# Fibre Composites in Structural Engineering

ETHZ Course No. 101-0167-01

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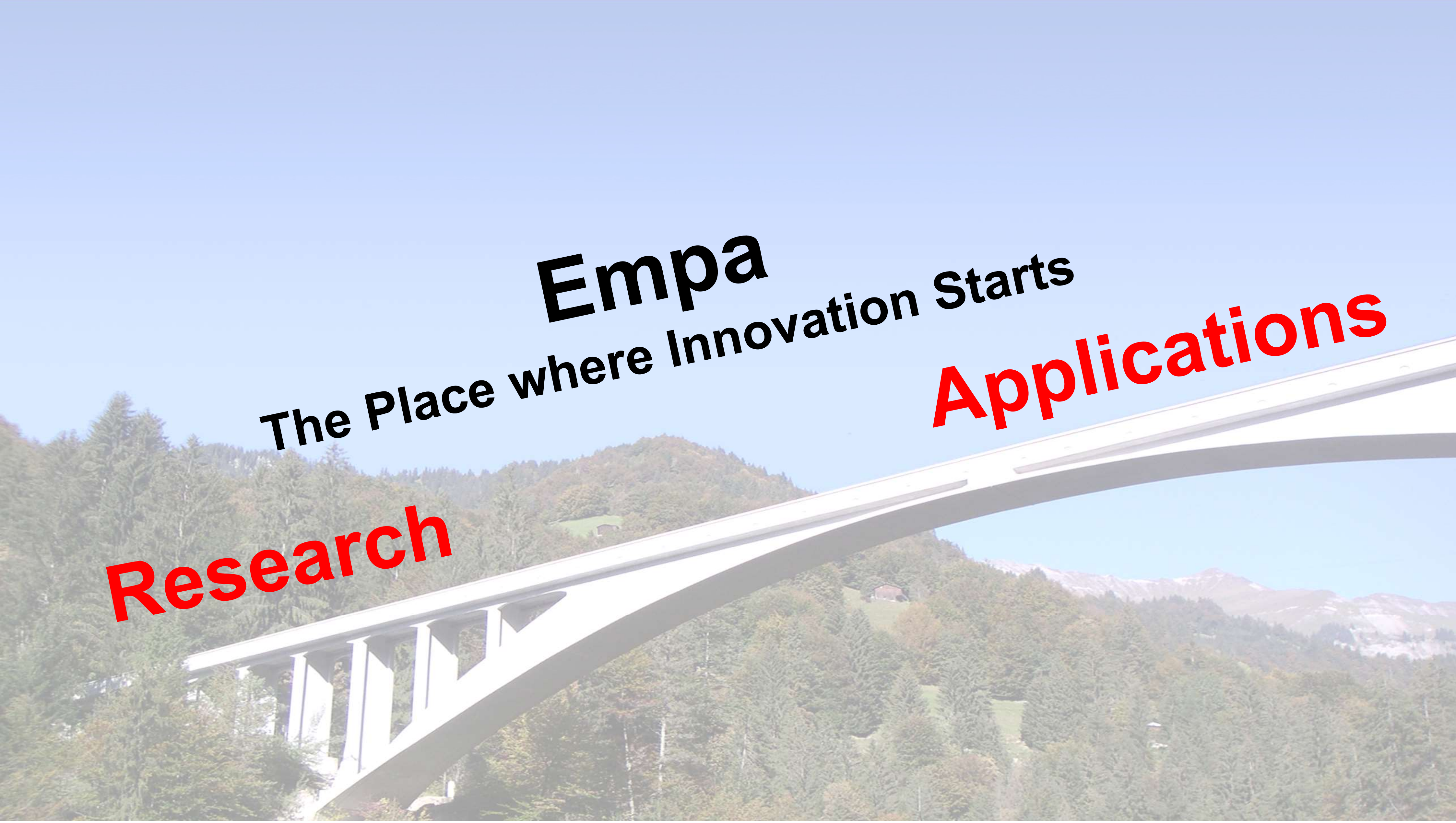
Materials Science and Technology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The Place where Innovation Starts
Applications
Research

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Human Health

Nanoscale
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Advanced Materials
and Key
Technologies

Industry, innovation and
infrastructure

Health and
well-being

Sustainable consumption and
production

Responsible Digital
Transformation

Health &
Performance

Built
Environment

Sustainable cities and
communities

Engagement and Dialog
with Society

Energy,
Resources &
Emissions

Energy, Climate and
Environmental
Sustainability

Affordable and clean
energy

Measures for climate
protection

# Table of content:

# 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. Yunus Hermanci, 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 2025 (HIL E10.1)

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

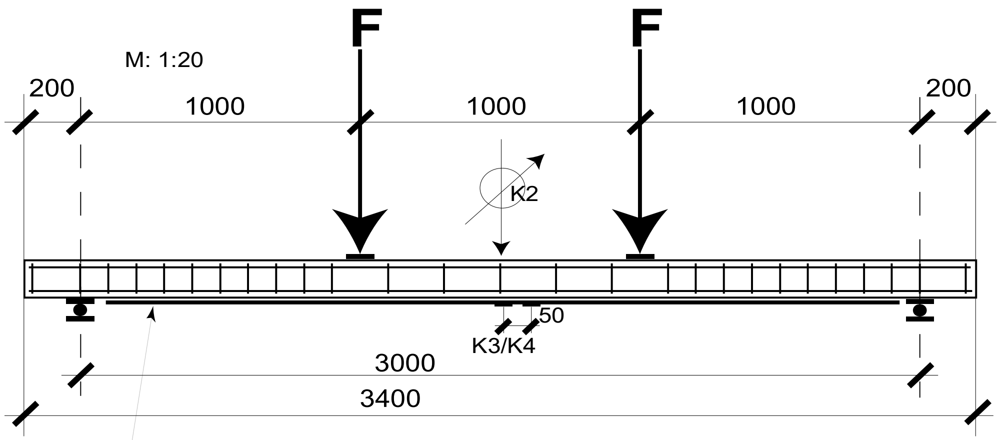
# …… Course Schedule, Fall Semester 2025

- 05/Nov : Externally Bonded FRP Reinforcement for Concrete Structures: Shear Strengthening; Column Confinement
- 12/Nov: Externally Bonded FRP Reinforcement for Metallic Structures (Hossein Heydarinouri)
- 19/Nov: Structural Health Monitoring (Yunus Hermanci) /
  Externally Bonded FRP Reinforcement for Timber Structures (Robert Widmann)
- 26/Nov: Application of Externally Bonded FRP Reinforcement in the Empa laboratory,
- 03/Dec: FRP-Reinforced Concrete Design - Internal Reinforcement
- 10/Dec: Laboratory experiments and Empa structural laboratory tour, **Second written midterm exam**
- 17/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

