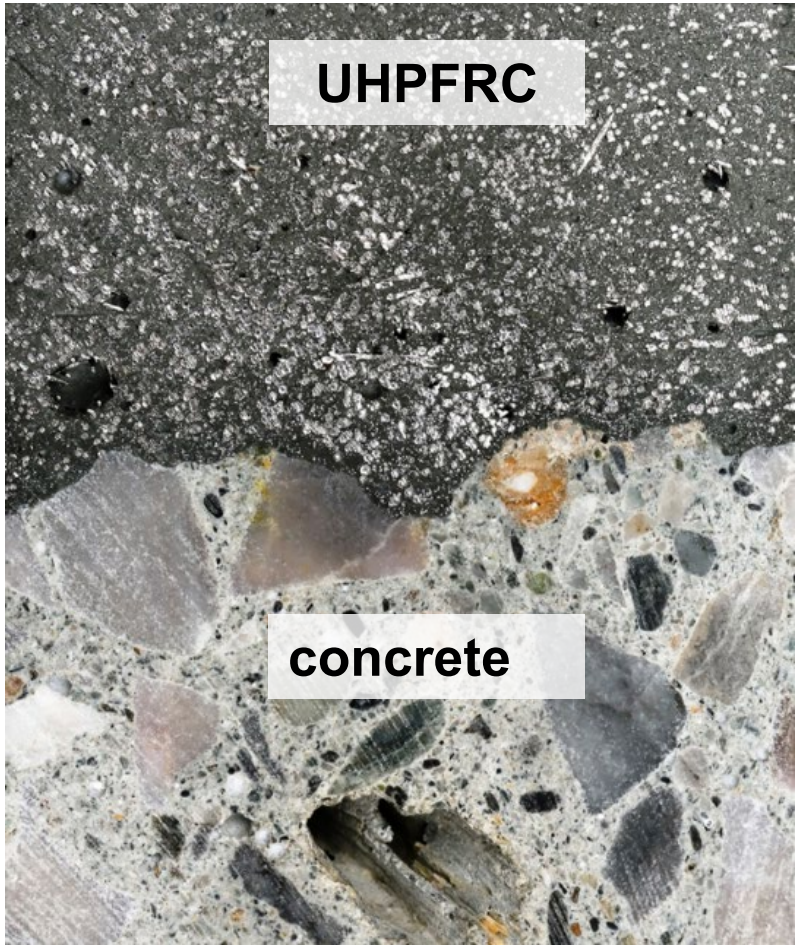
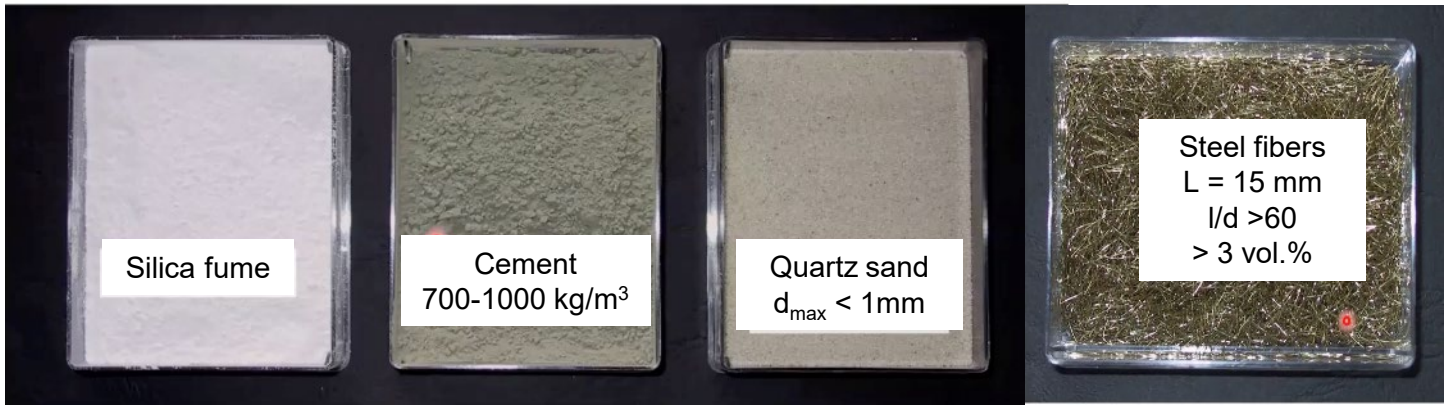
- Conclusions / Kết luận

