Future Infrastructure Forum 2

EPSRC Network for Resilient & Sustainable Infrastructure

CFRP Tendons: Quo vadis?

Urs Meier

EMPA, Swiss Federal Laboratories for

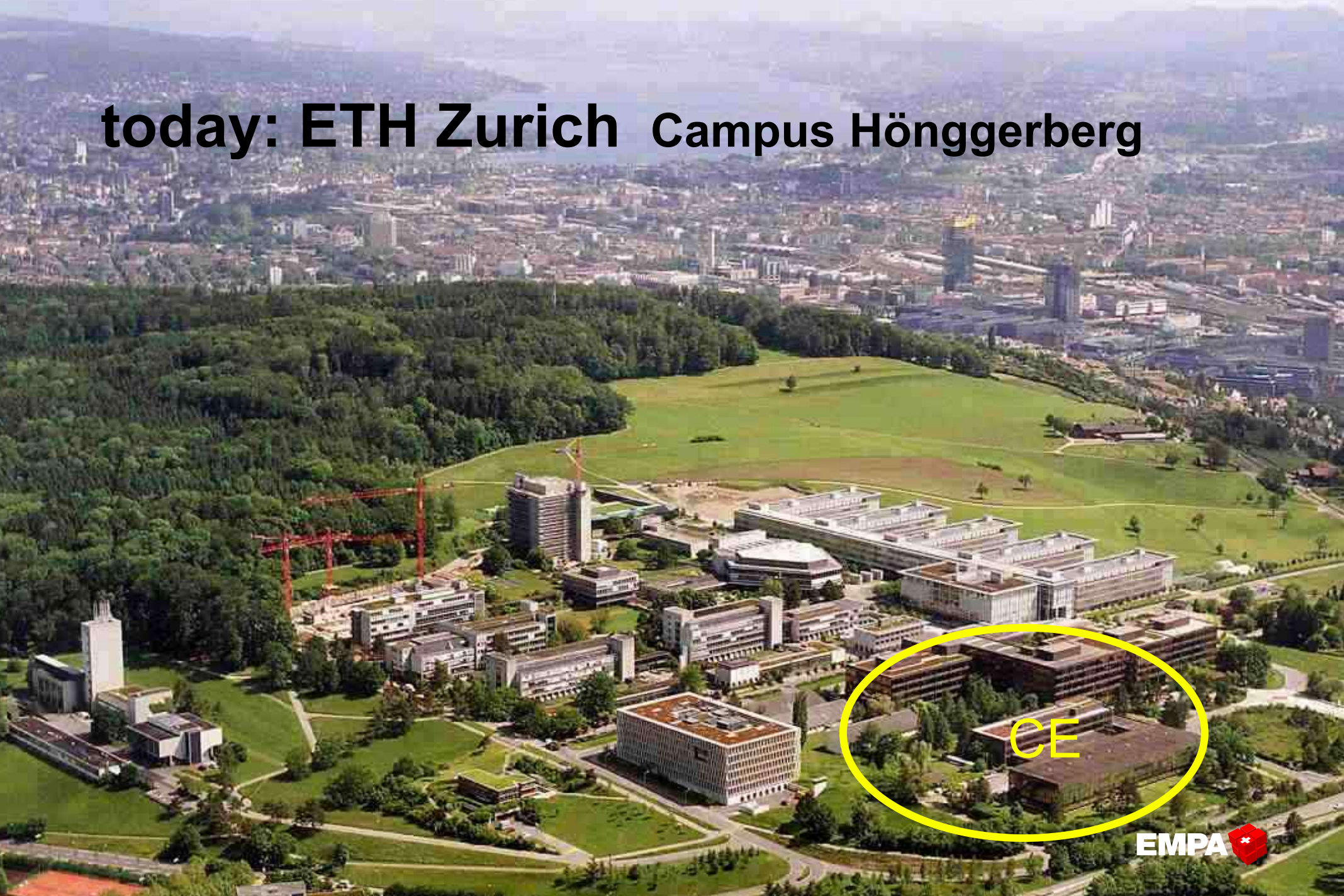
Materials Science and Technology

EMPA

today: ETH Zurich Campus downtown


today: ETH Zurich Campus downtown
Ranking according to Shanghai Jiao Tong University:
on European Continent # 1
worldwide # 23
VICENTINI
EMPA

today: ETH Zurich Campus Hönggerberg



EMPA today

132th anniversary

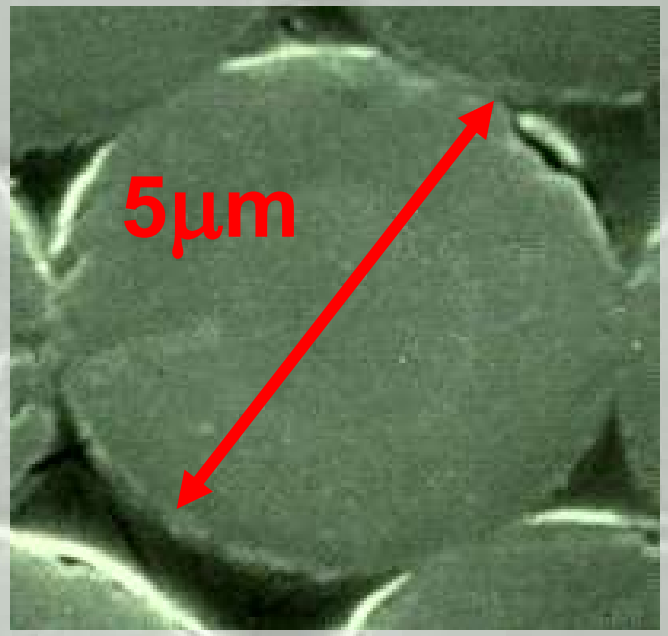
3 Sites

810 Employees

360 University graduates

10 Professors

120 PhD candidates



Scanning electron microscope cross section of wire made of Carbon Fibre Reinforced Polymers

Fibre volume content: 72%

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1972 Kurt Schuhmacher Bridge

crossing river Rhine in Mannheim

Worlds first cable stayed bridge with parallel steel wire bundles

Designers: Prof. Dr.-Ing. Dr. h.c. F. Leonhardt & Dr. Ing. W. Andrä

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1972 Kurt Schuhmacher Bridge

After only 15 years severe corrosion
and many broken wires!

This example was for EMPA the driving force to initiate in 1980 together with the Swiss Company BBR Ltd the development of CFRP parallel wire bundles.

EMPA

CFRP wire

- very high strength, 3’300 MPa
- high modulus, 150 … 400 GPa

5 mm diameter

- lightweight, 1.5 t/m^3
- no corrosion
- no stress corrosion
- outstanding fatigue

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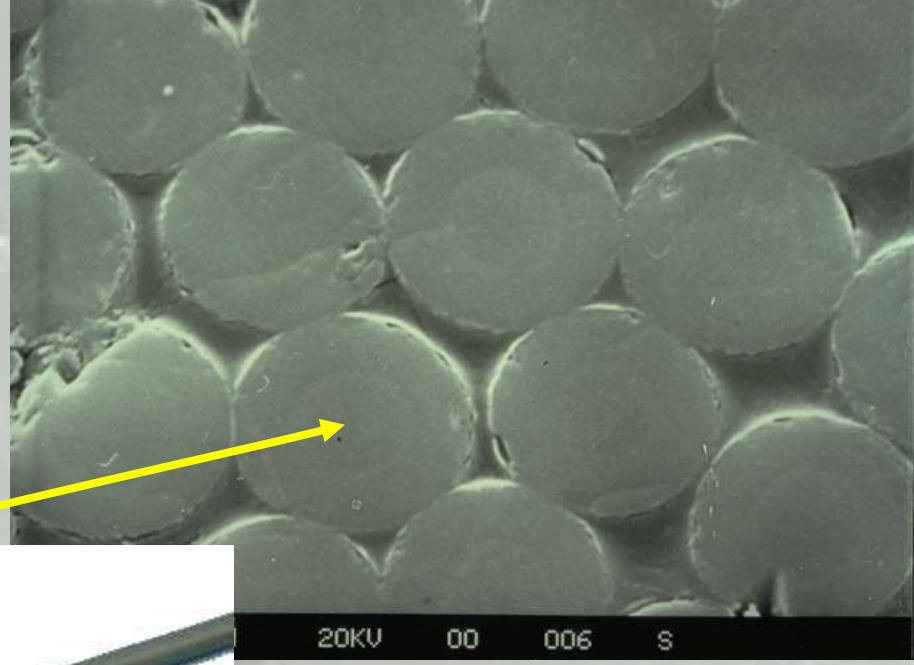
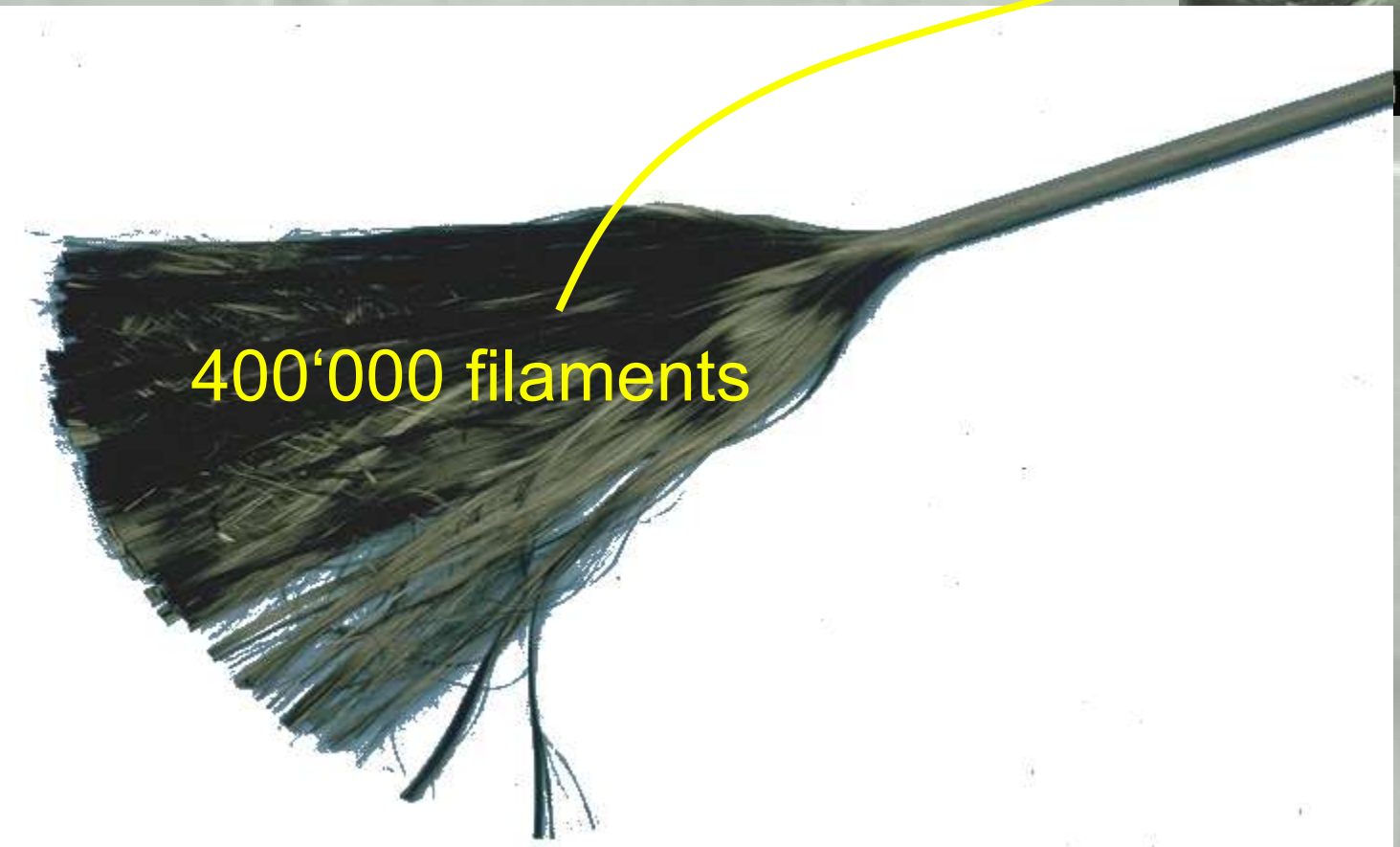
CFRP wire





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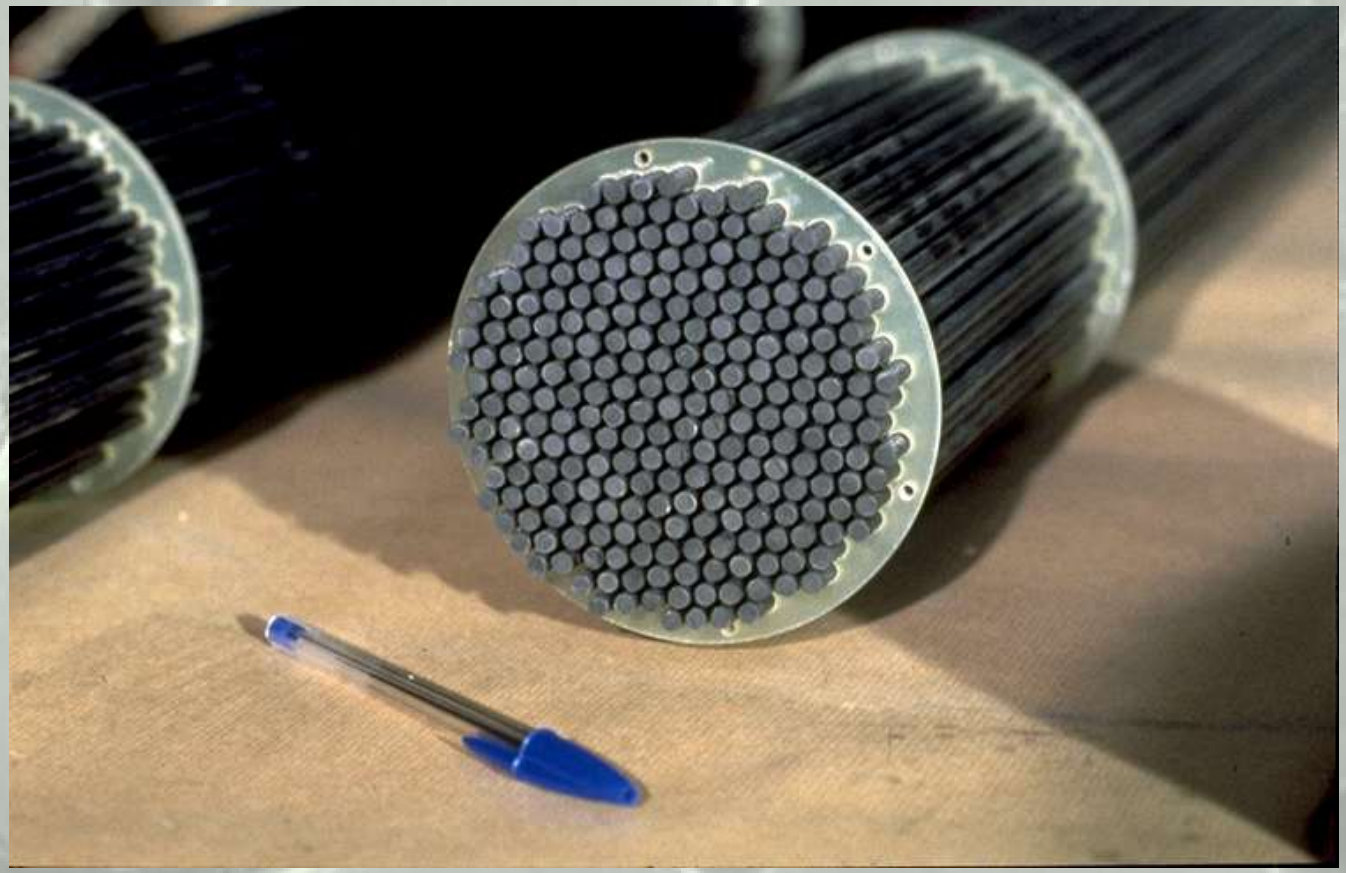
Development of anchorage system



First half of 80ties: “Blood, sweat and tears”, flops and failures

EMPA


However first success with CFRP post-strengthening
very easy application like „Structural Wallpaper“
EMPA


1991 World's first CFRP strip application
Ibach bridge
by accident …
EMPA

Ibach bridge 1991

CFRP strips are going to be prepared

only 6 working hours!

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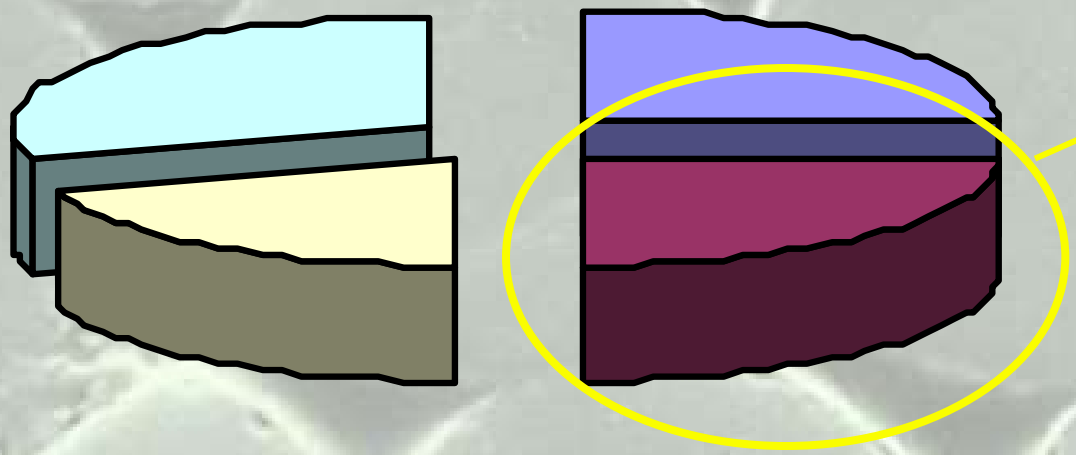
From JEC 2009 in Paris



Worldwide annual carbon fiber production in 2008: 35'000 t

Source Dr. Christophe Lanoud, R&D GE

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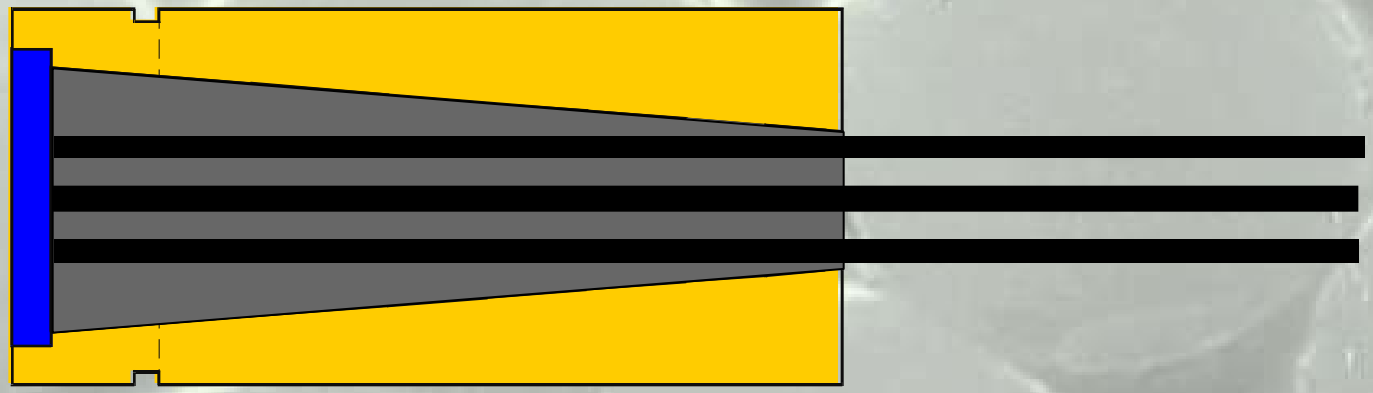
How do we grip the CFRP wires?

We developed a cone anchorage system similar to the BBR High-Am System



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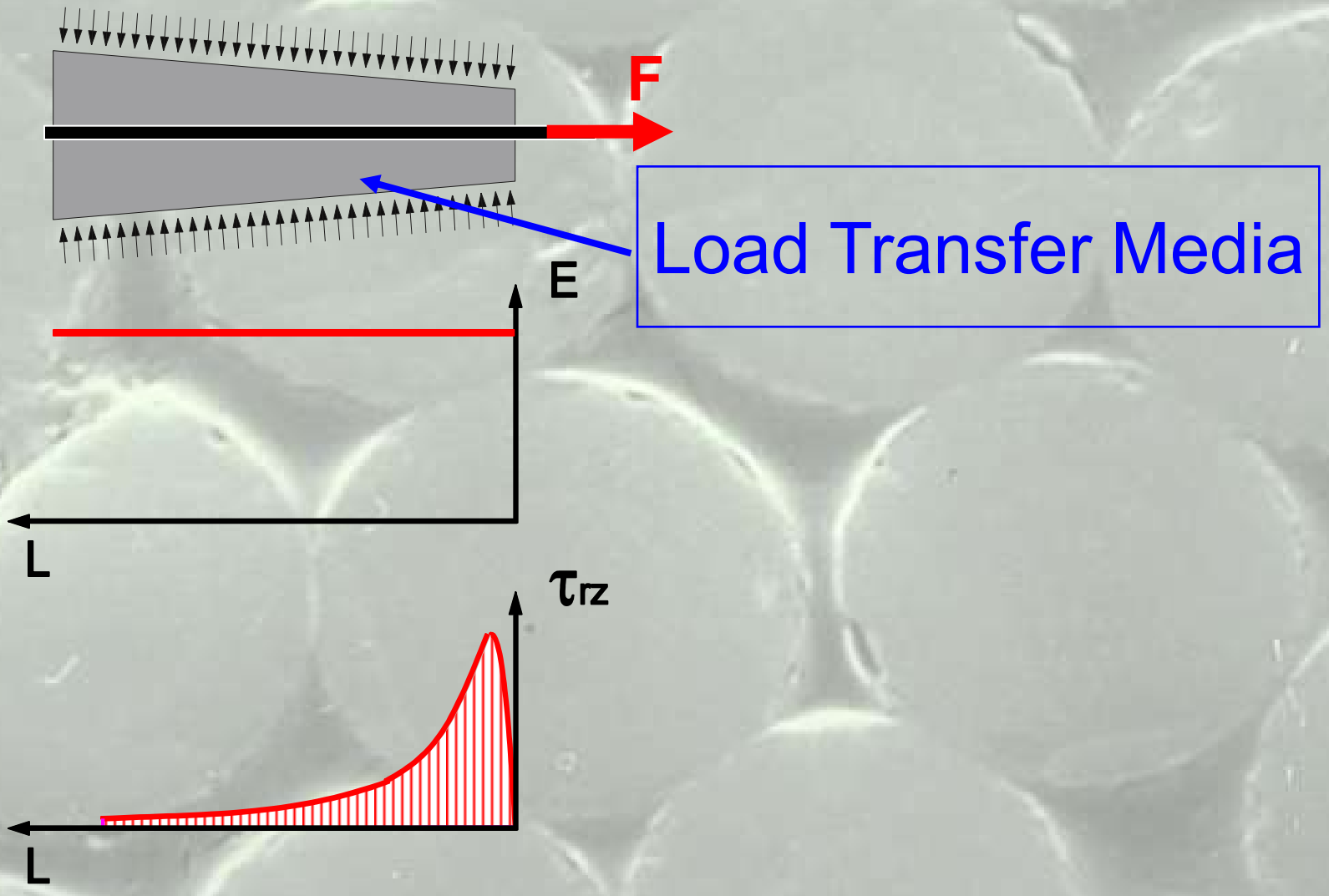
Which load transfer media (LTM)?