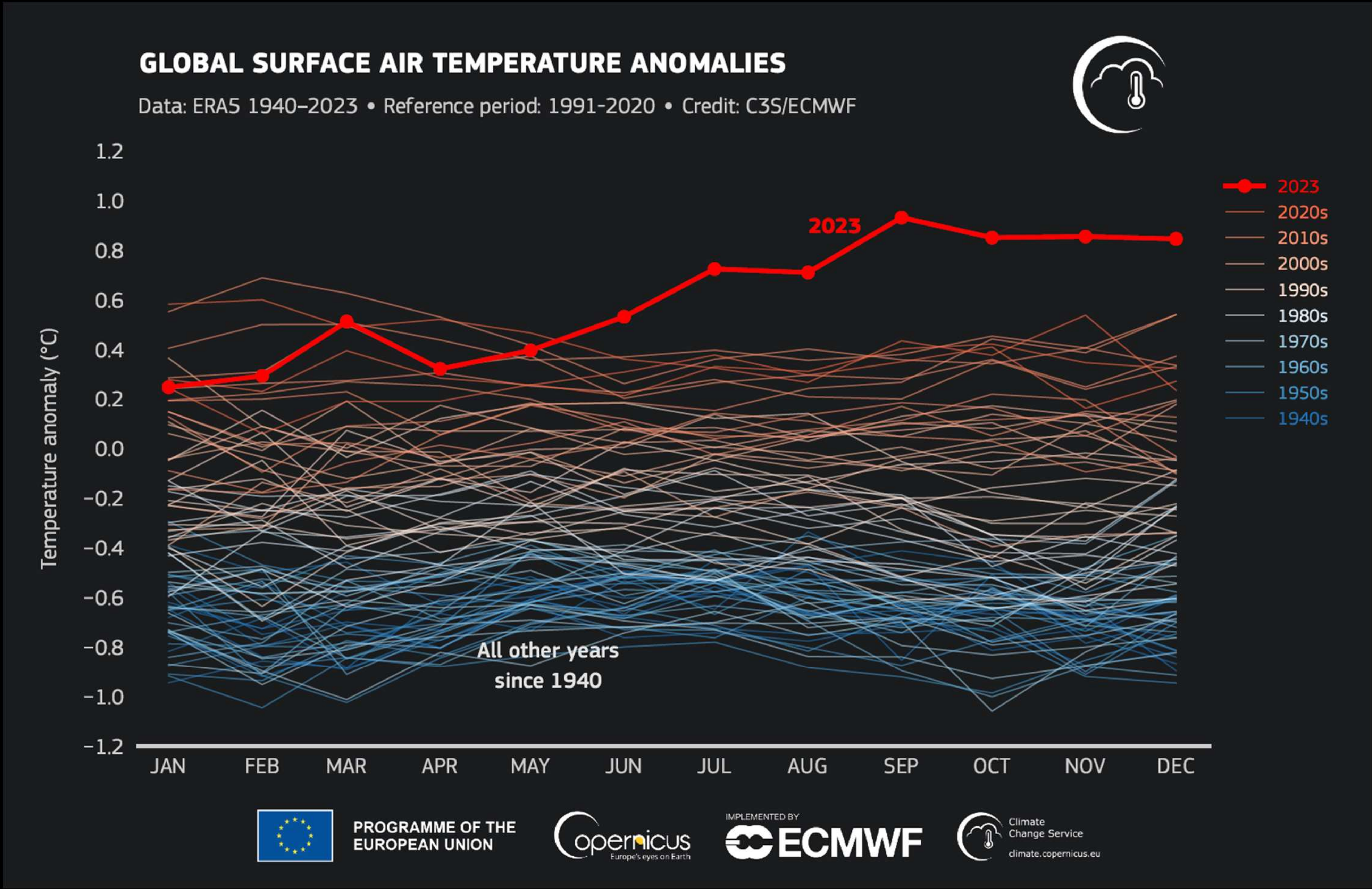
**Questions????**

# 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**

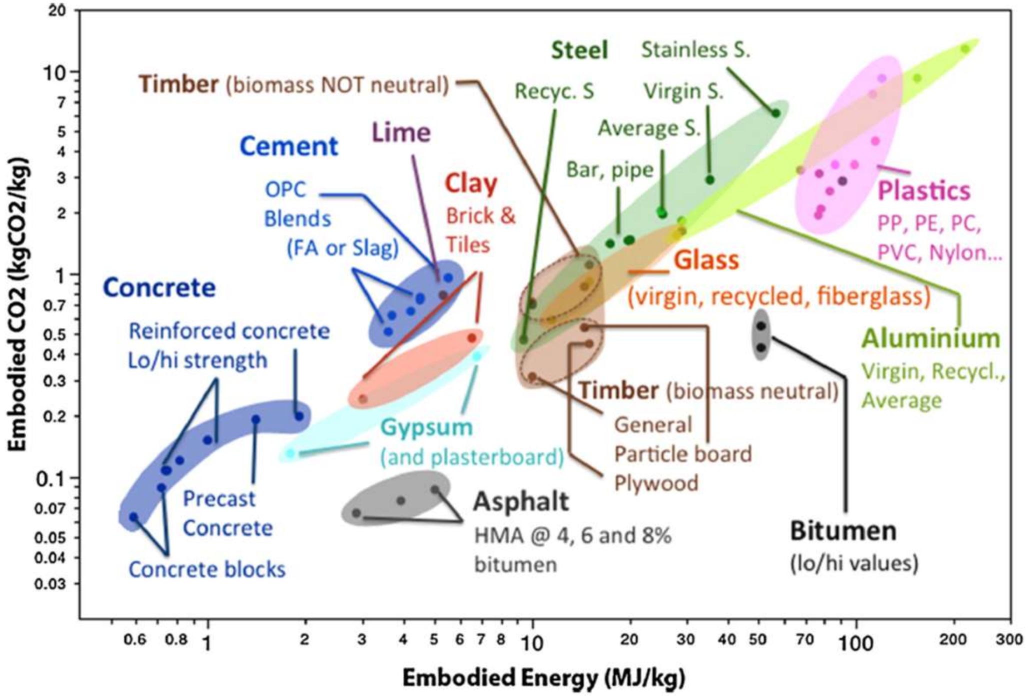

GLOBAL SURFACE AIR TEMPERATURE ANOMALIES
Data: ERA5 1940–2023 • Reference period: 1991-2020 • Credit: C3S/ECMWF
Temperature anomaly (°C)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2023
All other years since 1940
2023
2020s
2010s
2000s
1990s
1980s
1970s
1960s
1950s
1940s
PROGRAMME OF THE EUROPEAN UNION
Copernicus
Europe's eyes on Earth
IMPLEMENTED BY
ECMWF
Climate Change Service
climate.copernicus.eu

# Cement and Concrete: high emissions originate from high demand

Cement consumption Switzerland (2022):

4.15 Mt : **2.4 Mt CO2** (~6% inland emissions)

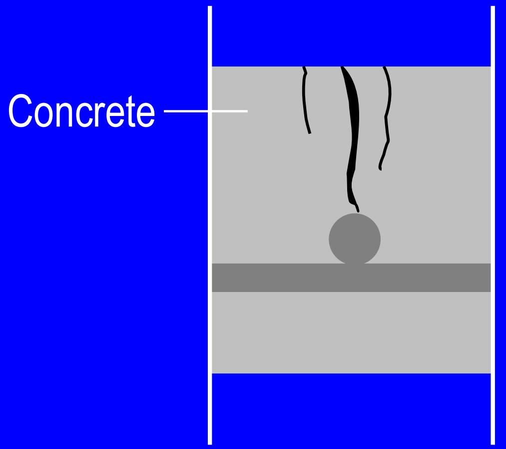
«Cemsuisse Jahresbericht 2022/2023»




«Barcelo et al. 2014»

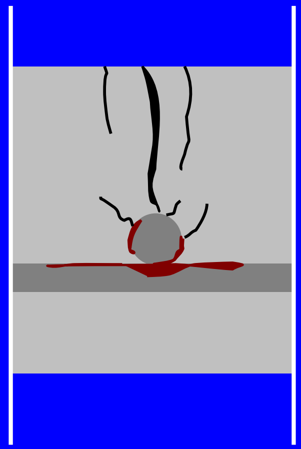
- A primary factor leading to extensive degradation…

**Corrosion**




Moisture, oxygen and chlorides penetrate

- *Through concrete*
- *Through cracks*



Corrosion products form

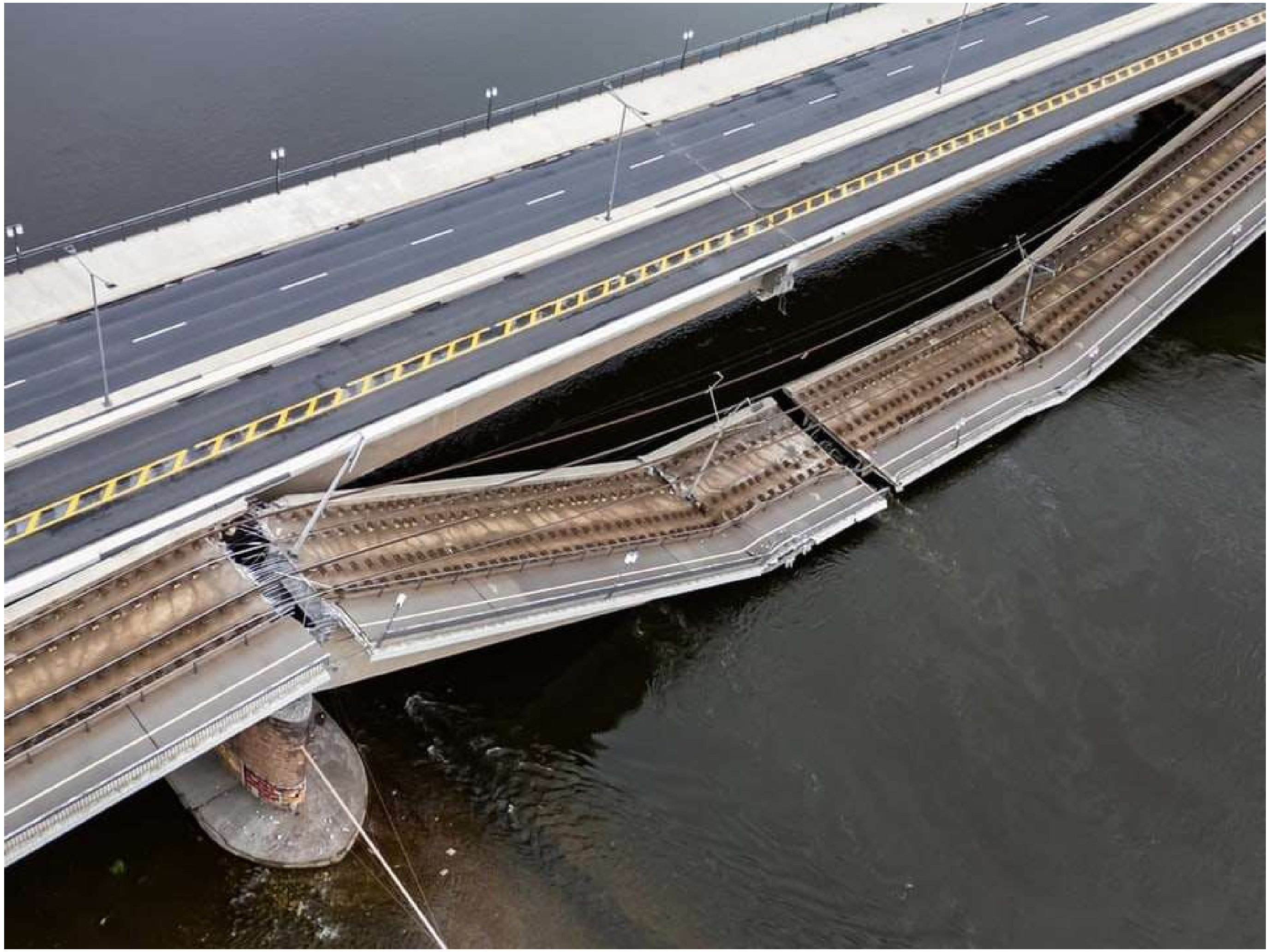
Volume expansion occurs

More cracking

Corrosion propagation

End result

# Collaps of the 53 years old Carola Bridge, Dresden, Germany, 11. September 2024,



# 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?

**Lightweight**

*Easy to handle*

**High Strength**

*5x steel*

**FRP Materials**

**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

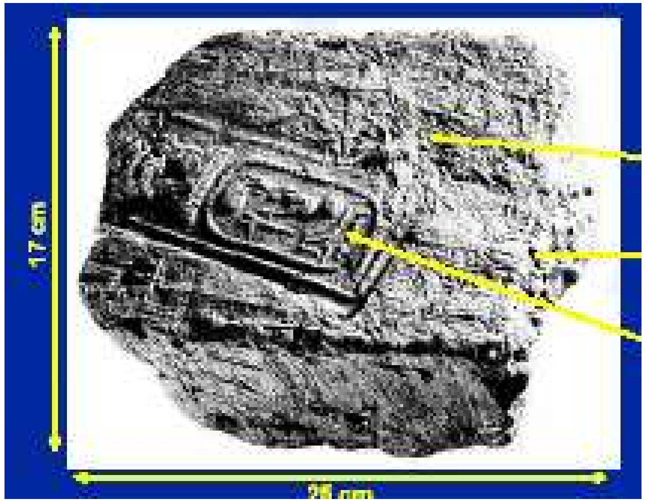
**Volume Usage per Year (old statistic!):**