# UHPFRC

**ULTRA-HIGH-PERFORMANCE FIBRE-REINFORCED CEMENTITIOUS COMPOSITE**

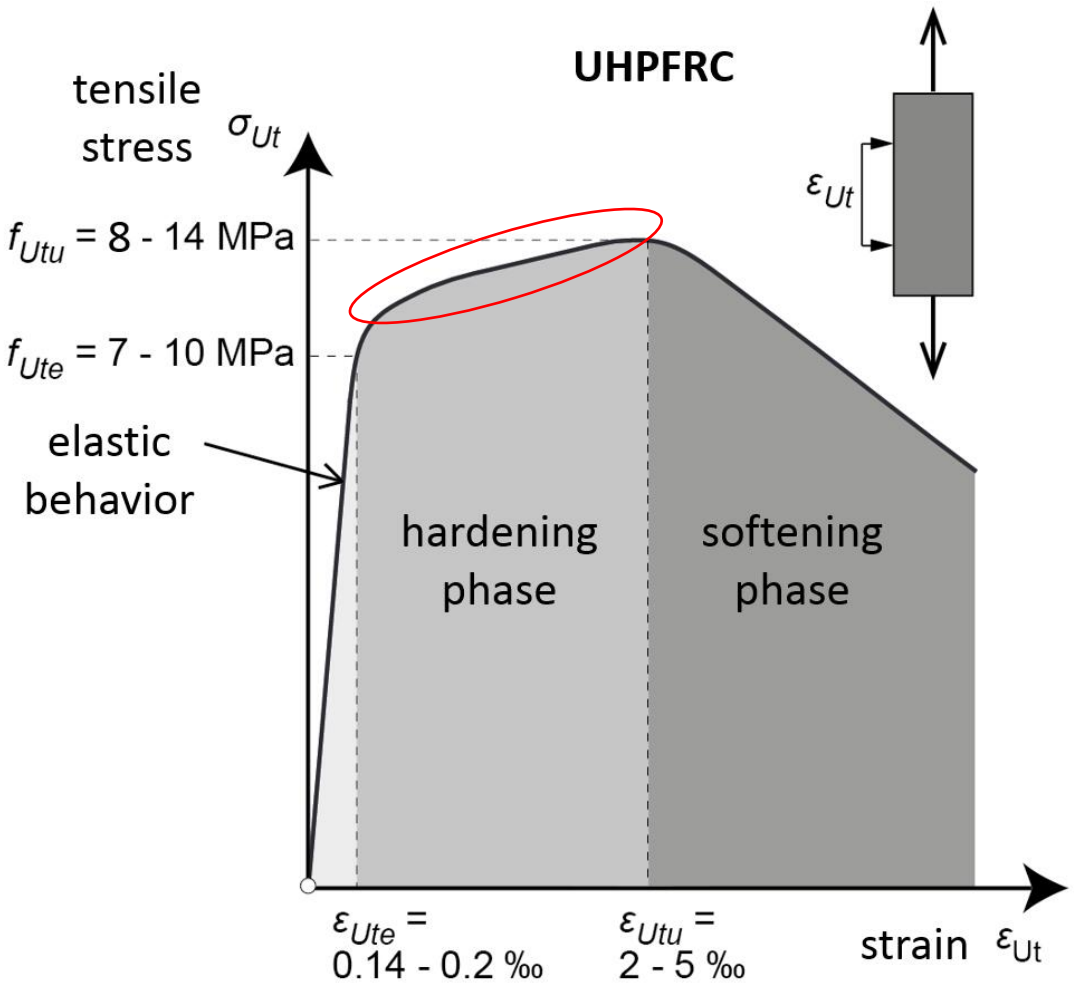



Water/Binder ratio = 0.13-0.17

# UHPFRC

**PROPERTIES**




## Compressive behaviour

Compressive strength: 150 – 200 MPa

## Tensile behaviour

Tensile strength: 8 – 14 MPa

strain hardening behaviour

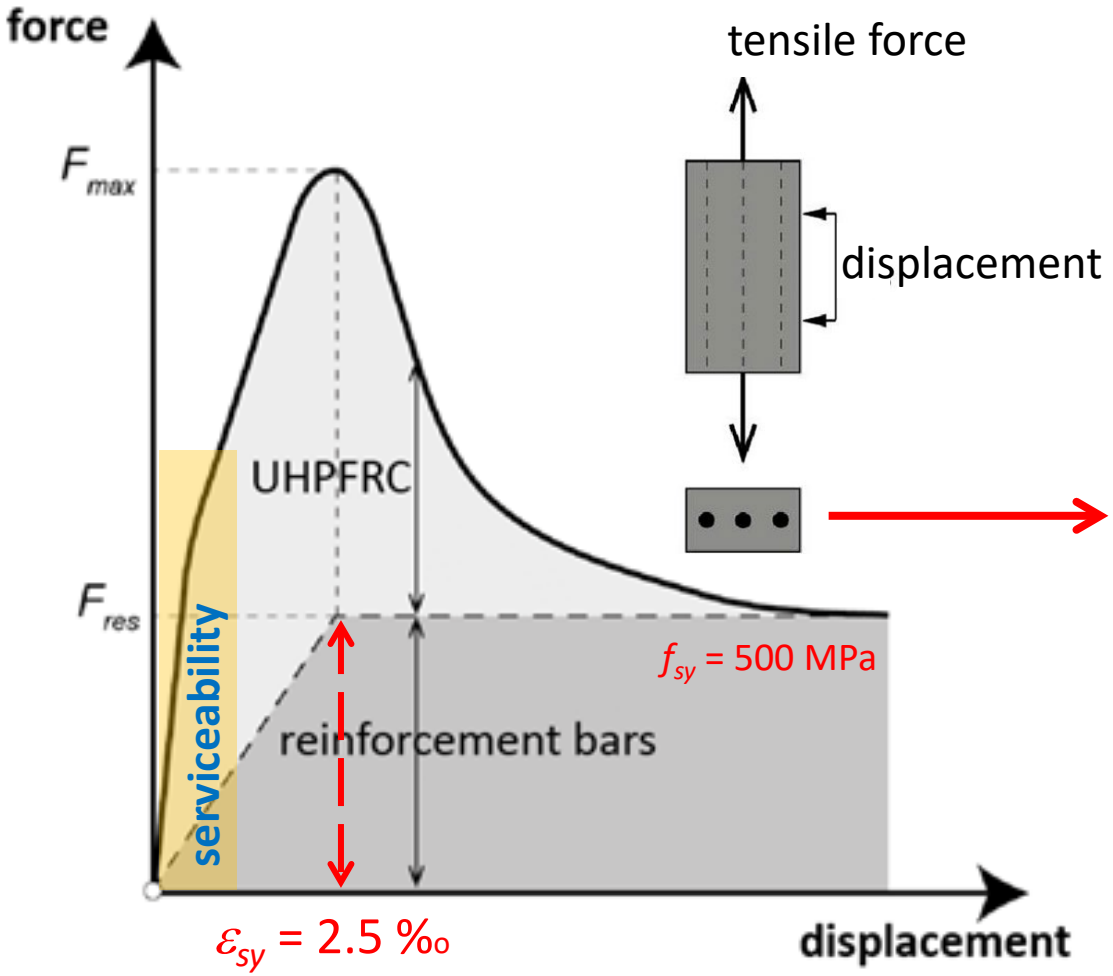
## Elastic behaviour

$\varepsilon_{Ute} = 0.14 - 0.2$ ‰

Young's modulus: 45 – 50 GPa

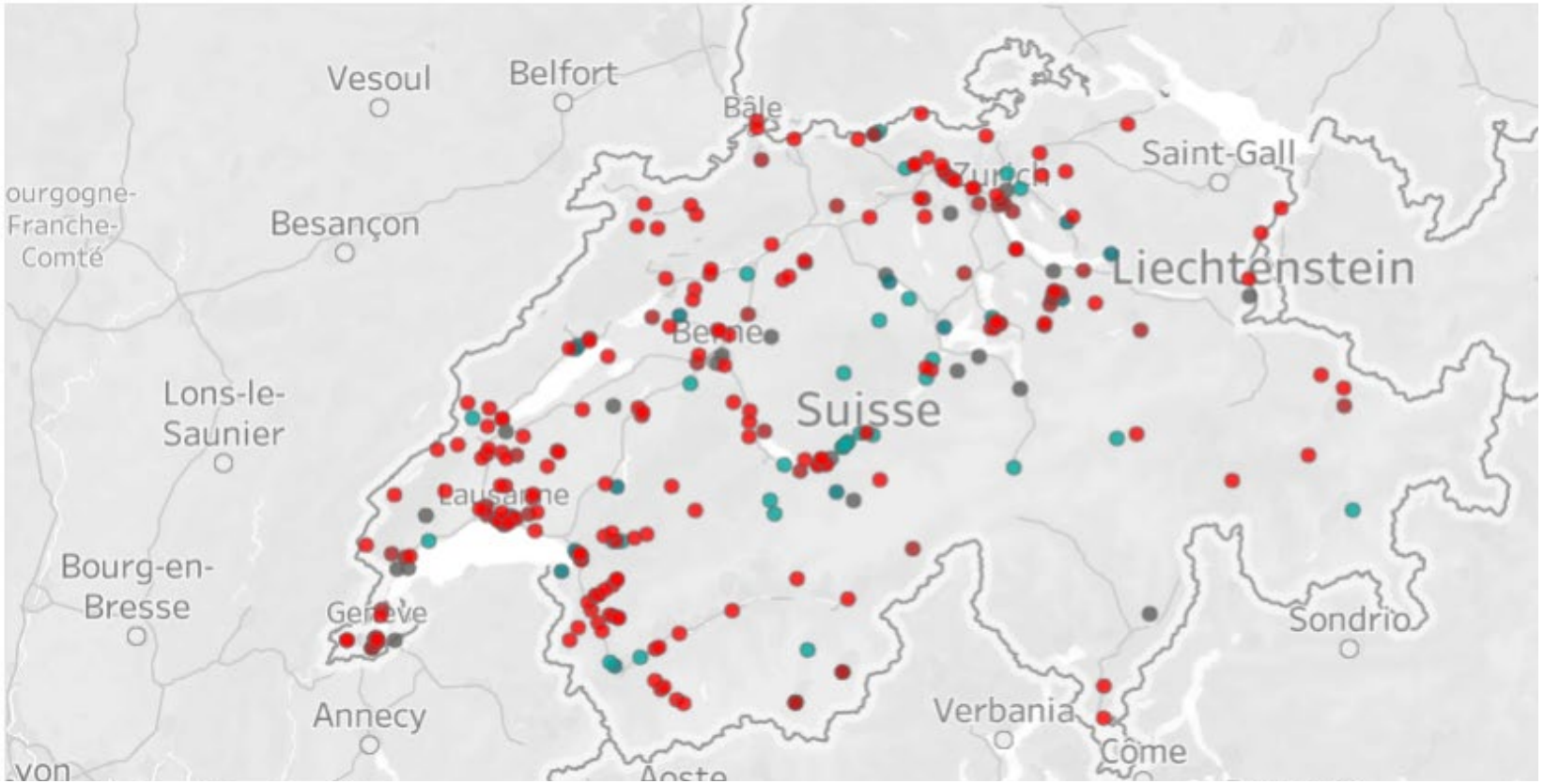
# R-UHPFRC

**SUPERPOSITION OF UHPFRC AND REBAR RESPONSES**



# UHPFRC

## APPLICATIONS IN SWITZERLAND




Type of structure

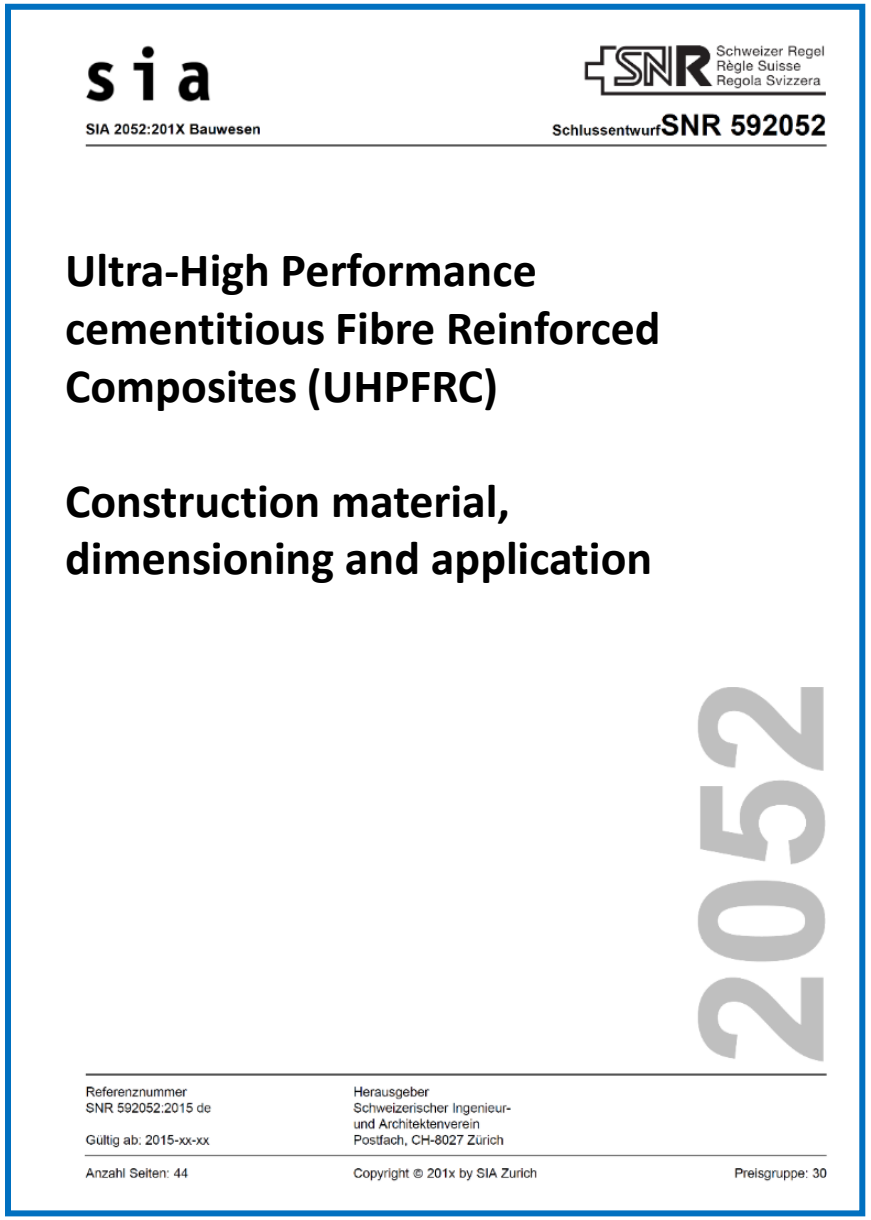
- Road
- Rail
- Other
- Building
- Footbridge

