Fibre Composites in Structural Engineering

ETHZ Course No. 101-0167-01

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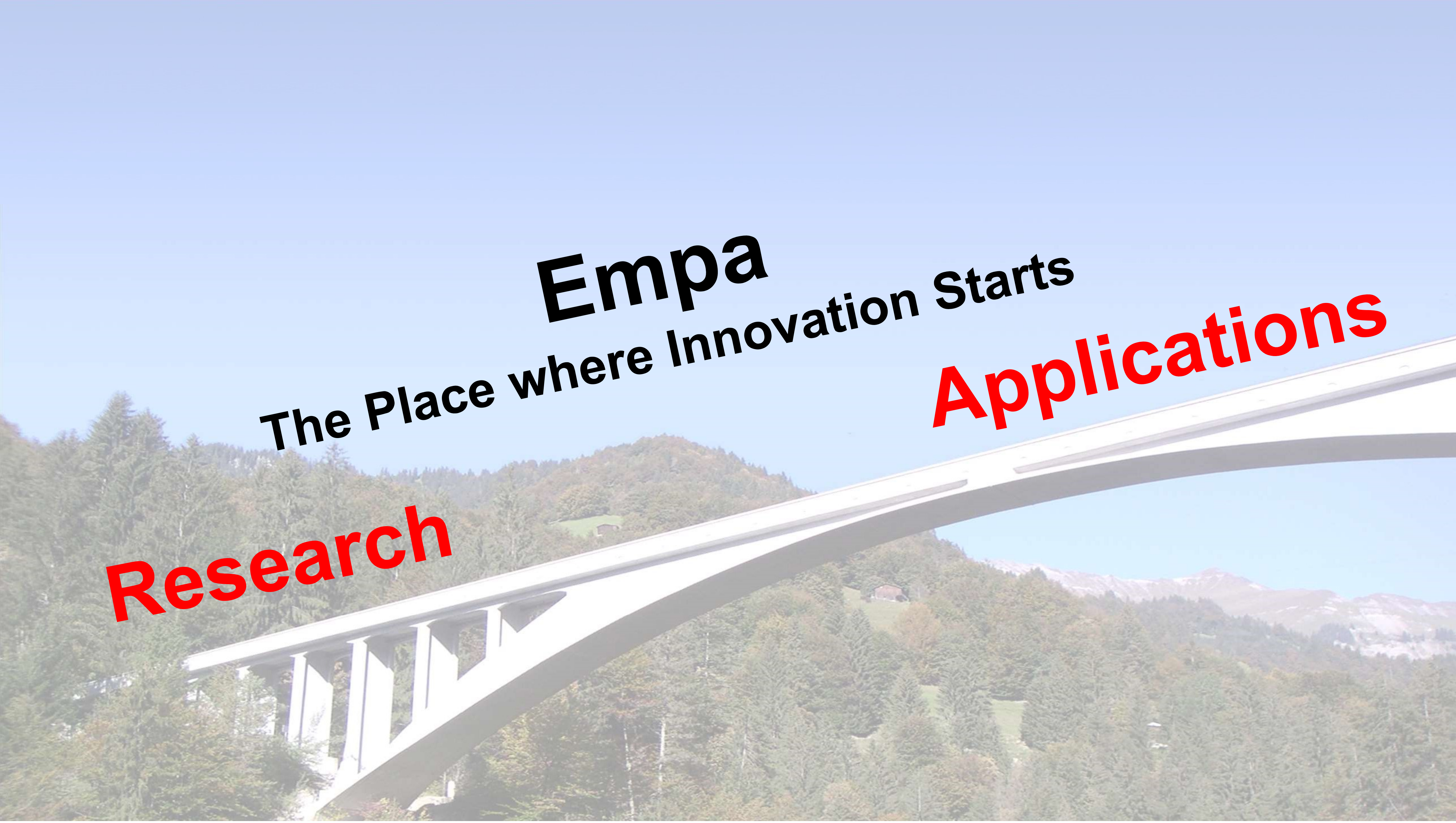
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Table of content:

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- Materials and Properties of Polymer Matrix Composites
- Mechanics of a Lamina
- Laminate Theory
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- Externally Bonded FRP Reinforcement for RC Structures: Introduction and Basics
- Flexural Strengthening
- Strengthening in Shear
- Column Confinement
- CFRP Strengthening of Metallic Structures
- FRP Strengthening of Timber Structures
- Design of FRP Profiles and all FRP Structures
- An Introduction to FRP Reinforced Concrete
- Monitoring and Testing of Civil Engineering Structures
- Composite Manufacturing
- Testing Methods

Team Members

- **Flexural Strengthening using FRP Composites: Swiss and other codes**

  Dr. Christoph Czaderski, Structural engineering Research Laboratory, Empa

- **External Strengthening of Metallic Structures**

  Dr. Hossein Heydarinouri, Structural engineering Research Laboratory, Empa

- **External Strengthening of Timber Structures**

  Robert Widmann, Structural engineering Research Laboratory, Empa

- **FRP Composite Profiles, All Composites Structures**

  Dr. Moslem Shahverdi, Structural engineering Research Laboratory, Empa

- **Measurement Techniques and Structural Health Monitoring**

  Dr. Matteo Breveglieri, Structural engineering Research Laboratory, Empa

Manuscript

Download pdf files from:

https://www.empa.ch/web/s303

References:

- Eckold G., Design and Manufacture of Composite Structures, ISBN 1 85573 051 0, Woodhead Publishing Limited, Cambridge, England, (1994)
- Lawrence C. Bank, Composites for Construction: Structural Design with FRP Materials, John Wiley & Sons, ISBN-13: 978-0471-68126-7
- fib bulletin 19, Externally applied FRP reinforcement for concrete structures, technical report, (2019), ISBN 978-2-88394-132-8
- SIA166 (2004) Klebebewehrungen (Externally bonded reinforcement). Schweizerischer Ingenieur- und Architektenverein SIA.

Internet Sites

- https://www.iifc.org/
- http://www.fiberline.com
- http://www.empa.ch
- http://www.compositesnews.com
- http://www.tenax-fibers.com
- http://www.hitco.com/
- http://www.automateddynamics.com

Course Schedule, Fall Semester 2023

- 20/Sept: Introduction and Overview, Material Properties
- 27/Sept: Mechanics of a Lamina: Micro Mechanics, Macro Mechanics
- 04/Oct: Laminate Theory,
- 11/Oct: Lamina and Laminate Theory, **First written midterm exam**
- 18/Oct: Design of FRP Profiles and All FRP Structures, Case Studies (Moslem Shahverdi)
- 25/Oct: Externally Bonded FRP Reinforcement for Concrete Structures: Overview
- 01/Nov: Flexural strengthening of Concrete Structures by Externally Bonded FRP Reinforcement: Swiss Code 166 and other codes, Introduction to the laboratory experiments (Christoph Czaderski)

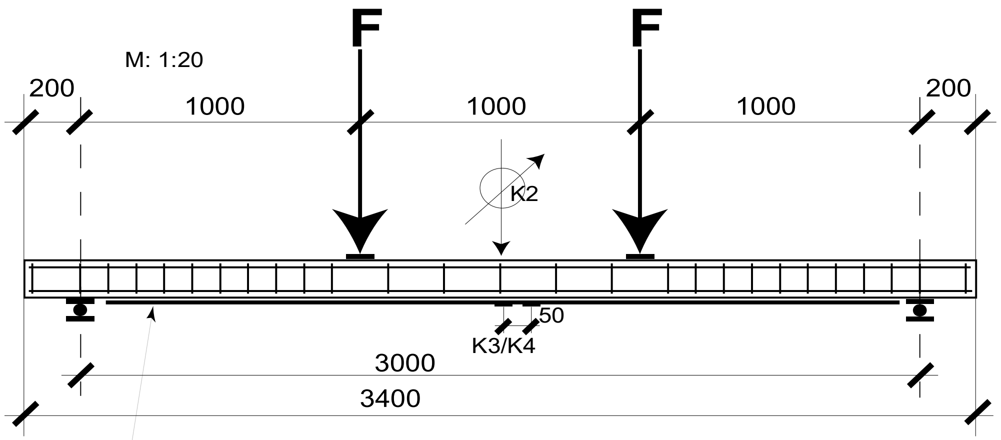
…… Course Schedule, Fall Semester 2023

- 8/Nov: Externally Bonded FRP Reinforcement for Concrete Structures: Shear Strengthening; Column Confinement
- 15/Nov: Externally Bonded FRP Reinforcement for Metallic Structures (Hossein Heydarinouri)
- 22/Nov: Externally Bonded FRP Reinforcement for Timber Structures / Structural Monitoring with Wireless Sensor Networks (Robert Widmann/ Glauco Feltrin)
- 29/Nov: Application of Externally Bonded FRP Reinforcement in the Empa laboratory,
- 06/Dec: FRP-Reinforced Concrete Design (Internal Reinforcement)
- 13/Dec: Laboratory experiments and Empa structural laboratory tour, **Second written midterm exam**
- 20/Dec: Manufacturing Methods; Testing Methods

- Exercise at Empa

Column Confinement

Static loading test of RC beam



Master-Thesis

- Thesis within ongoing research projects at the ‘Structural Engineering Research Laboratory, Empa’.

Application of advanced materials in Structural Engineering (Composites, Shape Memory Alloys, Multi Laminated Timber);

Digital fabrication (3D RC printing, Metal Additive Manufacturing)

Experimental and analytical/numerical tasks

- To be discussed.

- Midterm exam 1: 15%; written exam in English
- Midterm exam 2: 15%; written exam in English
- Final exam: 70%; 30 minutes, Oral exam; Language for the final exam can be selected: English or German
- Midterm exams will only be taken into account if both written midterm exams during semester are attended and if they improve the grade of the final exam

Questions????

Introduction

Book L. Bank, Chapter 1

Objectives

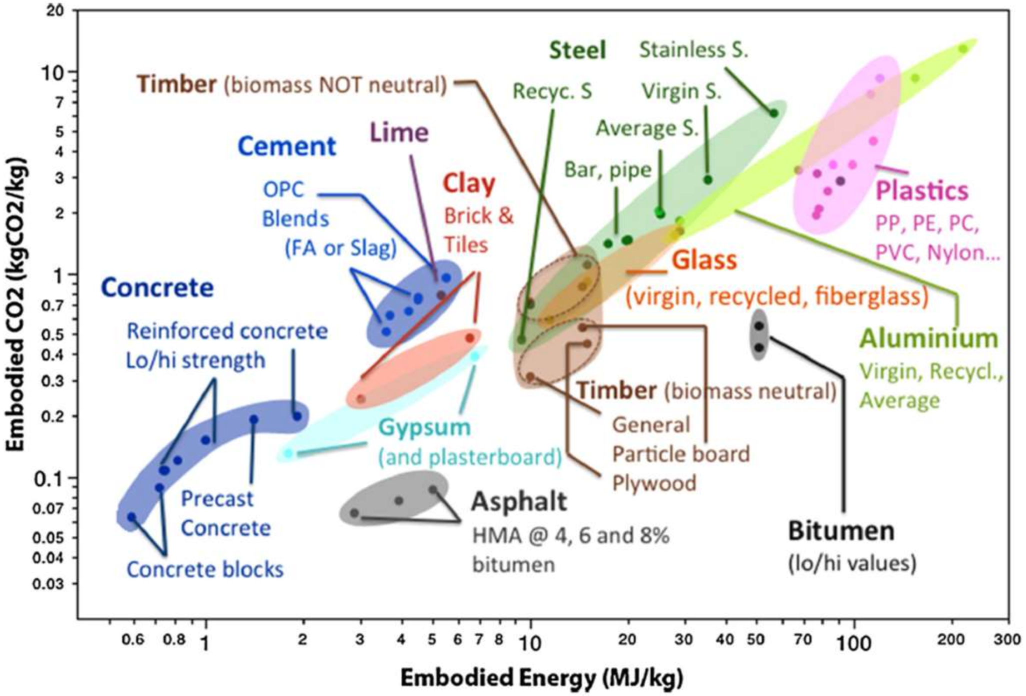
- To provide students with a general awareness of Fibre Reinforced Polymer (FRP) materials and their potential uses
- To provide information on some of the potential uses of FRPs in civil engineering applications
- To provide guidance for students seeking additional information on FRPs
- We will tackle three main worldwide interrelated global crisis: **Energy**, **CO2 Emission** and **Global Warming**

Cement and Concrete: high emissions originate from high demand

Cement consumption Switzerland (2022):

4.15 Mt : **2.4 Mt CO_2** (~6% inland emissions)

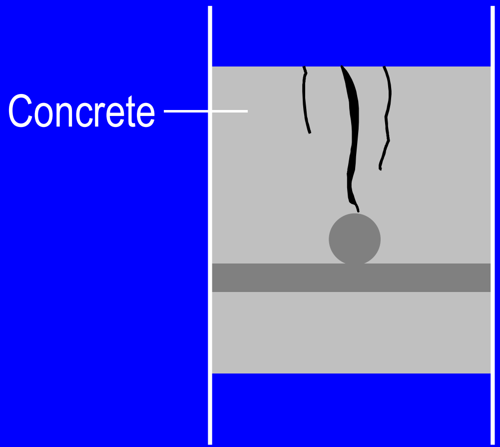
«Cemsuisse Jahresbericht 2022/2023»



«Barcelo et al. 2014»

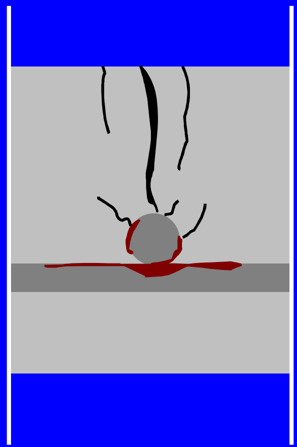
- A primary factor leading to extensive degradation…

Corrosion



Moisture, oxygen and chlorides penetrate

- *Through concrete*
- *Through cracks*



Corrosion products form

Volume expansion occurs

More cracking

Corrosion propagation

End result

Degradation in Steel Structures

Market:

Europe:

- 22% bridges are metallic
- 70% are older than 50 years

Switzerland:

- Swiss Federal Railways (SBB) has 6050 railway bridges
- 25% of bridges older than 80 years are metallic riveted

Problems in Metallic Bridges:

- Major problem: insufficient fatigue crack safety
- Need an upgrade to carry larger loads and more traffic

Most commonly used structural metals:
Steel, wrought irons, cast irons, Aluminum and …

Chajes et al. „*Fracture: Field testing of the I-95 bridge.*" In Third Annual Bridge Workshop: Fatigue and Fracture; Center of Innovative Bridge Engineering: Ames, IA,USA, 2004

Global Infrastructure Crisis

➊ **How can we prevent deterioration of infrastructure?**

➋ **How can we prolong the lives of existing structures?**

Going towards Net Zero CO2 emmision

- Why build and repair with the same materials?
- Why repeat the cycle?