| | | |
|---|---|---|
| **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

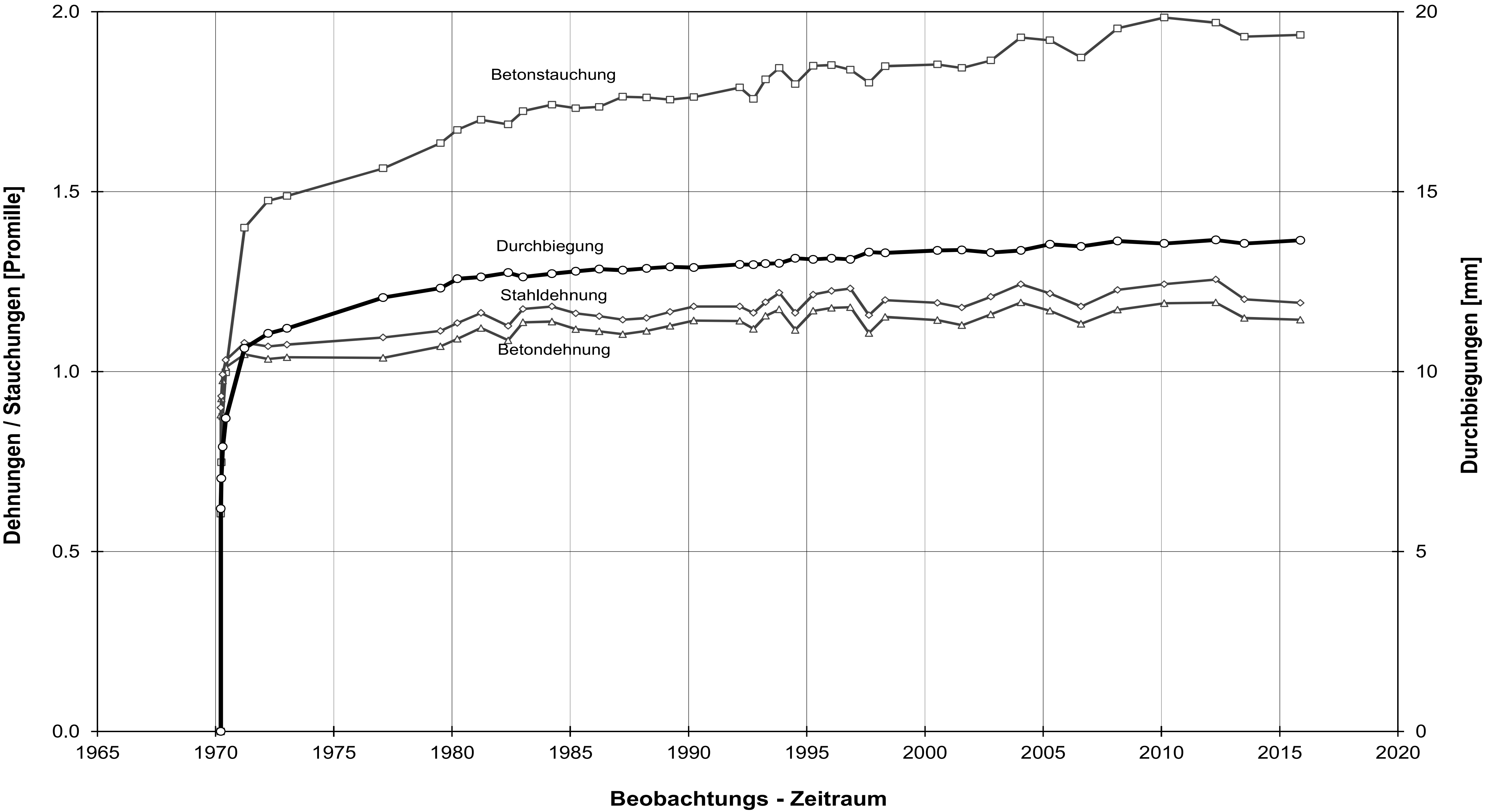
# Creep Test at EMPA-Switzerland

**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 %**



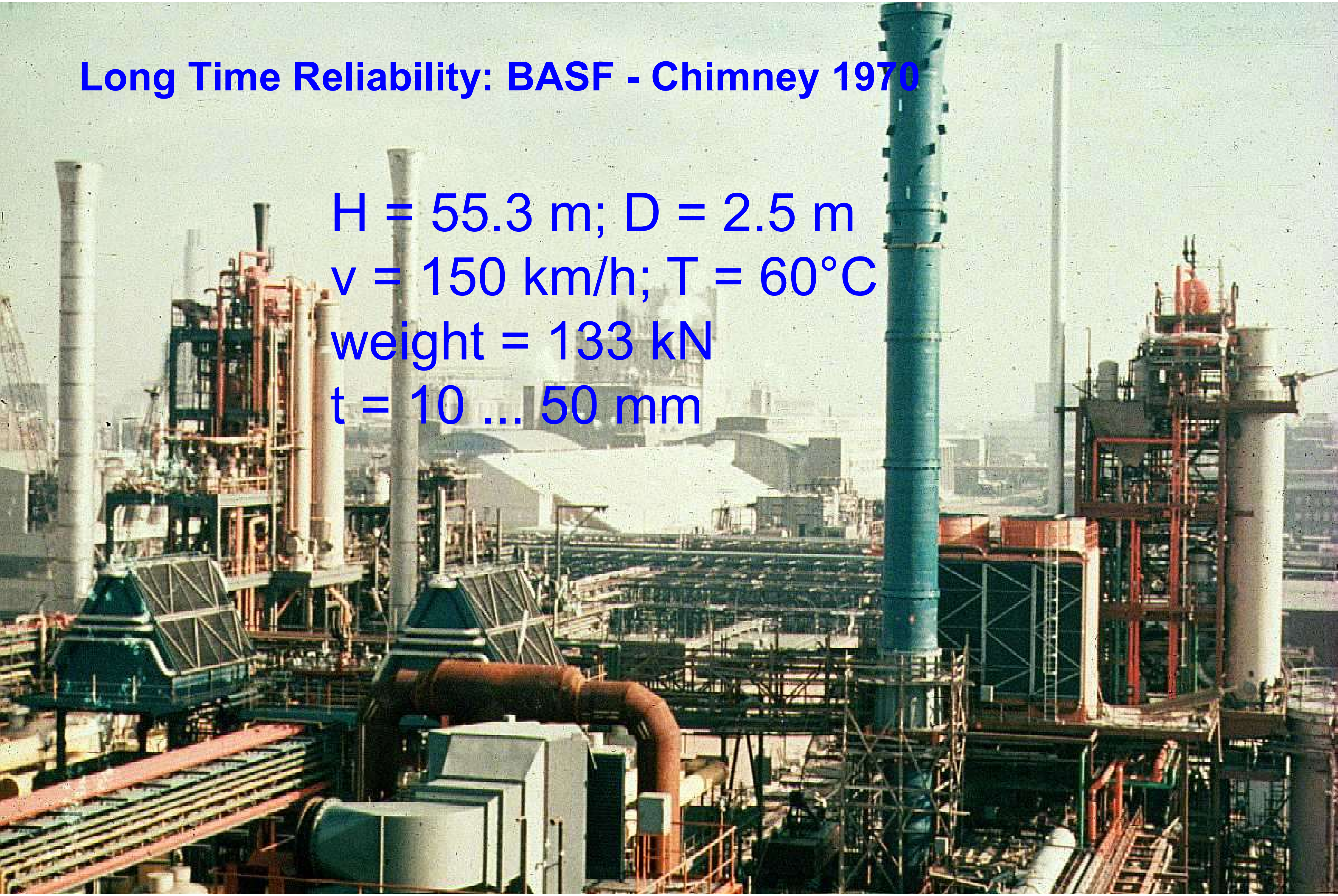
## Long Time Reliability: BASF - Chimney 1970