**> 300** applications and

**> 12’000 m³** since 2003 (September 2021)

Mostly for the rehabilitation and strengthening of existing RC bridges

# SWISS STANDARD SIA 2052 - UHPFRC



sia

SIA 2052:201X Bauwesen

Schweizer Regel
Règle Suisse
Regola Svizzera

Schlussentwurf SNR 592052

**Ultra-High Performance cementitious Fibre Reinforced Composites (UHPFRC)**

**Construction material, dimensioning and application**

2052

Referenznummer
SNR 592052:2015 de

Gültig ab: 2015-xx-xx

Herausgeber
Schweizerischer Ingenieur- und Architektenverein
Postfach, CH-8027 Zürich

Anzahl Seiten: 44

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Preisgruppe: 30

Publication: 1 March 2016, 44 pages: *user friendly, practice proven, pragmatic and allows for innovation !*

in German and French, translation in English, Japanese, Chinese, Russian, *currently under revision*

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6. Execution / Phương pháp thi công và bảo dưỡng

Appendix A: UHPFRC properties

Appendix B: Quality assurance

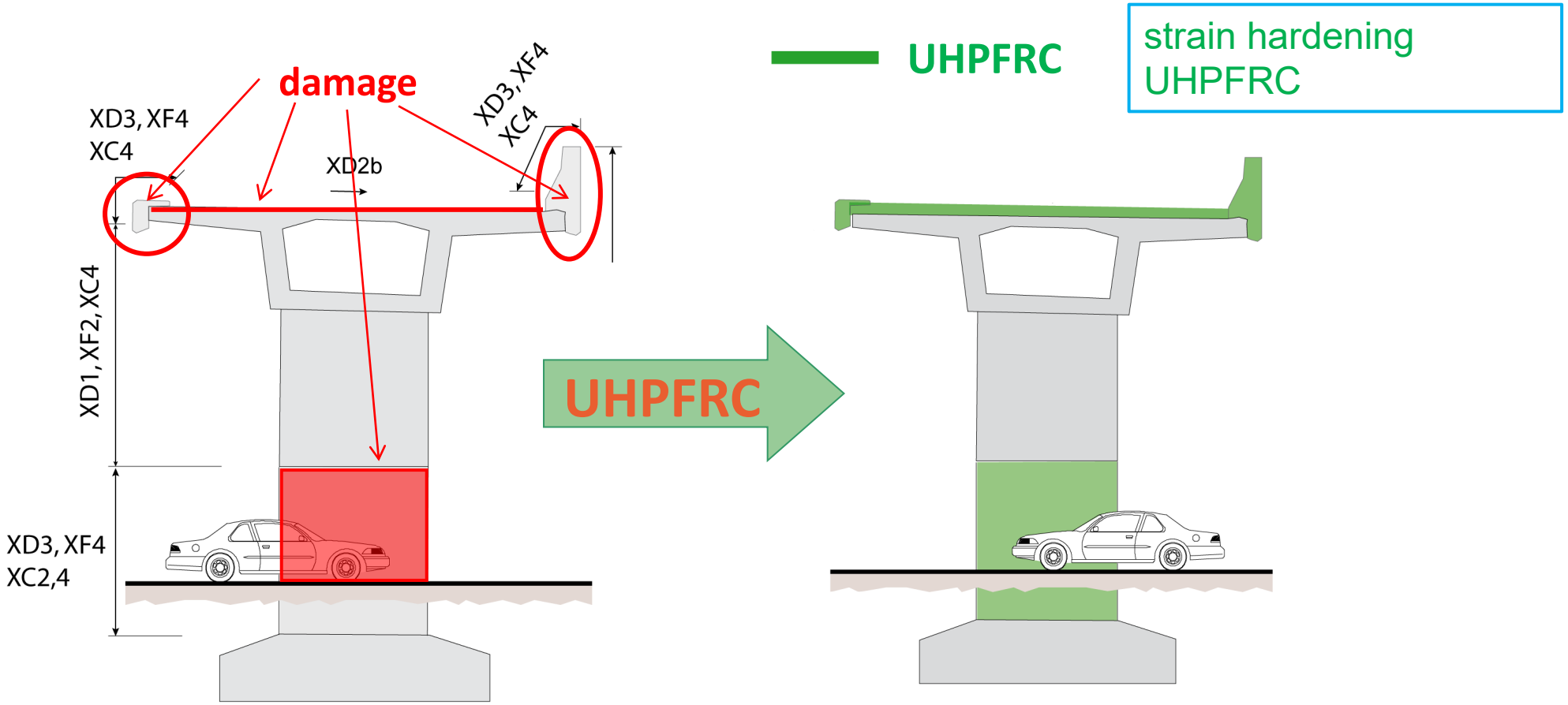
Appendix C: Tests on UHPFRC / Thí nghiệm và kiểm tra chất lượng

Appendix D: Direct tensile test

Appendix E: Bending tensile test

# SWISS STANDARD SIA 2052 - UHPFRC

**IMPROVING EXISTING RC STRUCTURES USING UHPFRC**

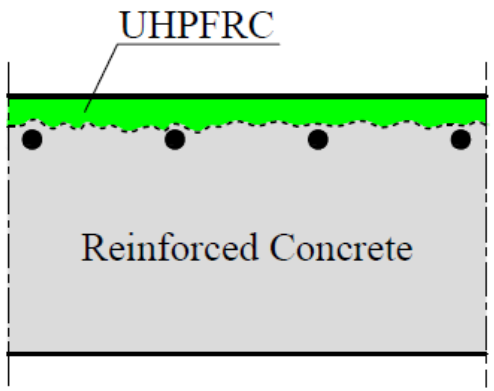



- Protective watertight **UHPFRC** layer to improve durability of RC / Sử dụng UPPFRC như lớp chống thấm và bảo vệ để tăng độ bền của kết cấu bê tông cốt thép
- Increase structural capacity (stiffness, ultimate resistance, fatigue resistance) / Tăng sức bền kết cấu (độ cứng, trạng thái giới hạn, độ bền mỏi)