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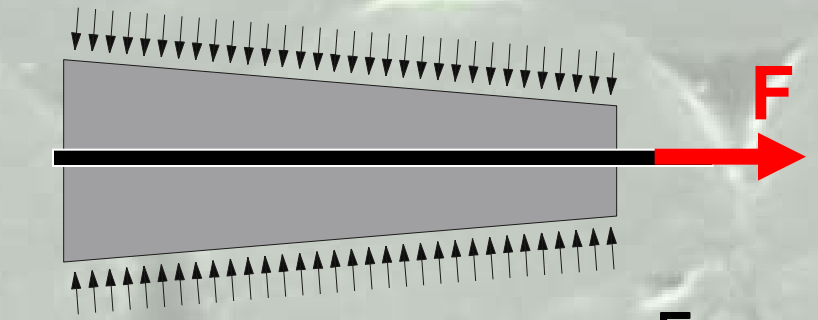
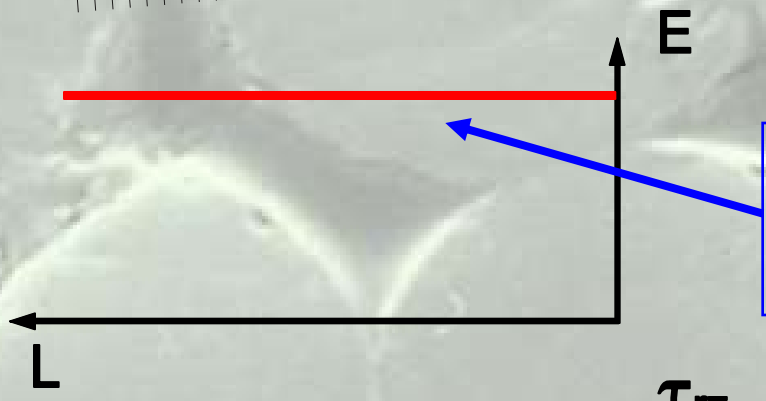
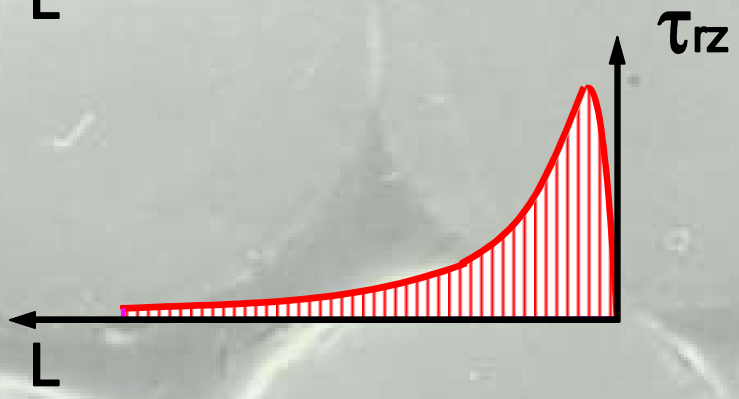




creep resistant
→ high modulus



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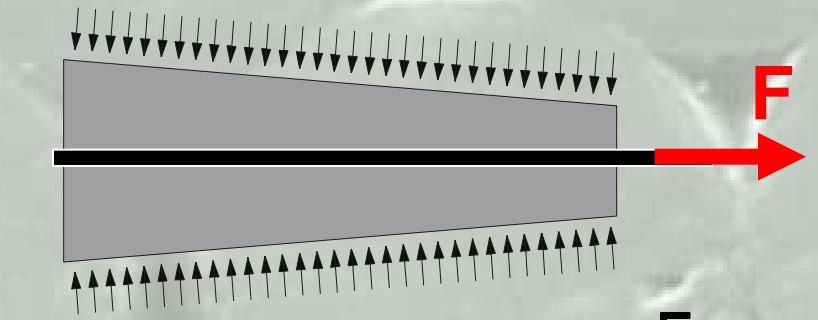
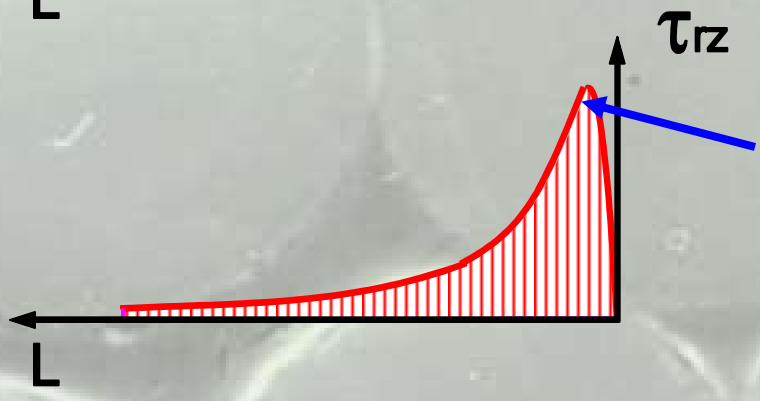
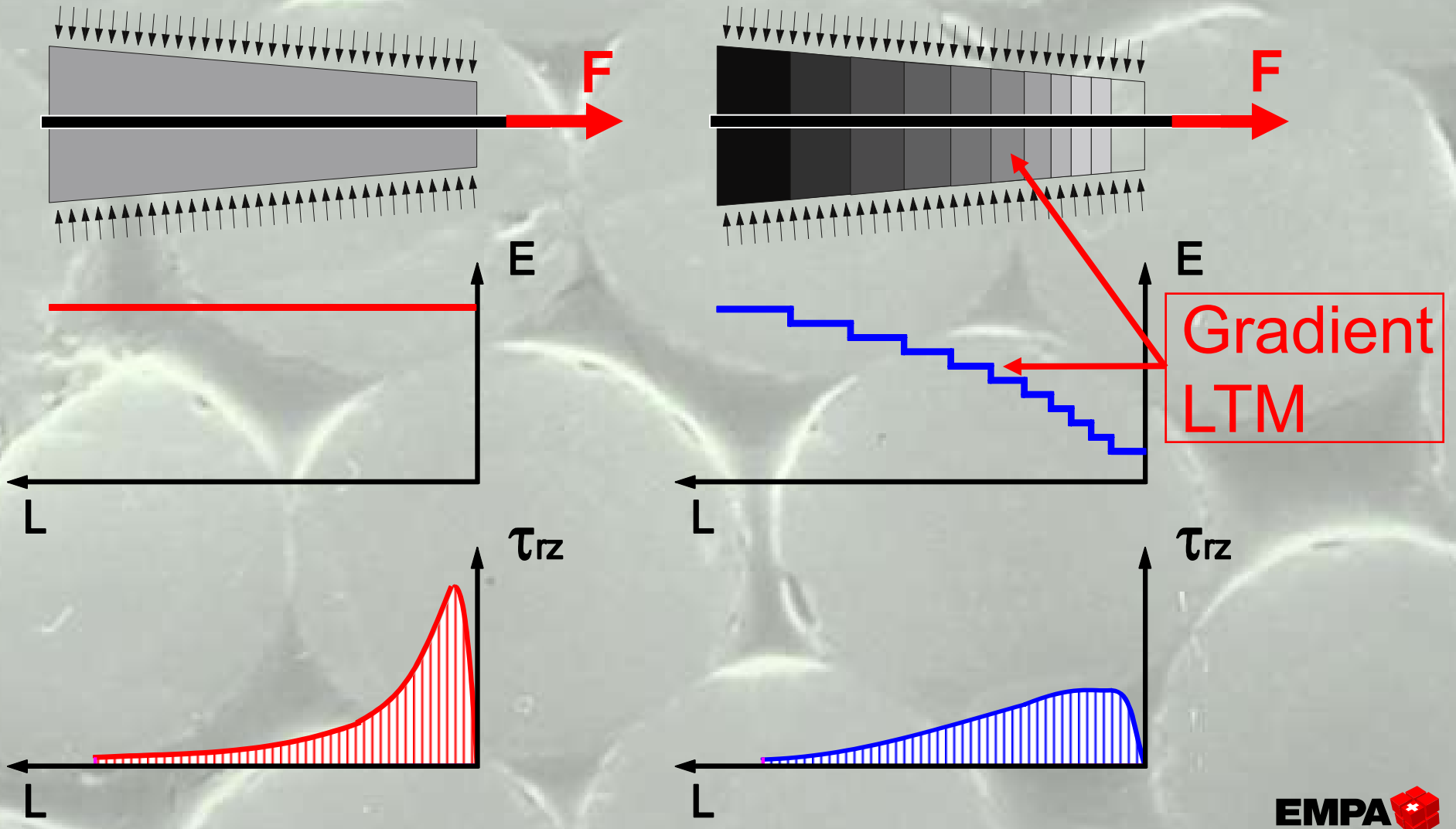




therefore
shear peak

EMPA

Which load transfer media (LTM)?



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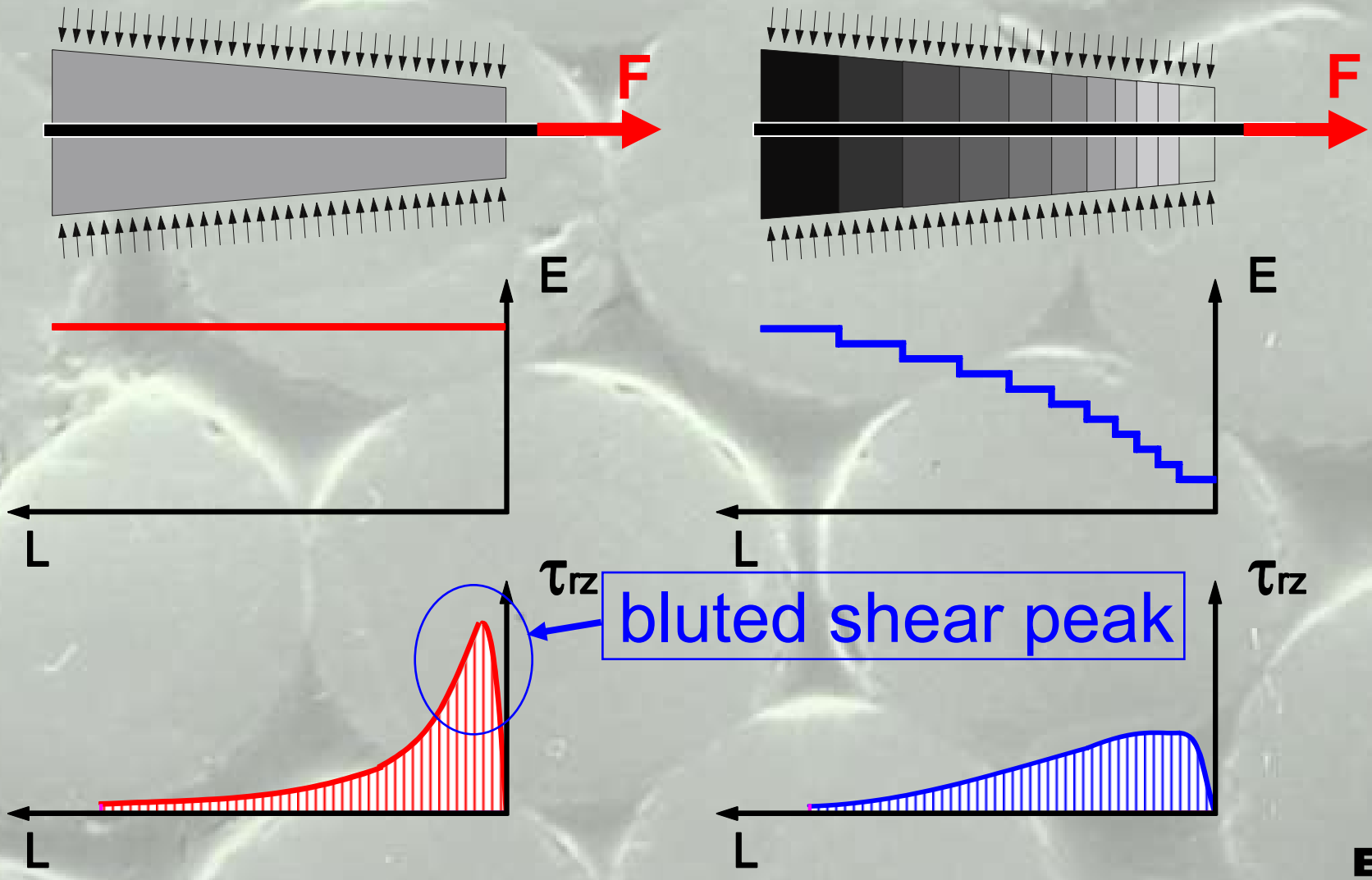

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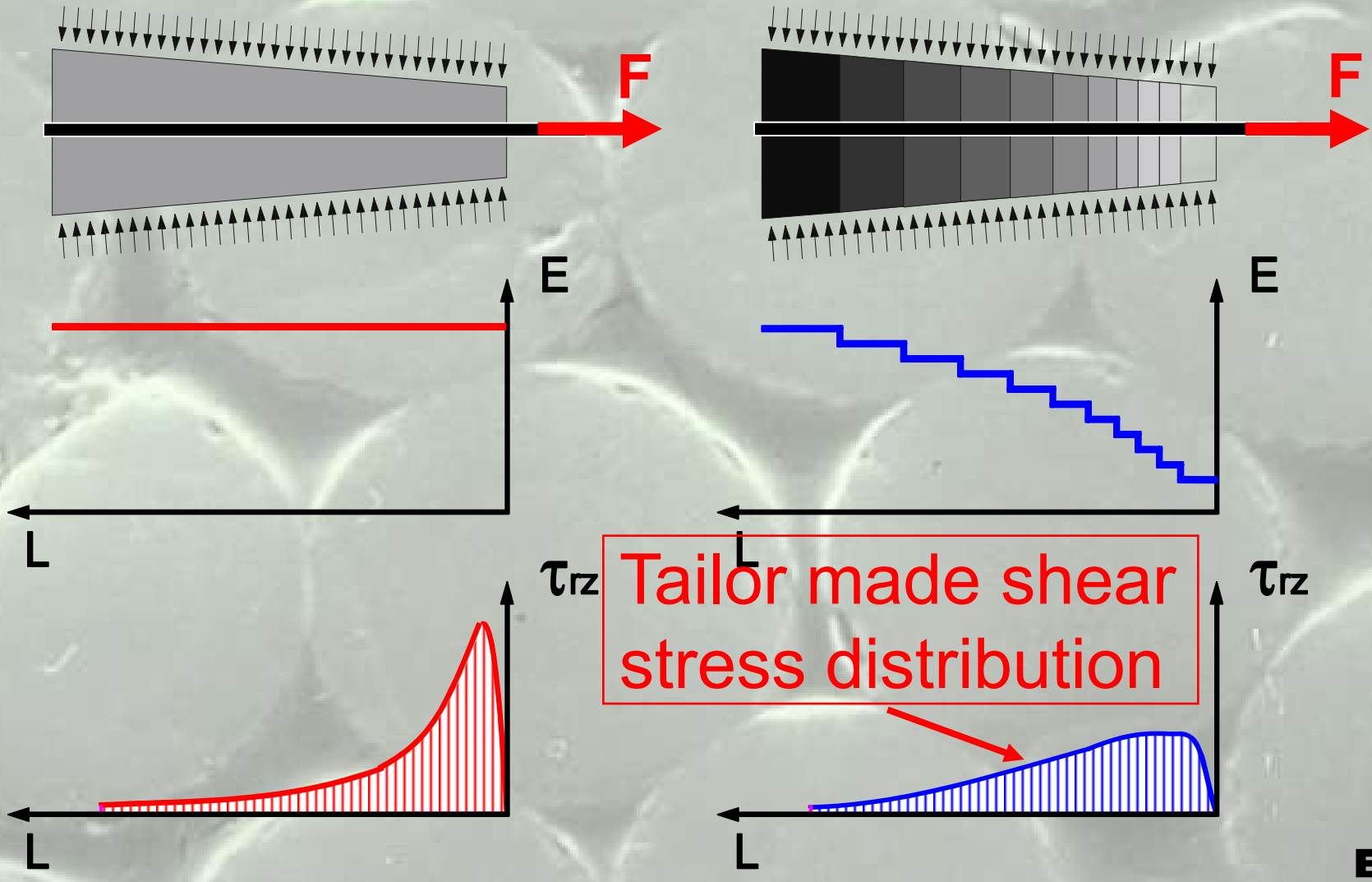
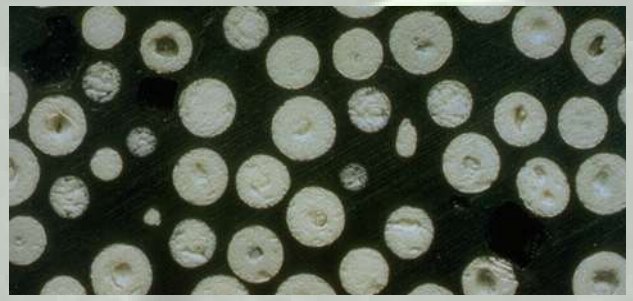
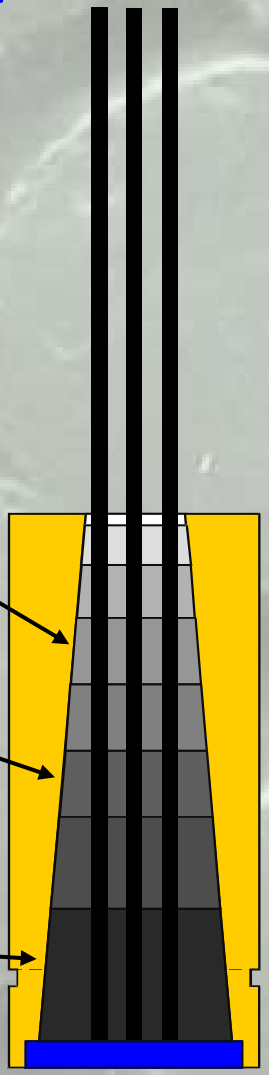



241 CFRP wires each 5 mm diameter, 12 MN

Concept of anchorage socket



Load **T**ransfer **M**edia
LTM



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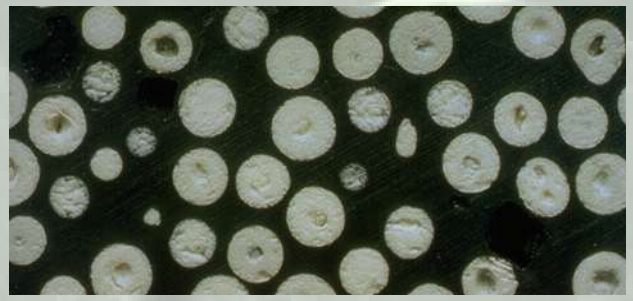
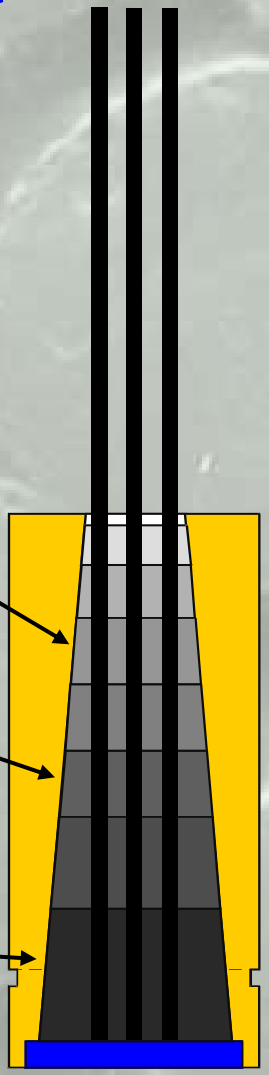
Concept of anchorage socket



Load **T**ransfer **M**edia
LTM



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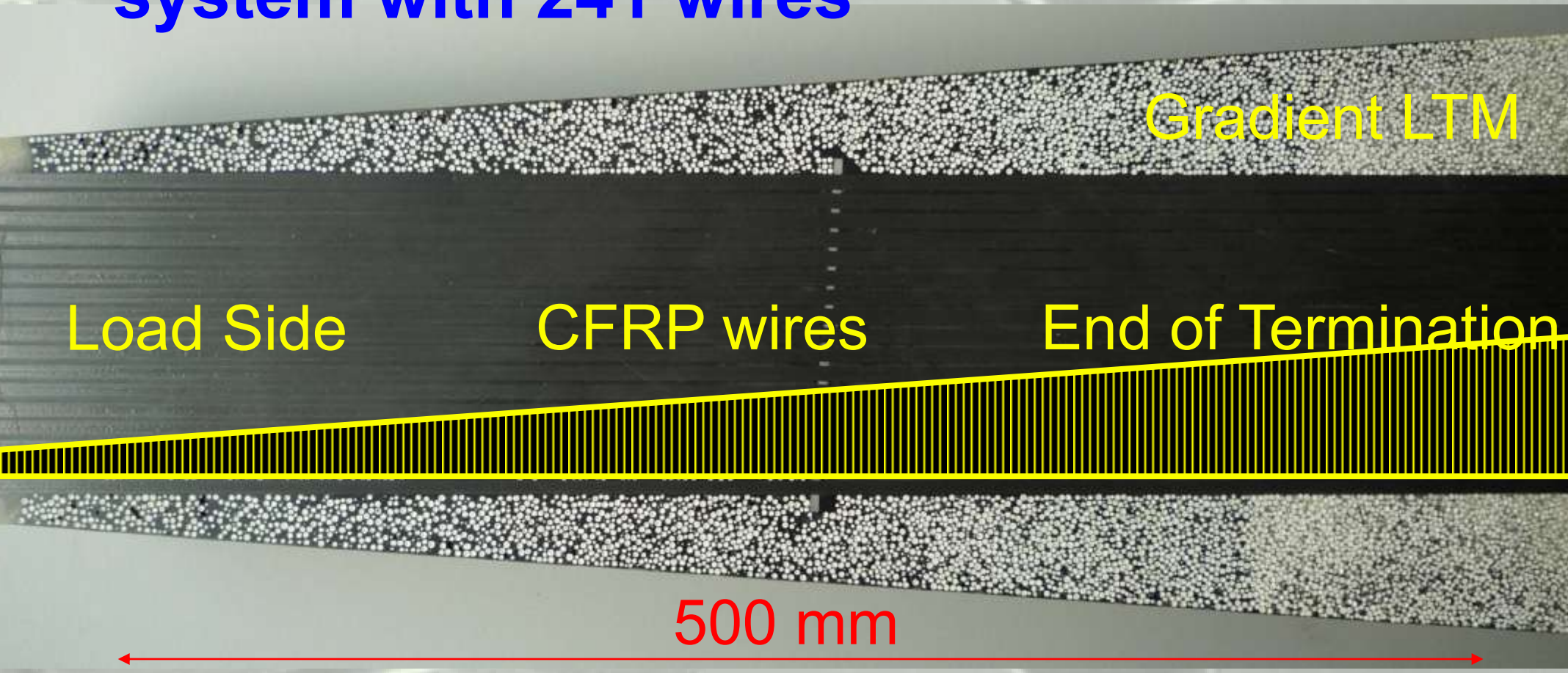
Longitudinal section of anchorage system with 241 wires



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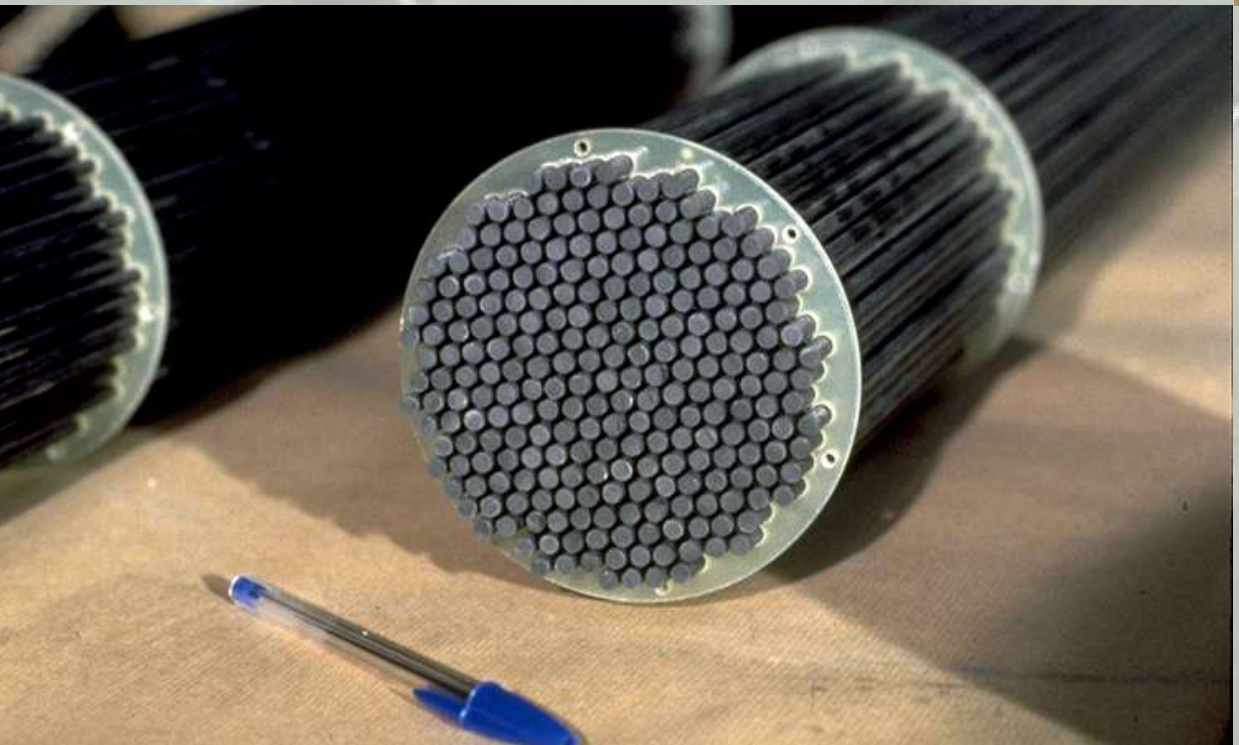
Parallel wire bundles



241 wires
(each 5 mm)
ultimate load: 12 MN

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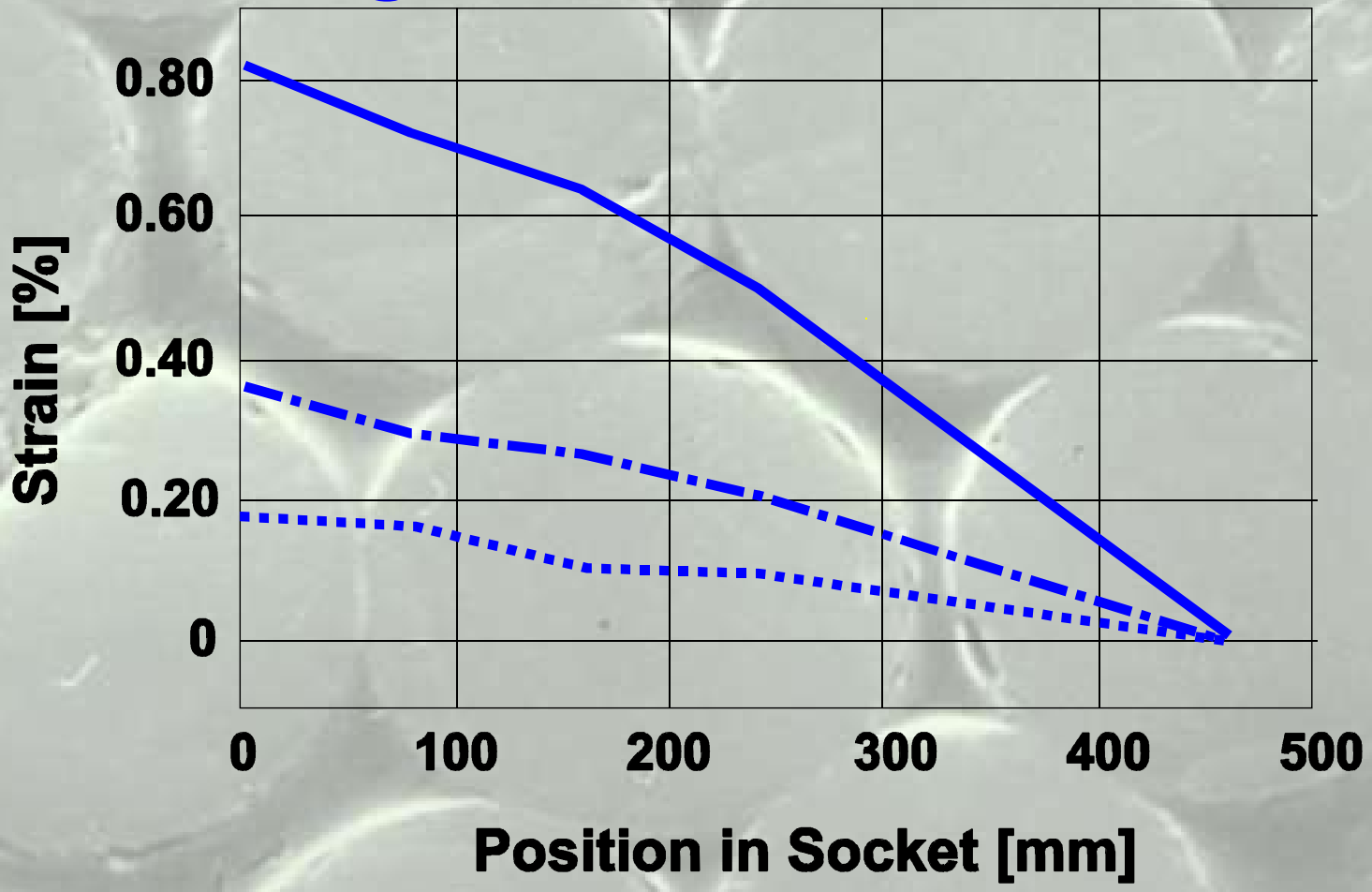
Longitudinal strain in a wire inside of anchorage