H = 55.3 m; D = 2.5 m

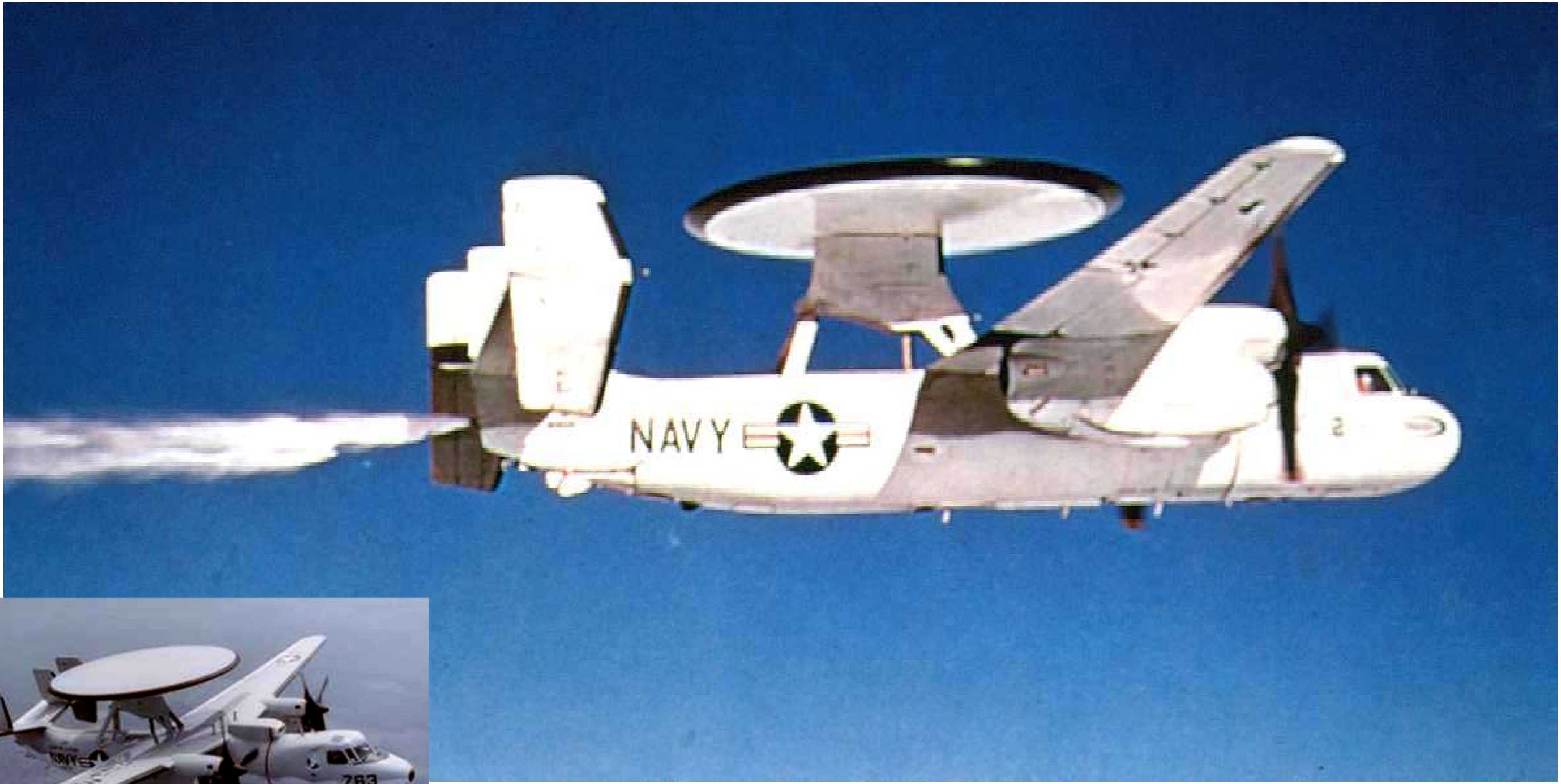
v = 150 km/h; T = 60°C

weight = 133 kN

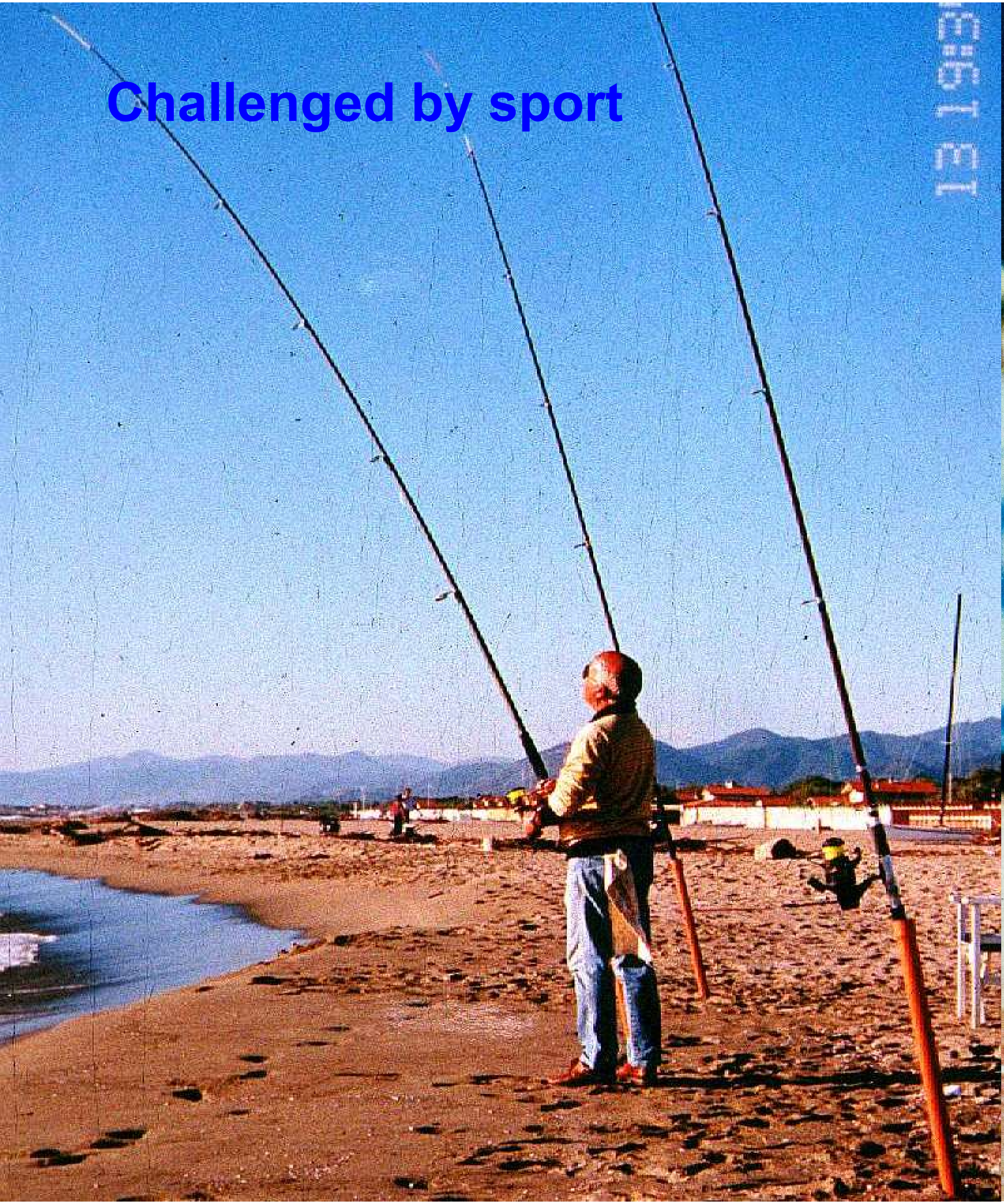
t = 10 ... 50 mm



# Long Time Reliability: E-2C Hawkeye since 1964




# Challenged by the sport items

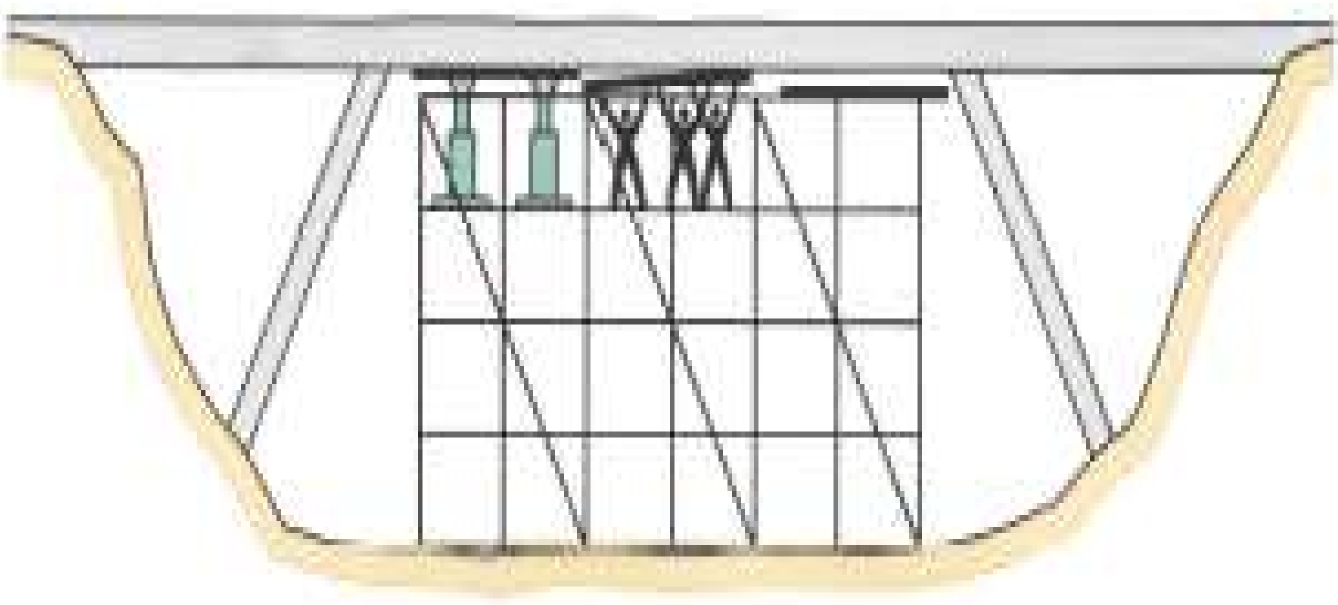

Challenged by sport


Steffi Graf , 1988 No. 1

# Challenged by sport

# State of technology today

# Post Strengthening using Steel Strips



## Reasons for strengthening

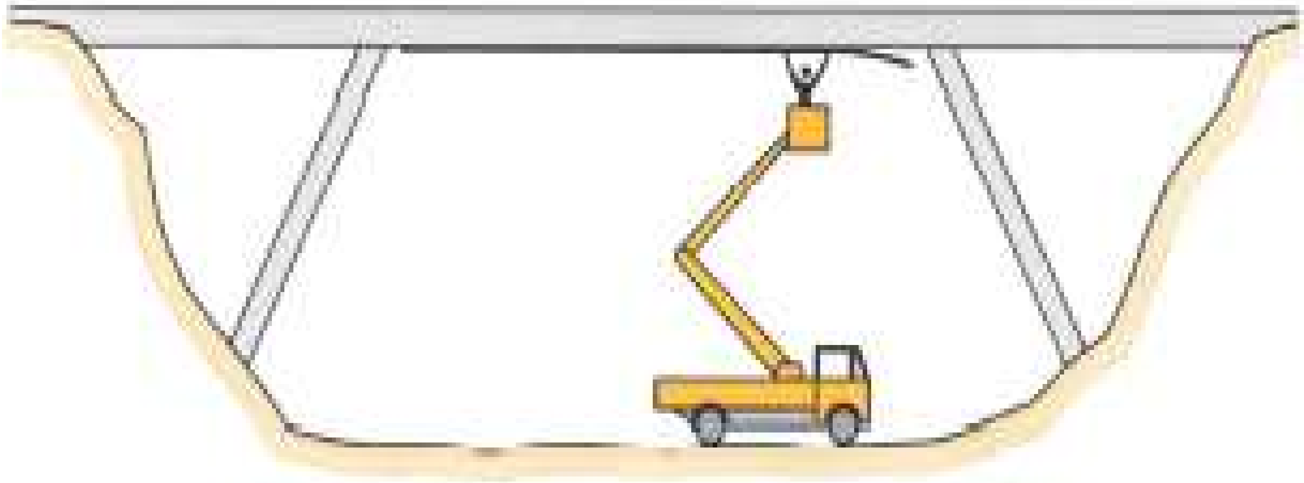
- Aging of our structures
- Renewal is too expensive
- Higher loads (railway bridges, …)
- Natural hazards (earthquake, …)
- Man made hazards (terror attacks, …)
- Repair