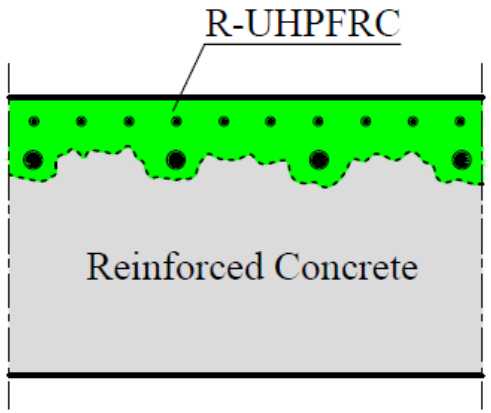
# SWISS STANDARD SIA 2052

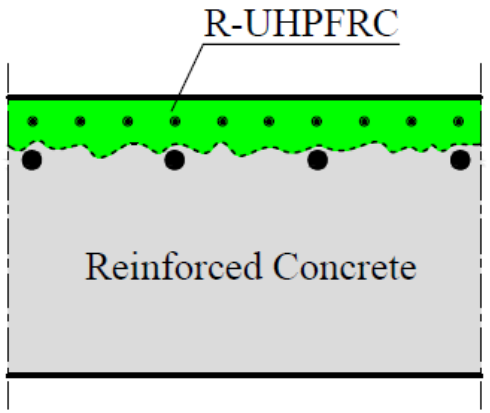
**IMPROVING EXISTING RC STRUCTURES USING UHPFRC**

**Overlay :** thickness $t_U$ > 25 mm




**Strengthening layer:** $t_U$ > 40 mm, typically 50 to 80 mm



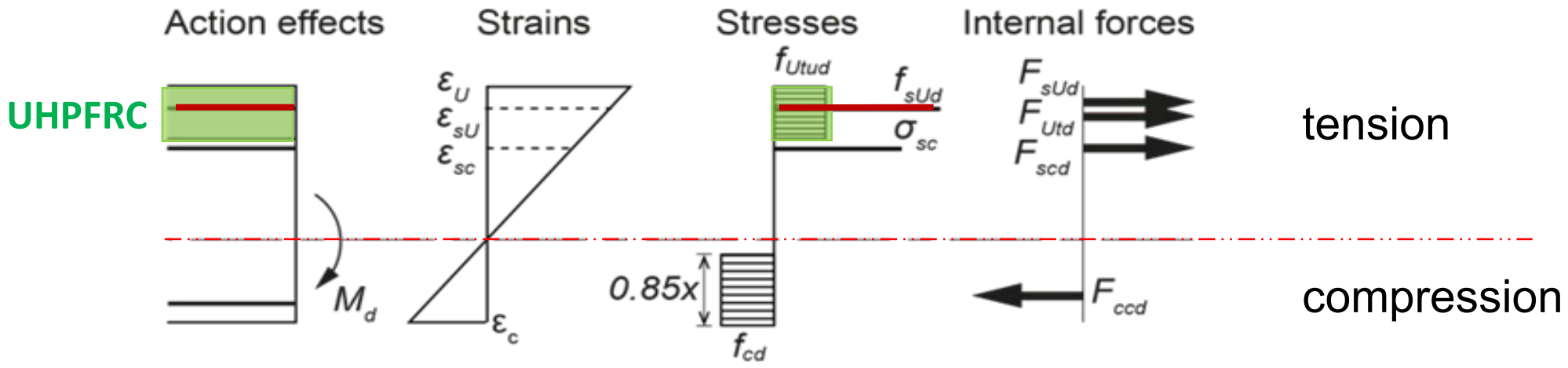



Photos: Prof. E. Brühwiler

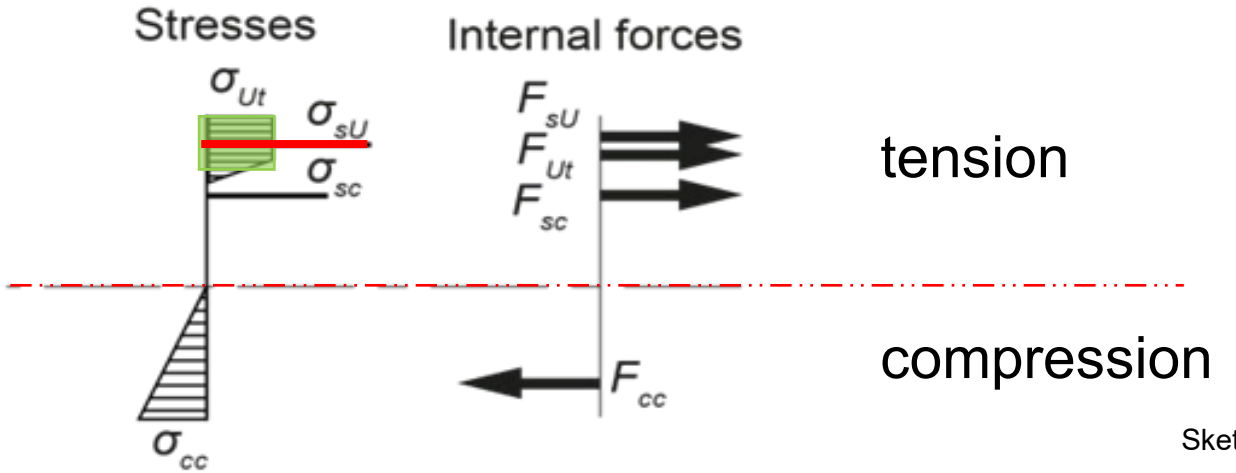
# SWISS STANDARD SIA 2052

**IMPROVING EXISTING RC STRUCTURES - SECTIONAL ANALYSIS OF R-UHPFRC**

Ultimate bending resistance :




Fatigue stresses and fatigue resistance :

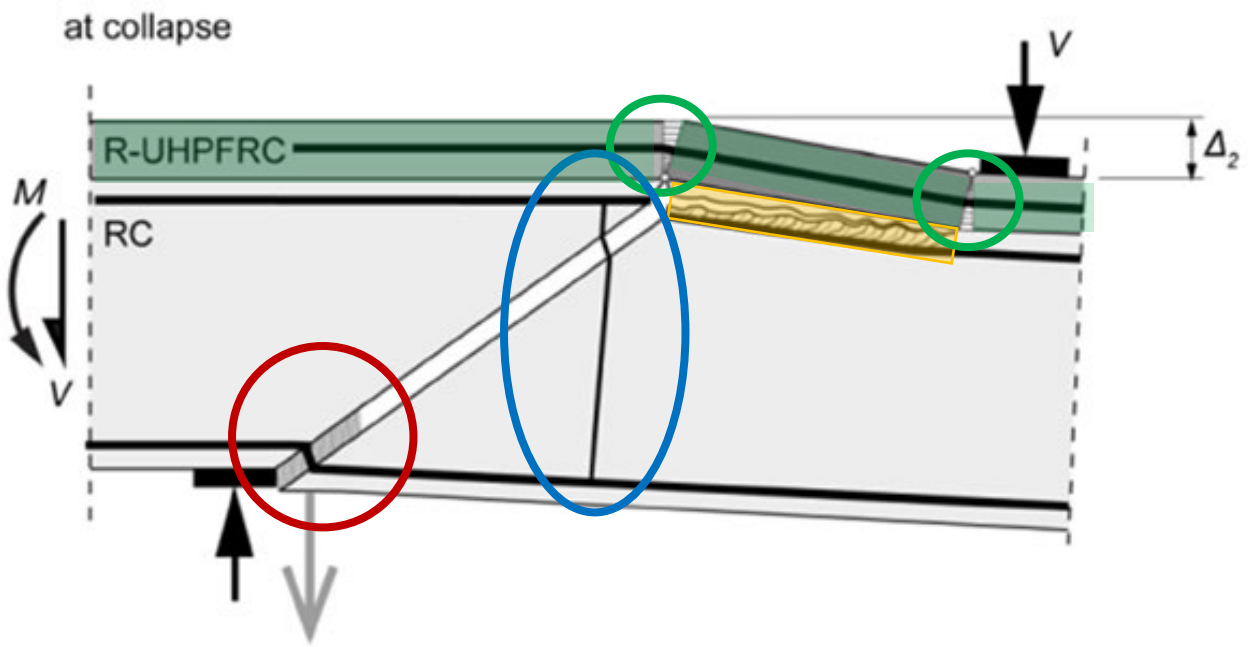



Sketchs:Prof E. Brühwiler

# SWISS STANDARD SIA 2052

**IMPROVING EXISTING RC STRUCTURES - SECTIONAL ANALYSIS OF R-UHPFRC**

## Ultimate resistance under combined shear and bending:



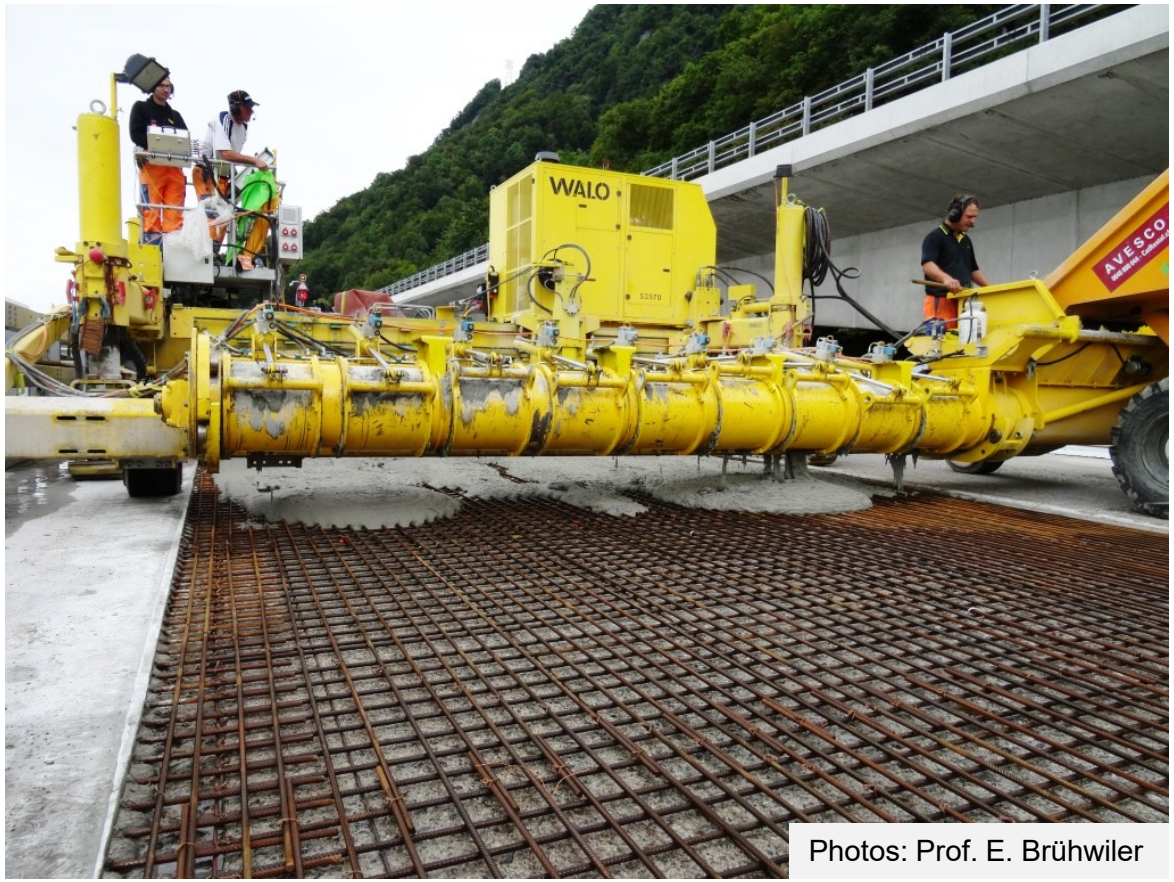

Confinement of RC due to the R-UHPFRC layer

Shear failure only occurs for particular configurations !