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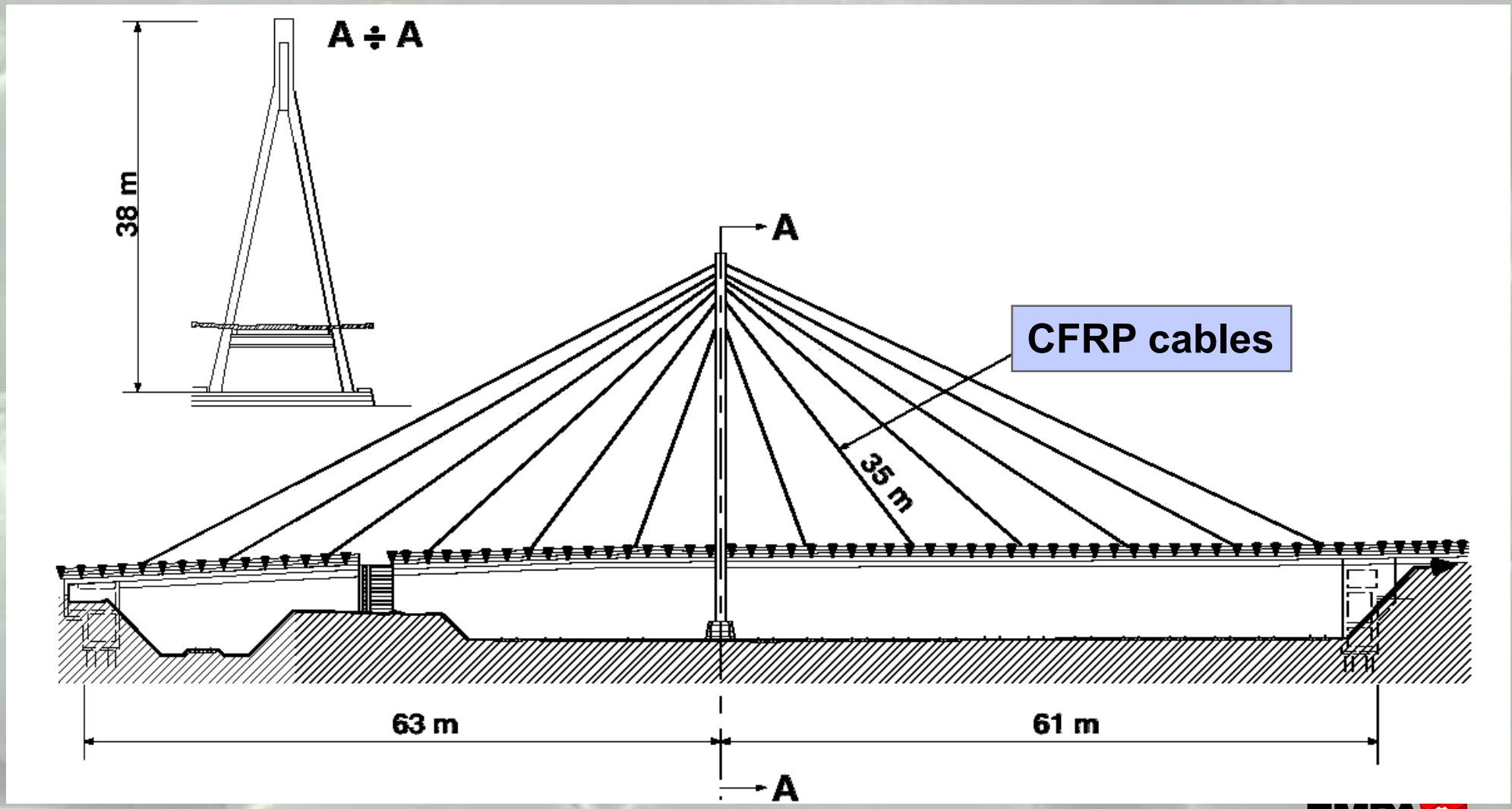
Loading of fatigue test rig with CFRP cable
EMPA

Fatigue loading



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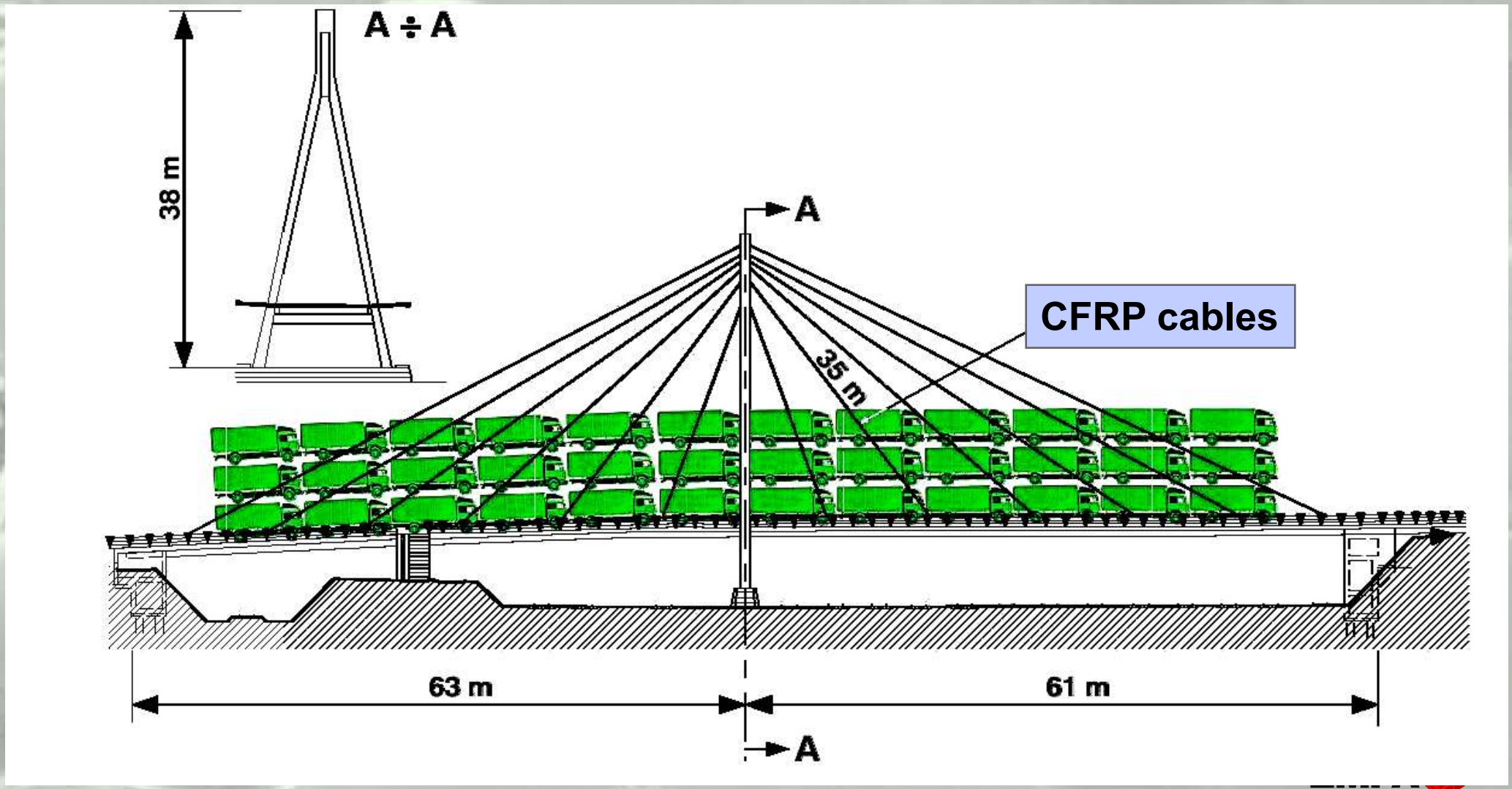
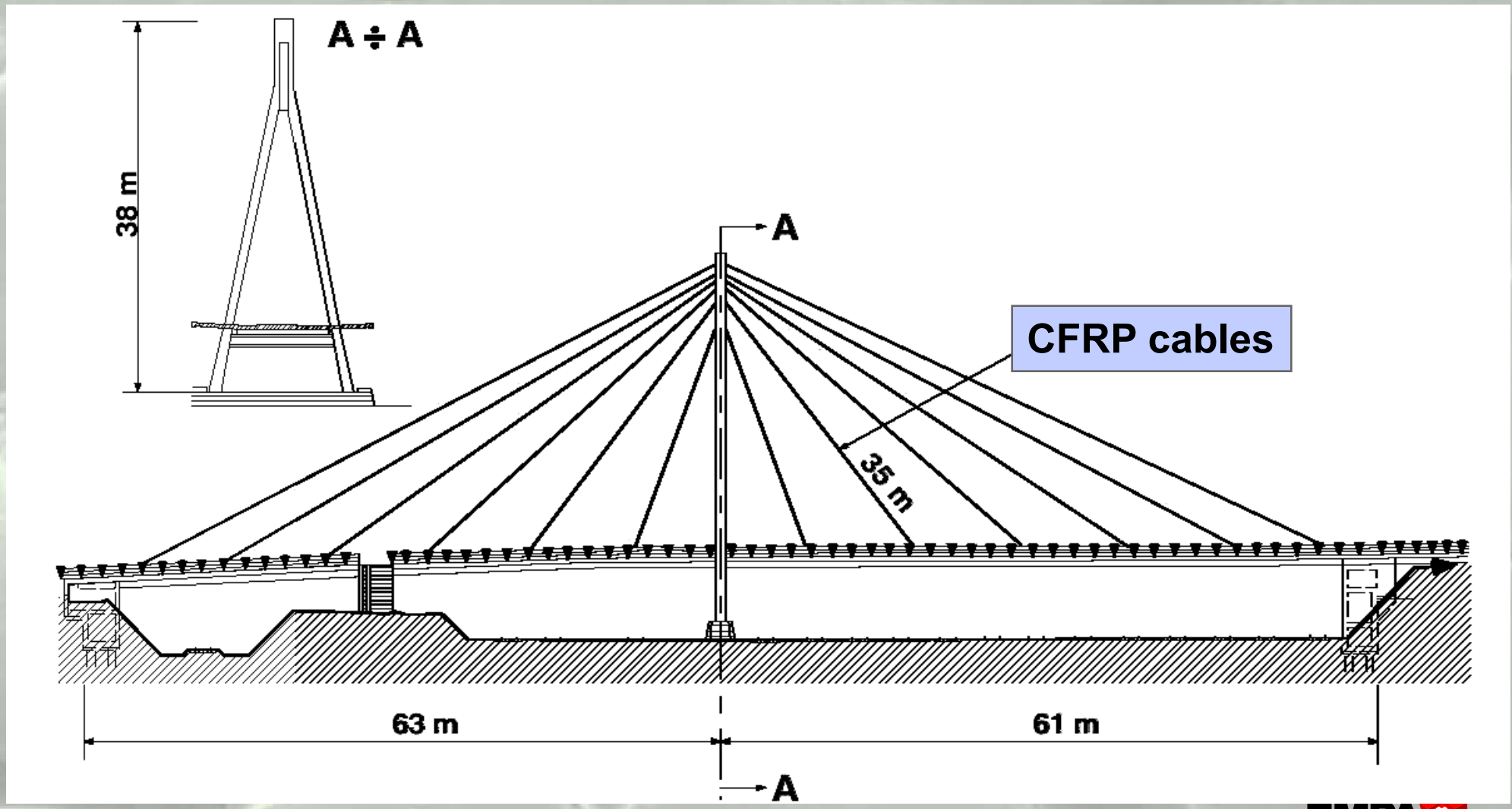
Fatigue loading



Fatigue loading



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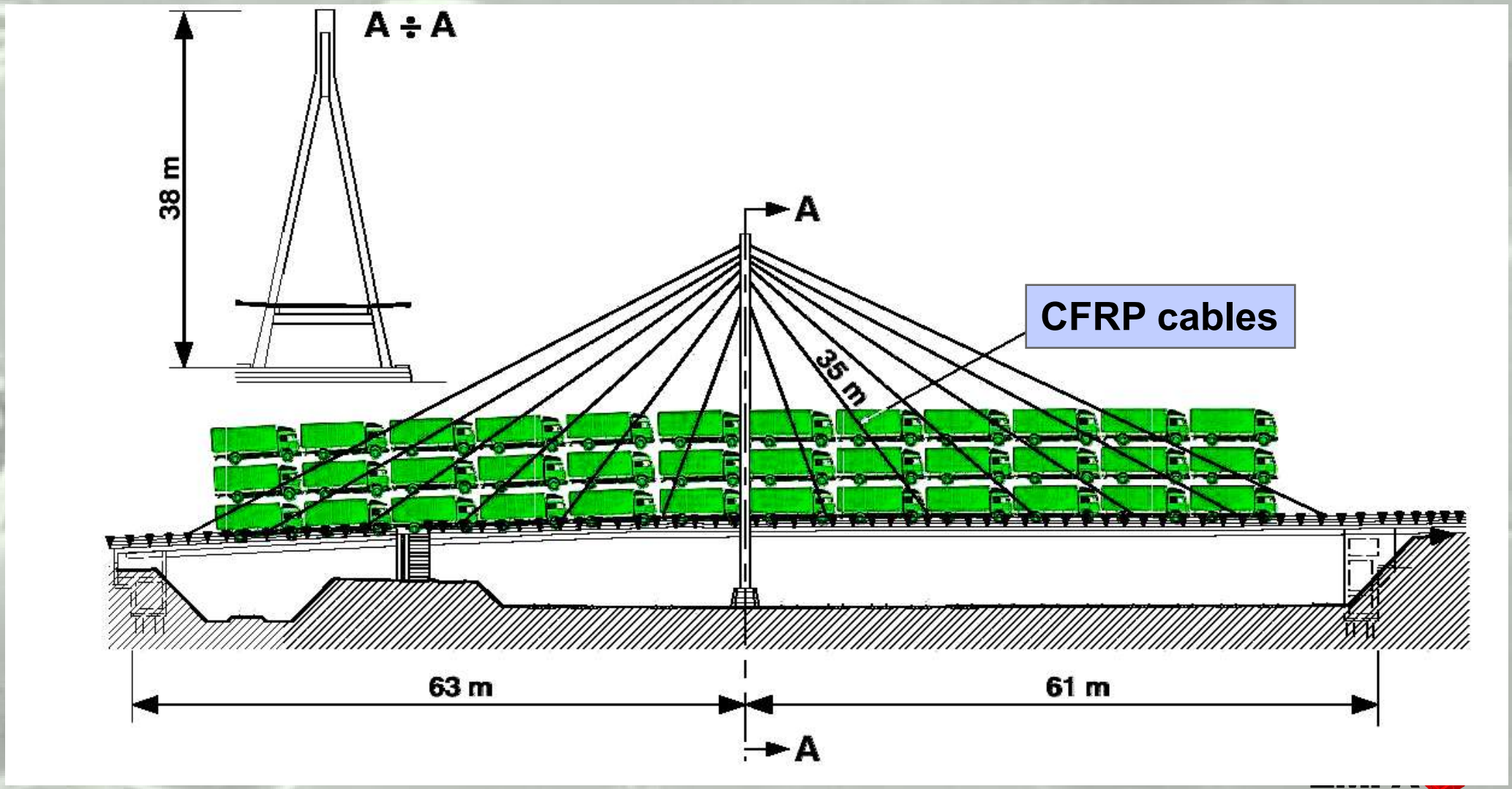
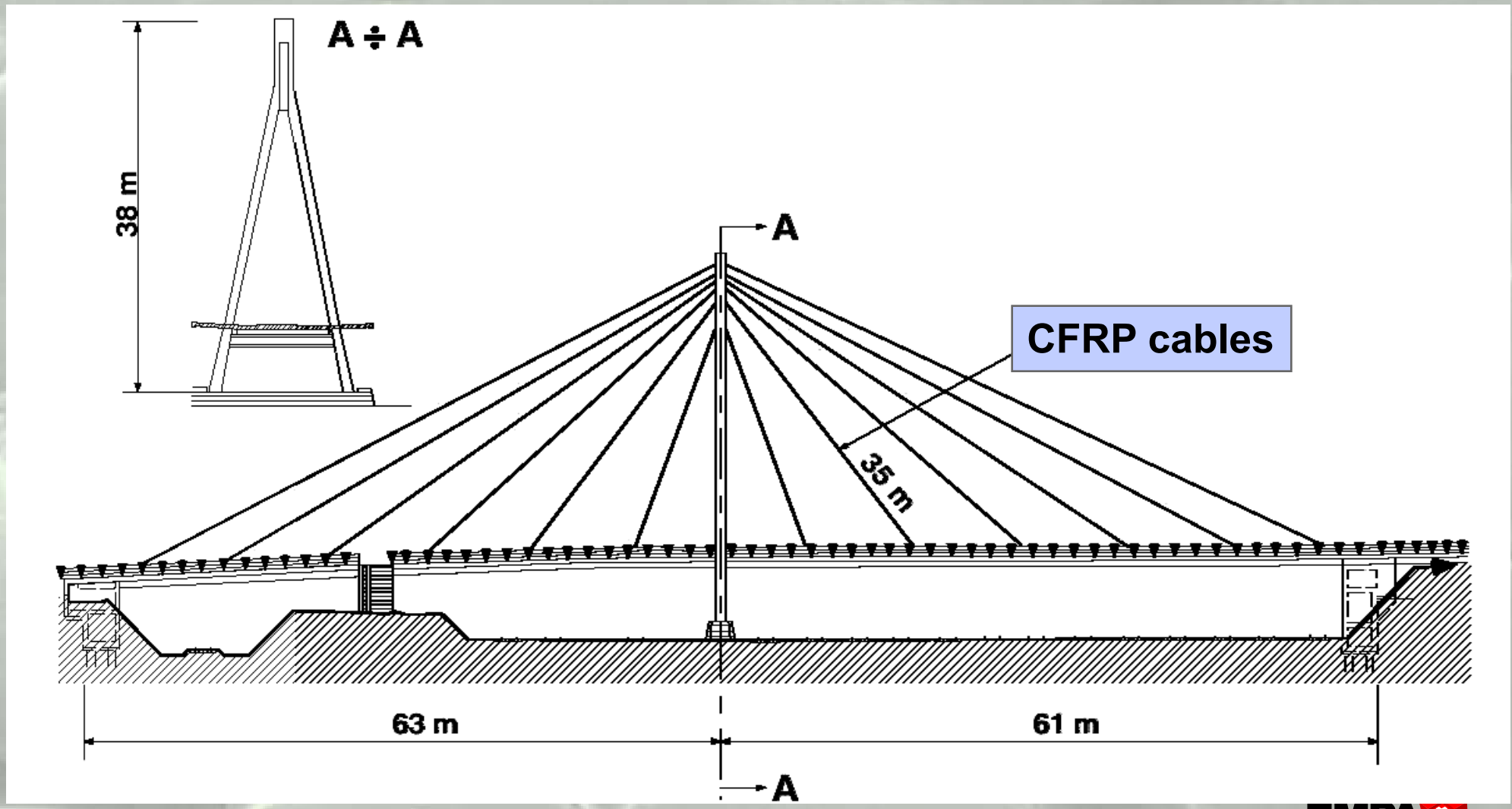
Fatigue loading



Fatigue loading



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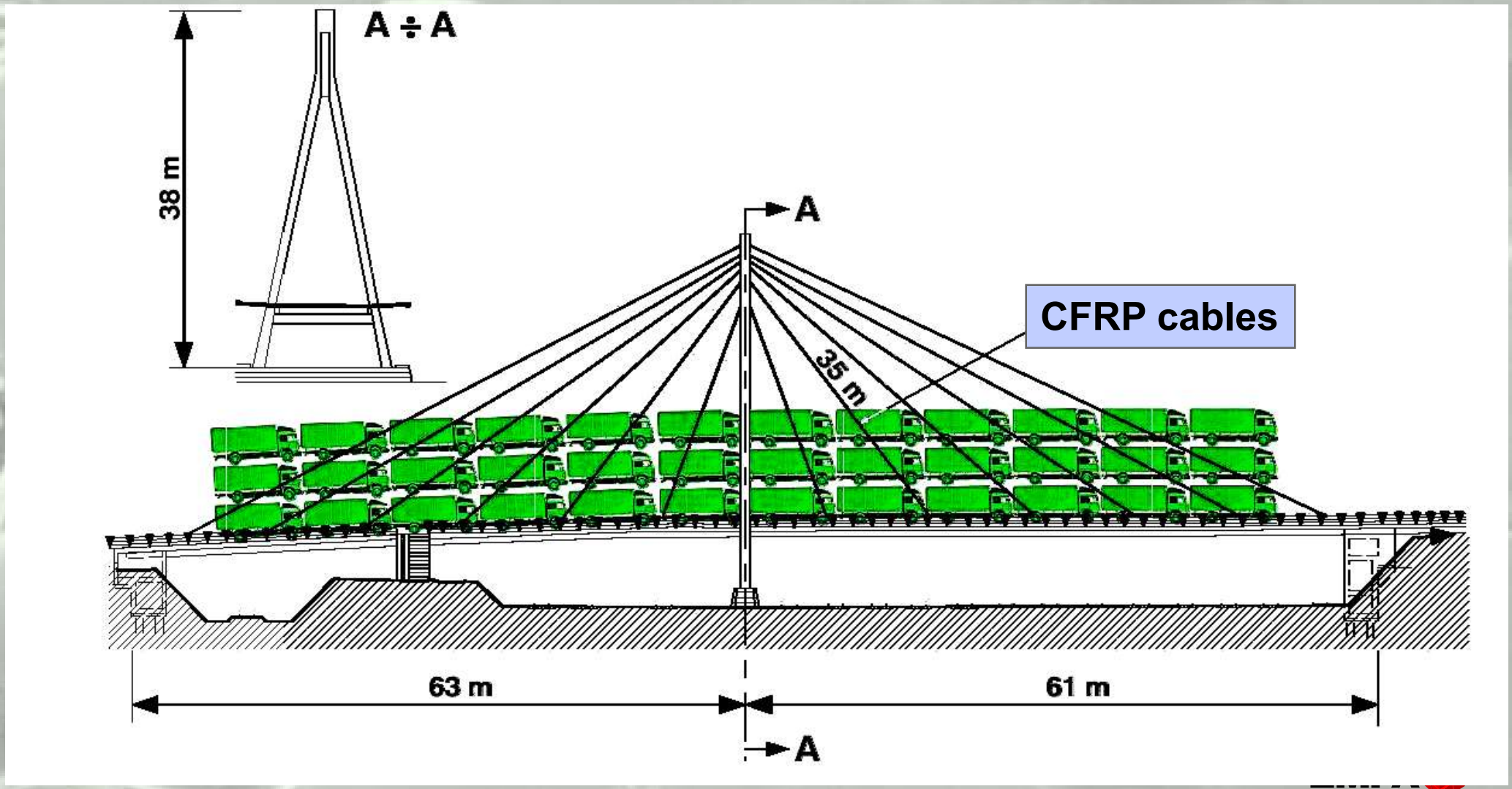
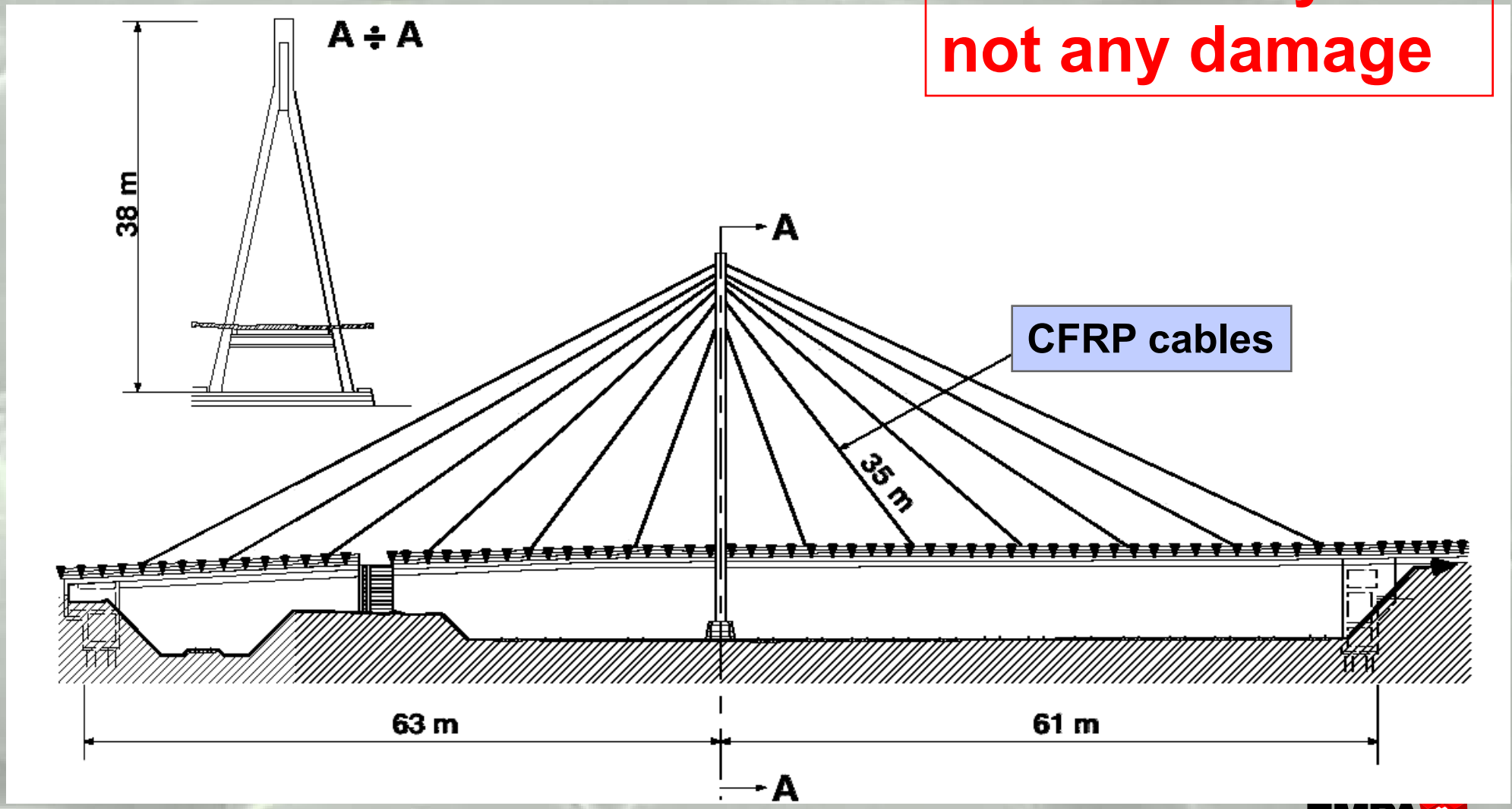
Fatigue loading