FRP Materials

Lightweight

Easy to handle

High Strength

5x steel

Corrosion resistant

Durable structures

Highly versatile

Suit any project

- Longstanding reputation in sport, automotive and aerospace industries
- Over the past 30 years have FRP materials been increasingly considered for civil infrastructure applications

FRP costs have decreased

New, innovative solutions needed!

FRPs now recognized as **effective** and **efficient** structural materials

Increased use of FRPs in infrastructure applications attributable to:

FRP advantages

Will not corrode electrochemically (durability)

High strength-to-weight ratio

Electromagnetically inert

Ease and speed of installation

Ability to tailor mechanical properties (versatility)

Low thermal conductivity

Potential FRP disadvantages

FRPs are linear elastic materials

Addressed through careful design procedures

High initial material cost

But not when "life-cycle" costs are considered

All-FRP structures

FRP-reinforced concrete

Repair and rehabilitation

Hybrid FRP structures

Smart materials

FRP ground anchors

architectural panels

Infinite possibilities...

- Background
- Reliability
- Challenged by the Sport Items
- State of the Technology Today
- Future Challenges

Background

Material Application per Year (old statistic!):

- **Steel 795‘000‘000 t**
- **Polymer 120’000’000 t**
- **E-Glass Fibre 2’200’000 t**
- **Carbon Fibre 17’000 t**

Quiz

Volume Usage per Year:

A: Volume Steel >> Volume Polymer

B: Volume Steel = Volume Polymer

C: Volume Steel << Volume Polymer

Answer to Quiz

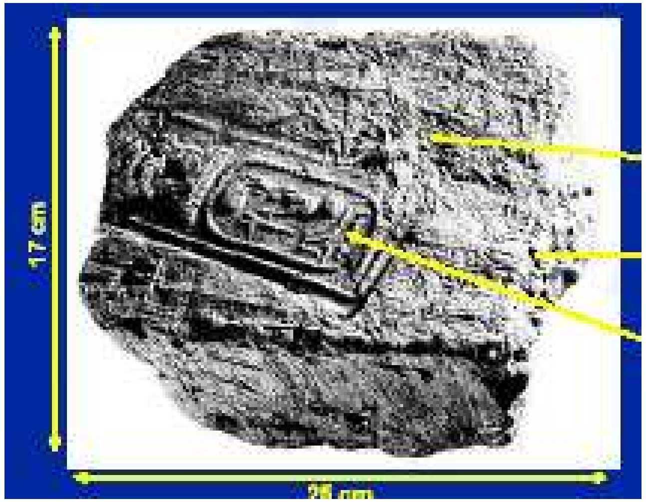
Volume Usage per Year (old statistic!):

Volume Steel	**=**	**101‘923‘000 m^3**
Volume Polymer	**=**	**104‘348‘000 m^3**

B: Volume Steel = Volume Polymer

Composites are not new !!!

Brick: Egypt 1279-1212 BC



Fibres: straw

Matix: Clay

RAMSES II

Trabant, „Plastic Bomber“ DDR 1957

Phenol resin/Cotton fibers

- **First Polymer Composite Bridge:**
- **Appr. 1969 in USA**

Historical Bridge Sins, Switzerland

Built in 1807
Post strengthening of lateral profile with CFRP in 1992

Reliability

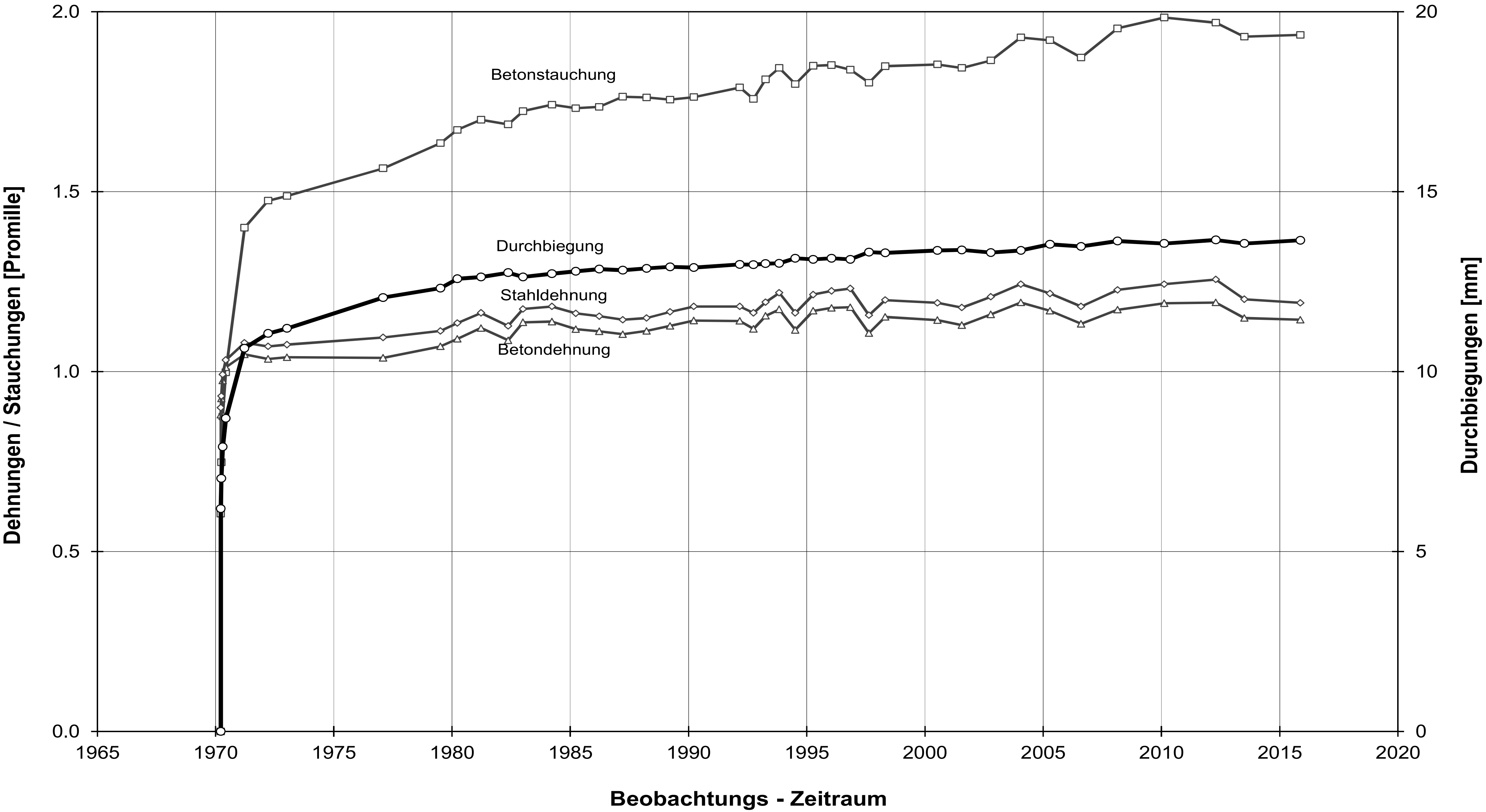
Creep Test at EMPA-Switzerland

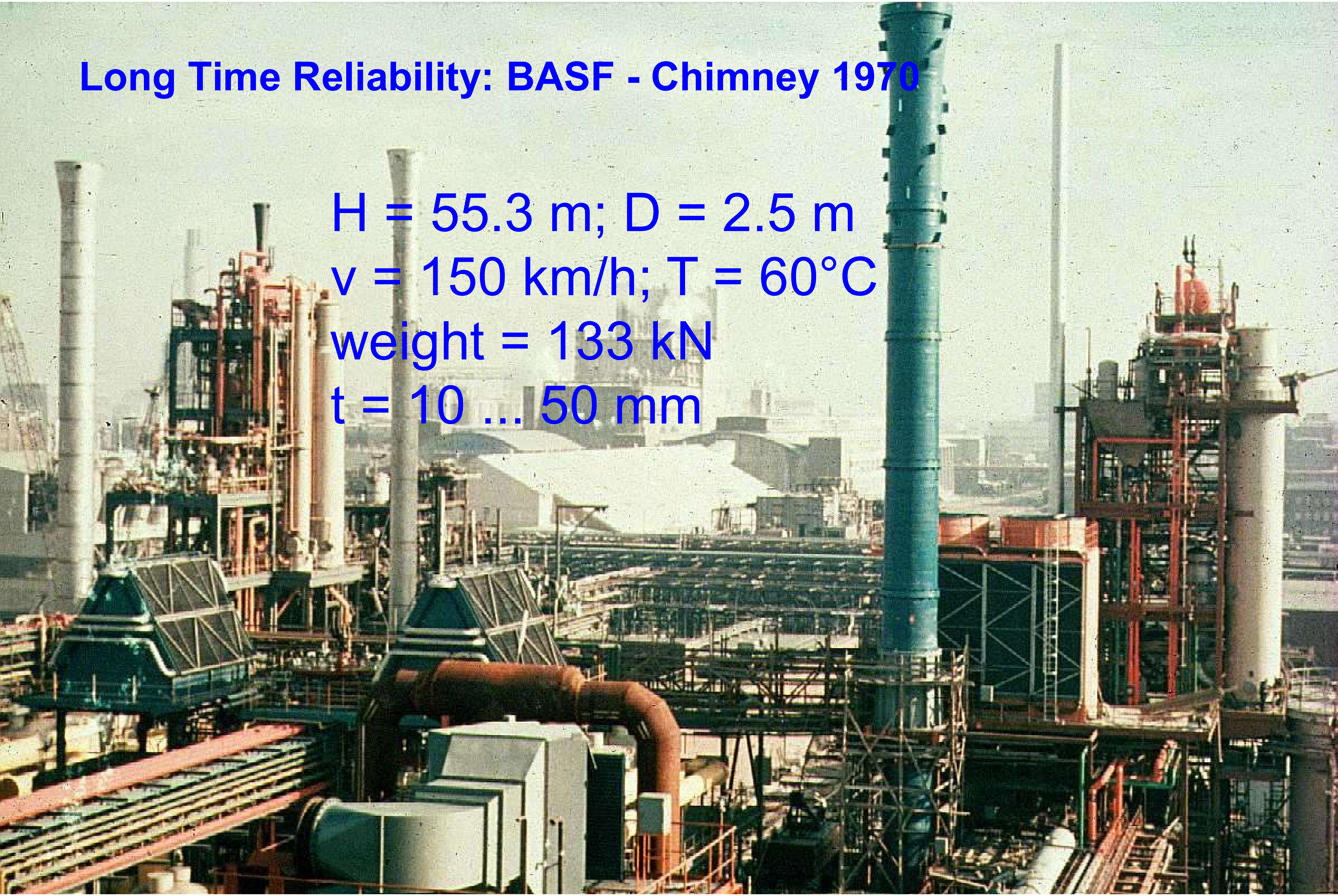
RC beam strengthened with one glued steel plate (7X120 mm)
Loading: 2 X 30 kN (88% of failure load!)