ultimate shear resistance : $V_R = V_{Rc} + V_{Rs} + V_{RU}$

# APPLICATIONS OF UHPFRC TO EXISTING STRUCTURES

**CHILLON VIADUCTS, SWITZERLAND**




Photos: Prof. E. Brühwiler

Highway bridges,  2.1 km long heritage structures

2’400 $m^3$ of UHPFRC

Rehabilitation in 2014/2015

# APPLICATIONS OF UHPFRC TO EXISTING STRUCTURES

**RIDDES VIADUCT, SWITZERLAND**

Photo: rts.ch

1.2 km long PC structure from 1976:

- Corrosion of prestressing tendons
- Steel rebar corrosion
- Alcali-aggregate reaction

=> The R-UHPFRC intervention was most cost-effective and rapid

# APPLICATIONS OF UHPFRC TO EXISTING STRUCTURES

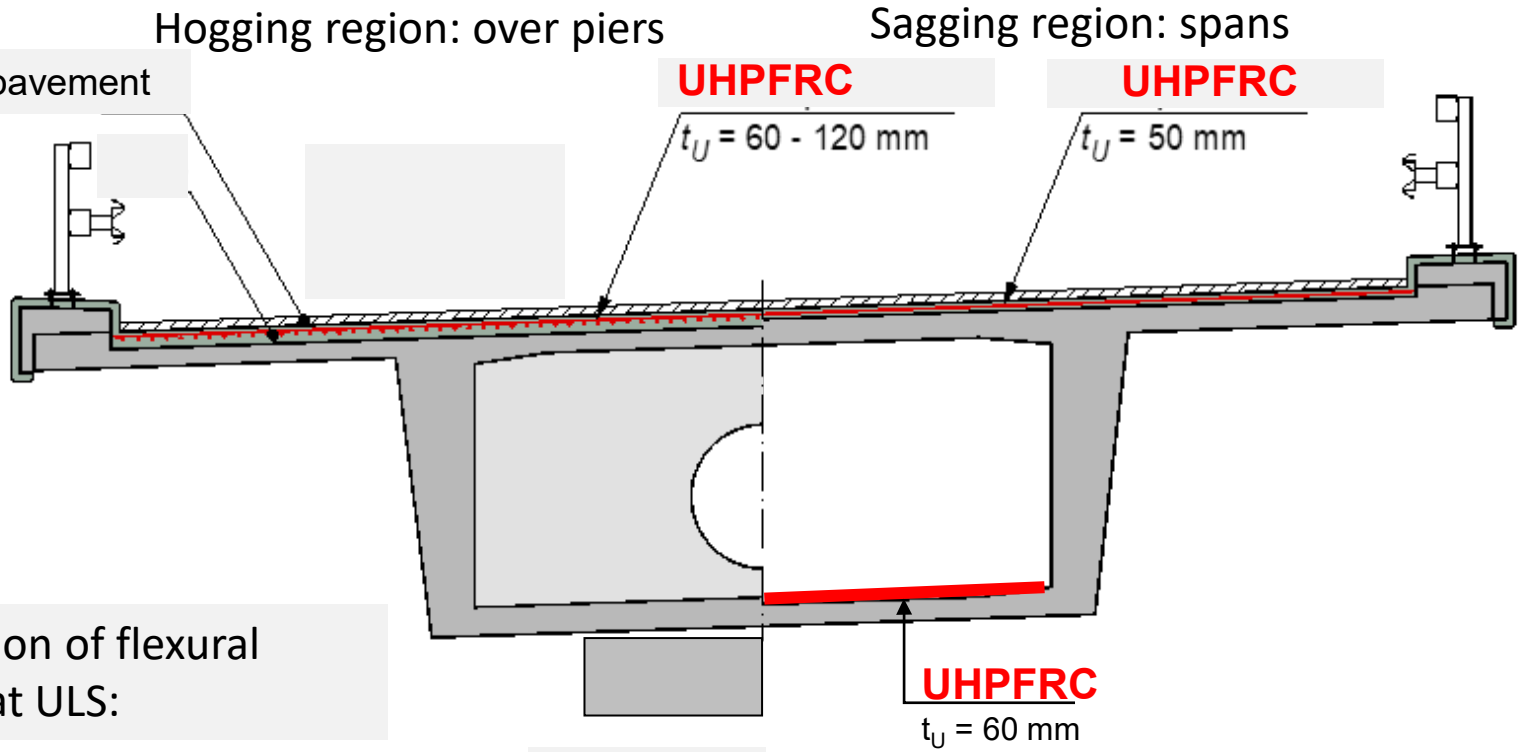
**RIDDES VIADUCT, SWITZERLAND**

Objective:

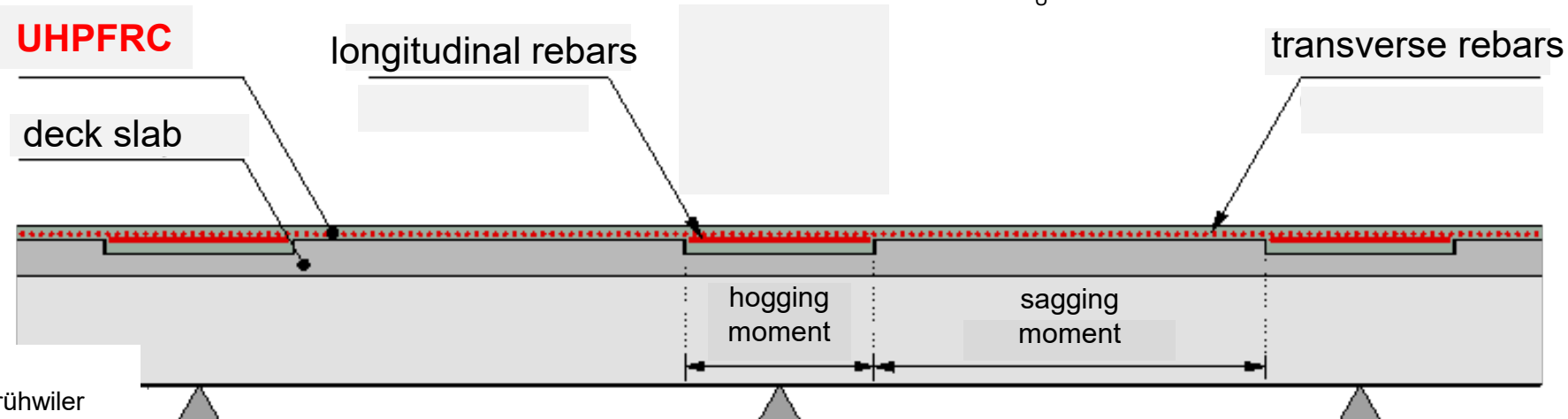
over-strengthen to accommodate for loss of:

- ✓ 1/3 of post-tensioning and
- ✓ 30% AAR-related concrete strength reduction

Photos: tracés 3518




Redistribution of flexural resistance at ULS:




Sketchs:
Prof E. Brühwiler

moist surface preparation

UHPFRC cast using finisher

UHPFRC ready mix plant

Two parallel 1.2 km long viaduct structures in post-tensioned concrete from 1976

Owner: OFROU
Design: Ingphi SA
Contractor: Walo SA
Photos: E. Brühwiler

# SWISS STANDARD SIA 2052 - UHPFRC

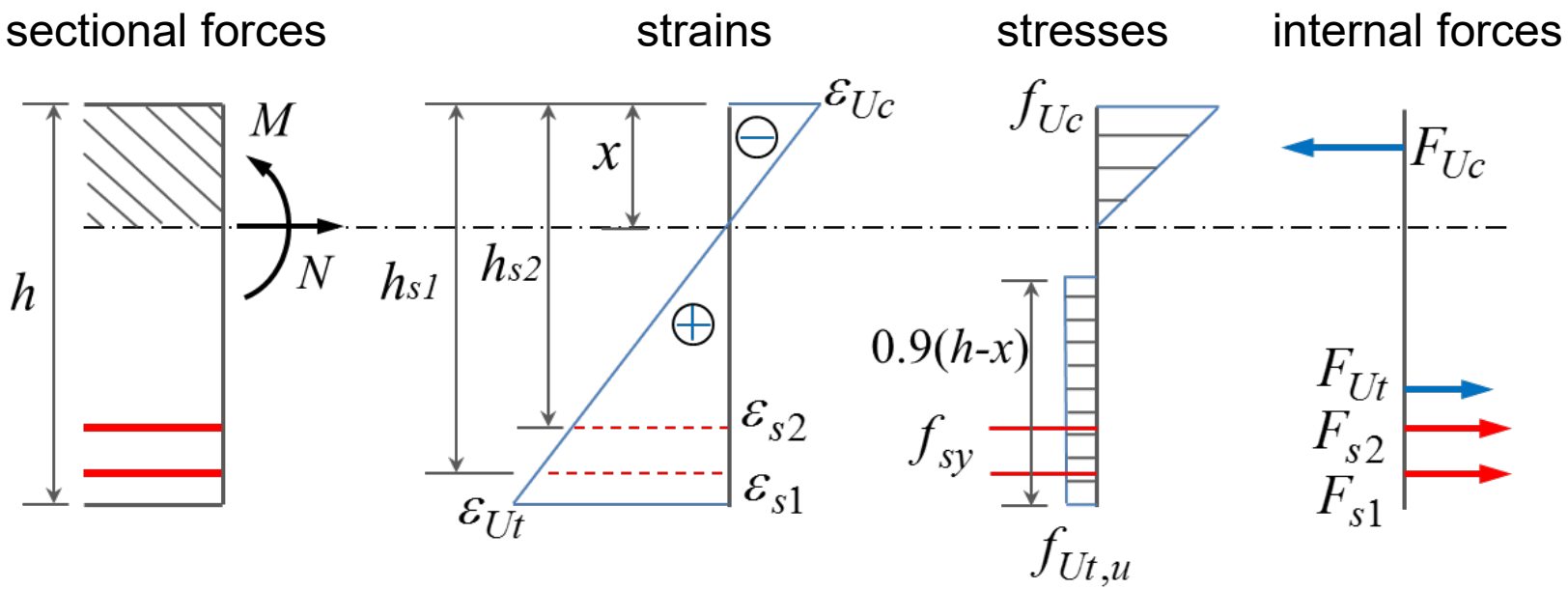
**TO BUILD NEW STRUCTURES - DESIGN PRINCIPLES**

- ✓ lightweight structures (kết cấu nhẹ)
- ✓ precasting (kết cấu chế tạo trước)
- ✓ accelerated construction (thi công nhanh)
- ✓ durability: low maintenance (tăng độ bền vững)
- ✓ UHPFRC construction cost (giá xây dựng công trình UHPFRC) $\leq$ cost for traditional construction (giá cho xây dựng công trình truyền thống)

# SWISS STANDARD SIA 2052

**NEW STRUCTURES – DESIGN PRINCIPLES**

Sectional model for ultimate bending resistance :




Hypotheses:

- plane sections remain plane; linear strain distribution
- stress block for UHPFRC under tension
- superposition of UHPFRC and steel reinforcement (rebars)

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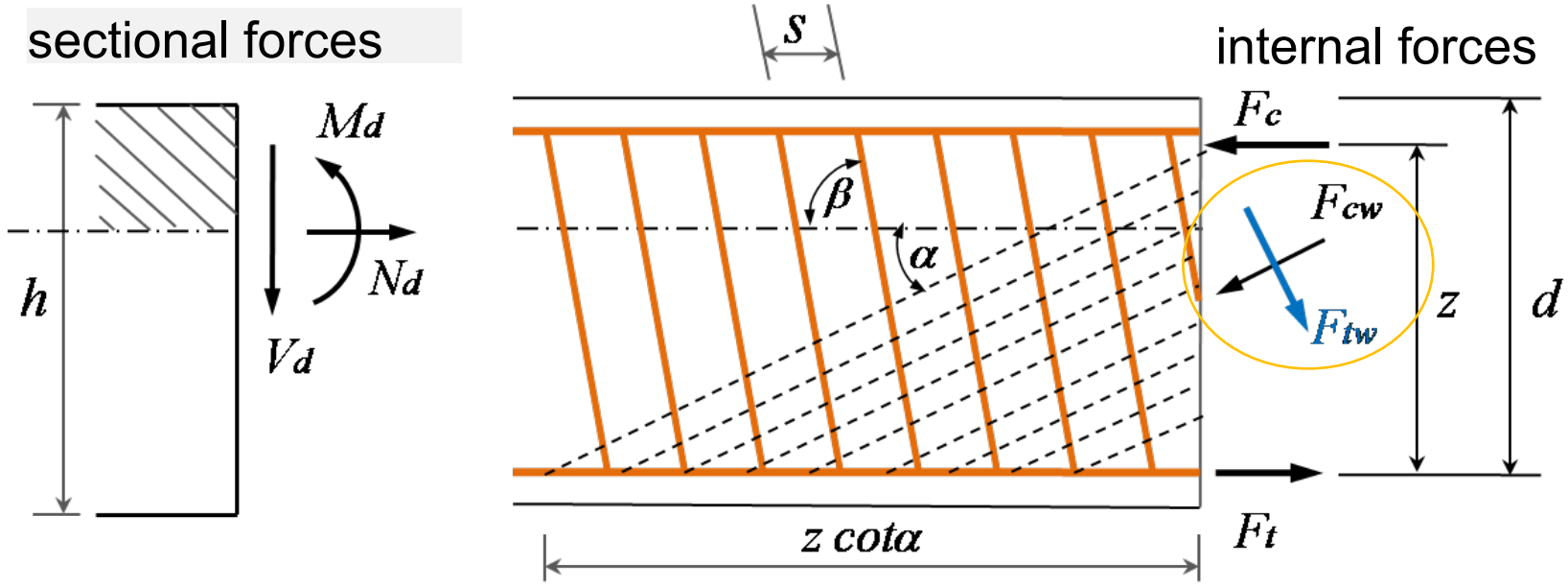
Sketchs: Prof E. Brühwiler

# SWISS STANDARD SIA 2052

**NEW STRUCTURES – DESIGN PRINCIPLES**

Model for ultimate shear resistance :




Hypotheses:

- shear force taken by the web
- stress field of variable inclination with a compression strut and a tension strut perpendicular to it
- superposition of shear resistance of UHPFRC and shear reinforcement (single vertical rebars, stirrups)

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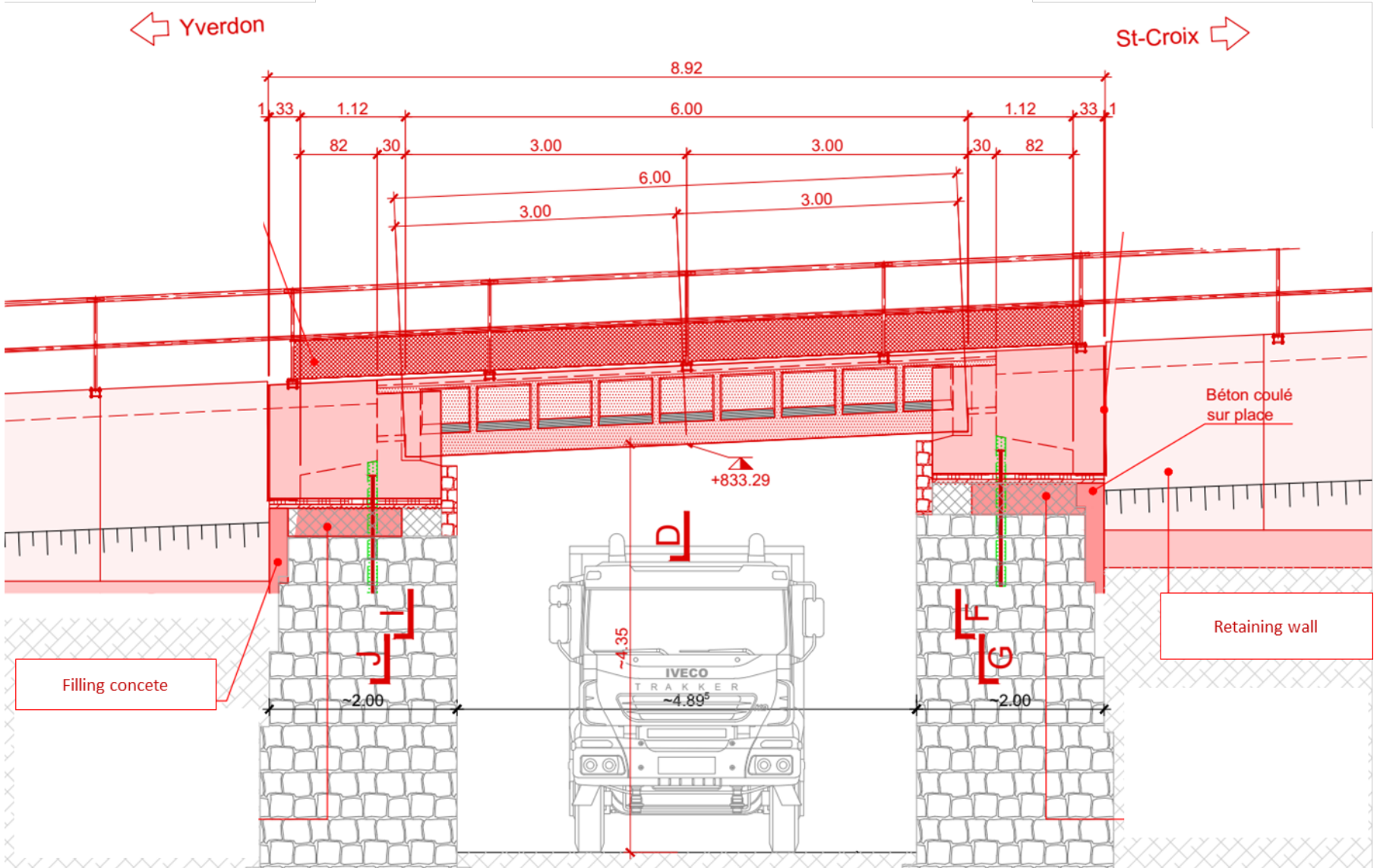
Sketchs: Prof E. Brühwiler