Fatigue loading

10 million cycles: not any damage



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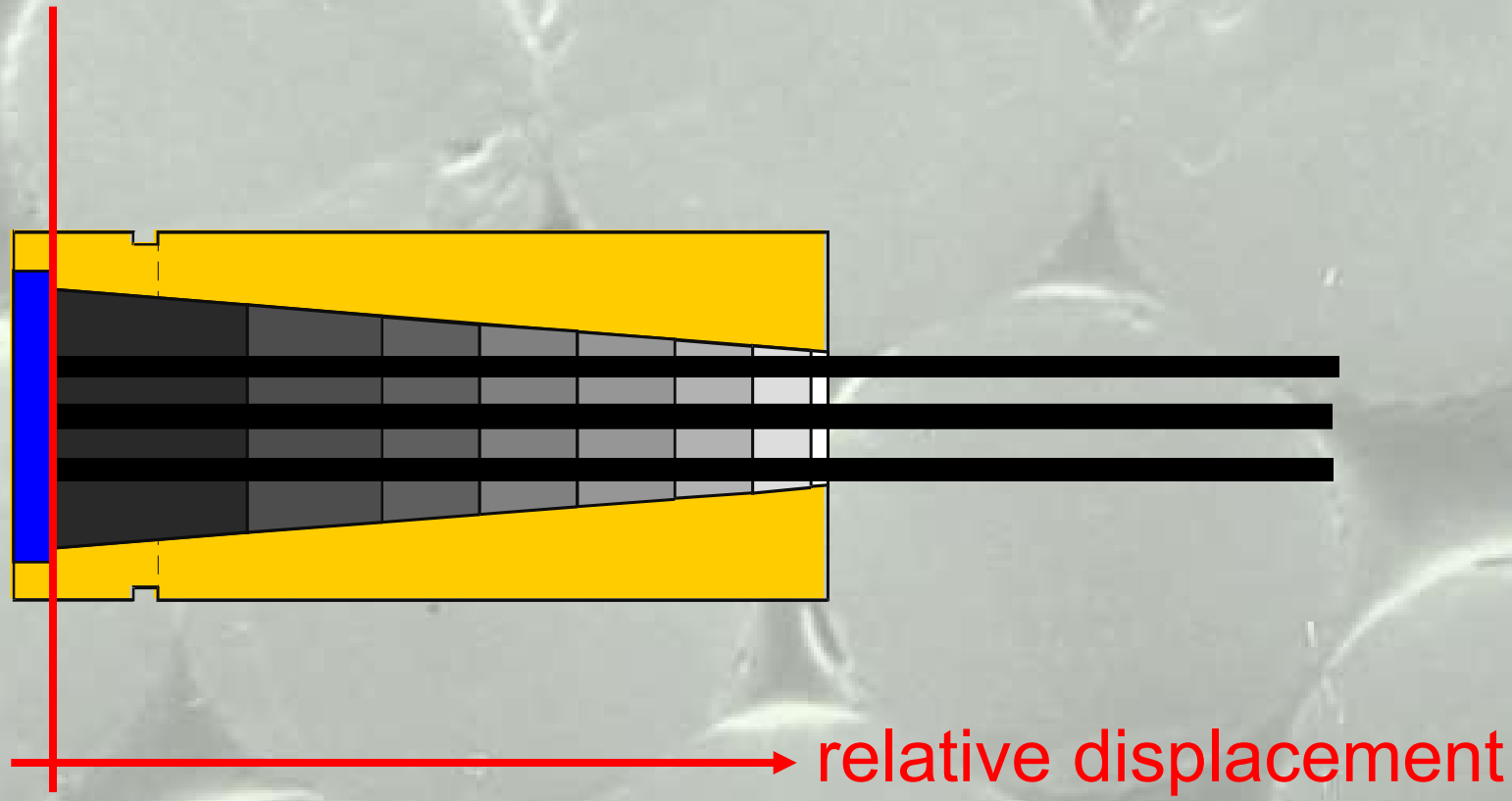
Ziltener AG
Ziltener AG
Ziltener AG
SCANIA
MAN

Stork bridge 1996 (124 m span, 2 lanes)

Desired radial pressure



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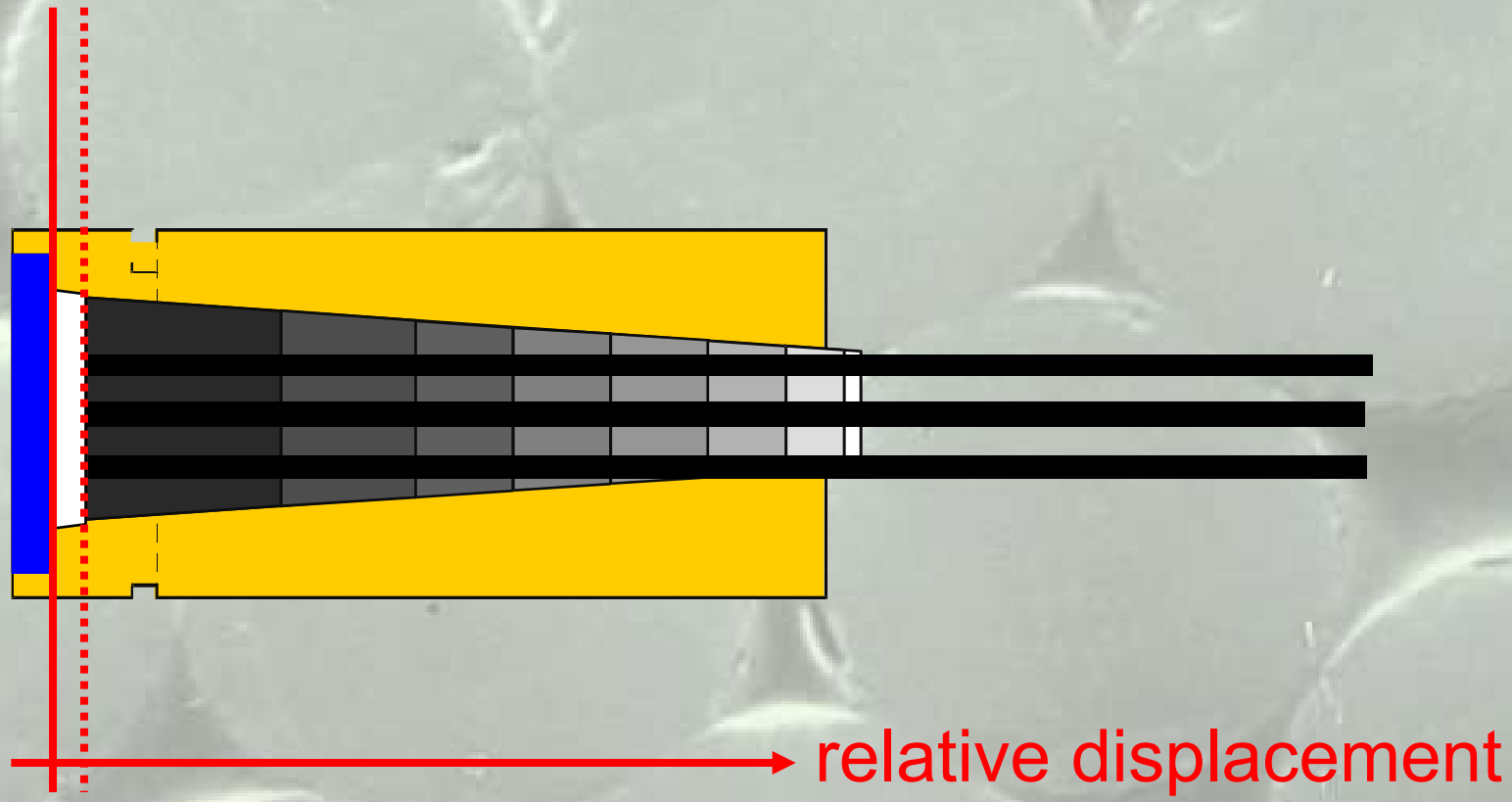
Desired radial pressure



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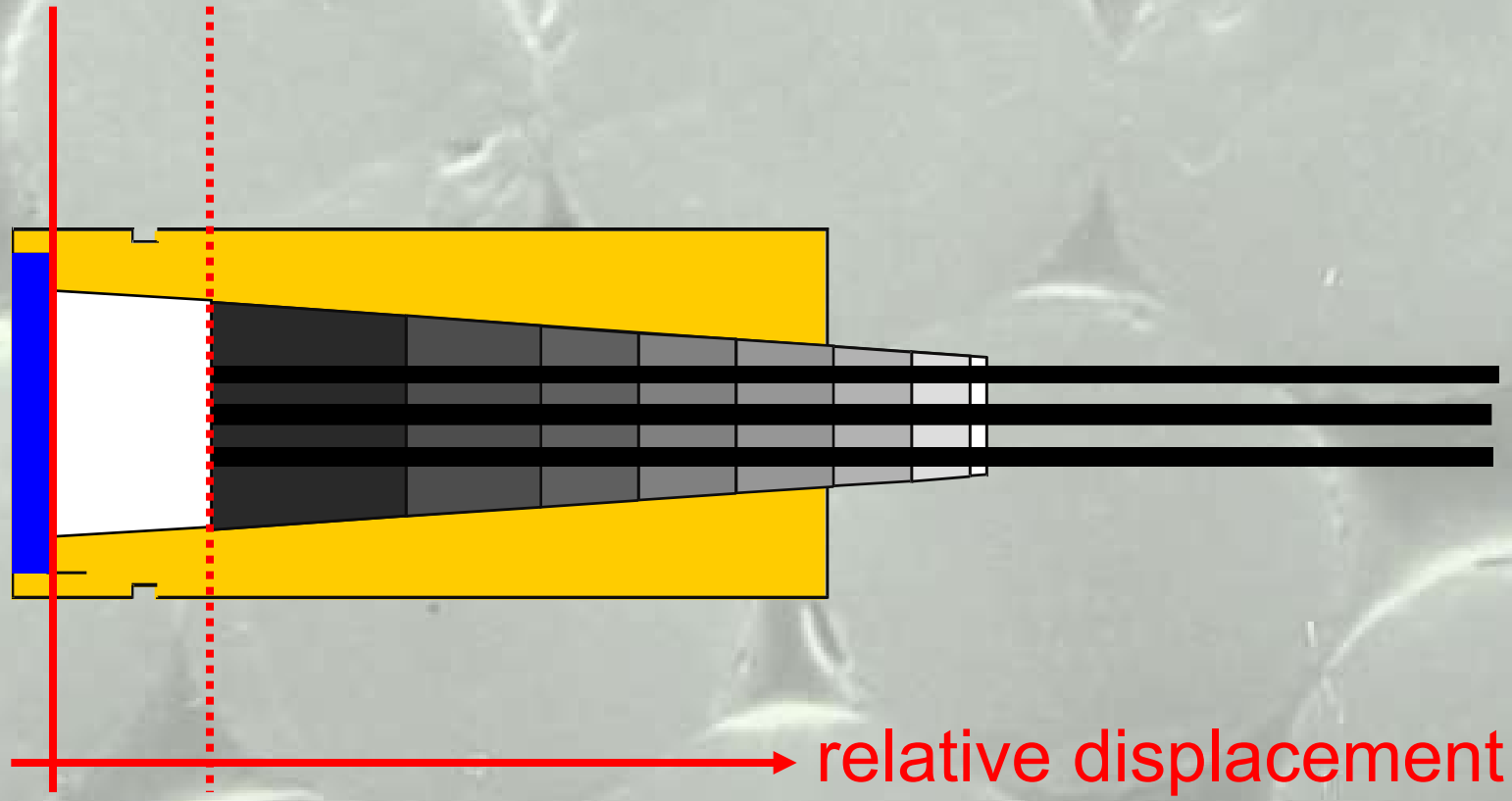
Danger of creep failure (pull-out)



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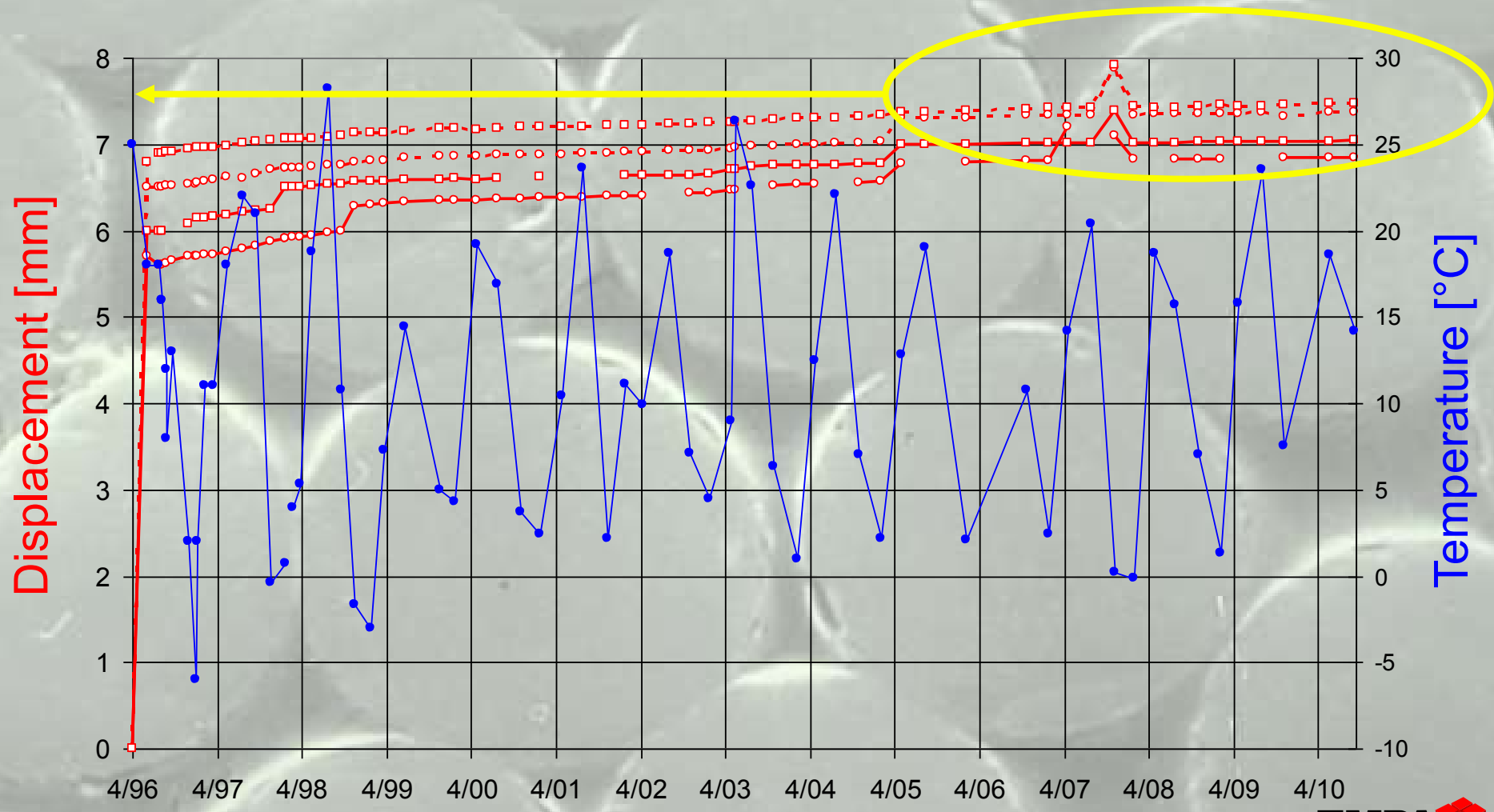
Stork Bridge, Winterthur



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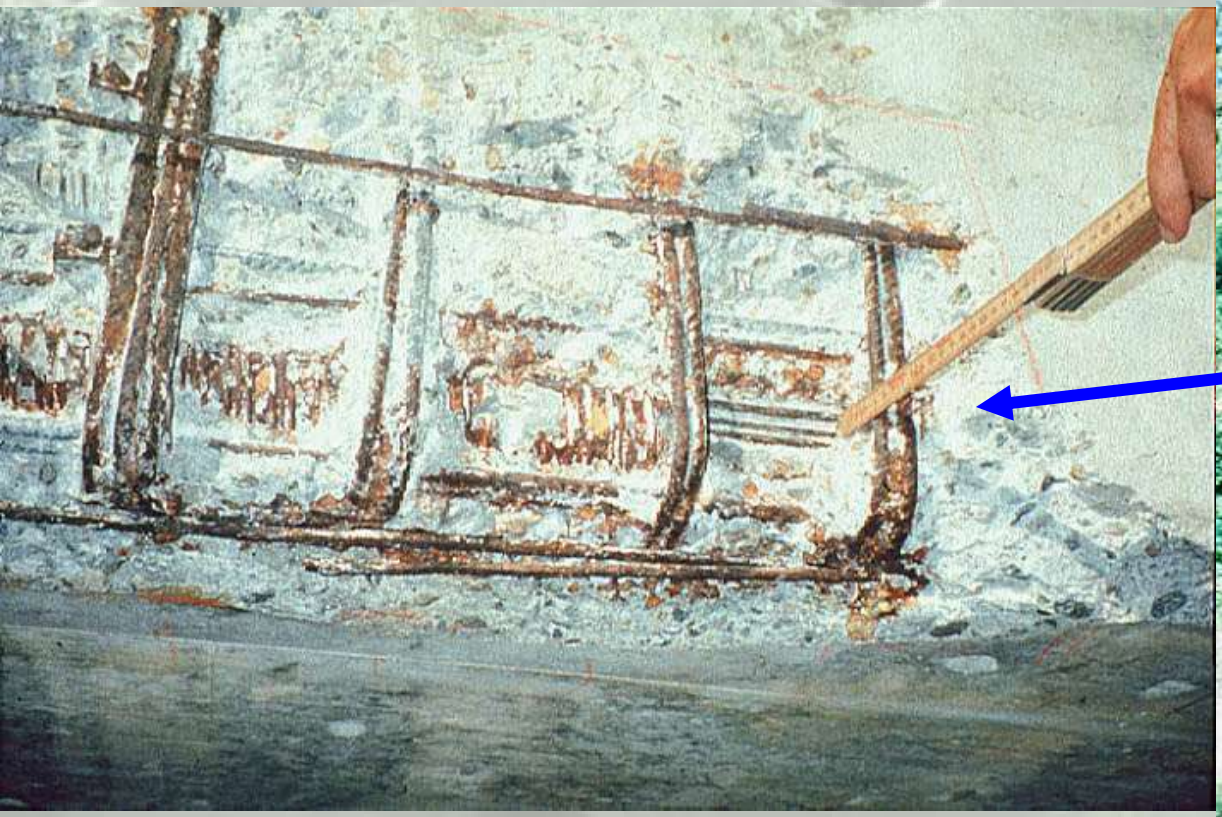
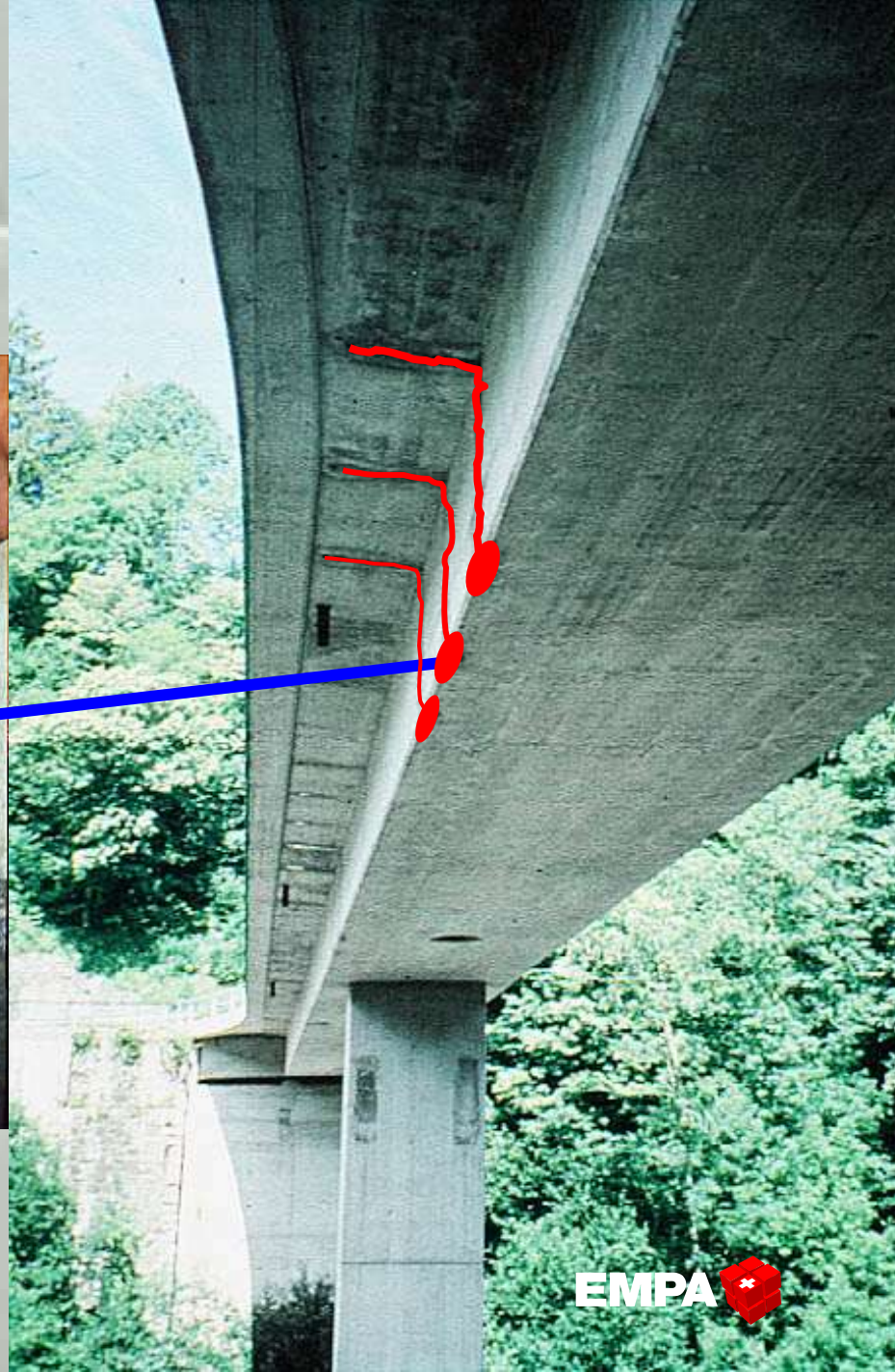
Verdasio Bridge: External post-tensioning
1998
post-tensioned RC
EMPA

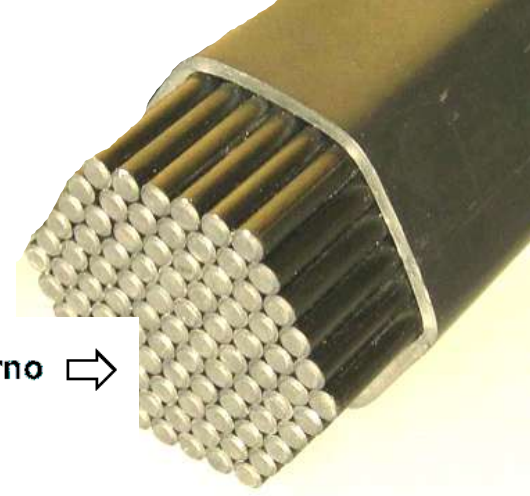
Verdasio Bridge

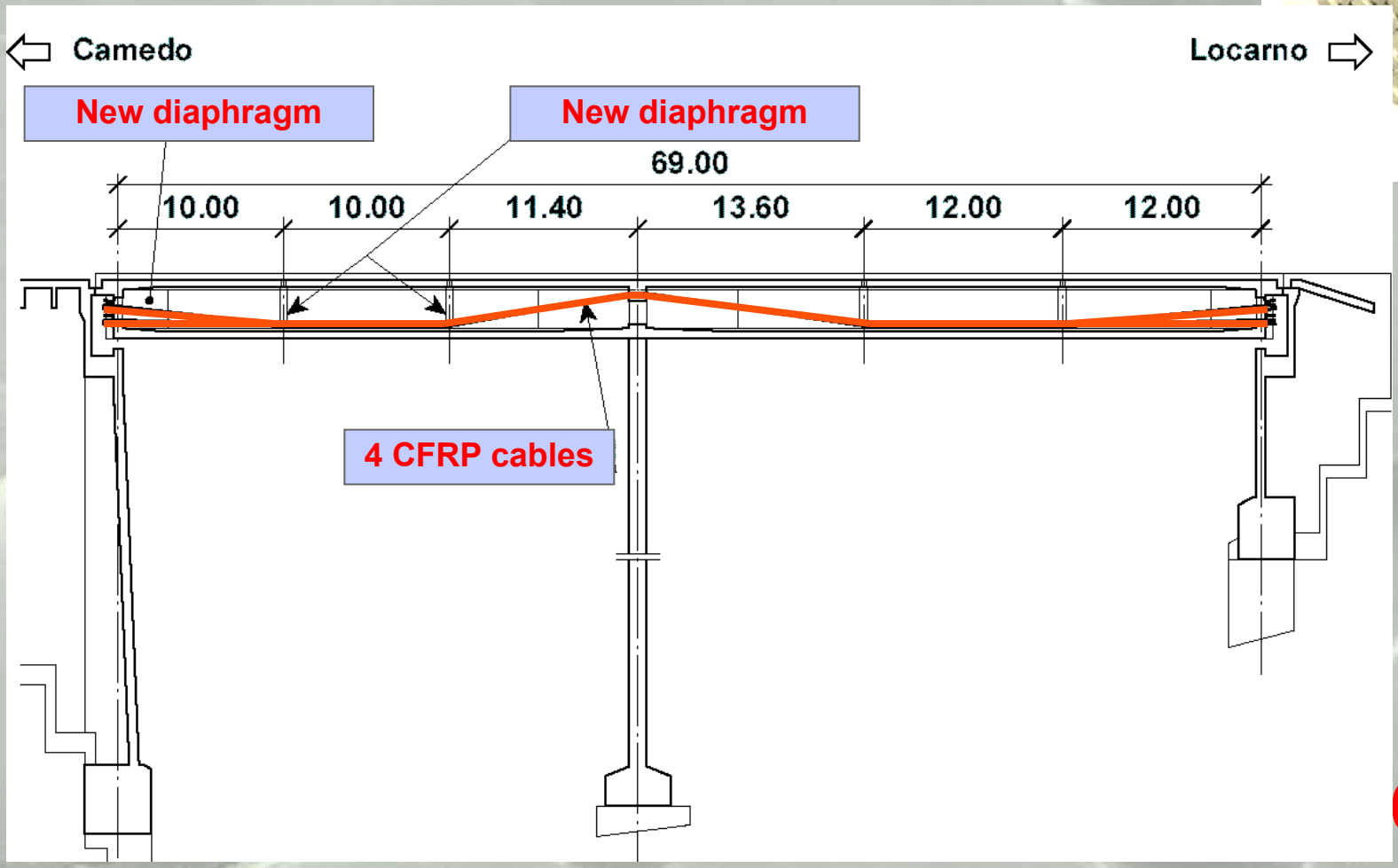


BBR Ltd, Zurich



Continuous 2-span girder





0 MPa

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Verdasio Bridge, inside Box Girder