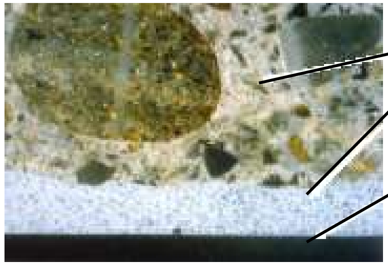
- Heavy
- Corrosion

- Requires scaffold
- Requires many joints

# Post Strengthening using CFRP Strips

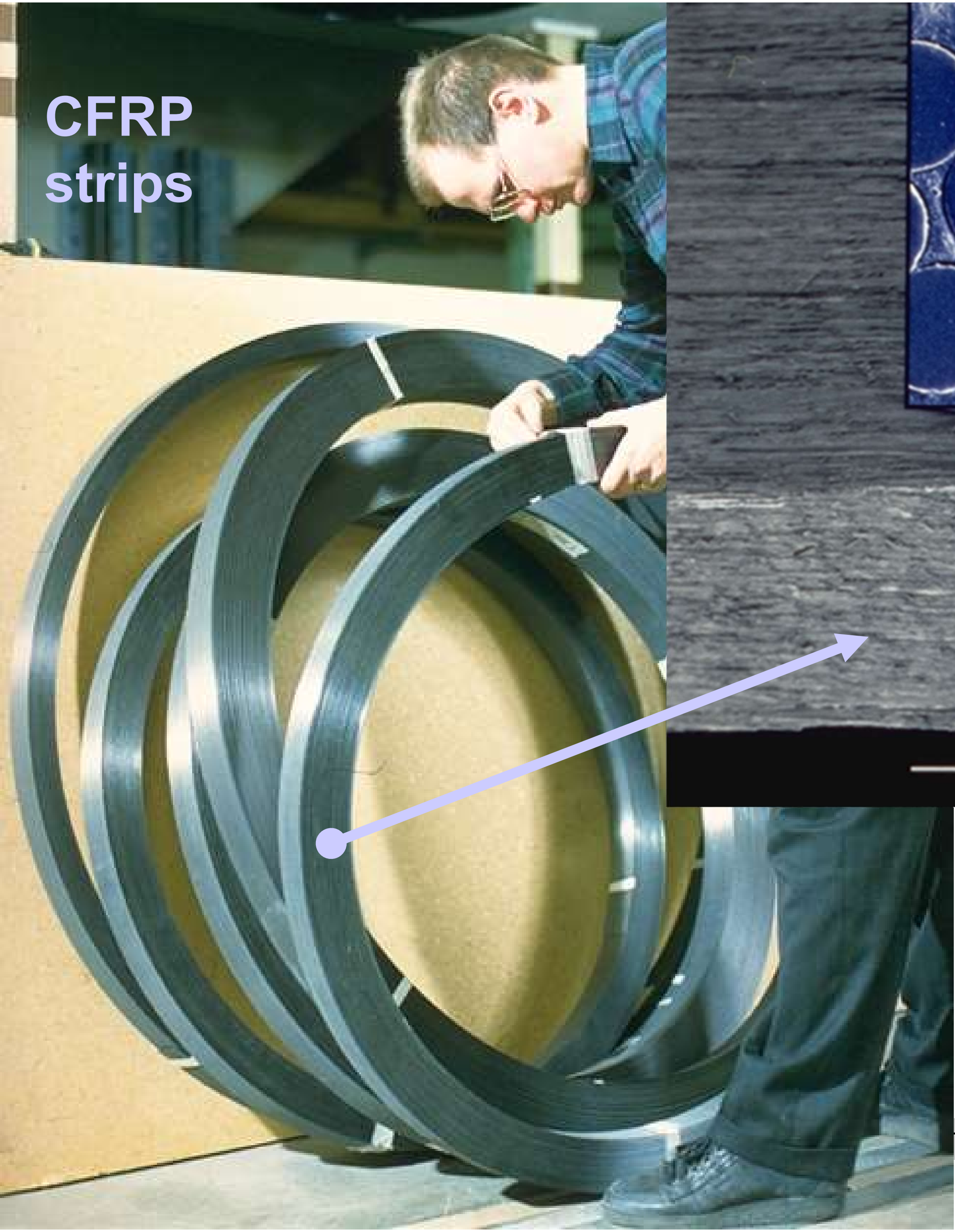
**Introduced by Prof. Urs Meier (EMPA Switzerland) in 80's**