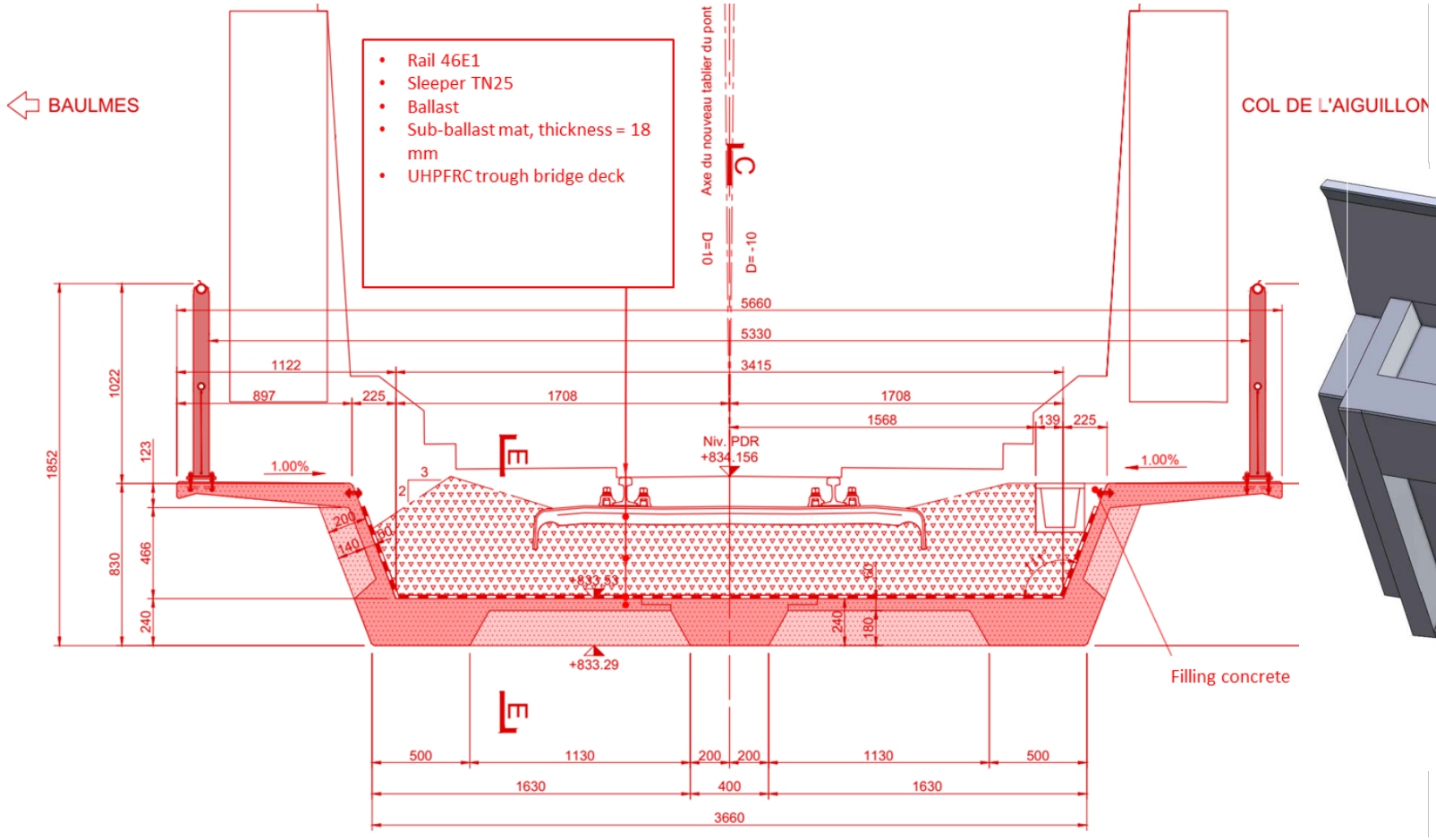
# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