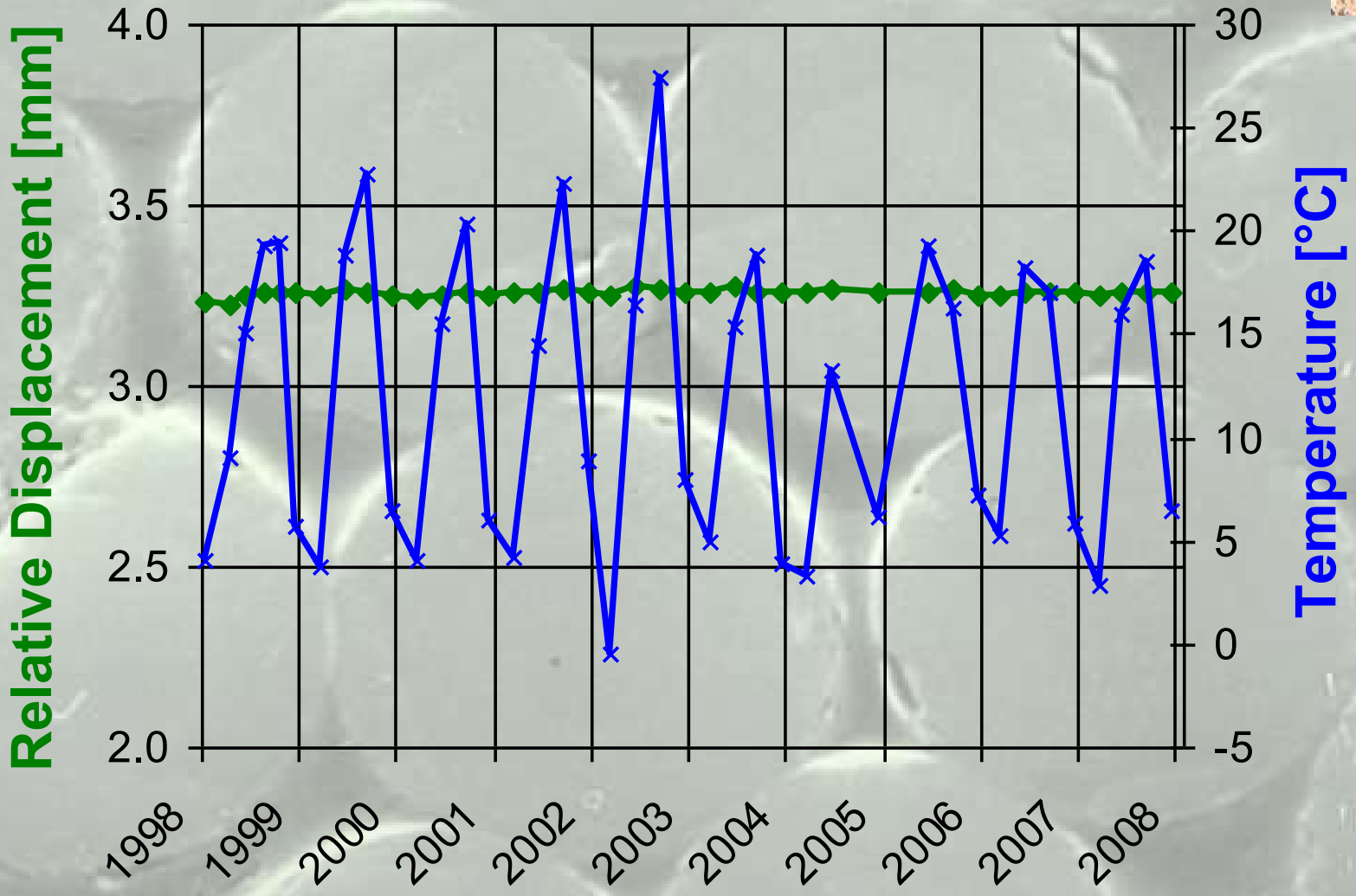
BBR Ltd, Zurich

EMPA

Verdasio Bridge

EMPA

Verdasio Bridge



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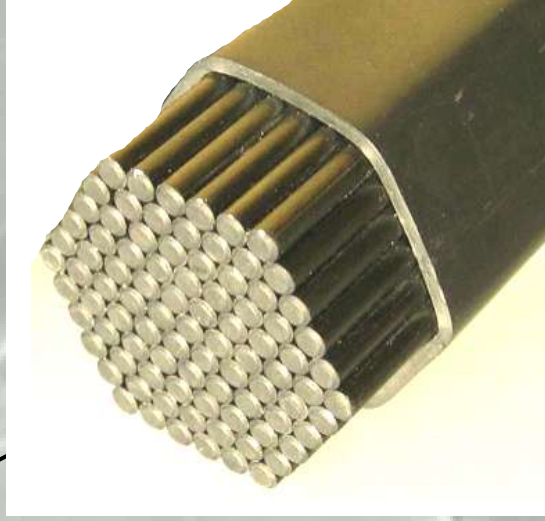
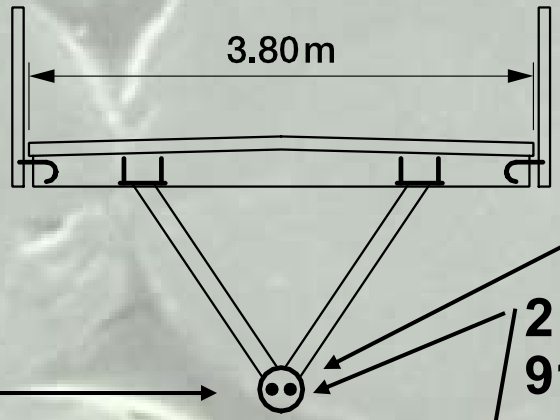
Bridge over the "Kleine Emme“ 1998



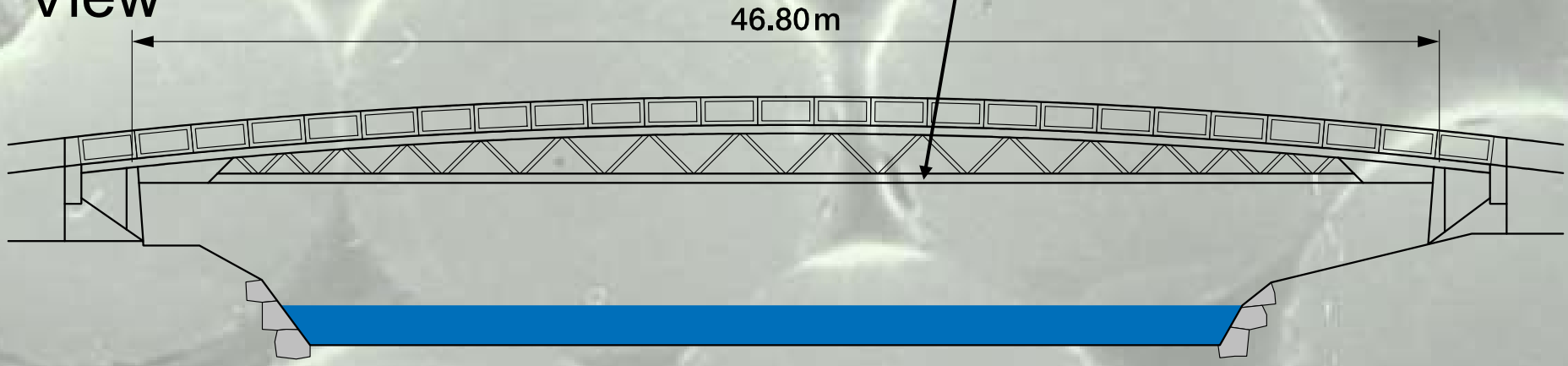
Cross section



total post-tensioning force = 4.8 MN

2 CFRP cables each of 91 wires of 5 mm diameter

View



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Bridge over the Kleine Emme

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Dintelhavenverkeersbrug 1999

Dutch Ministry of Transport and Public Works
Spanstahl BV, BBR, TNO, CUR R-Committee 97A

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Dintelhavenverkeersbrug 1999

4 CFRP cables each 91 wires ø 5 mm, length 75 m

Sustained stress 1480 MPa

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4 CFRP cables each 91 wires ø 5 mm, length 75 m

Sustained stress 1480 MPa

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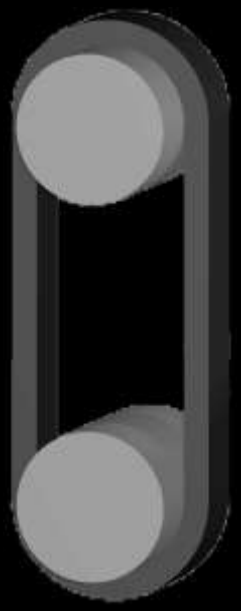
Too expensive anchorage system for tendons below 1 MN load capacity!

EMPA

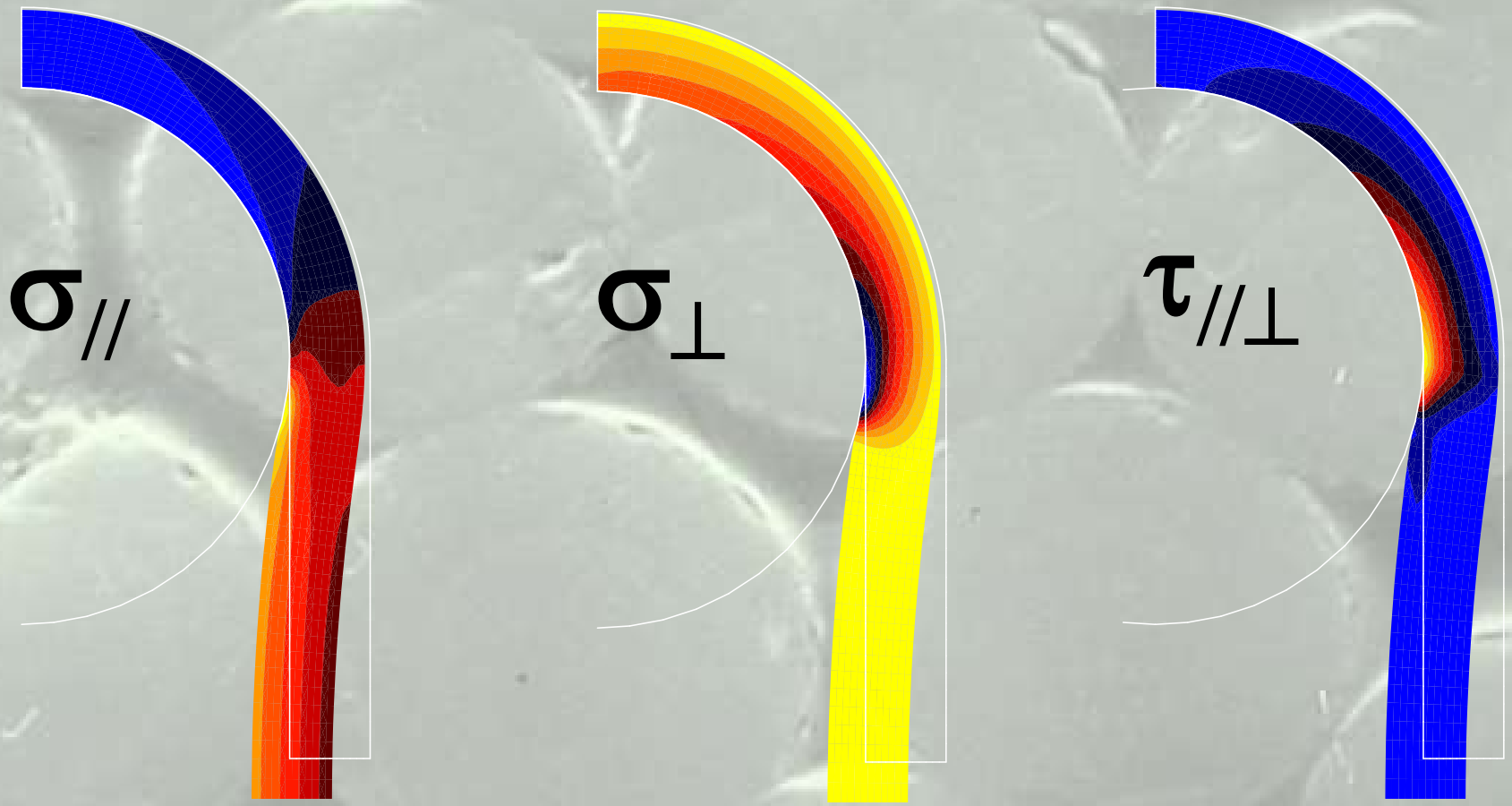
Alternative choice:

Laminated CFRP strap



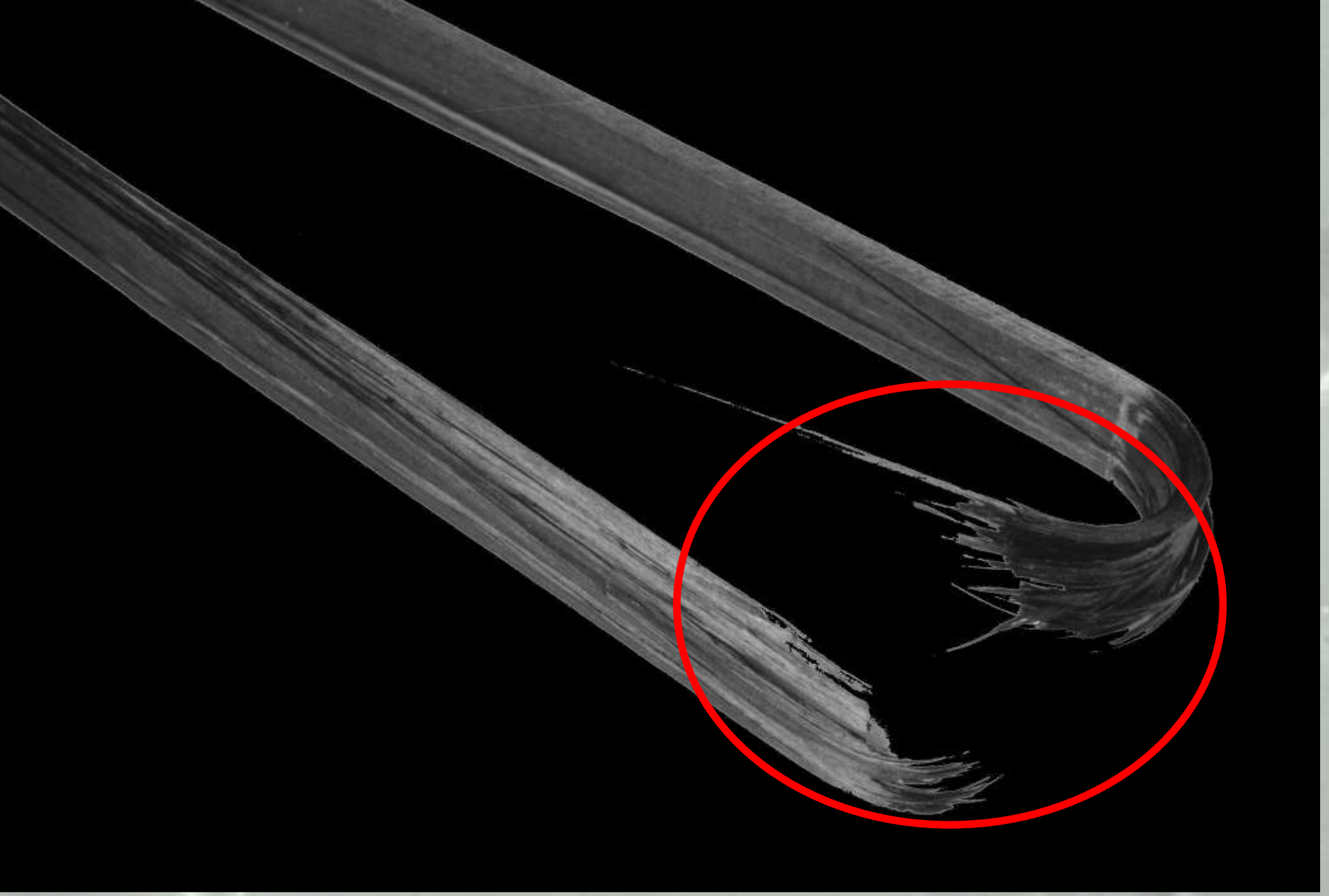
Pin loaded

Pin Loaded, laminated CFRP Strap

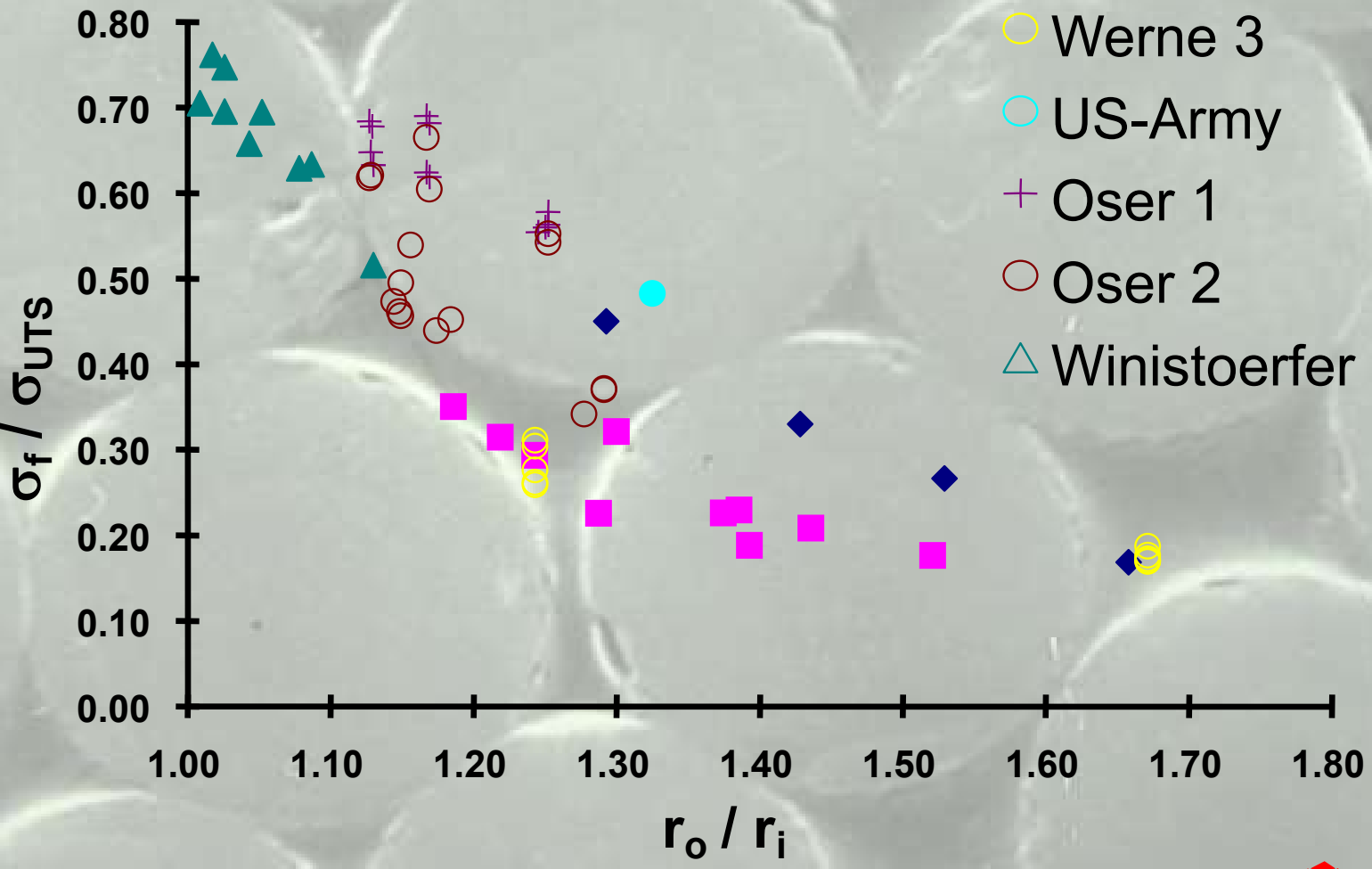


Dr. A. Winistörfer

EMPA



Relative strength vs. radii



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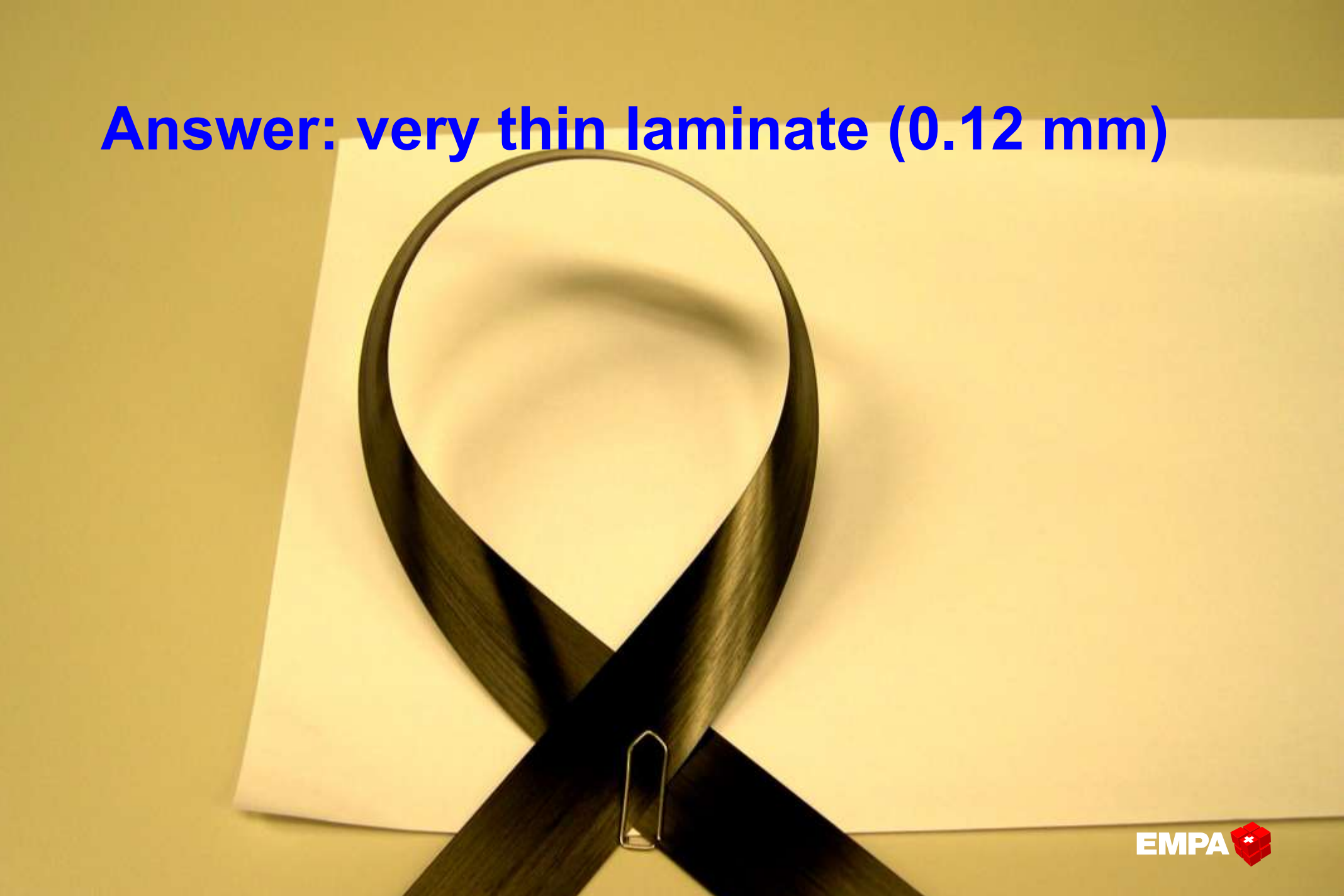
Answer: very thin laminate (0.12 mm)



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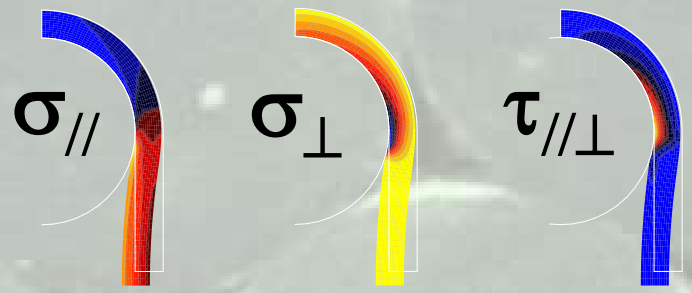
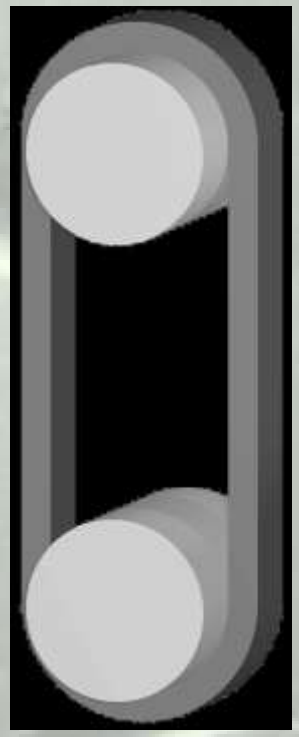
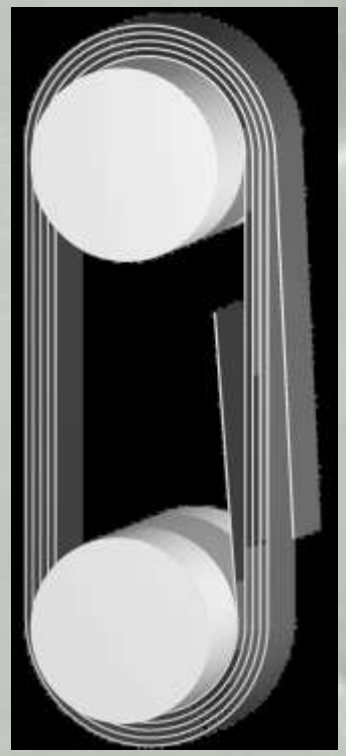