Since March 1970

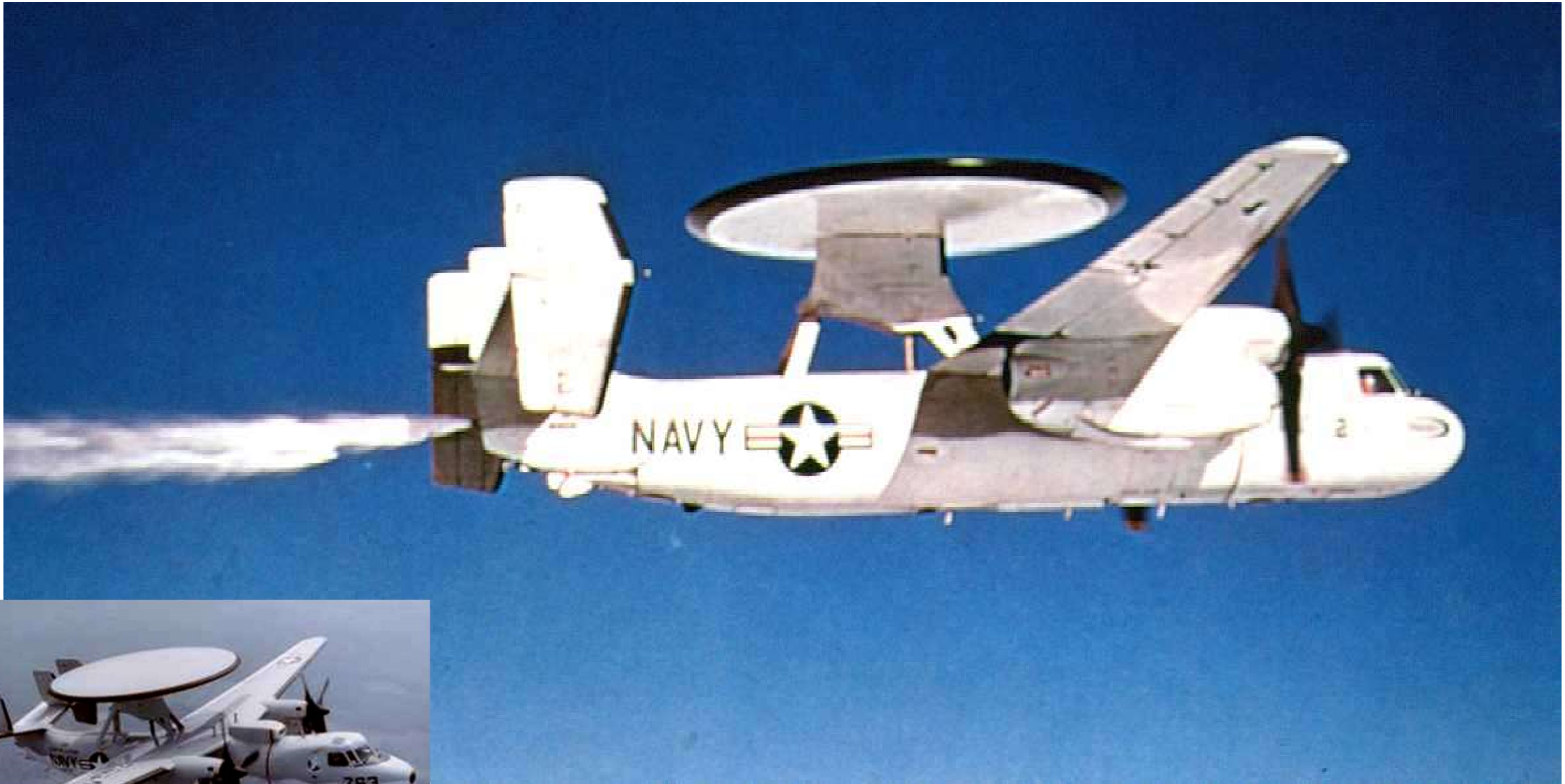
Langzeitversuch mit geklebter Bewehrung

Versuchsbedingungen : Temp. 16 .... 24 °C, relative Luftfeuchtigkeit 30 .... 70 %

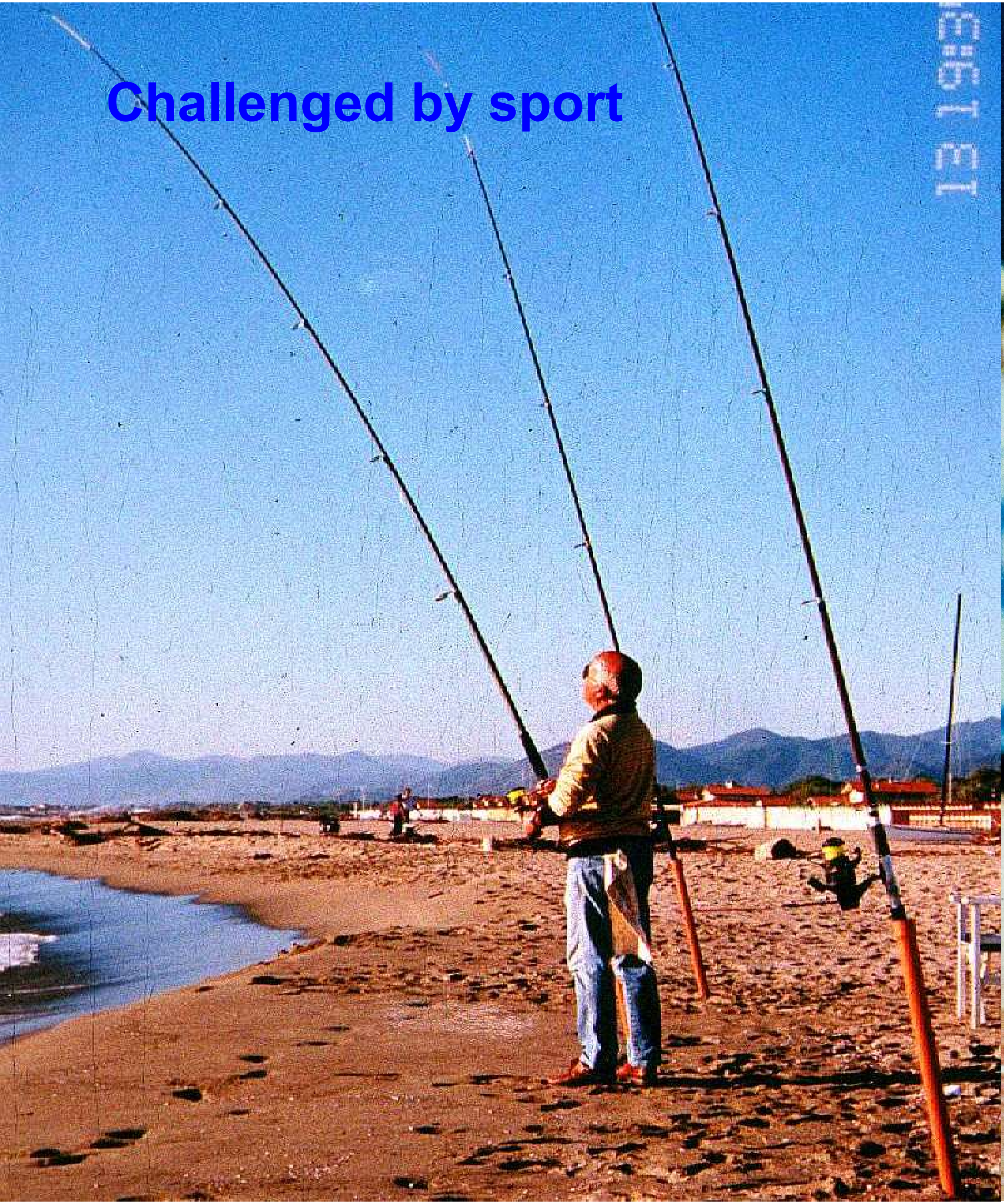



Long Time Reliability: BASF - Chimney 1970
H = 55.3 m; D = 2.5 m
v = 150 km/h; T = 60°C
weight = 133 kN
t = 10 ... 50 mm

Long Time Reliability: E-2C Hawkeye since 1964



Challenged by the sport items

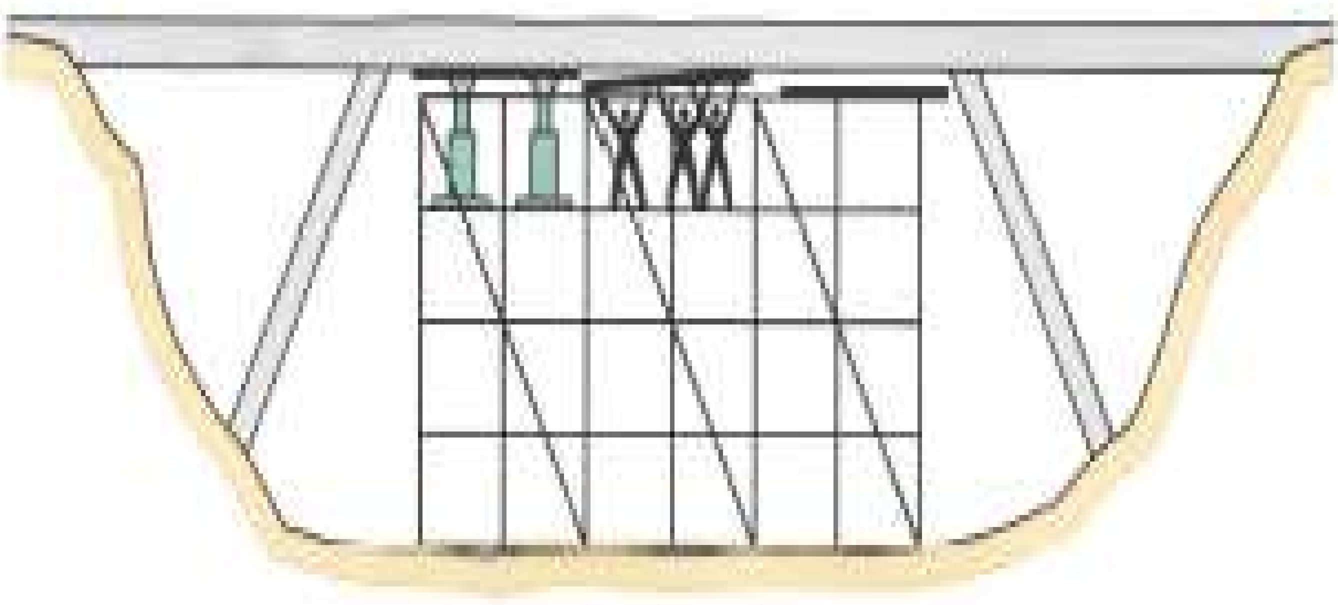

Challenged by sport


Steffi Graf , 1988 No. 1

Challenged by sport

State of technology today

Post Strengthening using Steel Strips



Reasons for strengthening

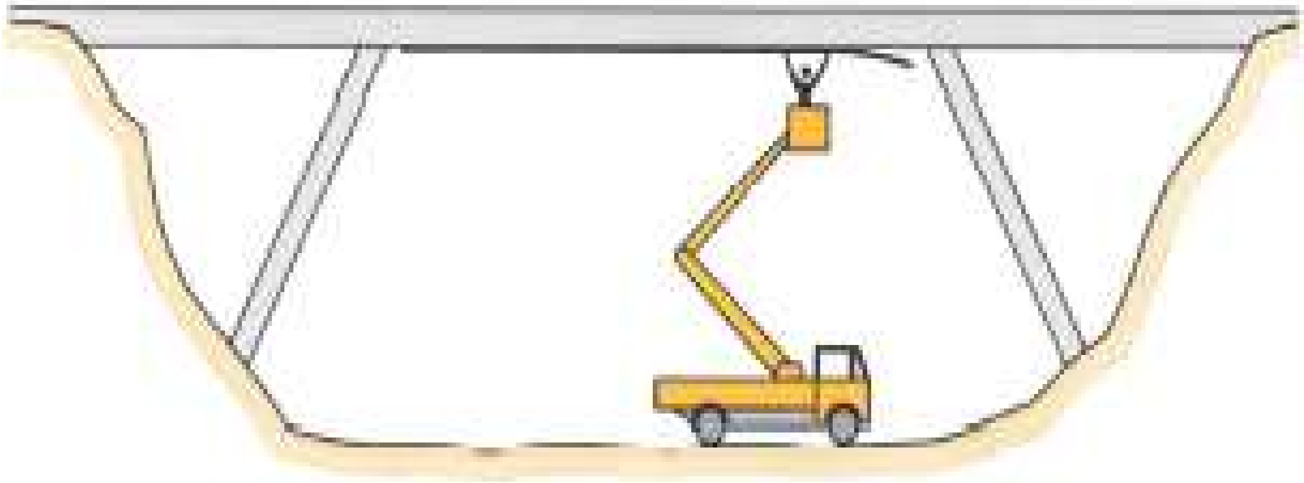
- Aging of our structures
- Renewal is too expensive
- Higher loads (railway bridges, …)
- Natural hazards (earthquake, …)
- Man made hazards (terror attacks, …)
- Repair