## AIGUILLON NEW RAILWAY BRIDGE, SWITZERLAND - ELEVATION

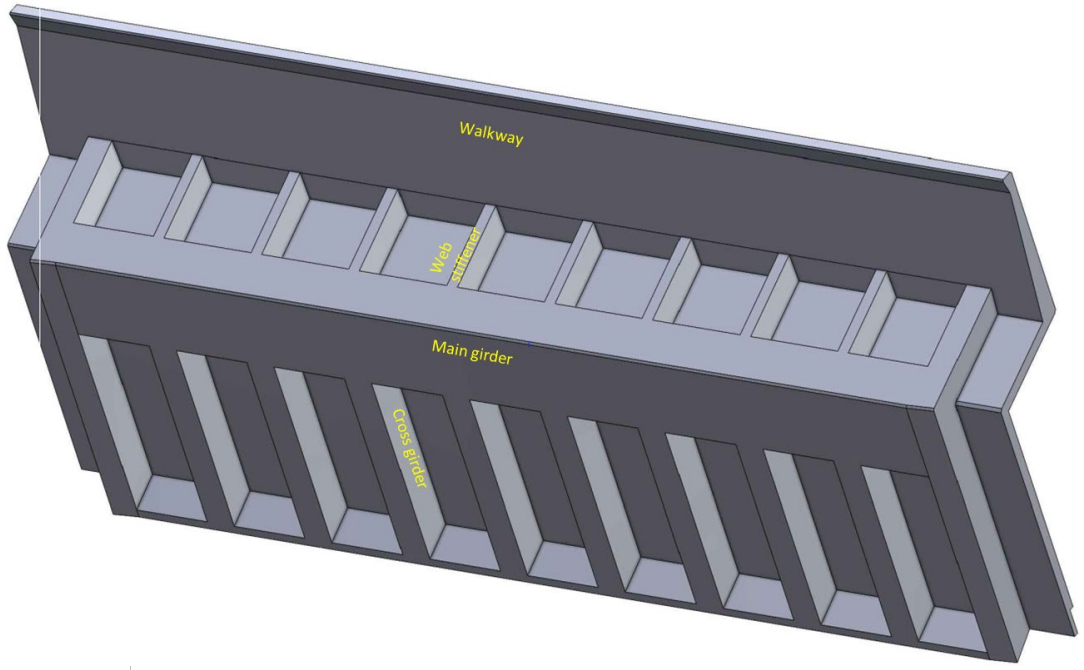


# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

## AIGUILLON NEW RAILWAY BRIDGE, SWITZERLAND



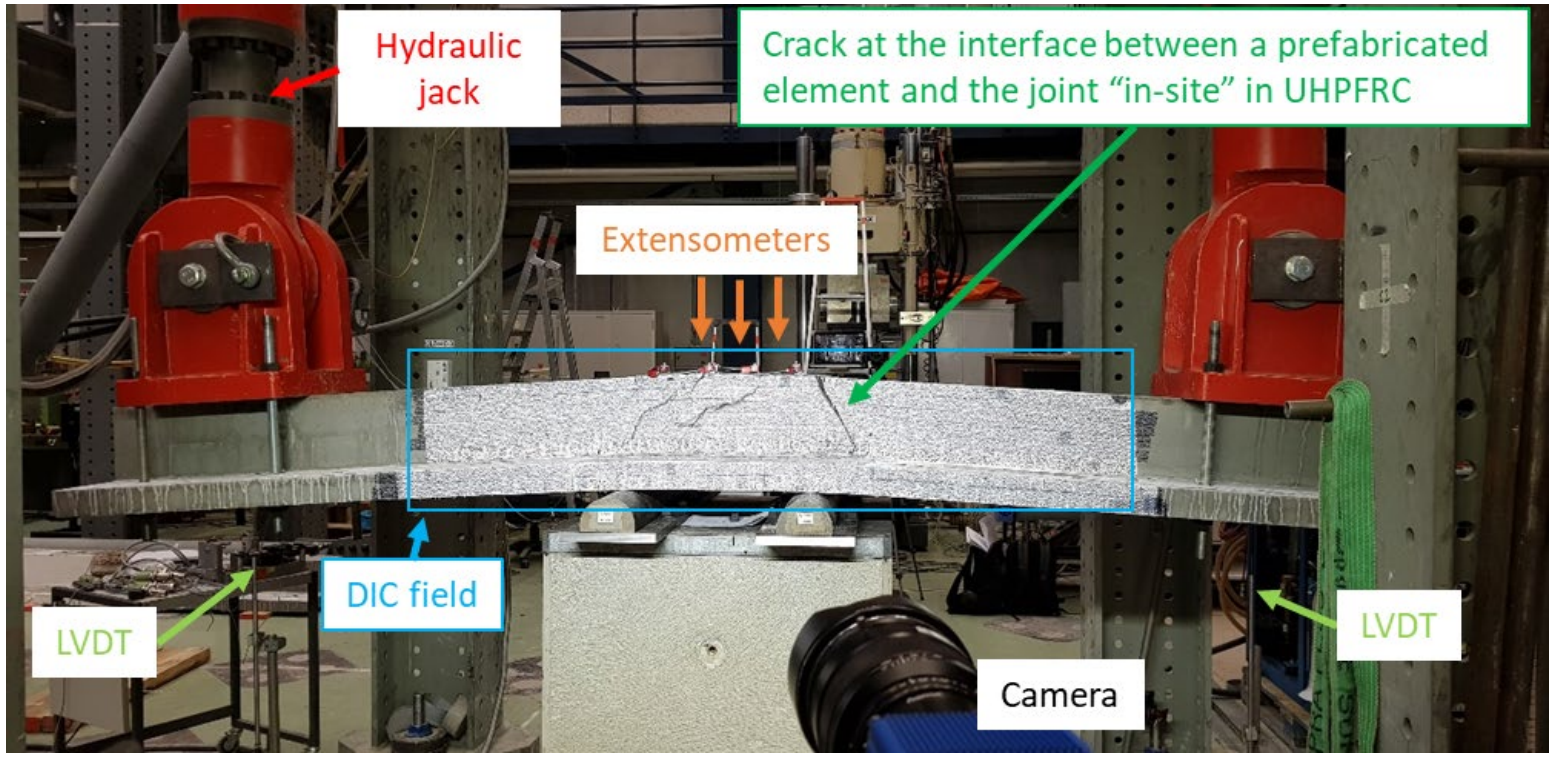

Bridge trough: cross-section



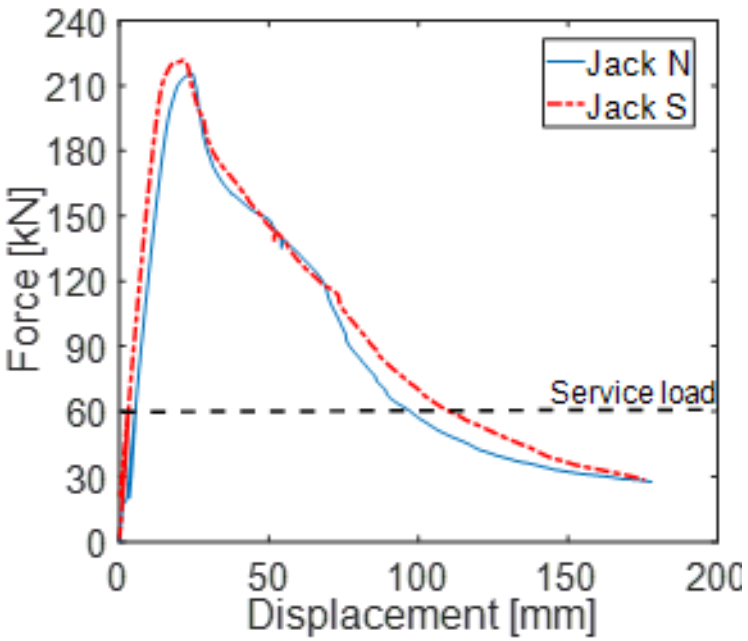

A prefabricated element in 3D of the bridge deck

# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

## LABORATORY EXPERIMENTS AT SWISS FEDERAL INSTITUTE OF TECHNOLOGY LAUSANNE (EPFL)




Laboratory experiment on the cross beam




Force-displacement response for crossbeams

Laboratory test movie

# EXECUTION & INSTALLATION

Casting of one half of the trough

Casting of the longitudinal joint using UHPFRC fabricated in-situ

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# EXECUTION & INSTALLATION

## AIGUILLON NARROW RAIL BRIDGE

Installation of the bridge trough at night

Owner: TRAVYS
Design: Gruner  Stucky Ltd
Contractor: Walo Ltd / Element Ltd
Photos: Thanh TRINH

# EXECUTION & INSTALLATION

## BRIDGE LOAD TESTING

# EXECUTION & INSTALLATION

**Before**

**After**

# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

**CHAUMENY FOOTBRIDGE, SWITZERLAND**

Features:

- original aesthetic expression
- precast elements assembled by posttensioning
- monolithic structure (no bearings, no joints)
- lightweight
- relatively stiff
- low material consumption

Owner: City of Montreux
Design: C-Design
Contractor: Praderlosinger / C-Design
Photos: Prof. E. Brühwiler

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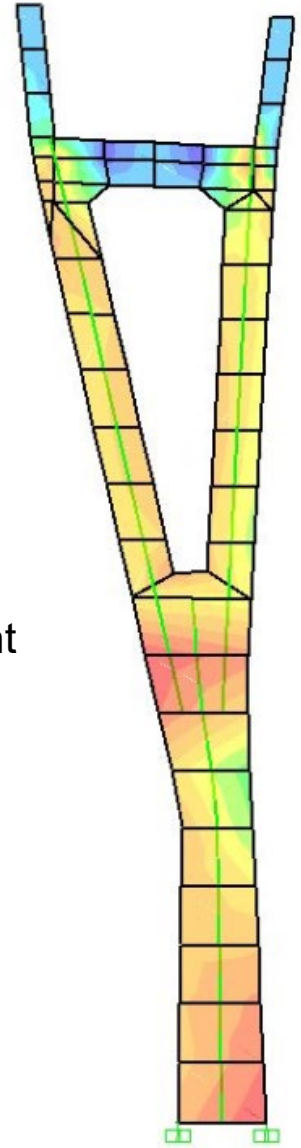
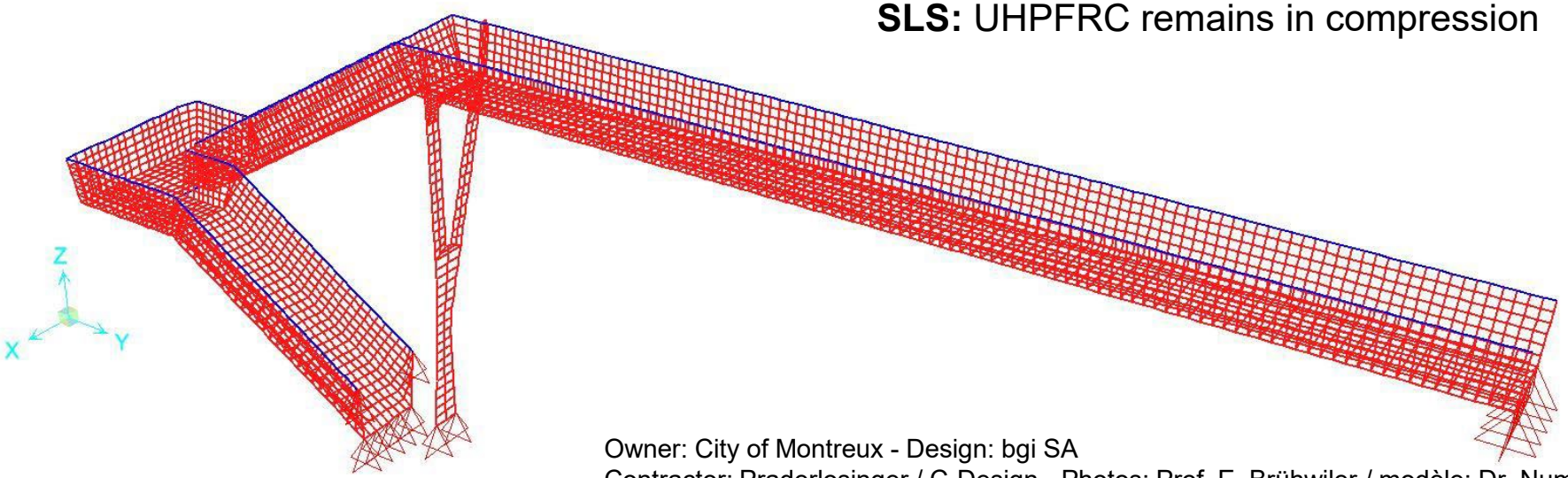
# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

**CHAUMENY FOOTBRIDGE, SWITZERLAND**



**ULS:** Post-tensioning tendons act as main reinforcement
**SLS:** UHPFRC remains in compression




Owner: City of Montreux - Design: bgi SA
Contractor: Praderlosinger / C-Design - Photos: Prof. E. Brühwiler / modèle: Dr. Numa Bertola

# CHAUMENY FOOTBRIDGE, SWITZERLAND

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Photos: Prof. E. Brühwiler

Photos: J.Meyer 2021

# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

**TAVERNE ROAD BRIDGE , SWITZERLAND**

**Design features:**

- severe requirements regarding river clearance and adjacent road level
- variable girder height from 0.75m to 1.25m
- 26m span
- driveable UHPFRC surface
- accelerated construction
- low material use
- low construction cost

Owner: Walo SA
Design: Opan SA
Contractor: Walo SA
Photos: Prof. E. Brühwiler

# APPLICATIONS OF UHPFRC TO NEW STRUCTURES

**TAVERNE ROAD BRIDGE , SWITZERLAND**

# CONCLUSIONS

UHPRFC are going to be applied widely in Switzerland. (UHPFRC đang được ứng dụng nhiều và rộng tại Thụy Sĩ)

UHPFRC allows (UHPFRC cho phép chúng ta):

> to strengthen existing structures and to rehabilitate existing reinforced concretes bridges (gia cường kết cấu hiện hữu và phục hồi lại cầu bê tông cốt thép hiện hữu)

> to design and to build lightweight, durable bridges and structures (thiết kế và xây kết cấu / công trình cầu nhẹ và bền)

> to reduce the consummation of “concrete” and to increase sustainability of construction (giảm lượng tiêu thụ bê tông và làm tăng tính xây dựng bền vững).

# ACKNOWLEDGEMENT

Sincerely thank my colleagues, Professor Eugen Brühwiler and Dr. Numa Bertola at **MCS Laboratory, Swiss Federal Institute of Technology in Lausanne** for their precious contributions to this presentation

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CHÂN THÀNH CẢM ƠN:

TRƯỜNG ĐẠI HỌC CÔNG NGHỆ GIAO THÔNG VẬN TẢI
TS. TRẦN BÁ VIỆT
TS. LÊ NGUYÊN KHƯƠNG