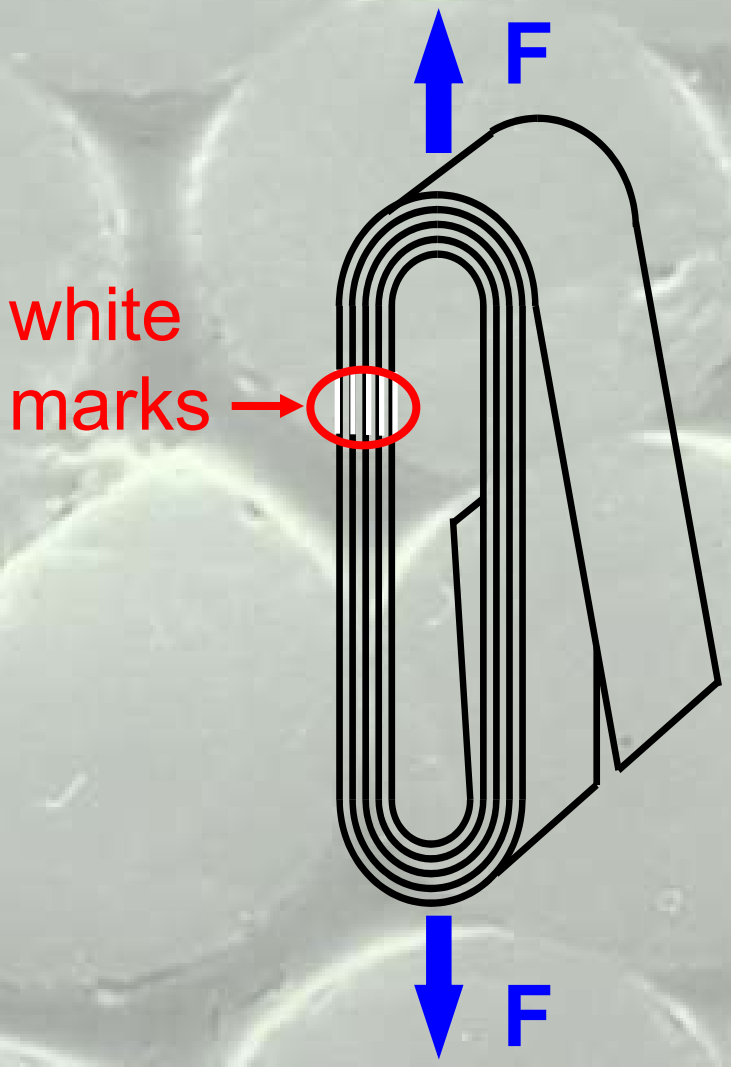
laminated

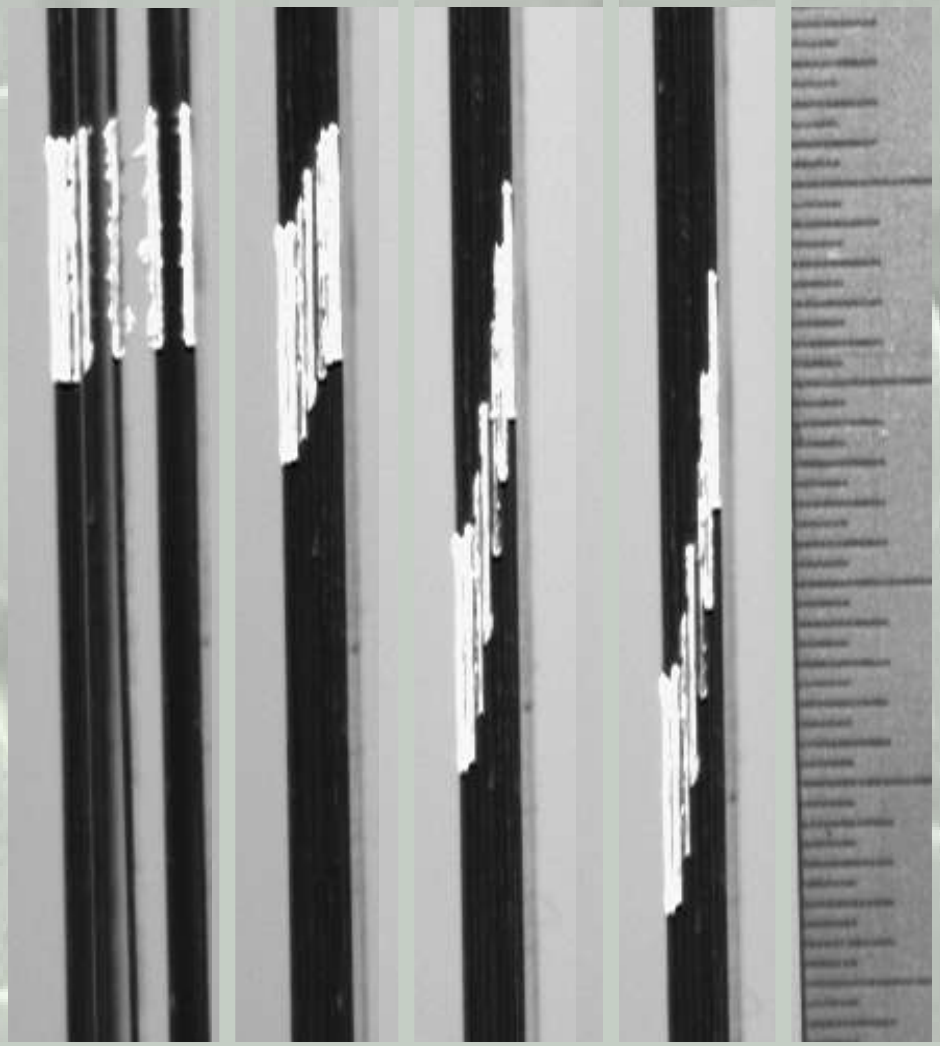


non-laminated

EMPA

Verification





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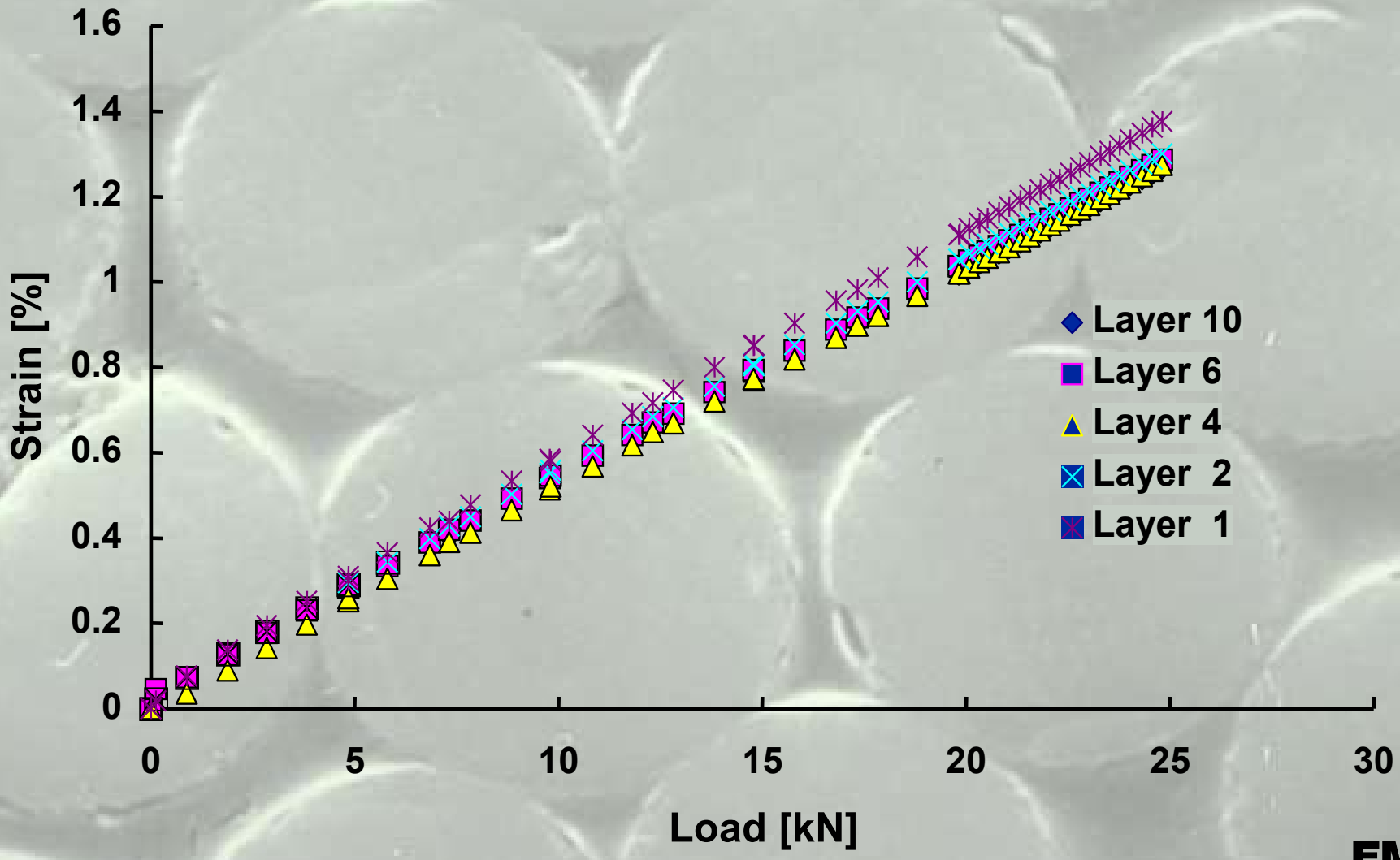
Verification



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3 MN Unit

A. Winistörfer

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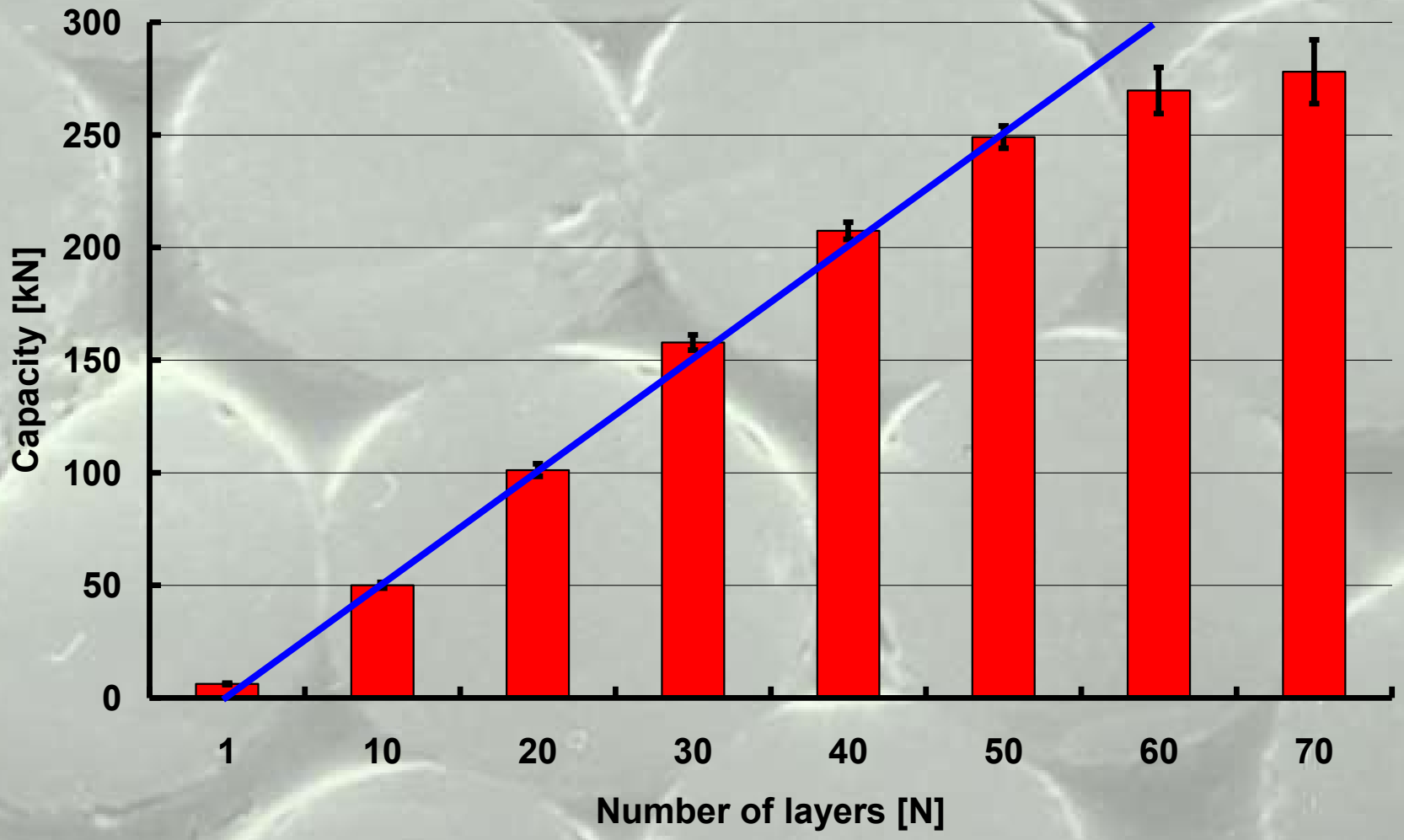
Efficiency



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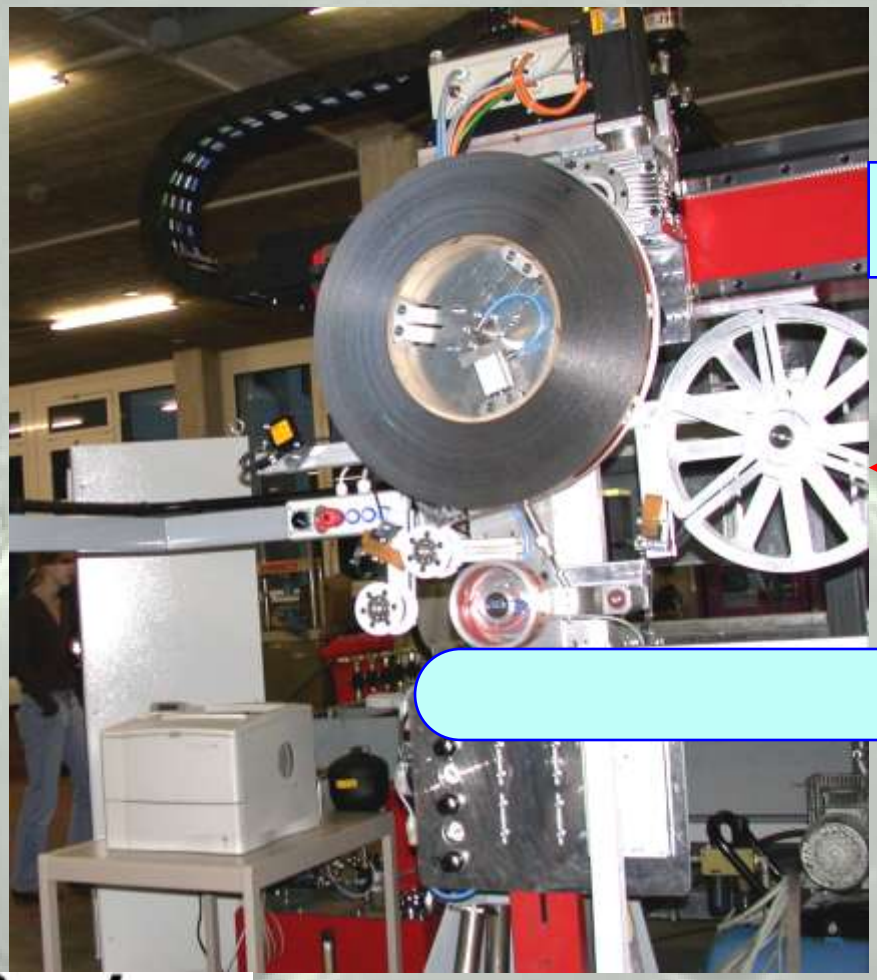
Production by tape laying machine



up to 48 m

Carbo-Link

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Creep experiments

Creep experiments

- 92 % of UTS since 7 years

After a first “consolidation” scarcely no more creep

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First applications

Carbo -Link

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Carbo
-Link

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Cable dredger

Carbo -Link

America's Cup Winner 2007 in Valencia Alinghi with Pin Loaded CFRP-Stays

Carbo
-Link

Dr. Adreas Winistörfer

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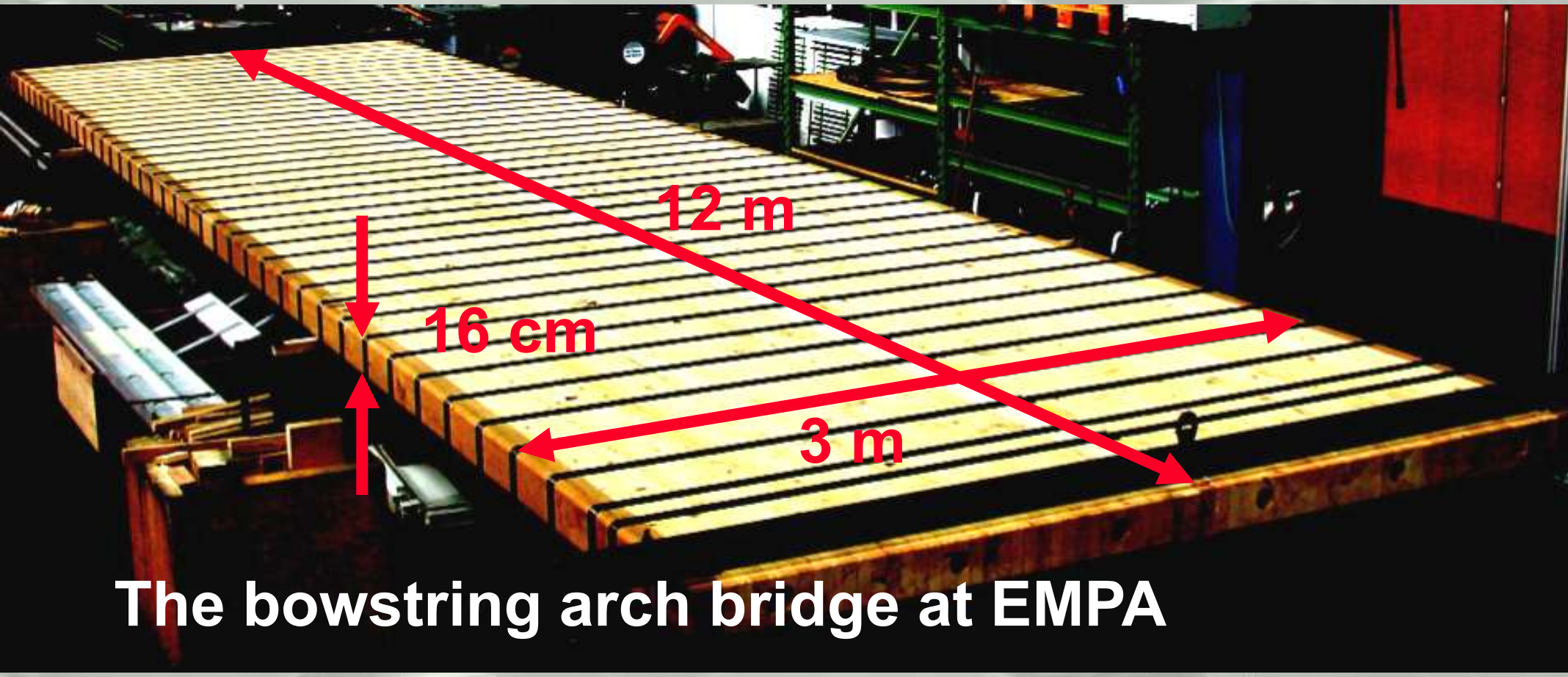
Pin loaded CFRP tendons



The bowstring arch bridge at EMPA

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Wooden spacers between Glulam and GFRP

Pin loaded CFRP tendons

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Pin loaded CFRP tendons

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Pin loaded CFRP tendons

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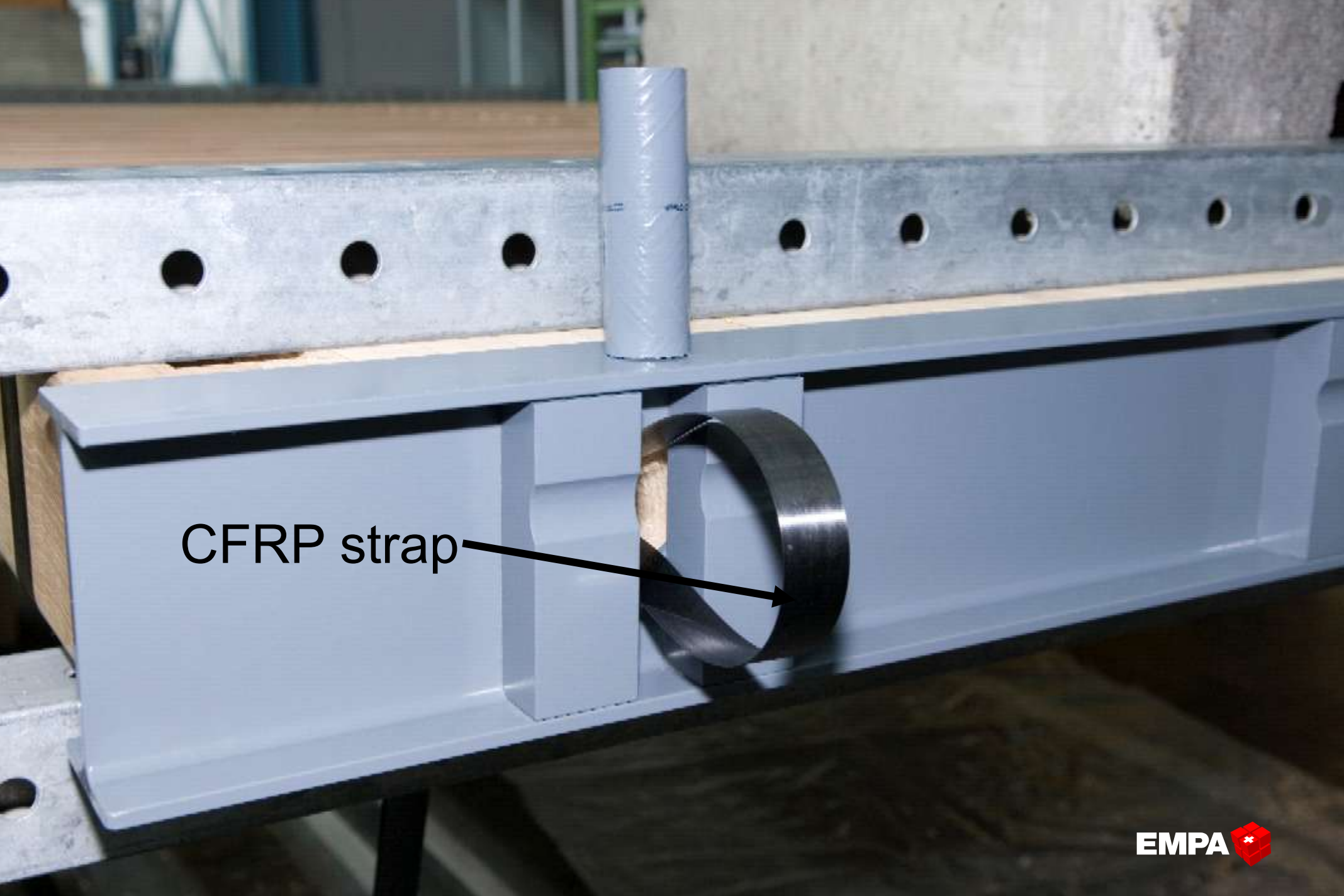
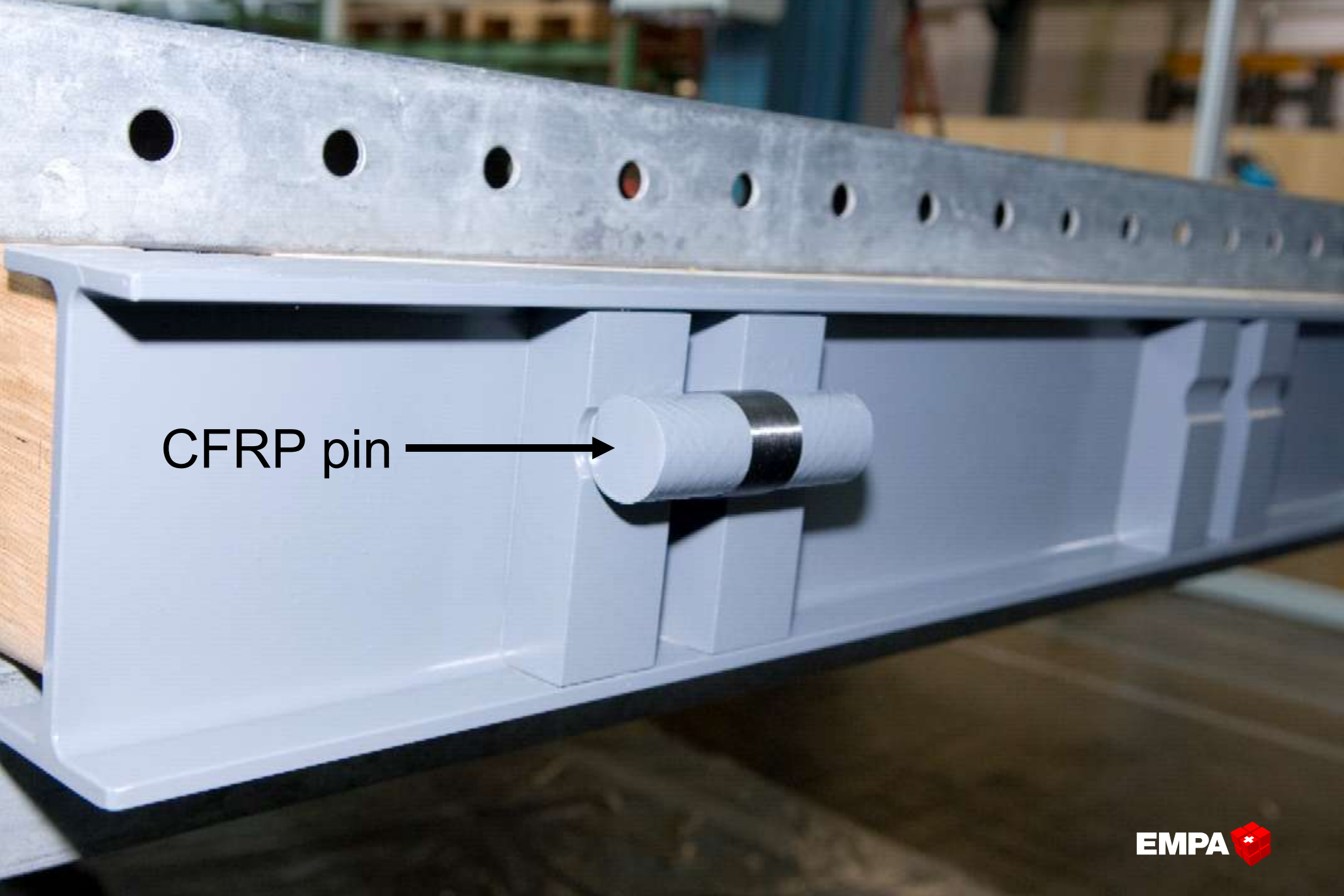

CFRP strap


CFRP pin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Pin loaded CFRP tendons

Now there is an umbrella needed!