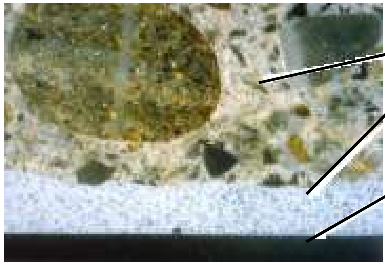
- Heavy
- Corrosion

- Requires scaffold
- Requires many joints

Post Strengthening using CFRP Strips

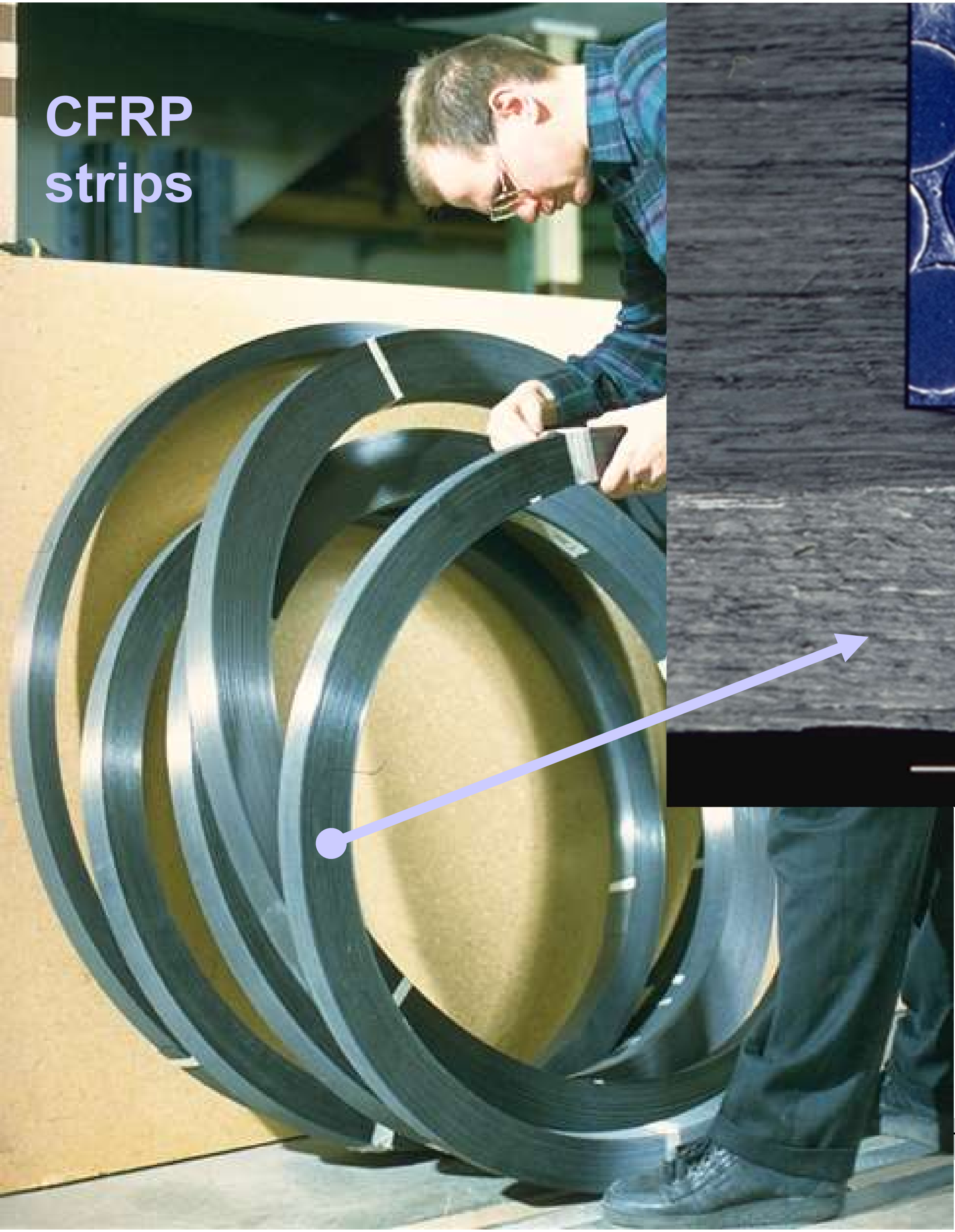
Introduced by Prof. Urs Meier (EMPA Switzerland) in 80’s