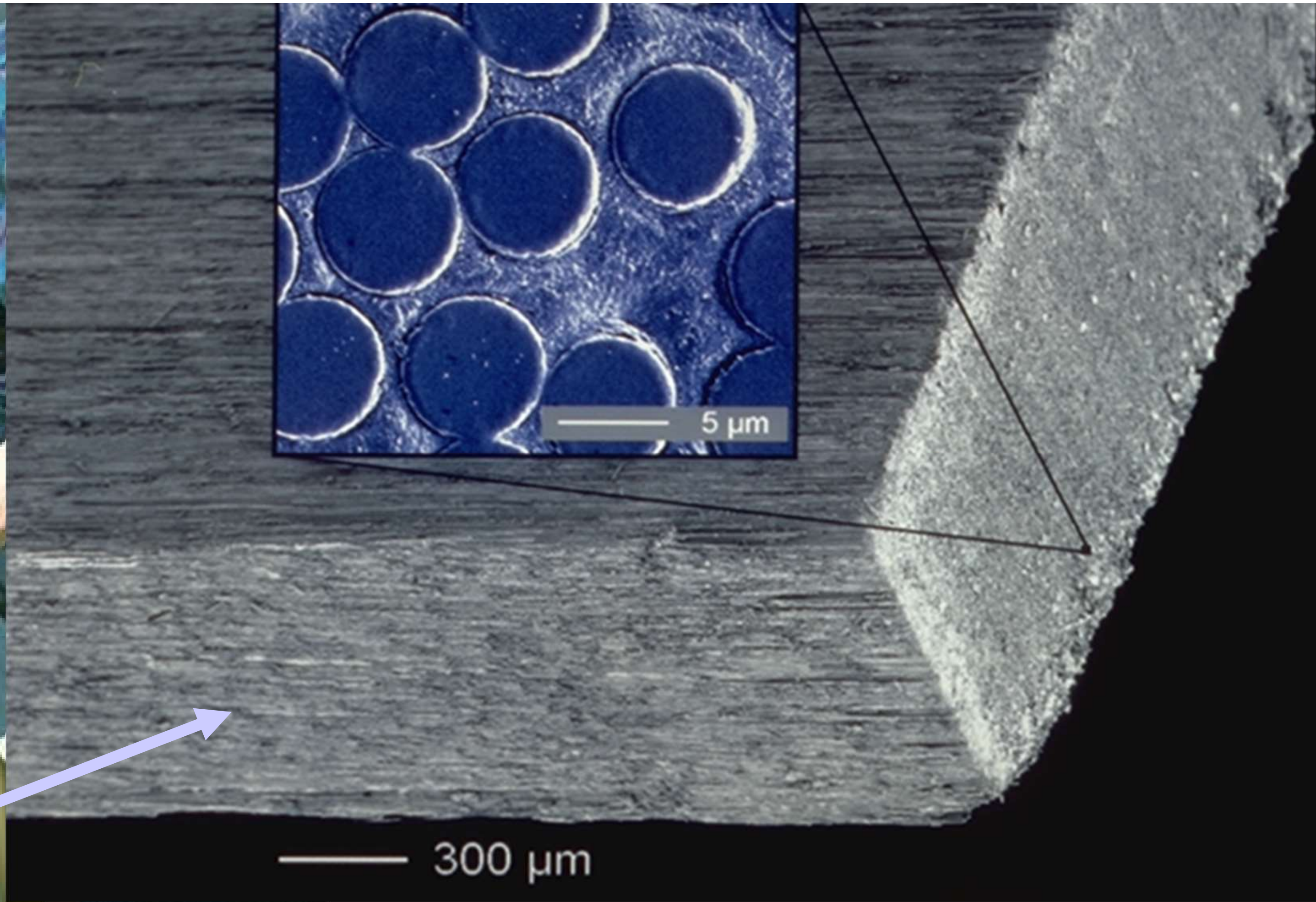





**- Light weight**
**- Corrosion resistant**

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



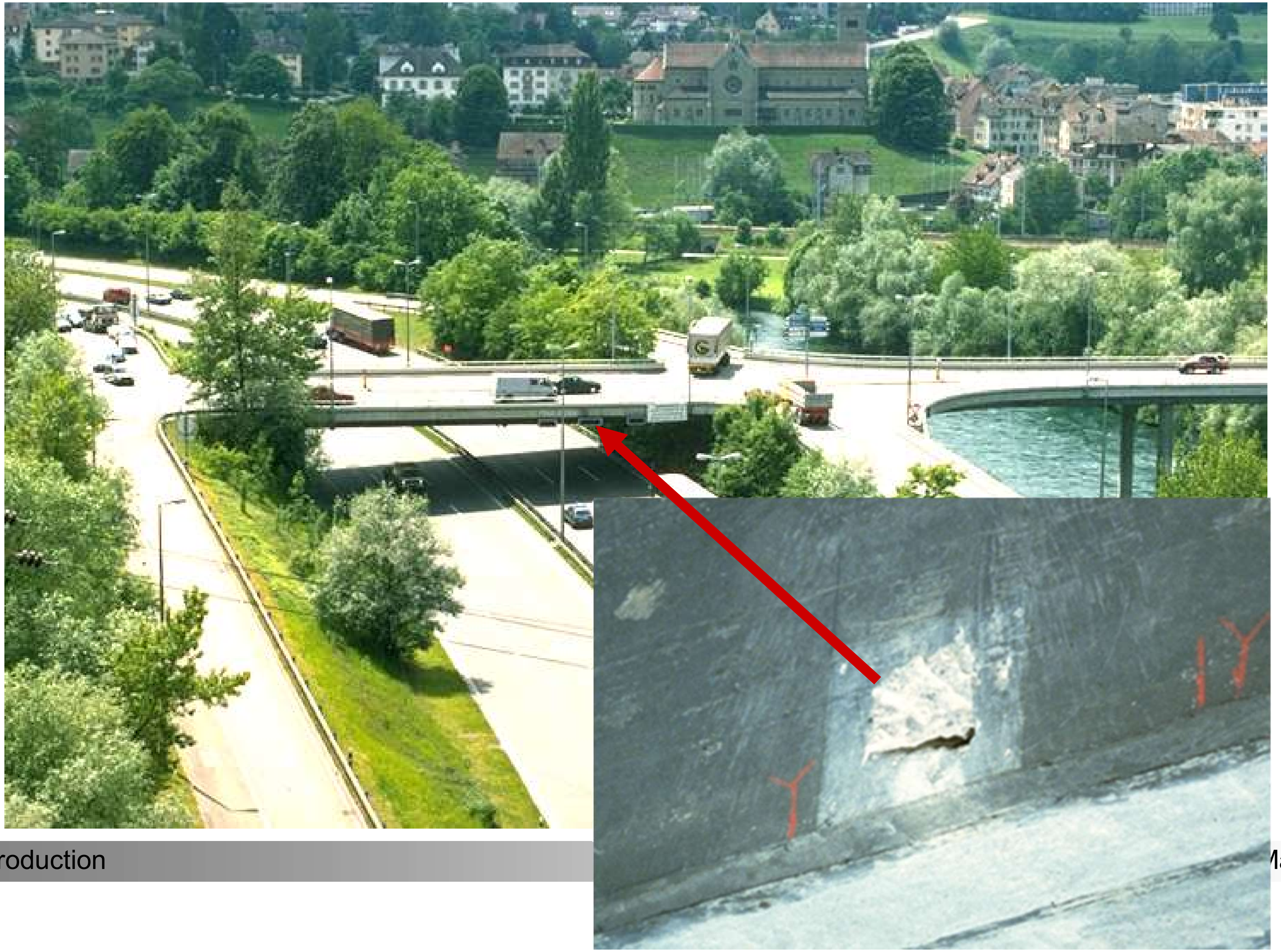




**CFRP Fibers:**
**65….72 vol%**

**Strength:**
**2500….3300 MPa**

**E-Modul:**
**150…300 GPa**

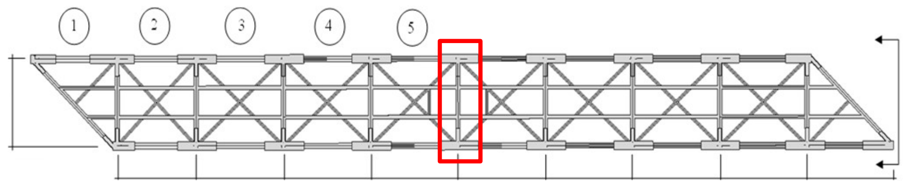
# Ibach Bridge, Switzerland 1991

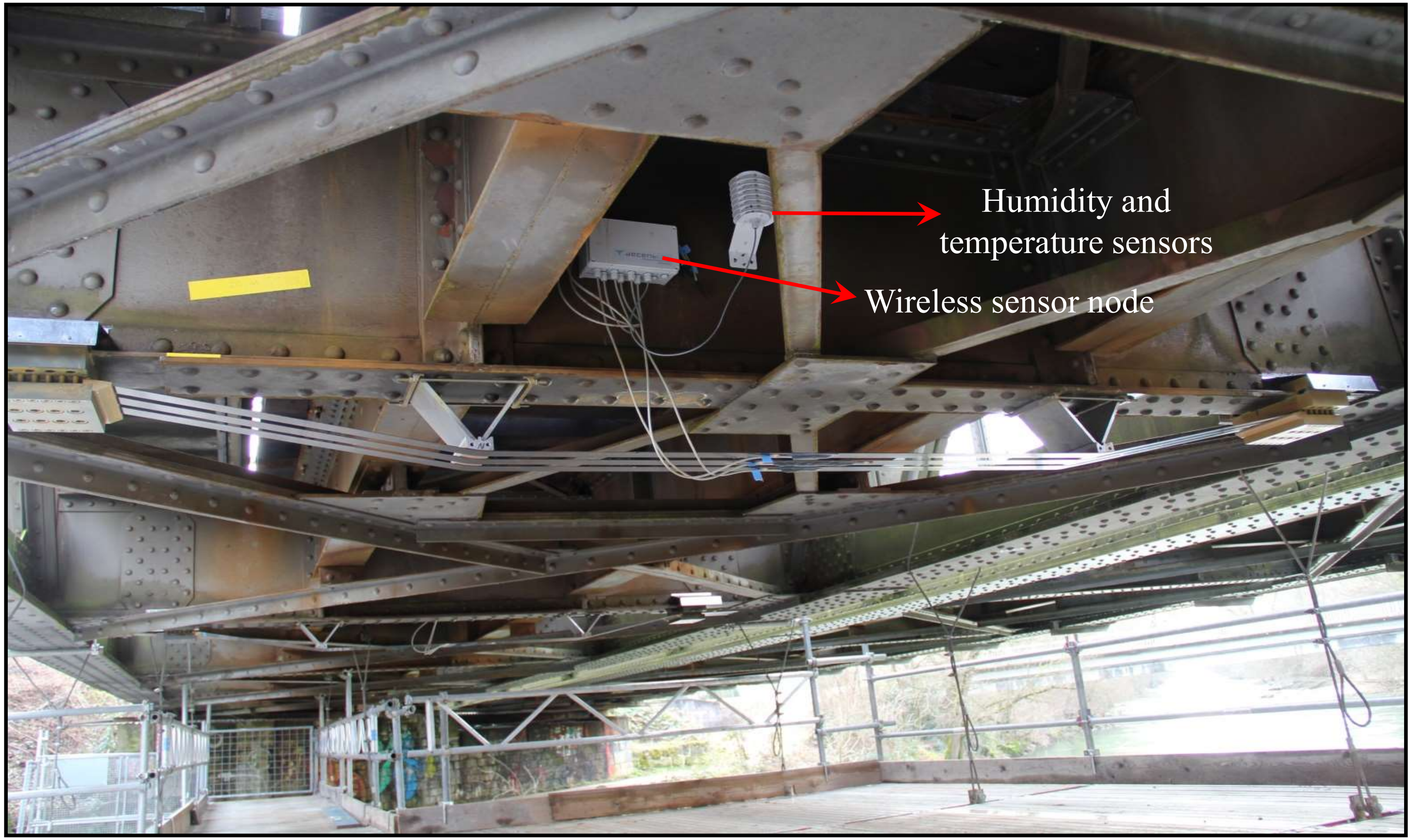


# Ibach Beridge, Switzerland 1991

# Steel Bridge Strengthening

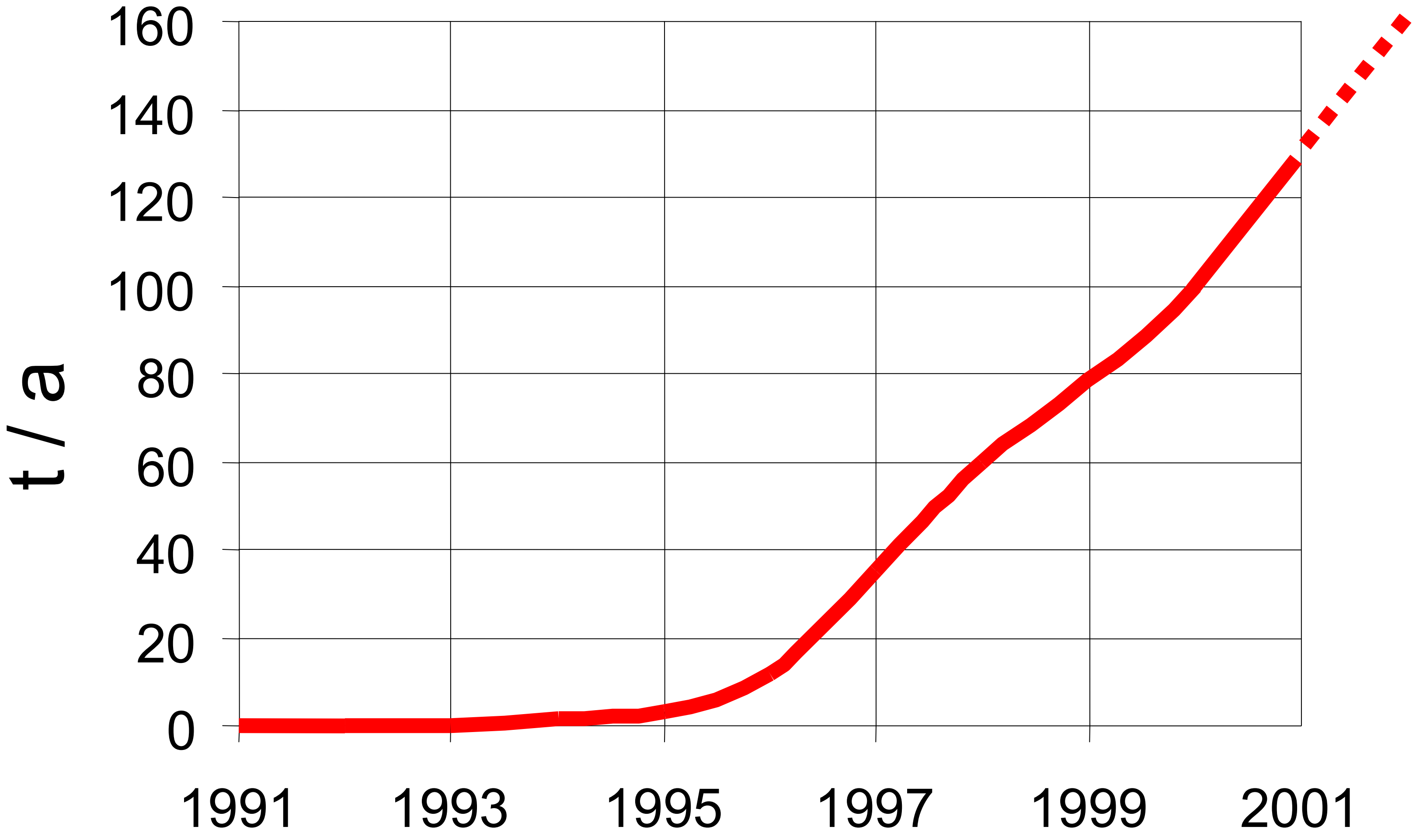
Münchenstein Railway Bridge, 120 years old near Basel