GFRP Deck
8 mm thick
Space

Pin loaded CFRP tendons

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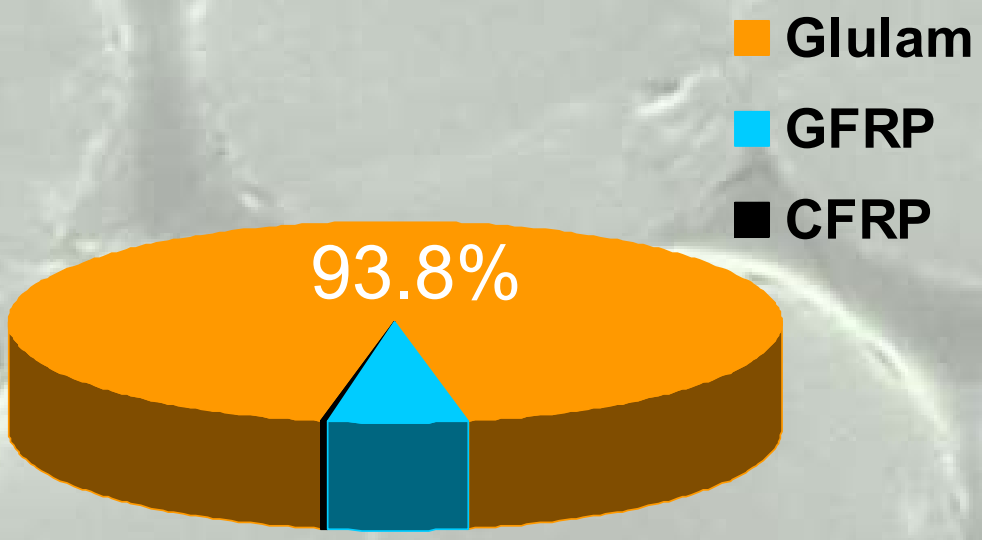
GFRP deck leaks


Silicone sealant leaks
GFRP deck
GFRP post

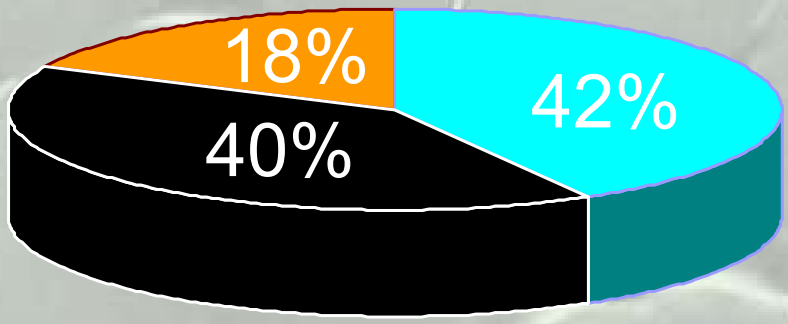
Volume versus Cost

Volume



0.3% 5.9%

Cost



CFRP	GBP 17‘000
GFRP	GBP 18‘000
Glulam	GBP 7‘800

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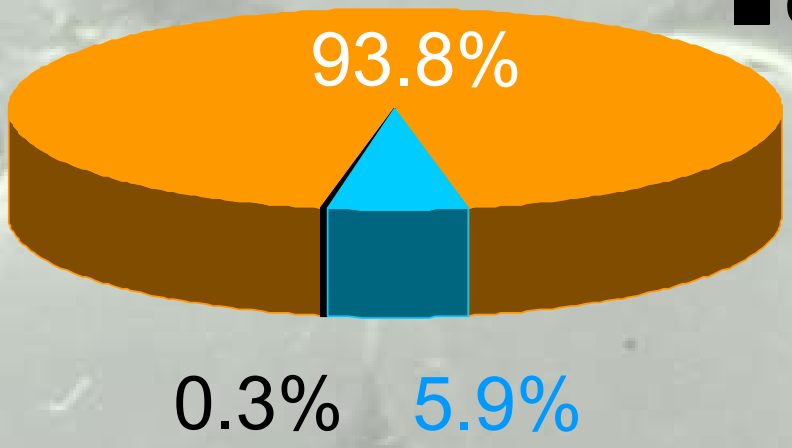
CO_2-Footprint

Volume



- **Glulam** negative!
- **GFRP** unknown, less considerable
- **CFRP** unknown, however considerable

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20 Years of Field experience proof that

- CFRP is a very reliable material in construction.
- In rehabilitation CFRP is in many cases the technically best suited and most economical solution.
- New construction: as long as not the whole lifecycle of a bridge is considered it is not economical.

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State-of-the-art?

- stay cables
- suspender (hanger) cables

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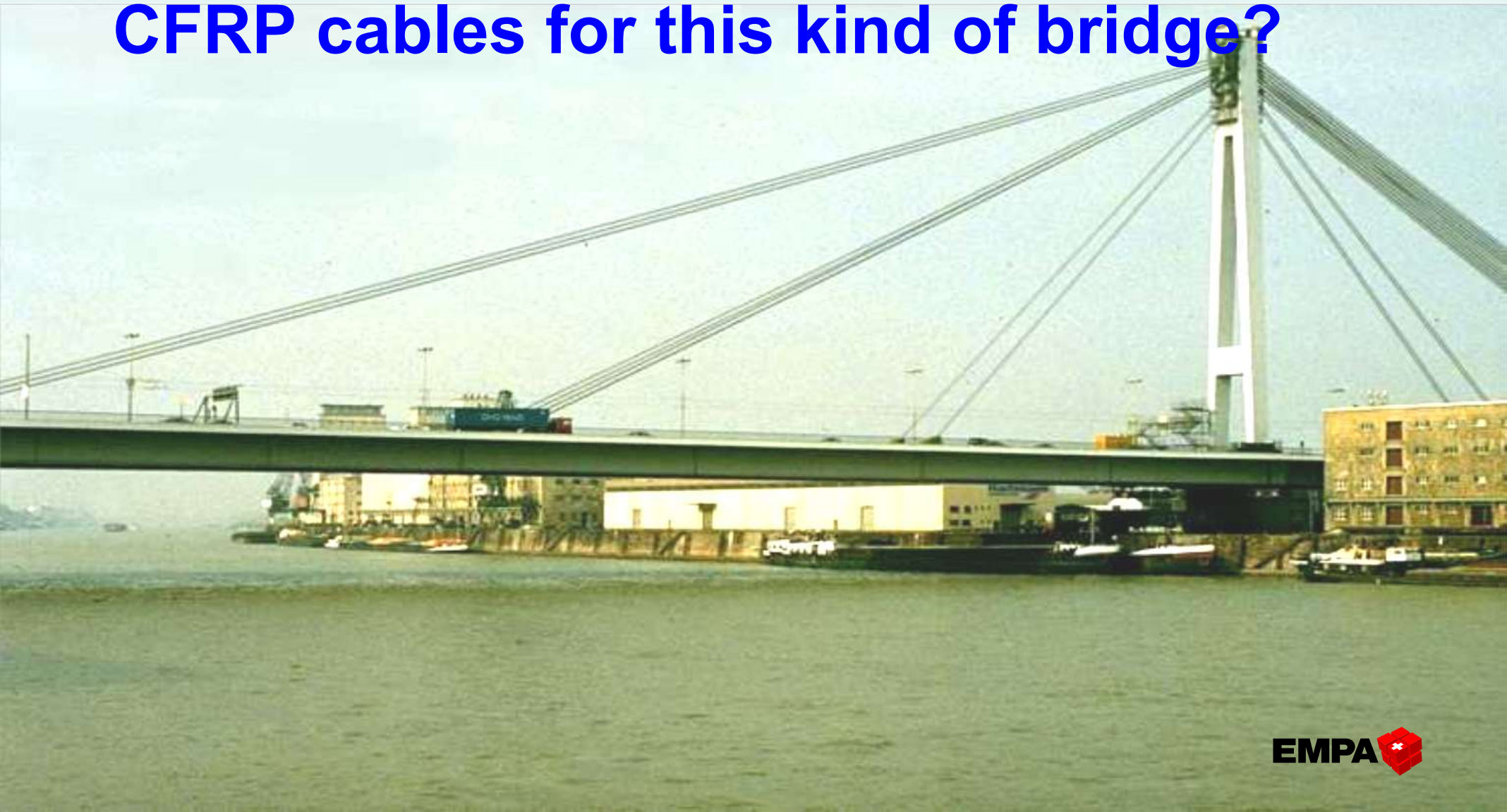
What if we get to-morrow a contract for CFRP cables for this kind of bridge?



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Yes we can immediately!

What if we get to-morrow a contract for CFRP suspenders for this bridge?

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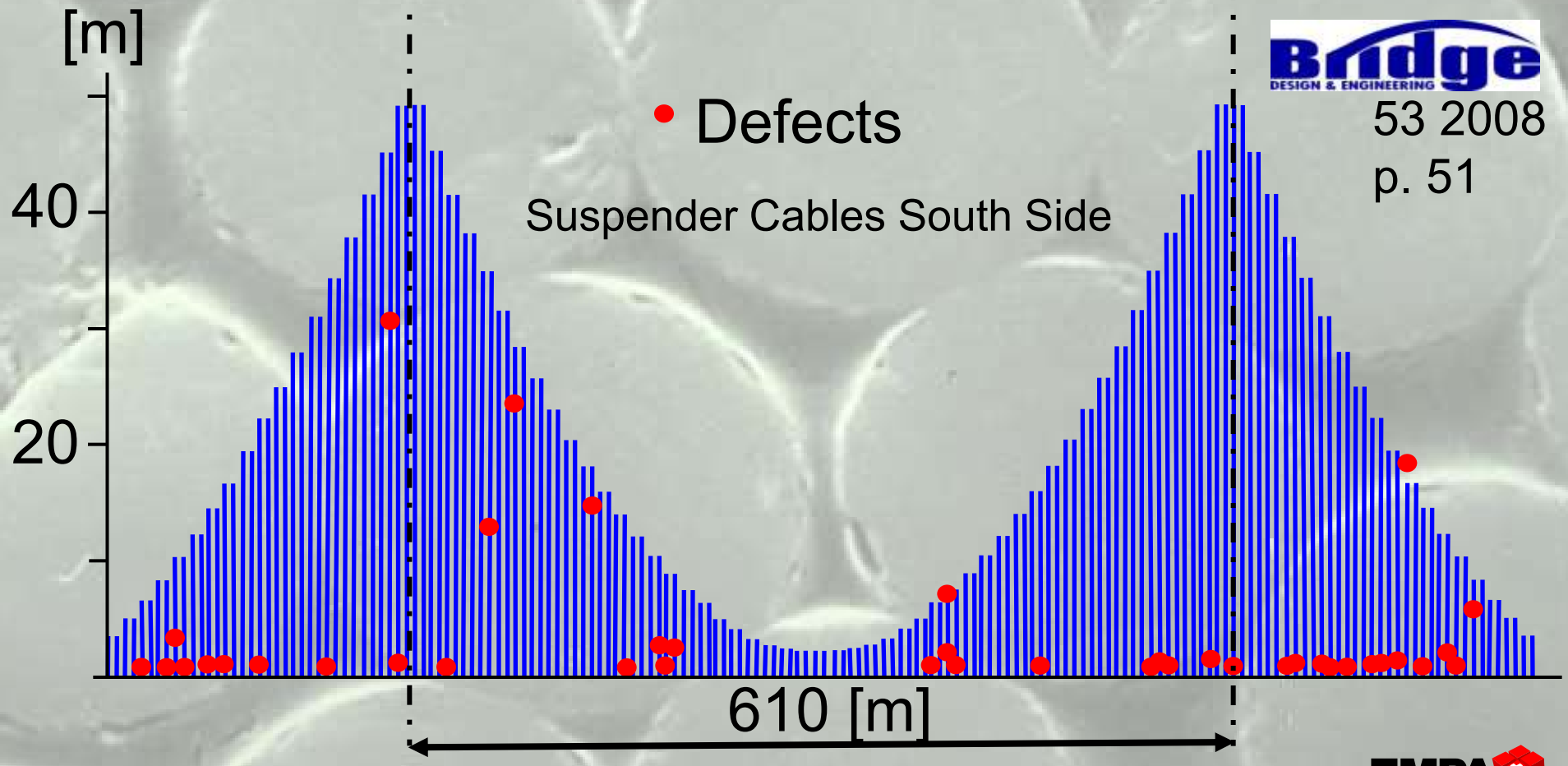
What if we get to-morrow a contract for CFRP suspenders for this bridge?



Bridge DESIGN & ENGINEERING
53 2008
p. 51

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Yes we can immediately!

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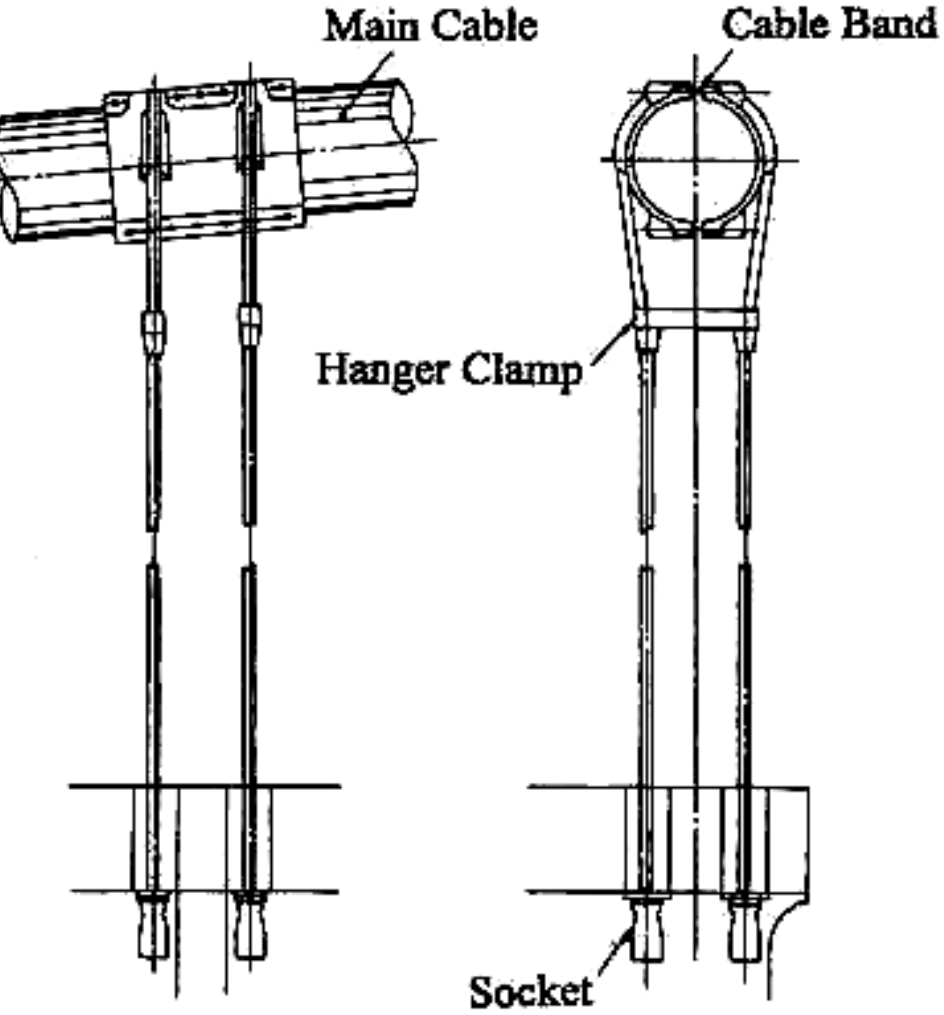
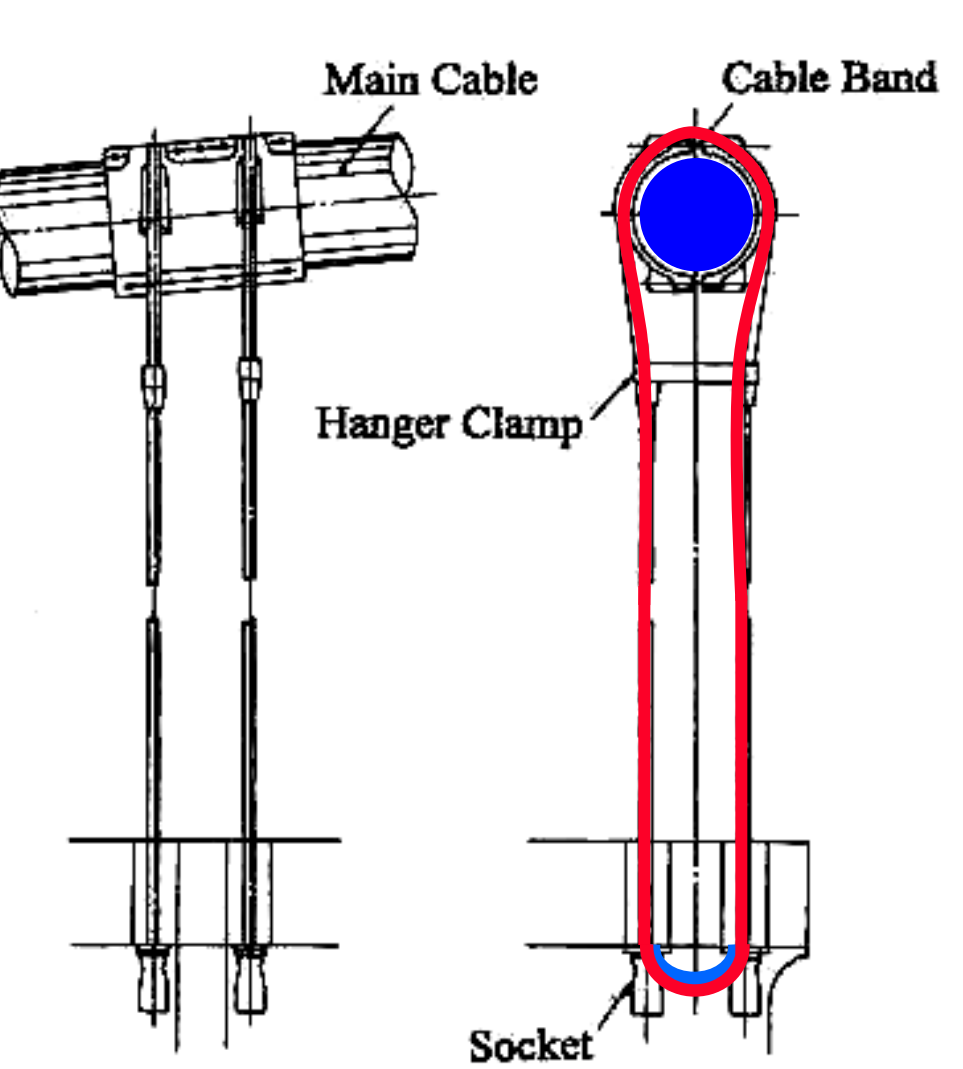
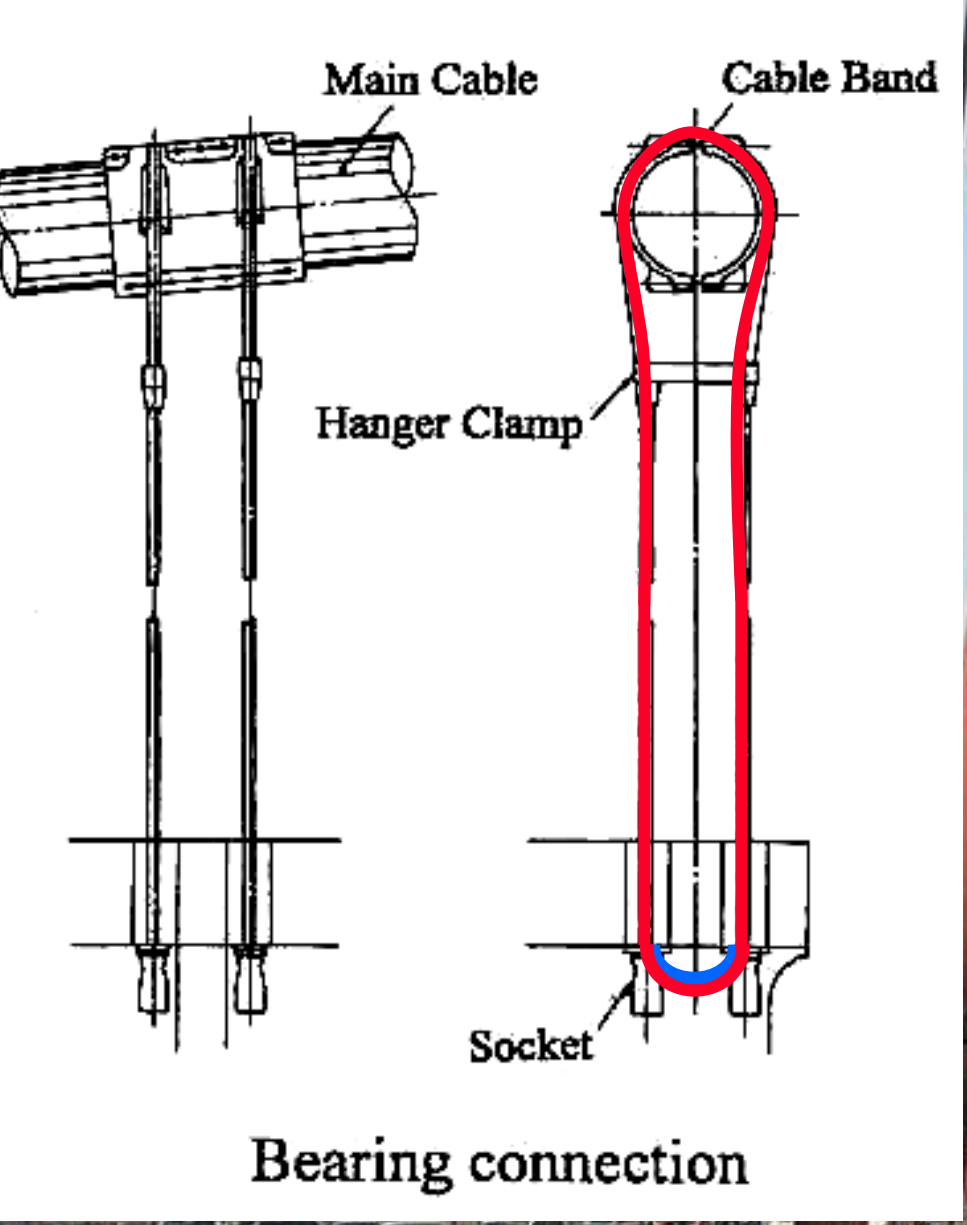
Hanger
Bearing
connection



Bearing connection

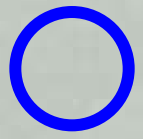


Bearing connection



Bearing connection

On site fabrication of bearing connection



main cable

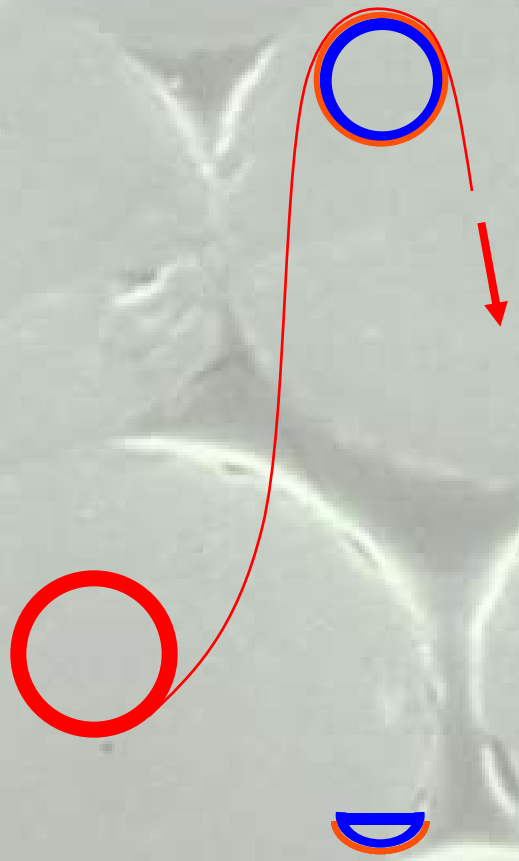
saddle

On site fabrication of bearing connection

wrap PTFE foil

wrap PTFE foil

On site fabrication of bearing connection



thread in
CFRP tape

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On site fabrication of bearing connection

thread in
CFRP tape

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On site fabrication of bearing connection

Adhere closed loop (temporary)