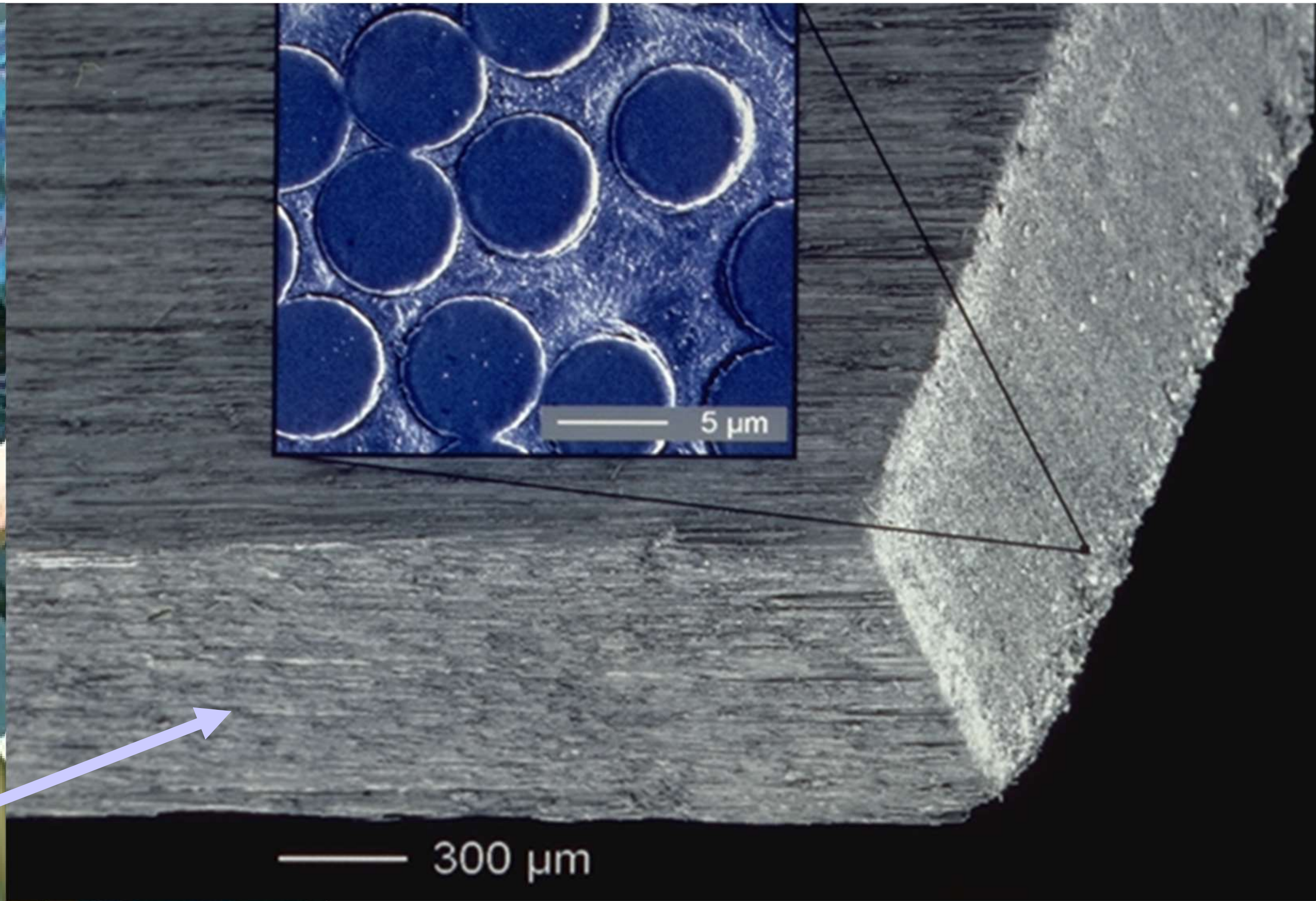




- **Light weight**
- **Corrosion resistant**

- **No scaffold**
- **No joints**



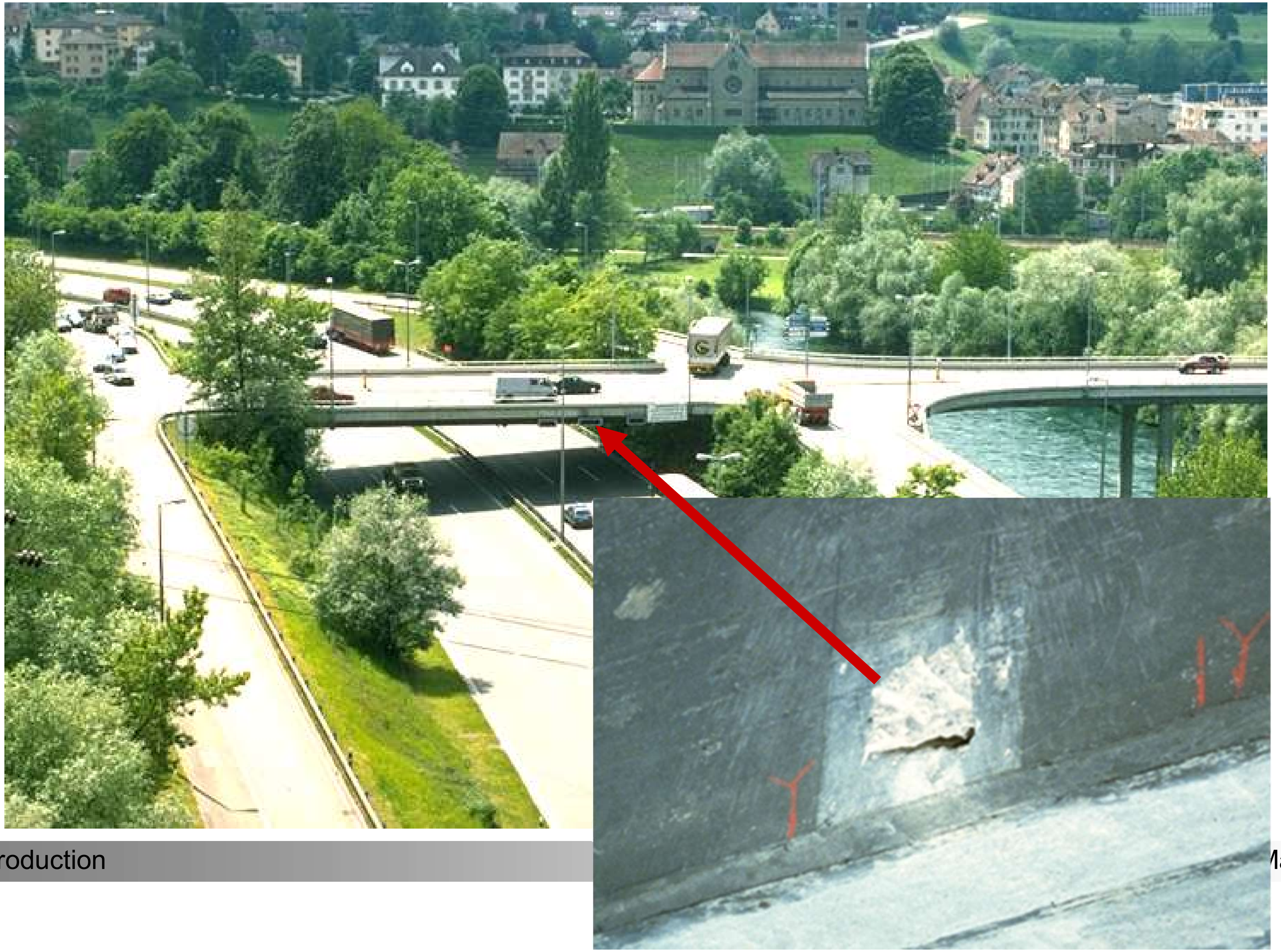


CFRP Fibers:
65….72 vol%

E-Modul:
150…300 GPa

Strength:
2500….3300 MPa

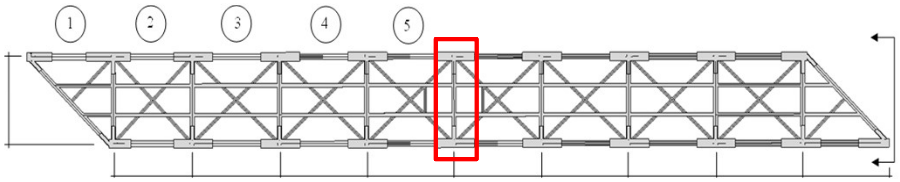
Ibach Bridge, Switzerland 1991

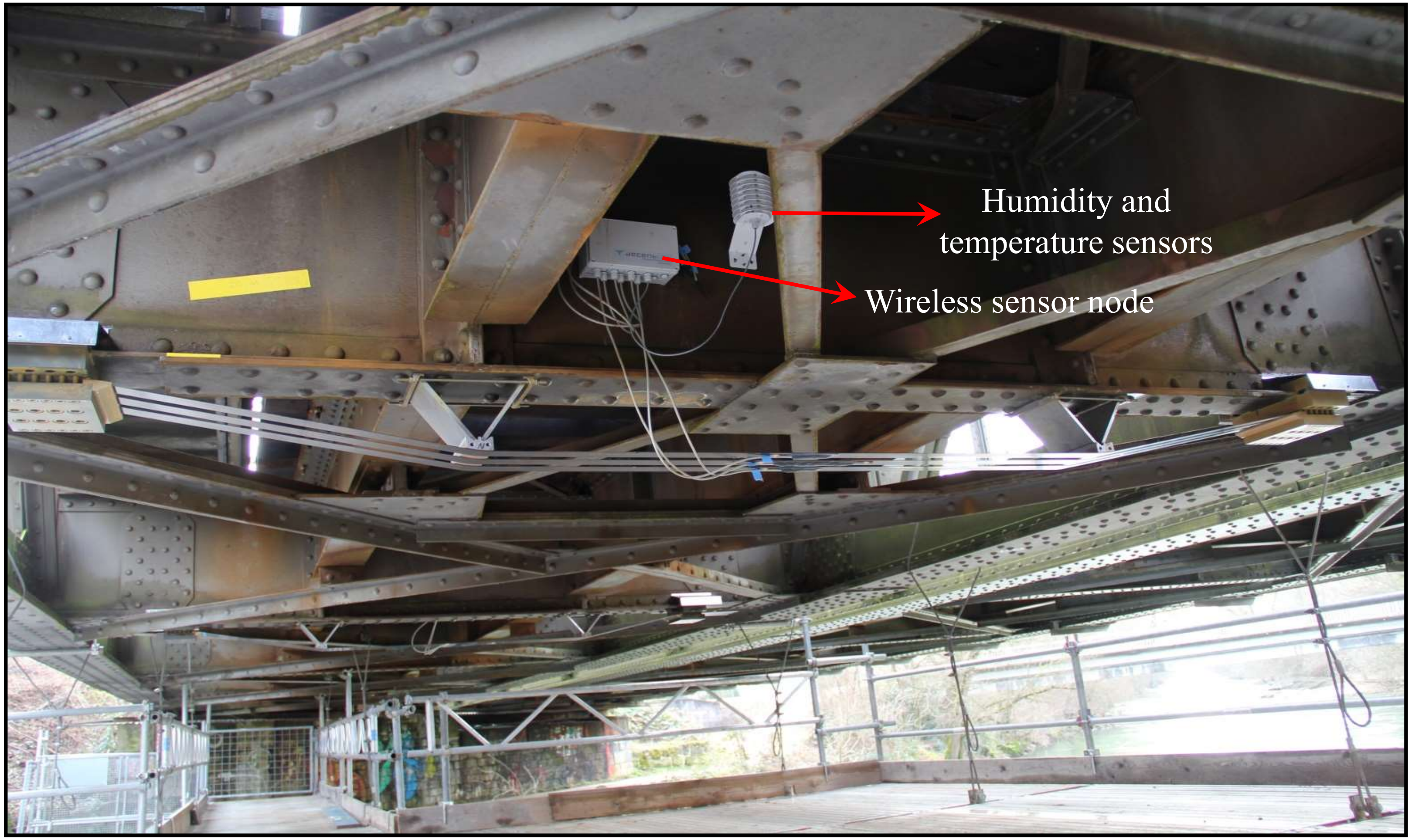


Ibach Beridge, Switzerland 1991

Steel Bridge Strengthening

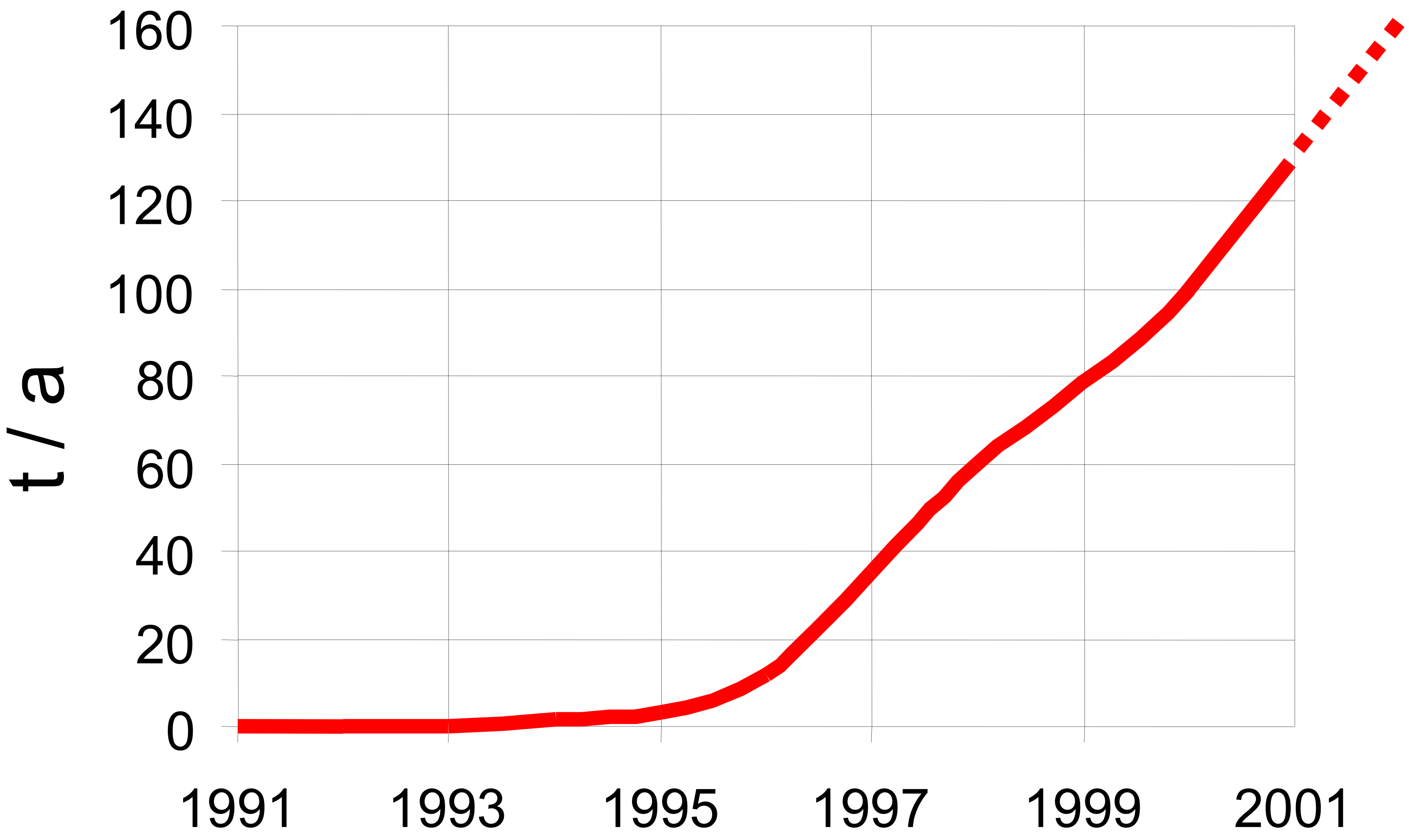
Münchenstein Railway Bridge, 120 years old near Basel



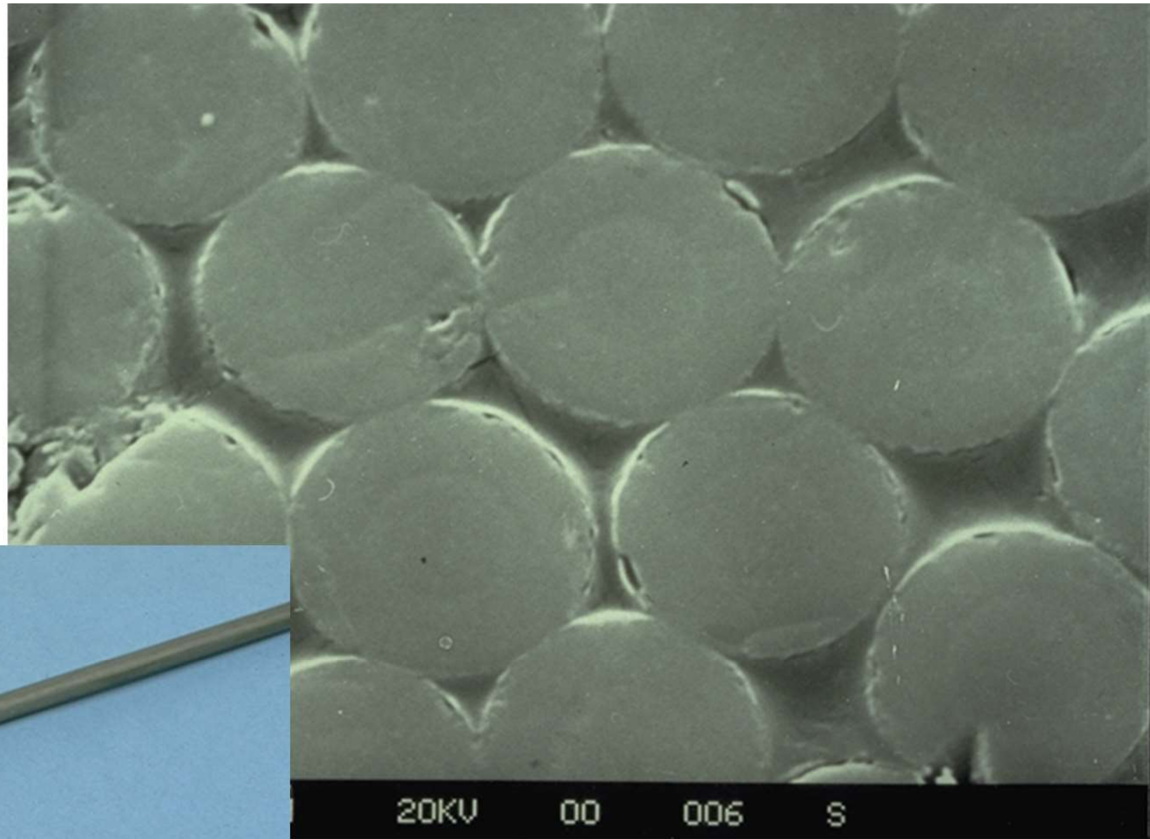


Daily Job

CFRP Strips in Switzerland

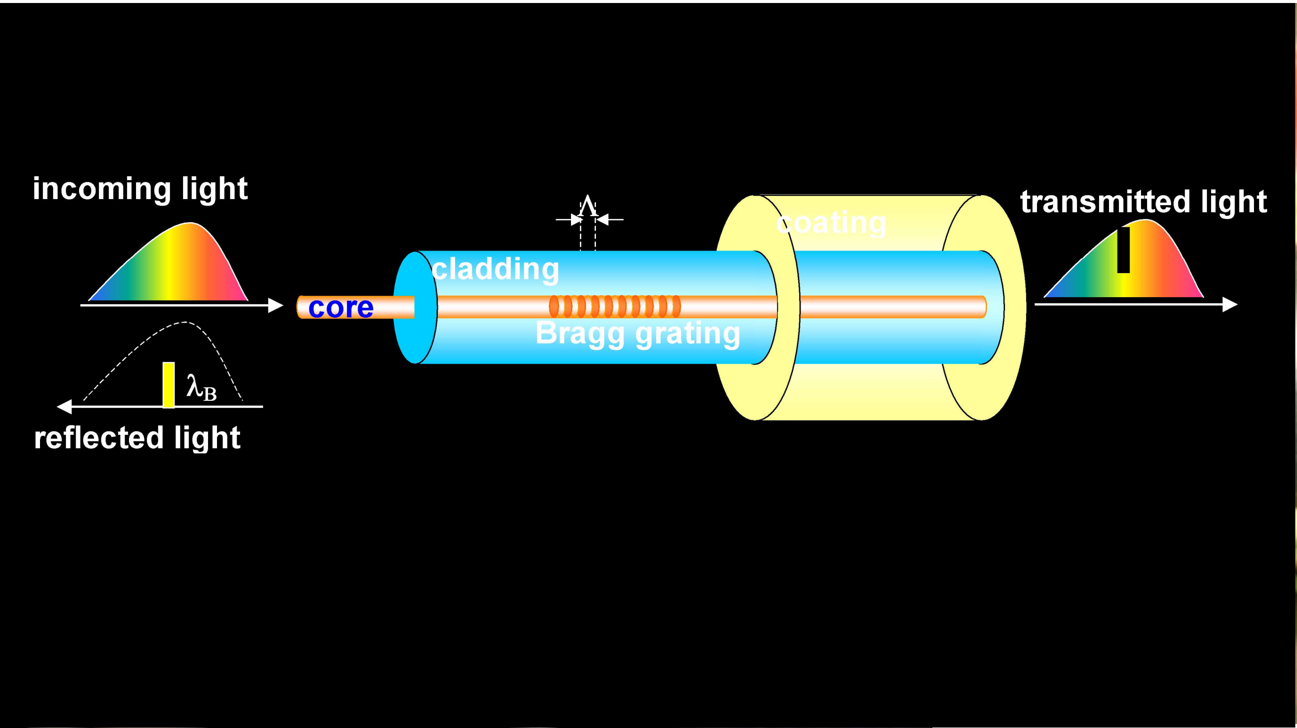


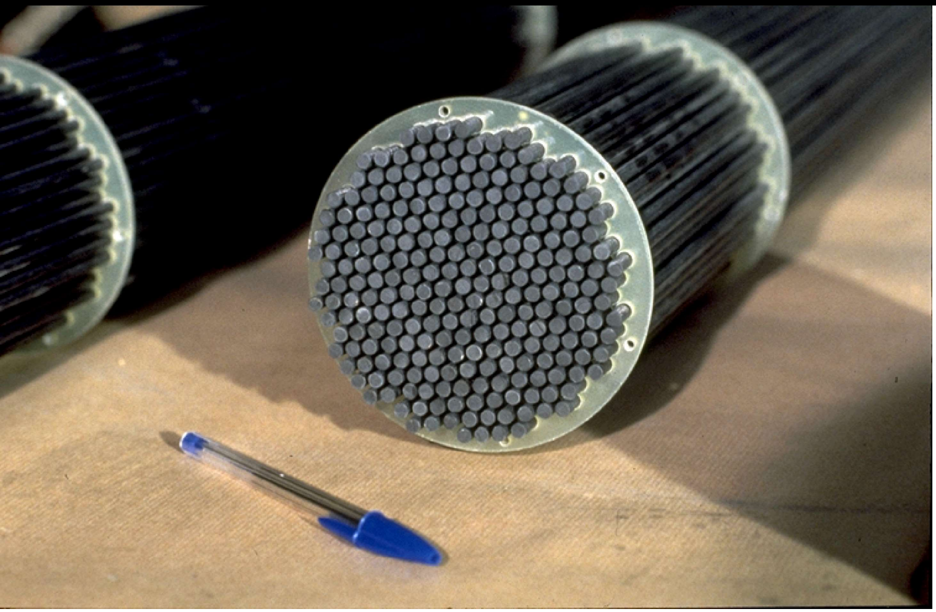
Alternative to Steel ?