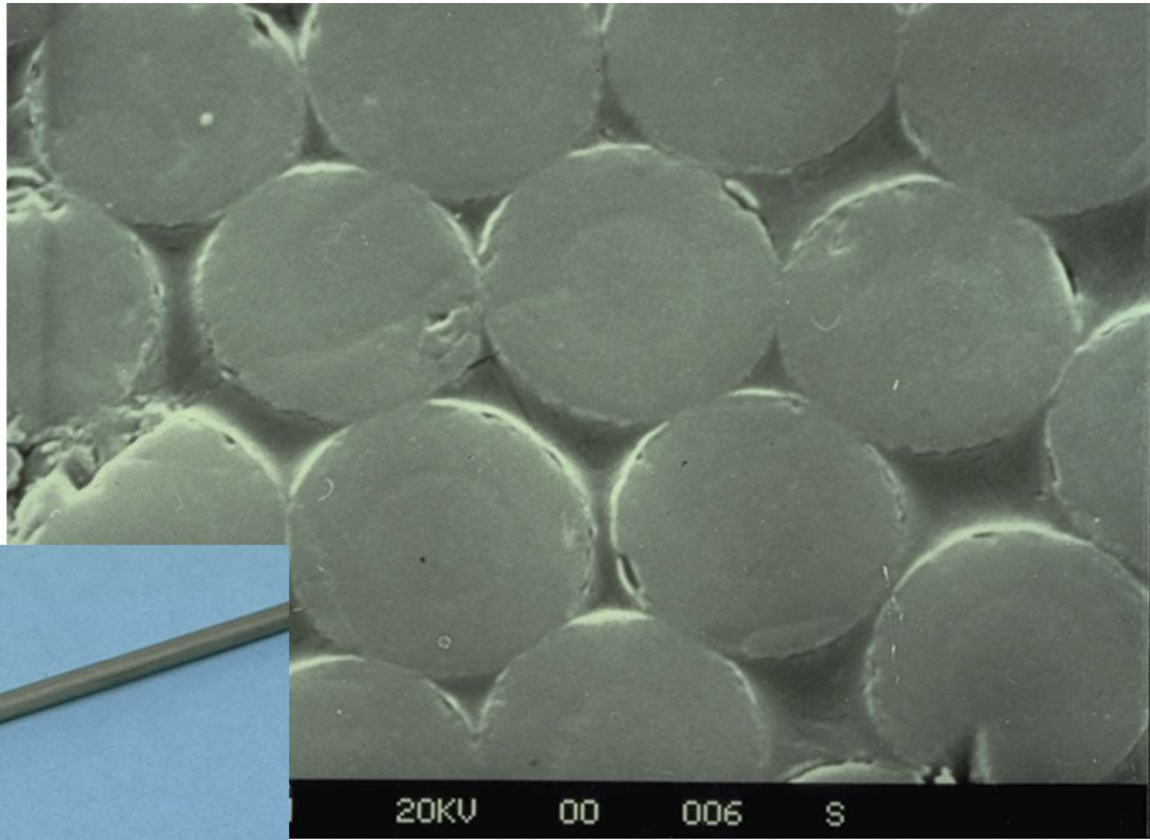



# Daily Job

# CFRP Strips in Switzerland

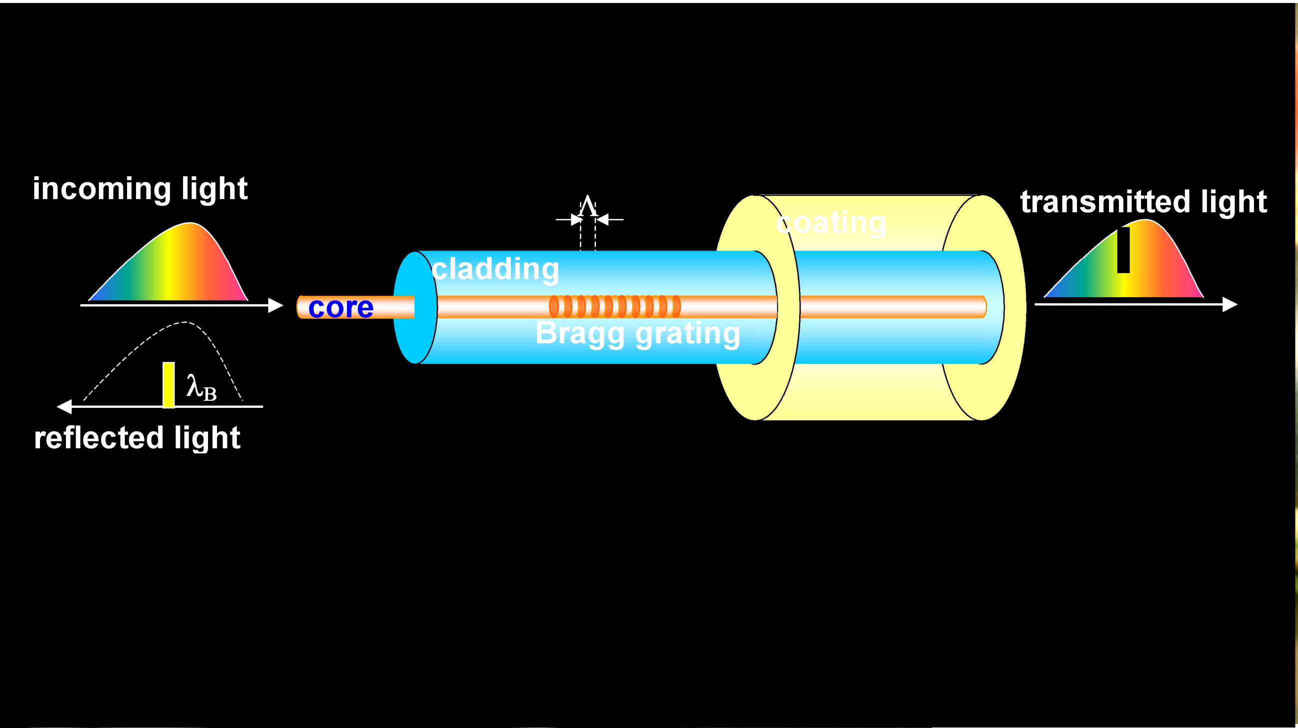


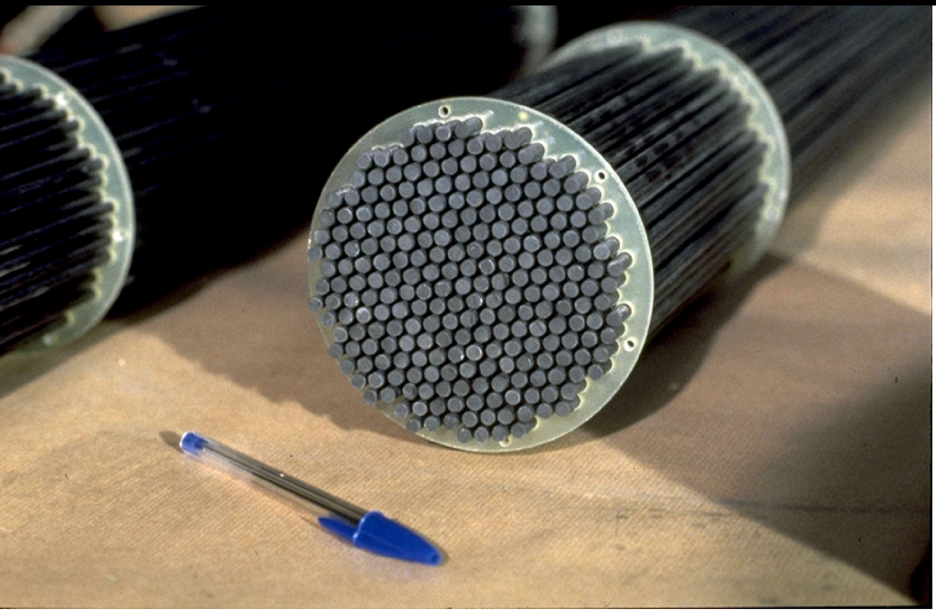
# Alternative to Steel ?




**For example:**

**Stay cables**



**Parallel wire cable**
241 wires
(Diameter 5 mm)
Load capacity: 12 MN

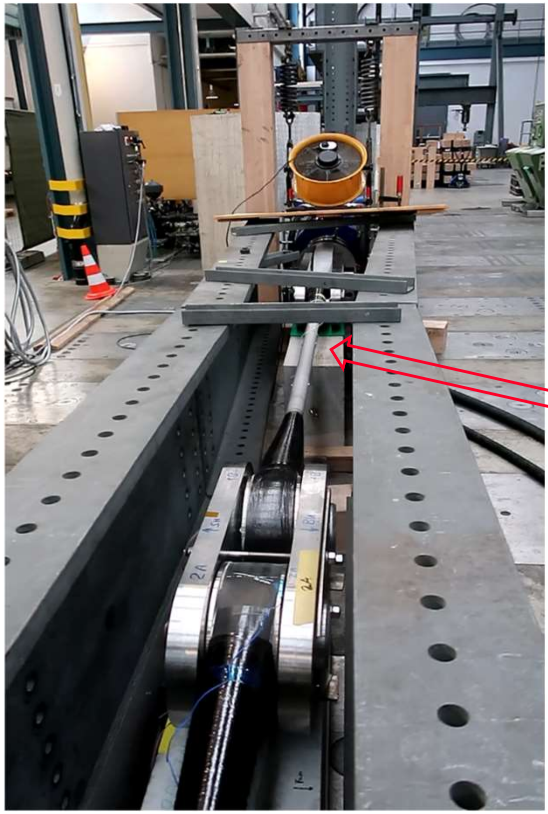
# Storch Bridge 1996, Winterthur, Switzerland

**(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 g... 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

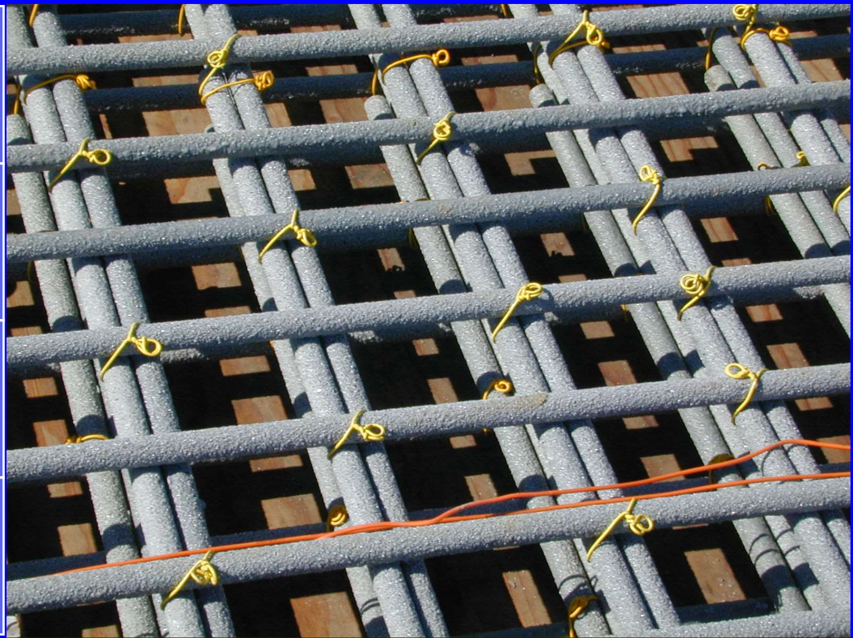
Laboratory testing of an FRP bridge deck panel