On site fabrication of bearing connection

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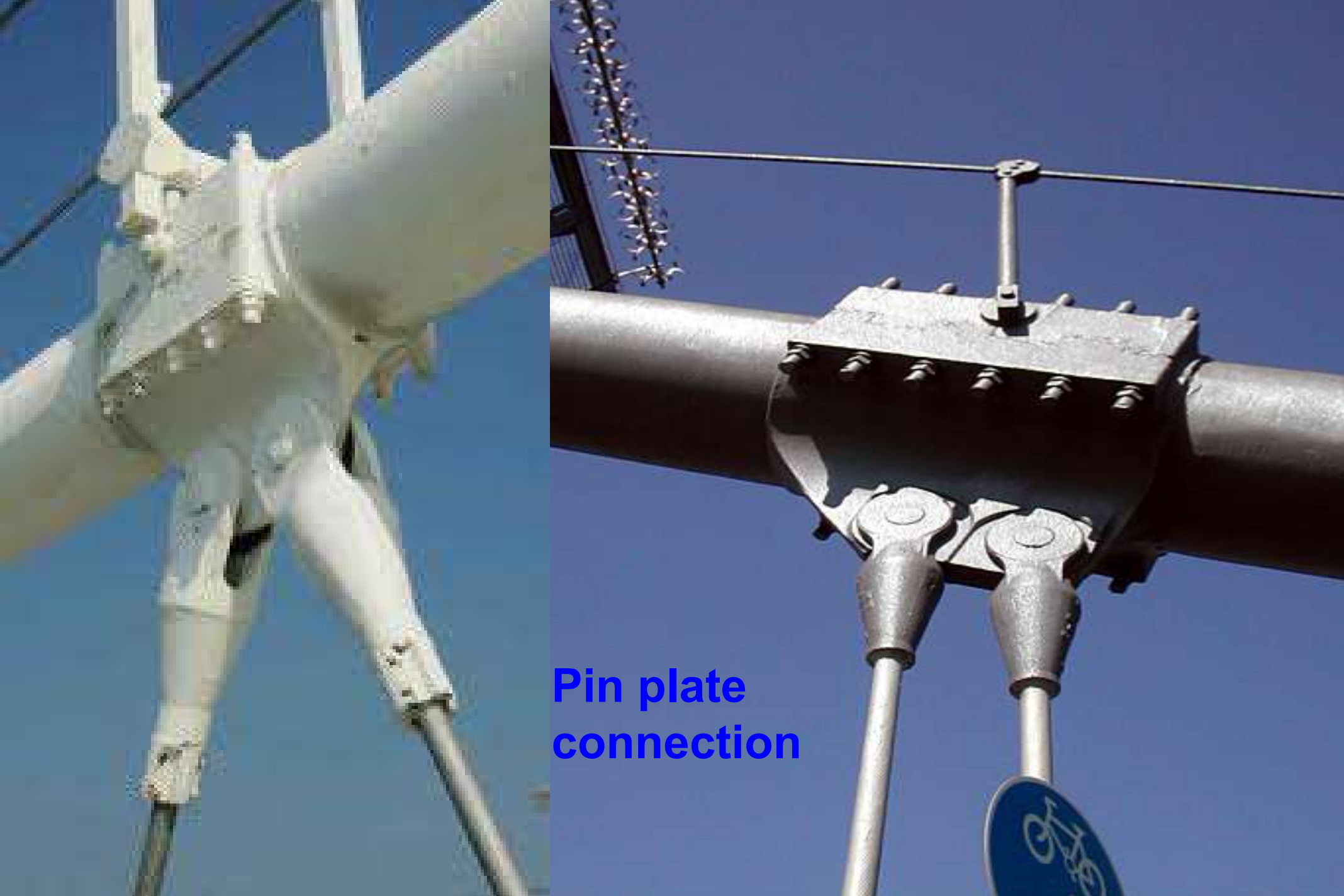
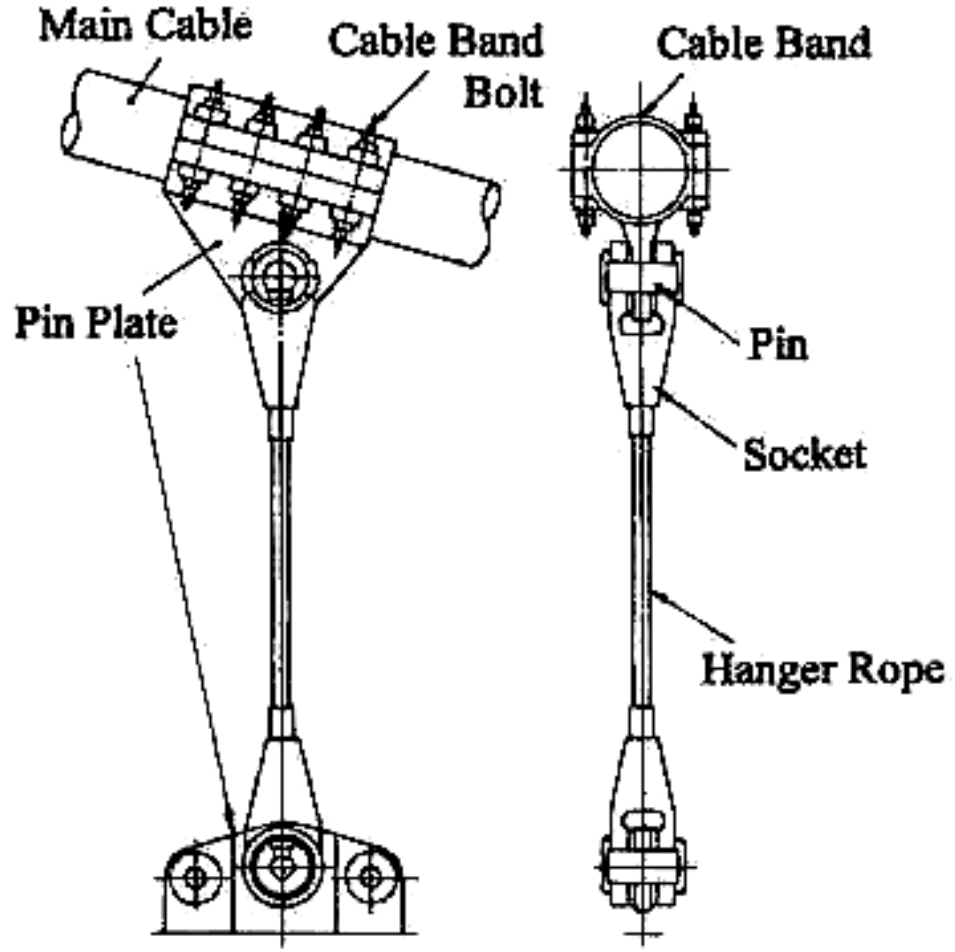
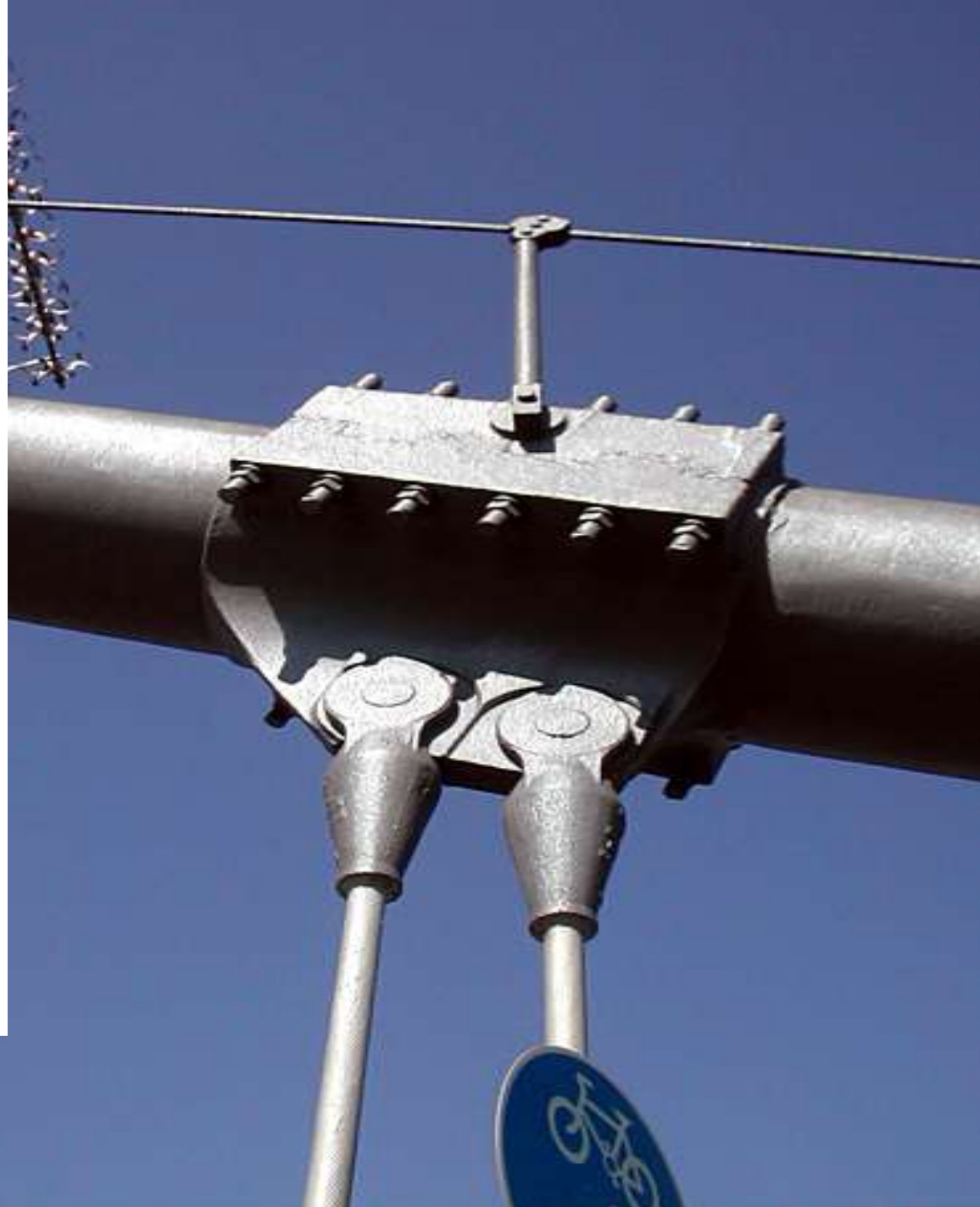
On site fabrication of bearing connection


Pin plate
connection



Pin plate connection



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Loss of a high percentage of cross section of main cables due to corrosion

Forth Road

Bronx Whitestone

and many others!

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What if we get to-morrow a contract for CFRP main cables for such a bridge?

Forth Road

Bronx Whitestone

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We cannot! We need more R&D

Problem: lateral stresses over the saddle

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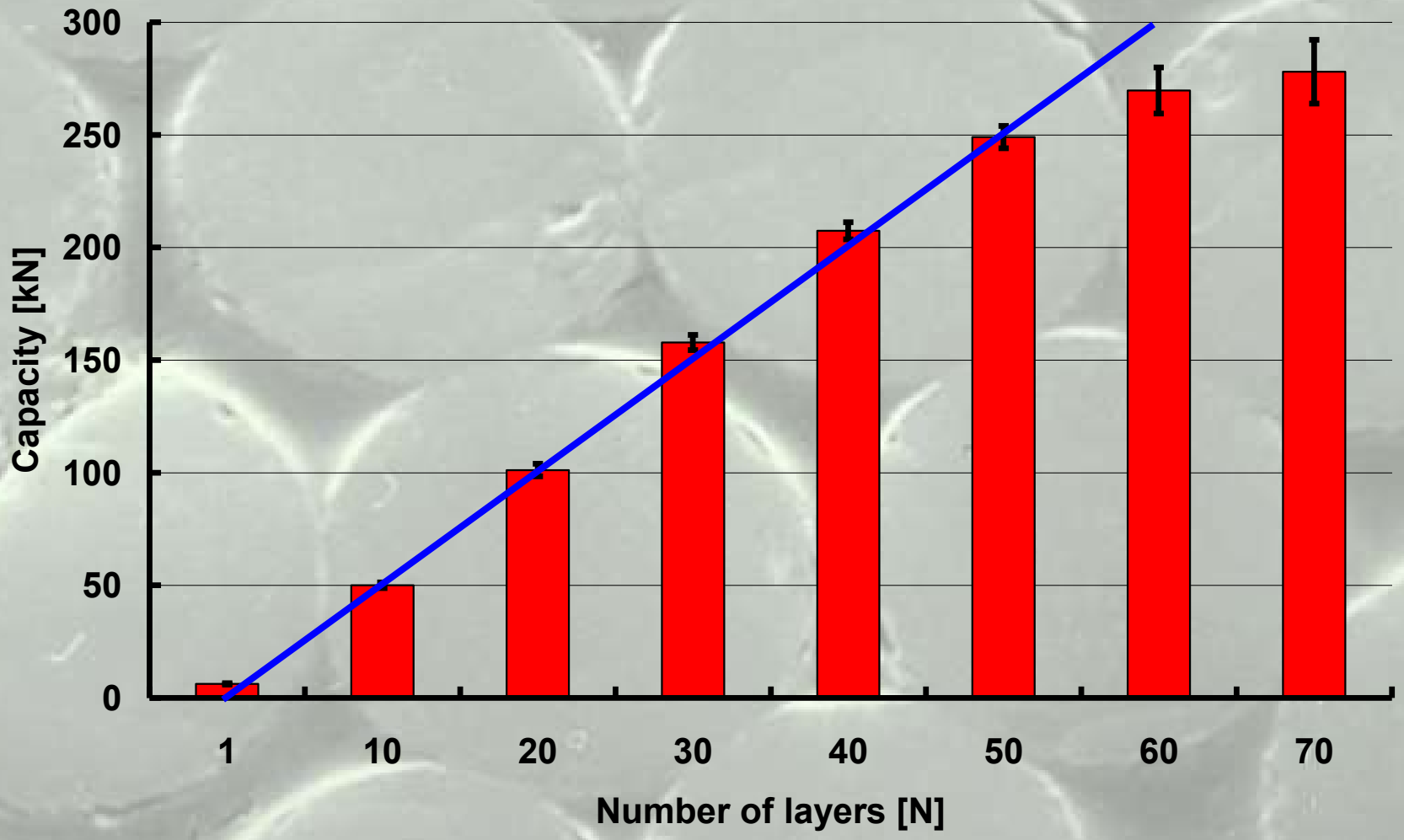
Remember: efficiency



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Future Needs

- R&D:
  - solution for saddles for main cables
  - solution for saddles for stay cables
  - development of CFRP anchorage socket

- Applications to build up confidence:
  - suspender cables
  - stay cables

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Visions for the Strait of Taiwan

Acad. Lin Yan Pei
Presentation at
Bridge Tech 2010 in
Shanghai

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A Vision for a Suspension Bridge across the Strait of Taiwan with a Main Span of 3500 m

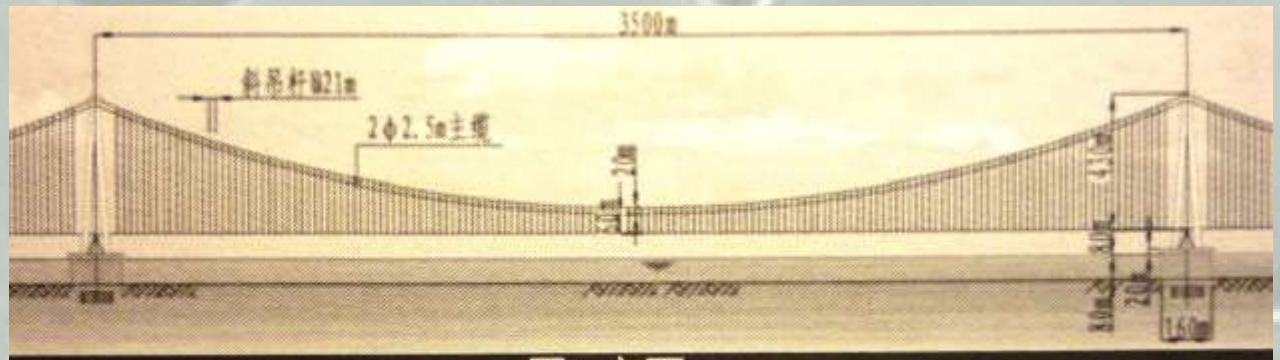


图1 立面

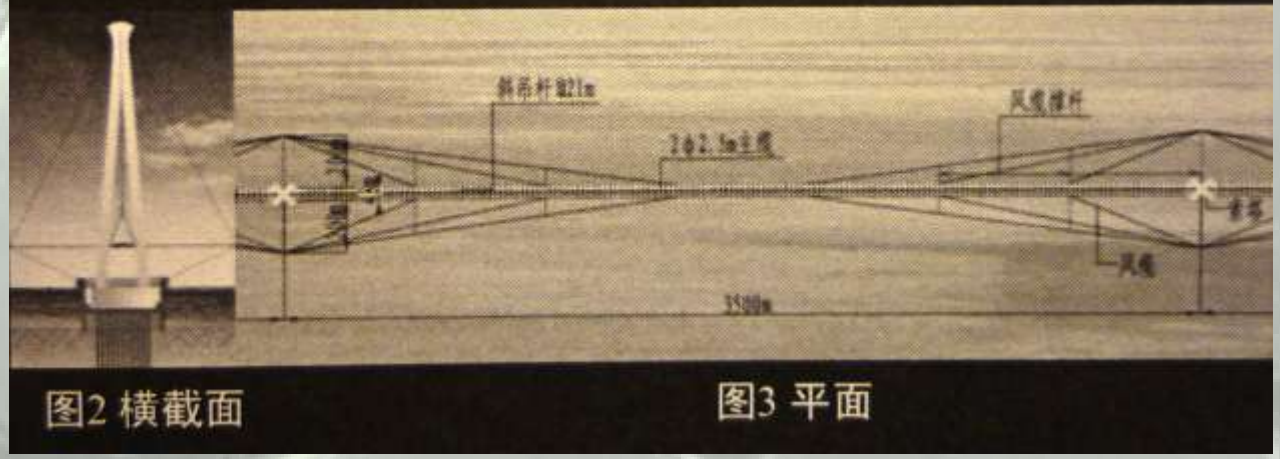
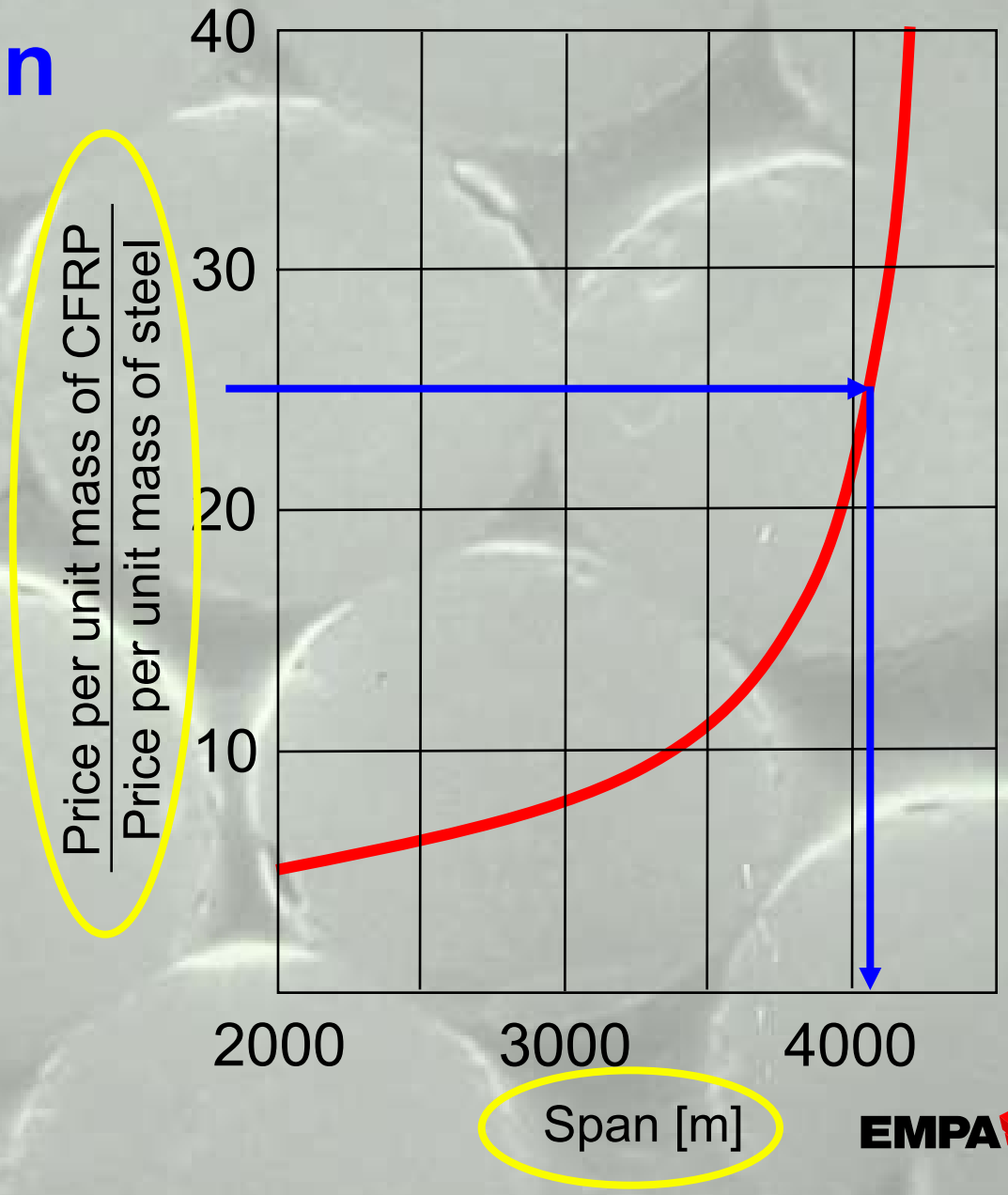


图2 横截面　　图3 平面

Break-Even Span for New Suspension Bridges

Break-even is a point where any difference between plus or minus changes side



“Break even span”
(analogous to the “break even point”)

Most economic materials for very long span bridges not considering maintenance:

span < 4000 m → steel

span > 4000 m → CFRP

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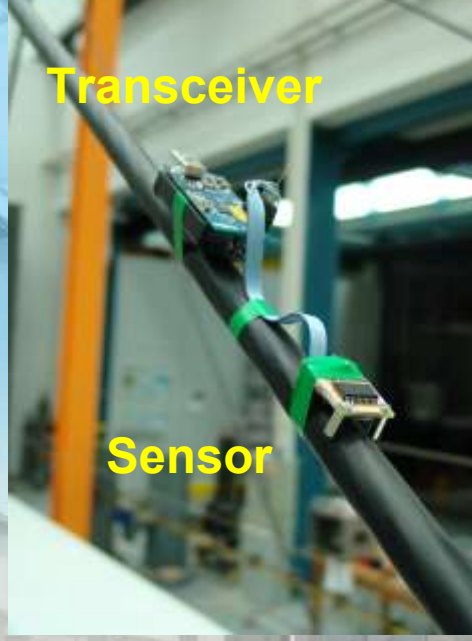
Research platform FRP bridge



Wireless Sensor

Goal: oscillation mitigation of light-weight bridges

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- Ciba-Geigy AG
- Kommission für Technologie und Innovation (KTI)
- Stahlton AG
- BBR VT International Ltd
- Stesalit AG
- Cellpack AG
- Kanton Luzern
- Sika Schweiz AG
- S & P Clever Reinforcement AG
- Stadt Winterthur
- Winterthur Versicherungen
- Sacac Schleuderbetonwerk AG
- Ingenieurbüro Kempe GmbH
- Sulzer Innotec AG
- Dr. Deuring + Oehninger AG
- Carbo-Link GmbH
- Fiberline Composites A/S
- Maagtechnic AG

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EMPA co-workers and students involved (chronological)

- Urs Meier
- Stephan Lingenhel
- Hanspeter Kaiser
- Heinz Meier
- Patrick Kim
- Thanasis Triantafillou
- Nikola Deskovic
- Masoud Motavalli
- Martin Deuring
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- Christa Jordi
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- Andreas Langenegger
- Michael Roth
- Tobias Huber

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Dr. Janet Lees, University of Cambridge

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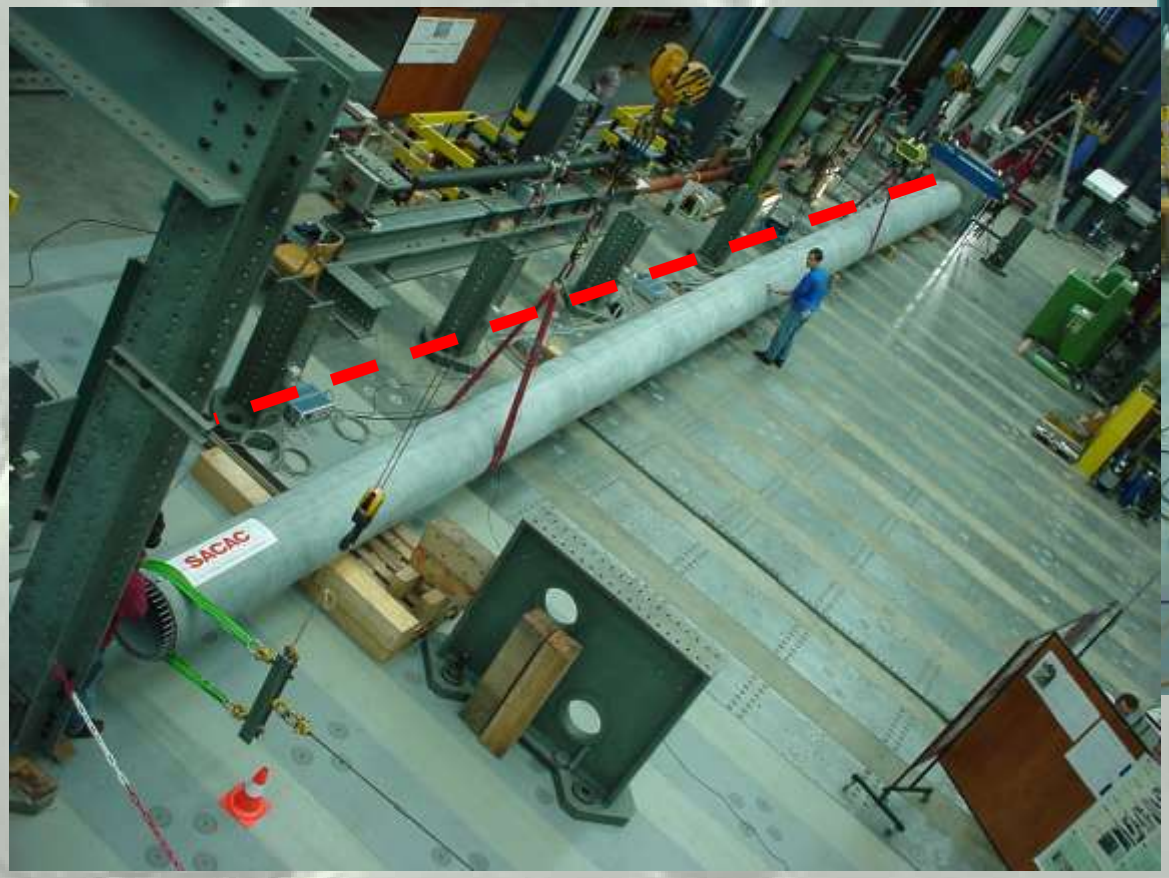
Flexural testing



Dr. Giovanni P Terrasi

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Made with Pre-tensioned CFRP
10 km CFRP wires
Giovanni P Terrasi / SACCAC
EMPA

Made with Pre-tensioned CFRP

19 km CFRP wires

Giovanni P Terrasi / SACCAC

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Thank you very much for your attention

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