For example:

Stay cables





Parallel wire cable

241 wires

(Diameter 5 mm)

Load capacity: 12 MN

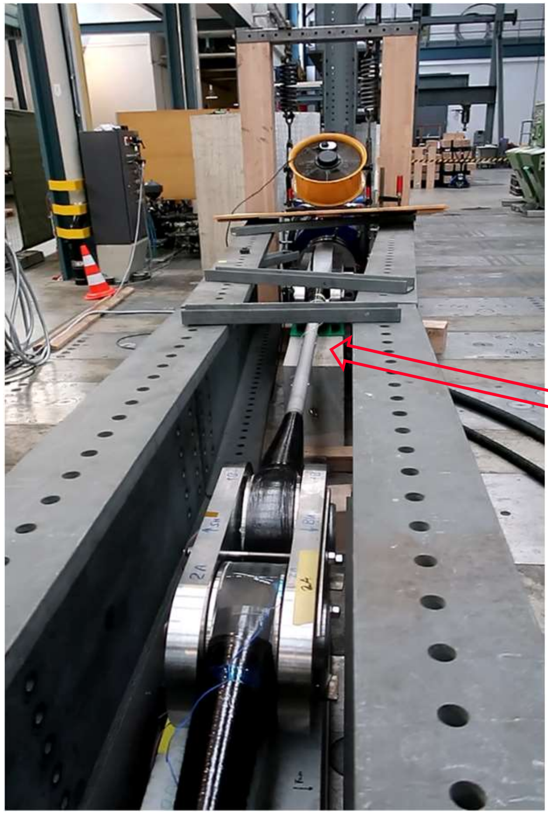
Storch Bridge 1996, Winterthur, Switzerland

(Span: 124 m, 2 Lanes)

Laroin Foot Bridge, 2002

1st bridge ever built in France using carbon composite cables

Light weight CFRP hangers for the railway bridge over the river Oder, Germany



https://www.rbb24.de/studiofrankfurt/panorama/2023/09/brandenburg-kuestrin-oderbruecke-eingeschoben-ostbahn.html

2023

Mo 04.09.23 | 20:27 Uhr 12

Video: rbb24 Brandenburg aktuell | 05.09.2023 | Material:

Am deutsch-polnischen Grenzfluss Oder finden Arbeiten für den Bau einer neuen Eisenbahnbrücke über den Fluss statt (Luftaufnahme mit einer Drohne). Die Eisenbahnbrücke über die Oder zwischen Küstrin-Kietz auf deutscher Seite und dem polnischen Kostrzyn gilt als grenzübergreifendes Symbol für das Zusammenwachsen Europas. Das derzeit größte Brückenprojekt der Deutschen Bahn in Brandenburg steht nun kurz vor dem Abschluss. (Foto: dpa)

In einer spektakulären Aktion wird eine Brücke über die Oder ge... Schritt, um mehr Verkehr auf die Schiene Richtung Polen zu bringen. Doch die weitere Entwicklung der Bahnstrecke stockt noch.

- *Bahnbrücke für Pendlerstrecke RB26 soll Ende des Jahres in Betrieb gehen*
- *Züge können mit bis zu 120 km/h die Oder passieren - Fahrzeiten verkürzen sich*
- *Bund sieht Verbindung nur als Nahverkehrsstrecke*

Das derzeit größte Brückenprojekt der Deutschen Bahn (DB) in Brandenburg steht kurz vor dem

GFRP Bridge „Sugar Grove“, VA

Bridge Decks

GFRP-Deck in Ohio

All FRP Structures

Length:	19.2 m
Width:	1.6 m
Height pylon:	7.5 m
Total weight girder:	1500 kg

Smart Cable Stayed GFRP-Bridge at Empa

All FRP Structures

FRP road bridge

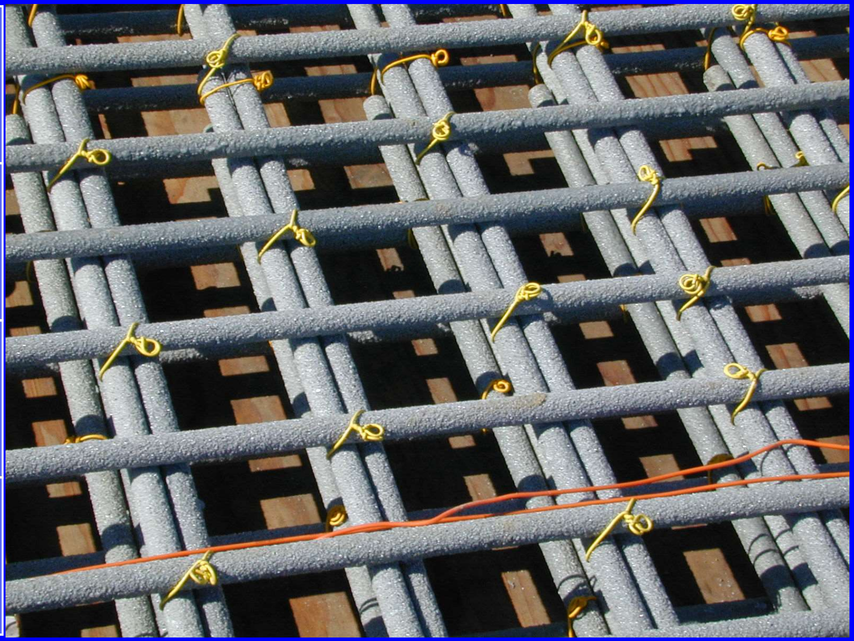
Laboratory testing of an FRP bridge deck panel

FRP-Reinforced Concrete

Placing the deck slab concrete

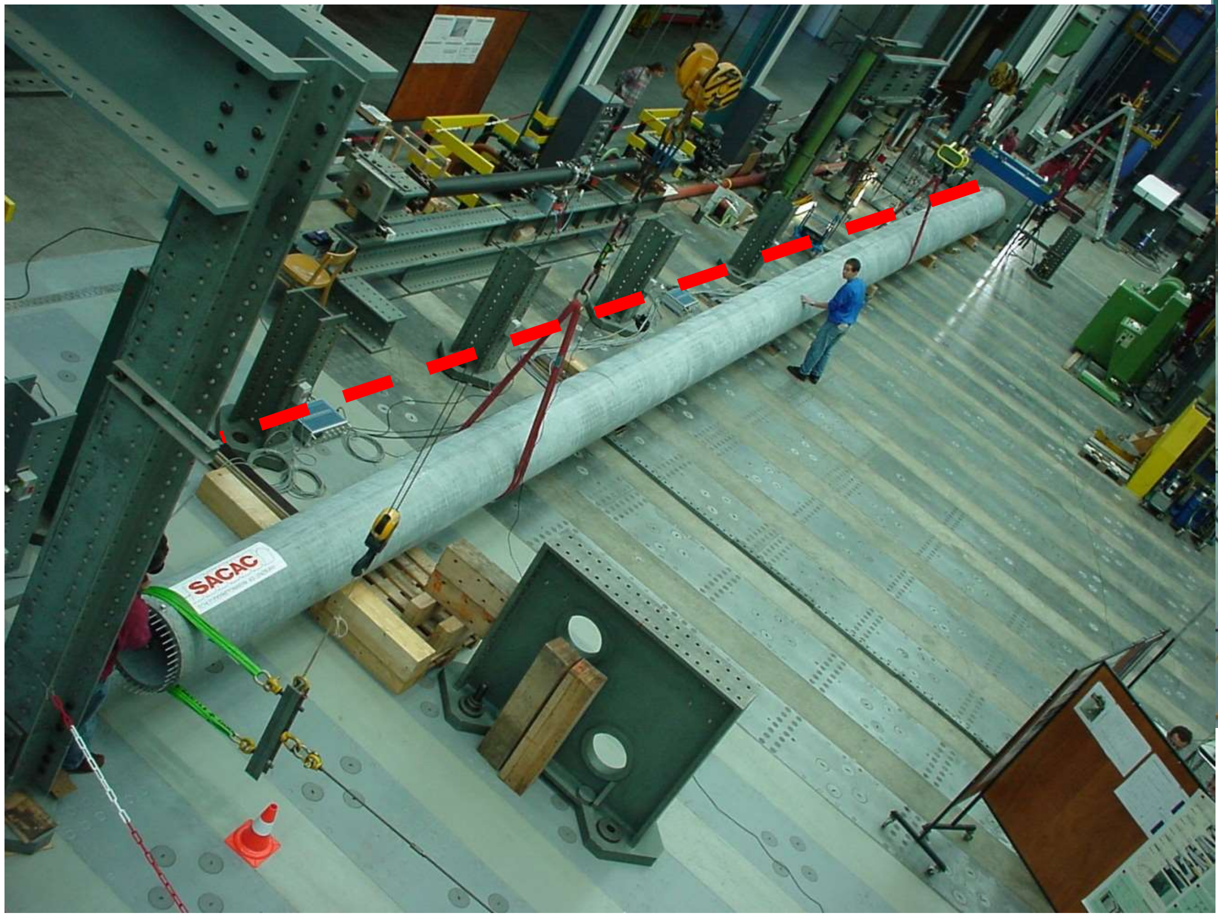
FRP-Reinforced Concrete

Morristown, Vermont
Re-opened 2002
43 metre span
ISOROD GFRP in deck slab

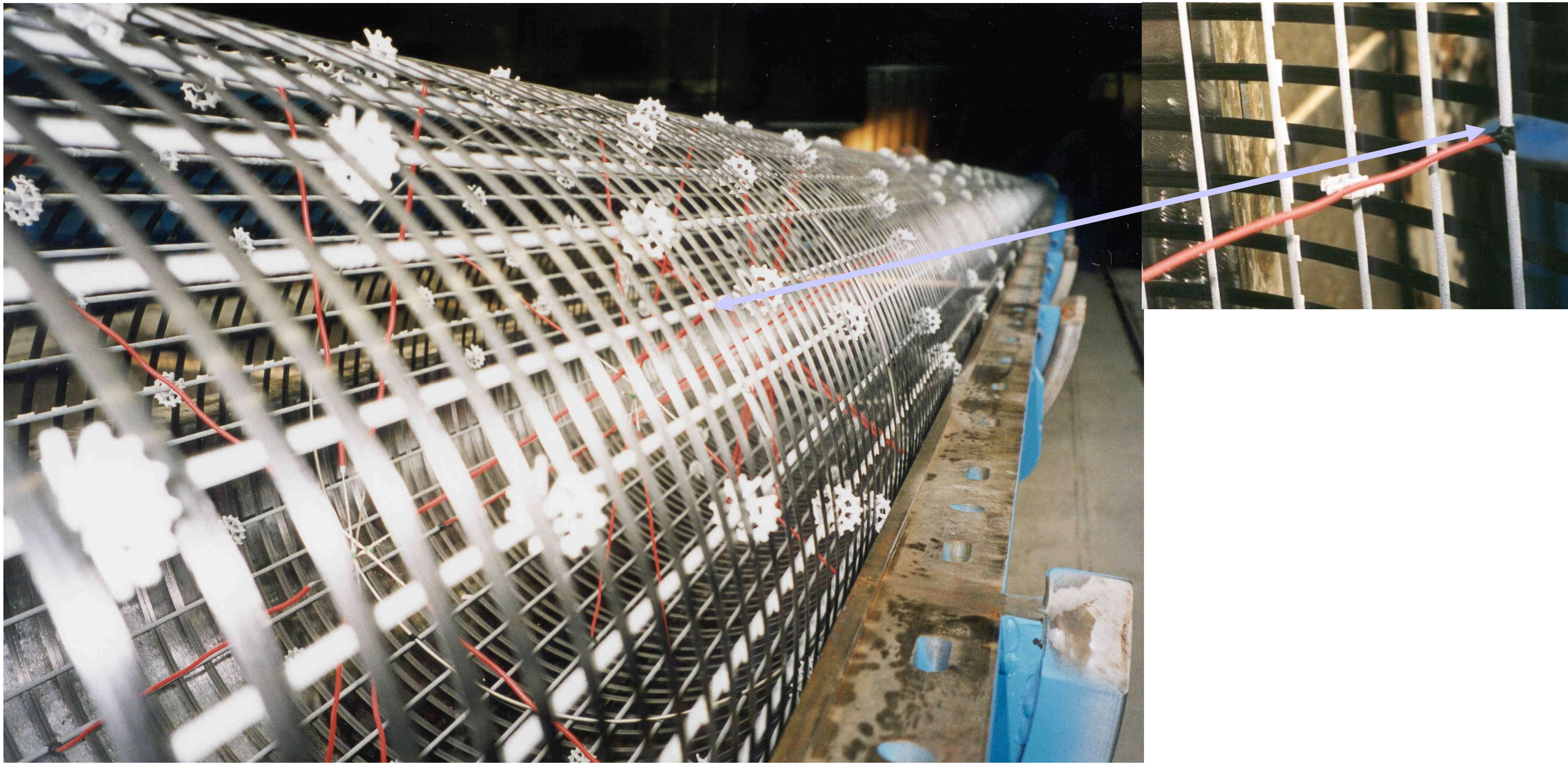


Bridge deck reinforcement

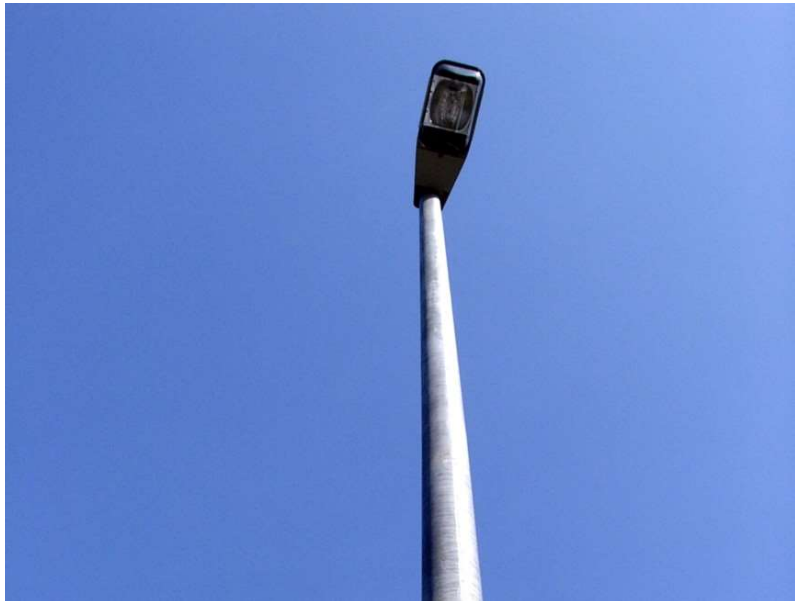
Flexural testing



CFRP reinforcement

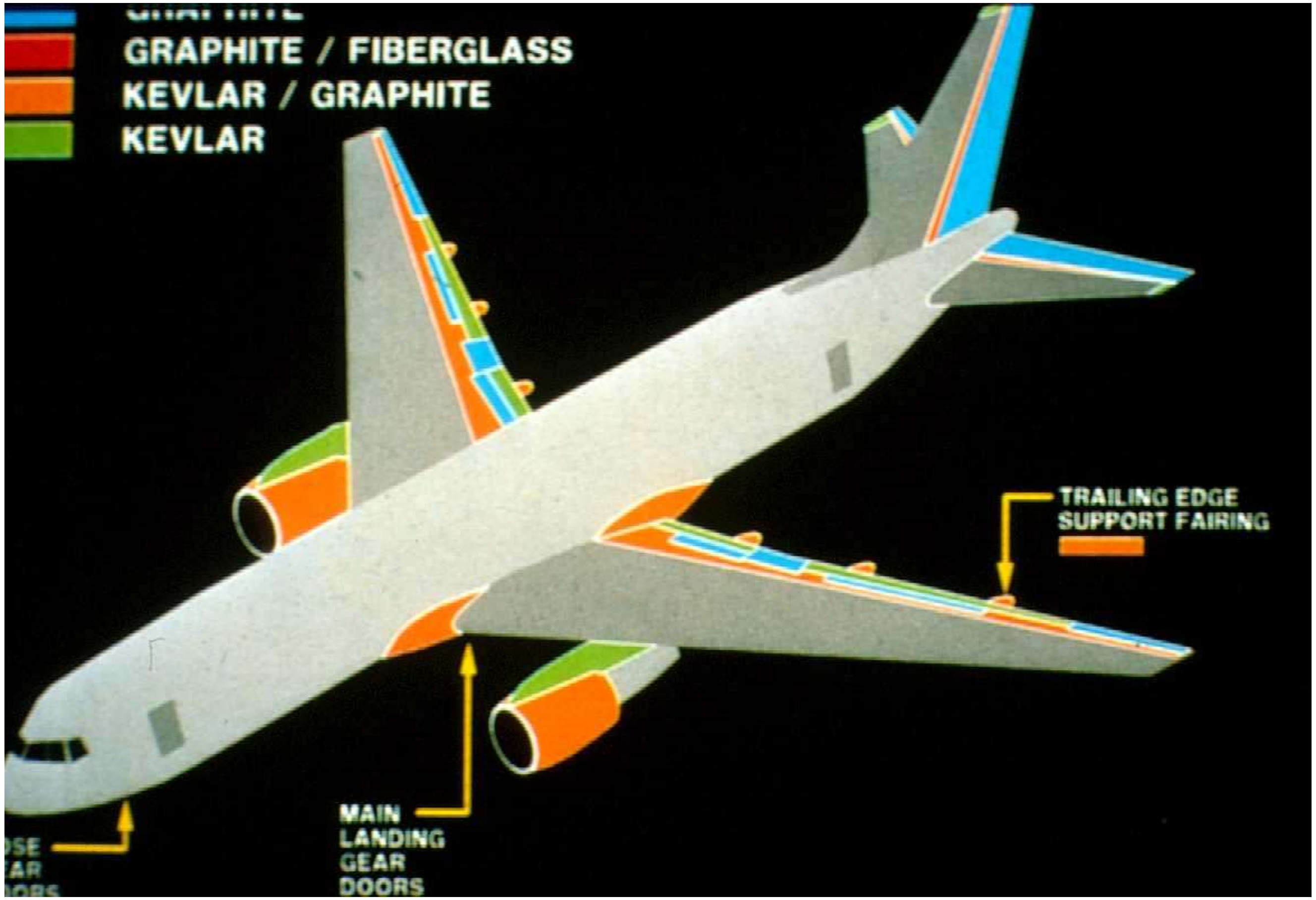


SACAC Carbolith Pole



- CFRP reinforced concrete
- L = 9.2 m
- Light point height = 8 m
- Mass 350 kg (= 65% of a classical pole!)

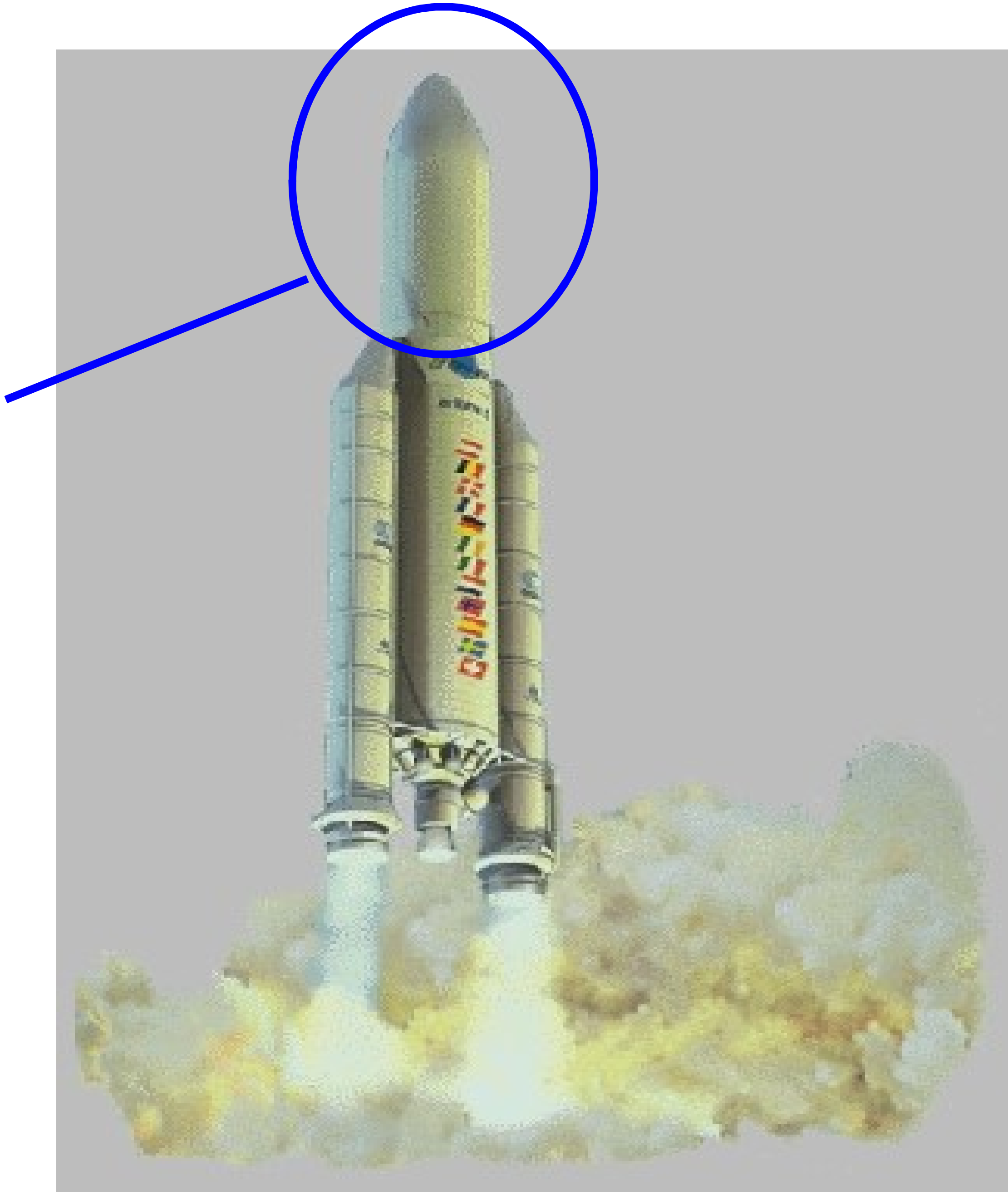
State of the technology : Airbus A300, 310 …



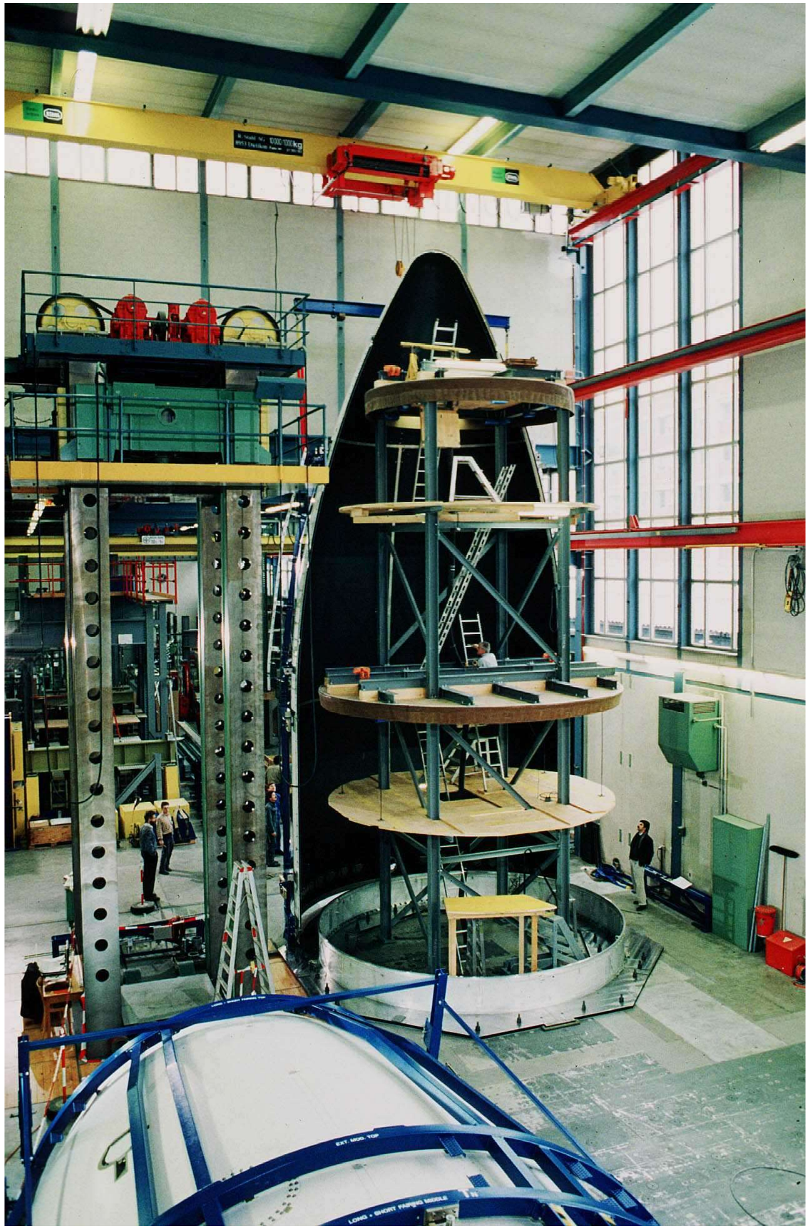
approved since 1974

Ariane V

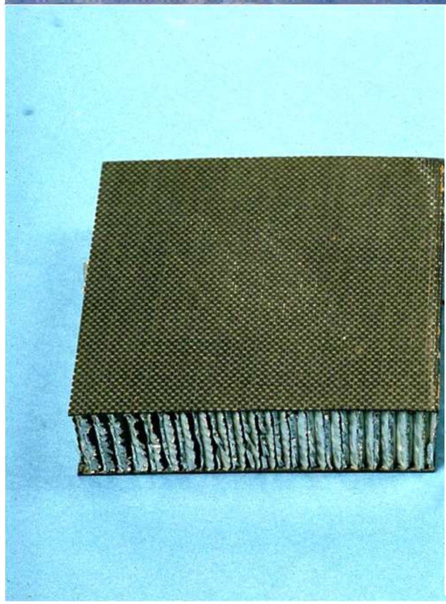
Live load cover



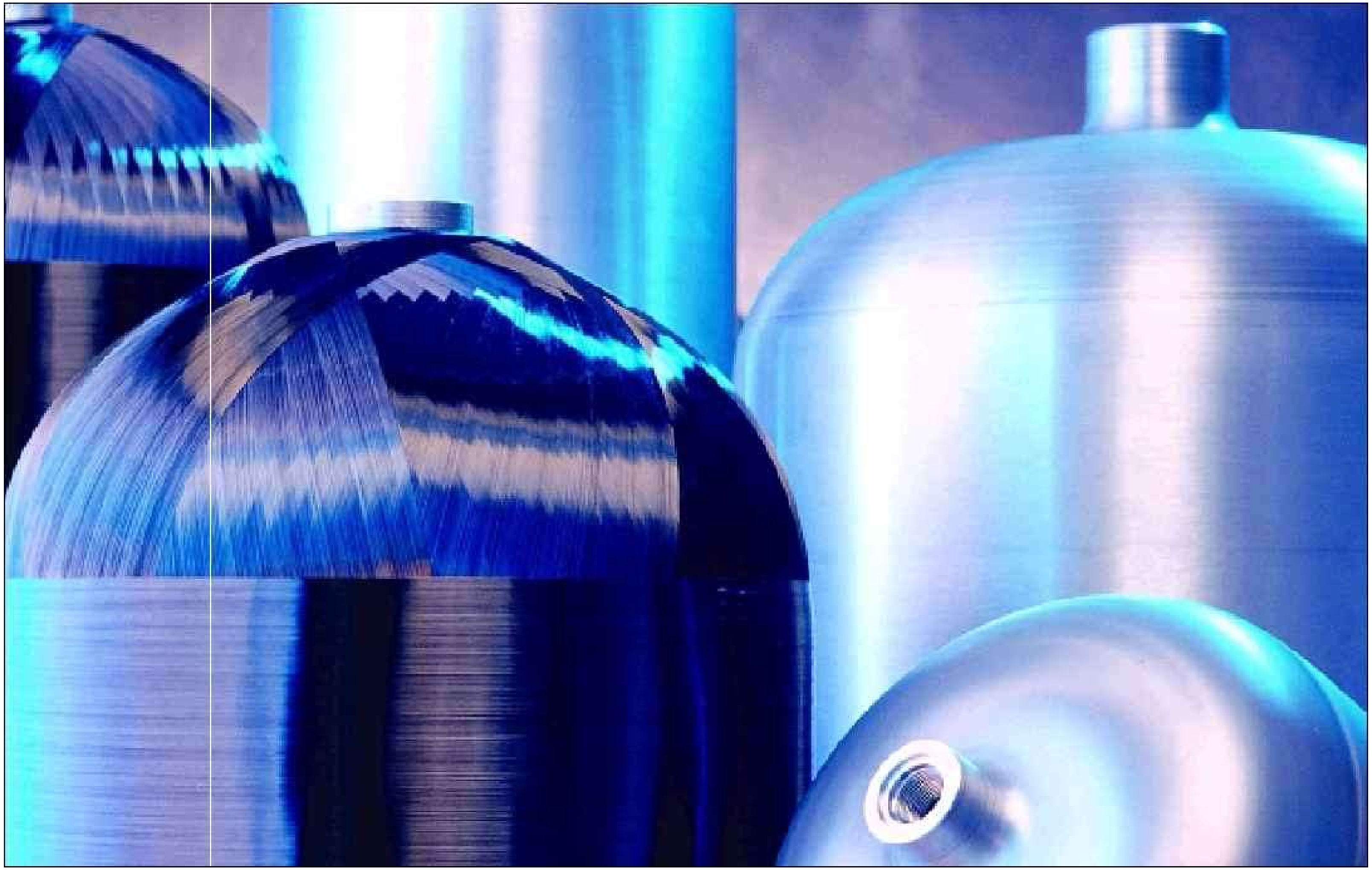
- H = 12,7 m
- D = 5,4 m
- 200°C, 110 km, 3 min
- Total mass = 1680 kg



Ariane V: **Static Tests at EMPA, Switzerland**



Pressure vessel (700 ... 2130bar)



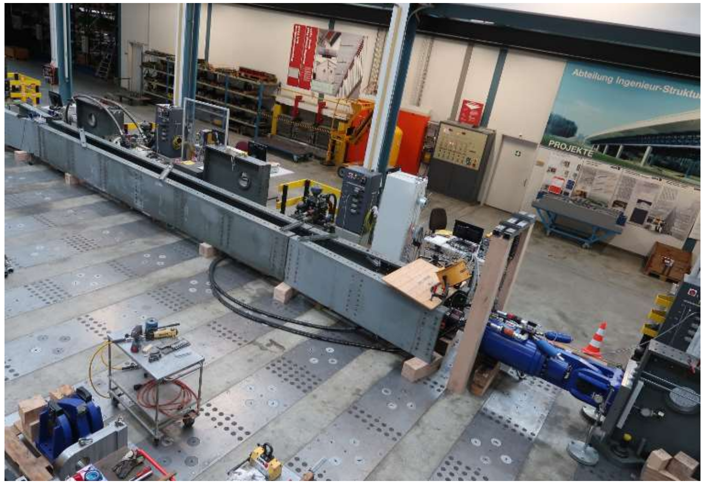
Future Challenges

Visions and Dreams

Messina: 3'300 m

CFRP hangers for network arch bridges

Fatigue experiments in 2020 on CFRP hangers



New bridge over the river Oder

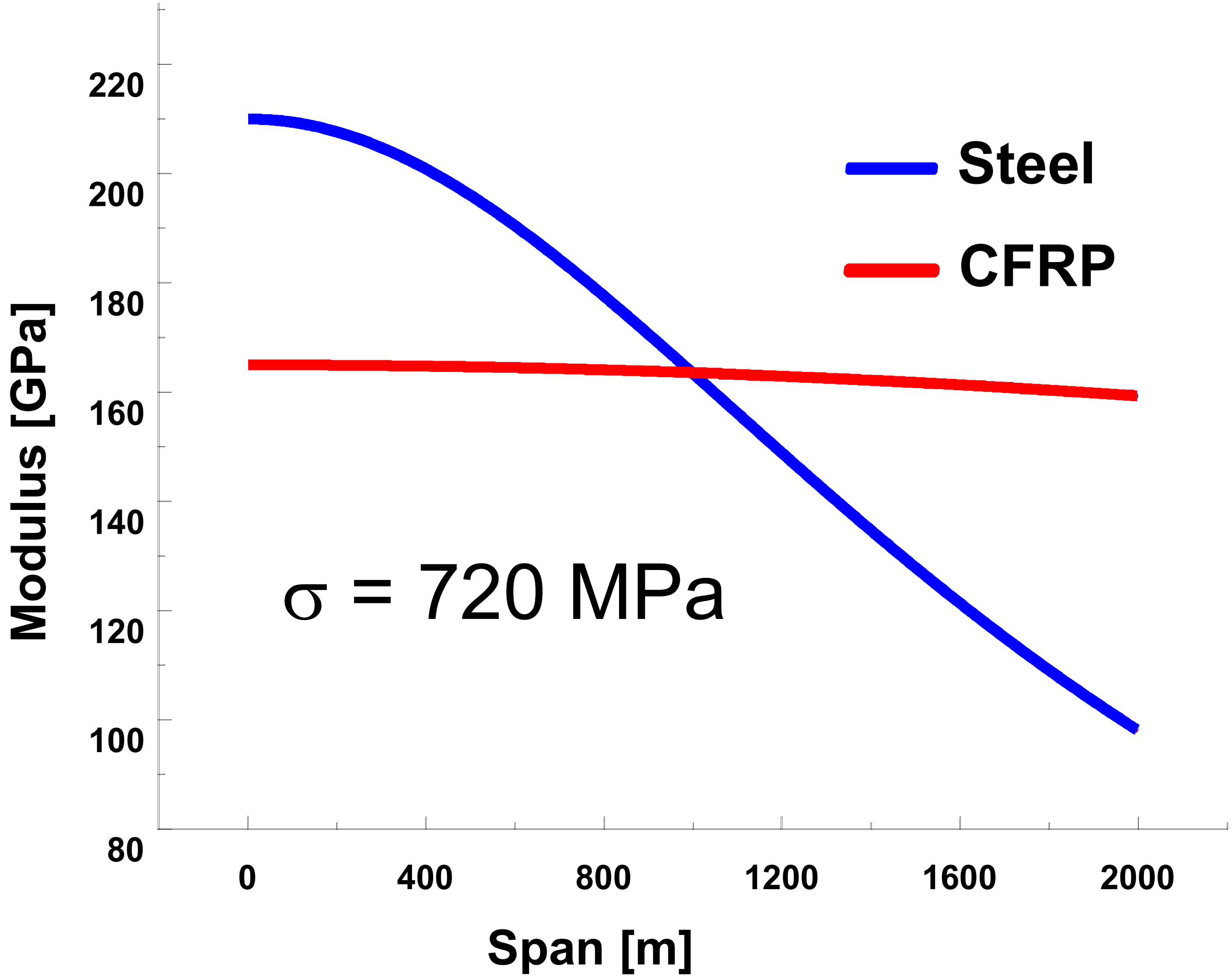
Picture from schlaich, bergermann, partner

DB

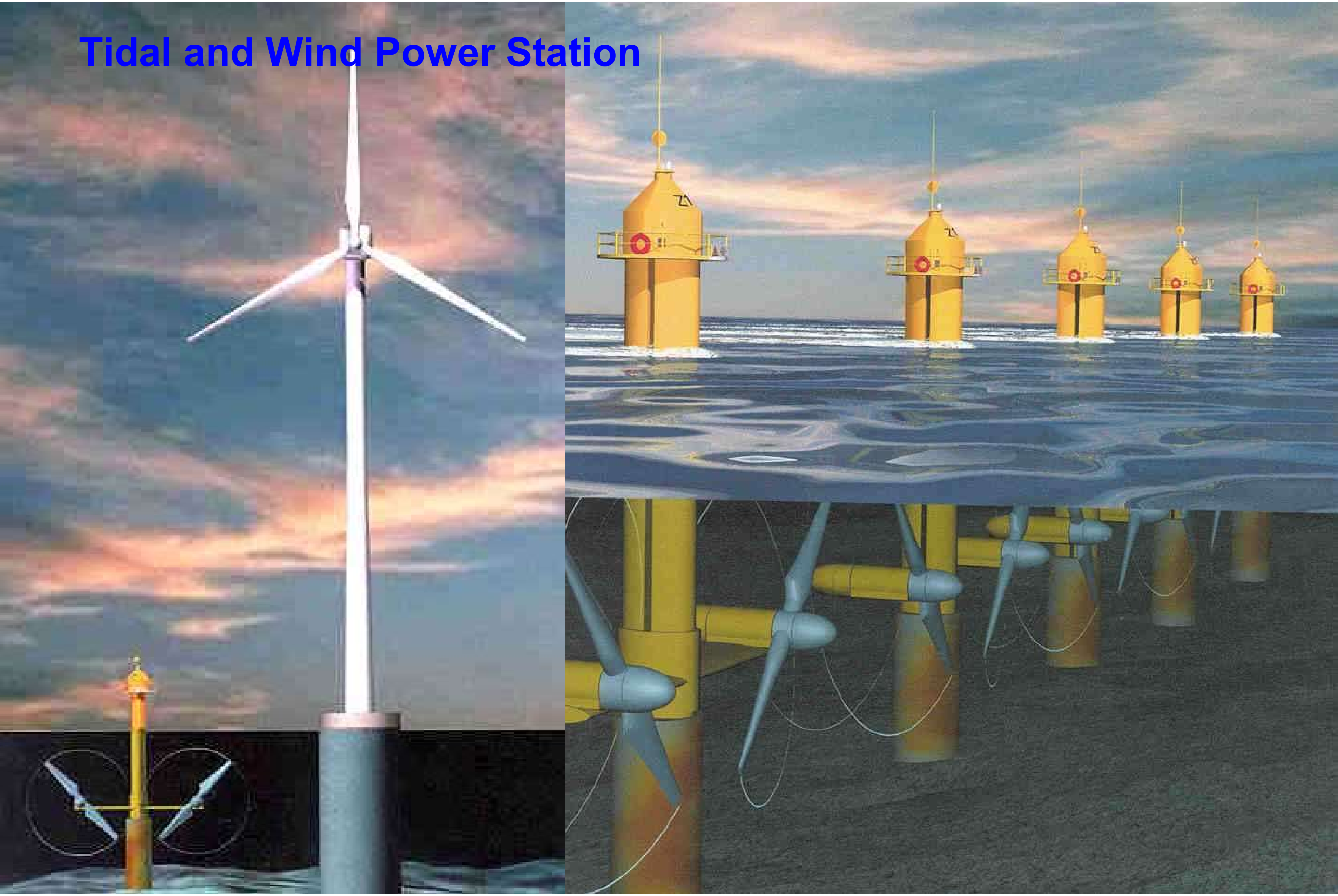
Carbo Link

sbp
schlaich bergermann partner

Relative equivalent Modulus



Tidal and Wind Power Station



Structural Health Monitoring

Wireless Monitoring Technology at Empa