# FRP-Reinforced Concrete

## Placing the deck slab concrete

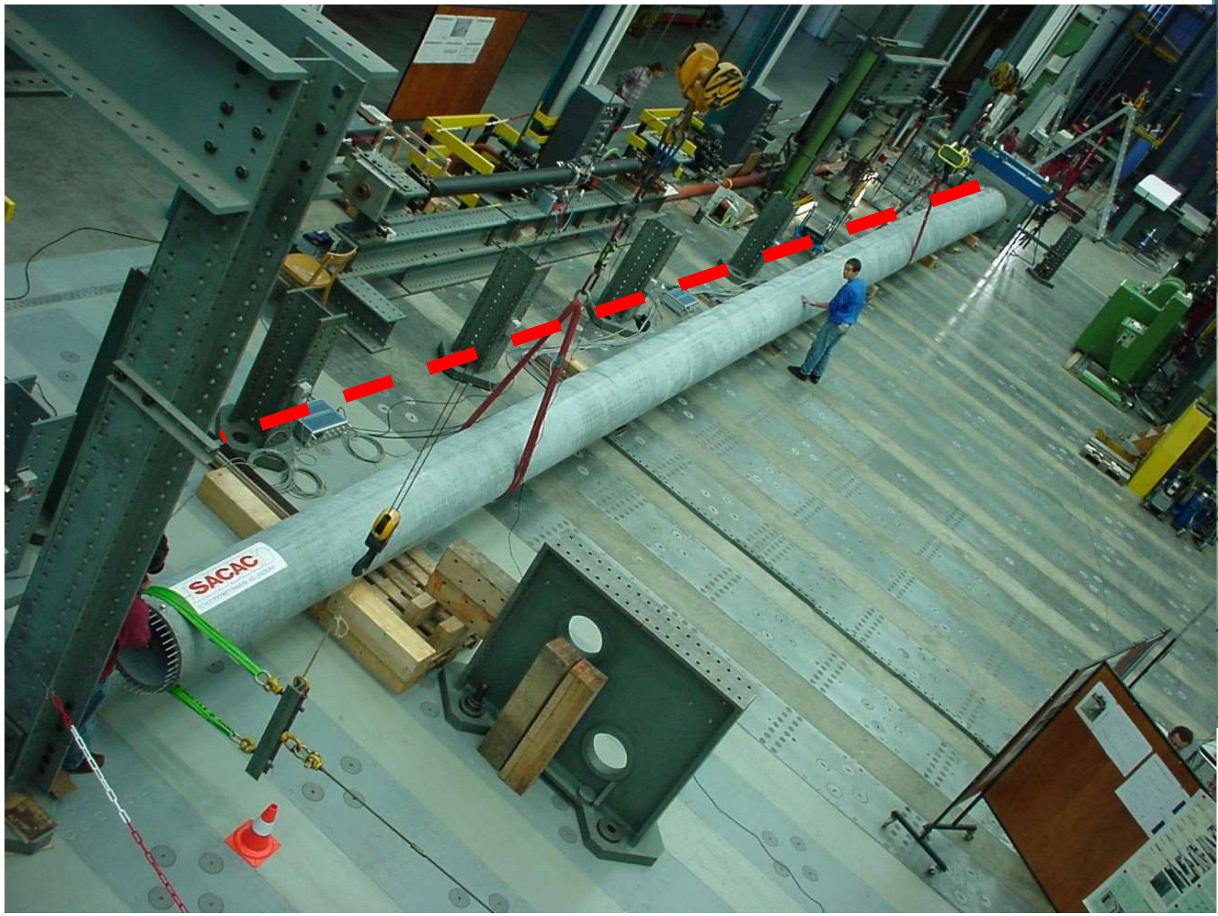
# FRP-Reinforced Concrete

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

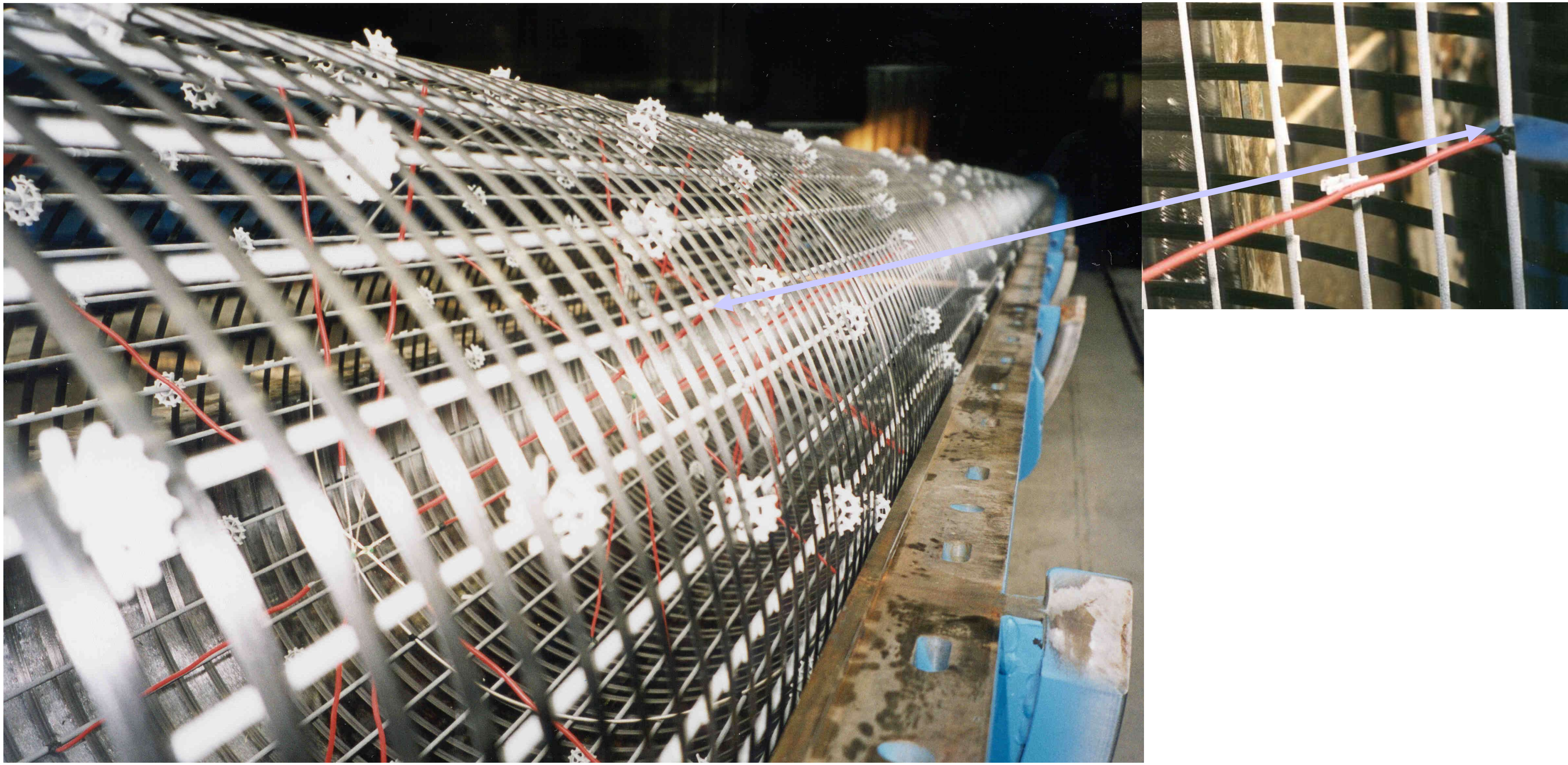


Bridge deck reinforcement

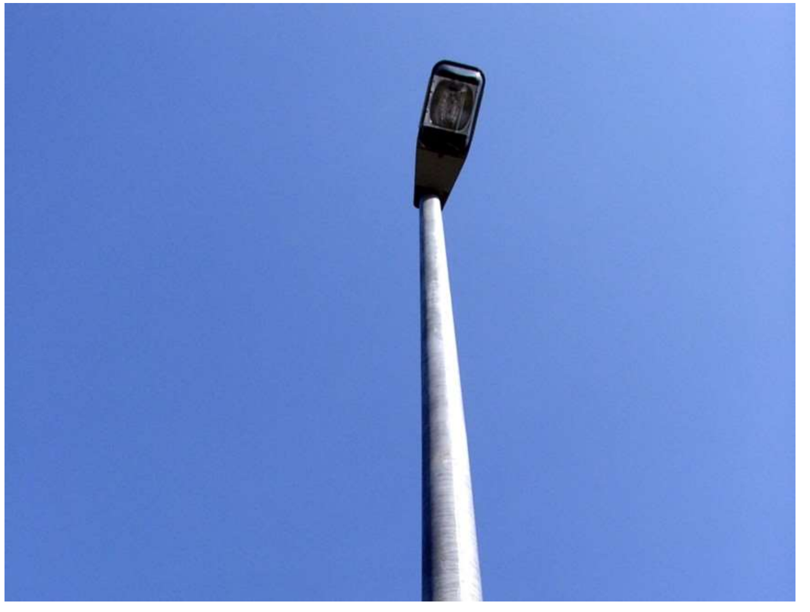
# Flexural testing




# CFRP reinforcement

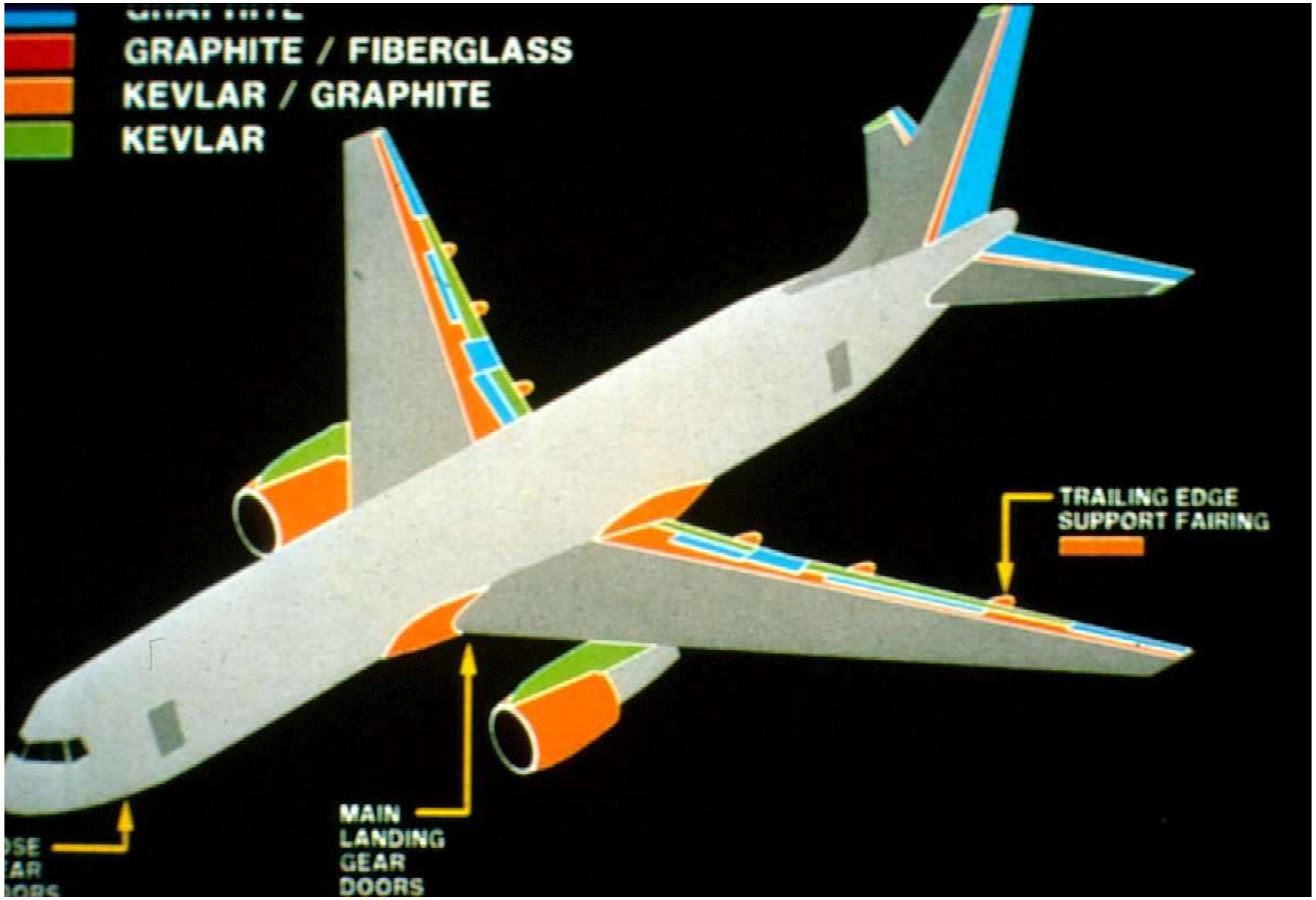


# SACAC Carbolith Pole



- 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 …

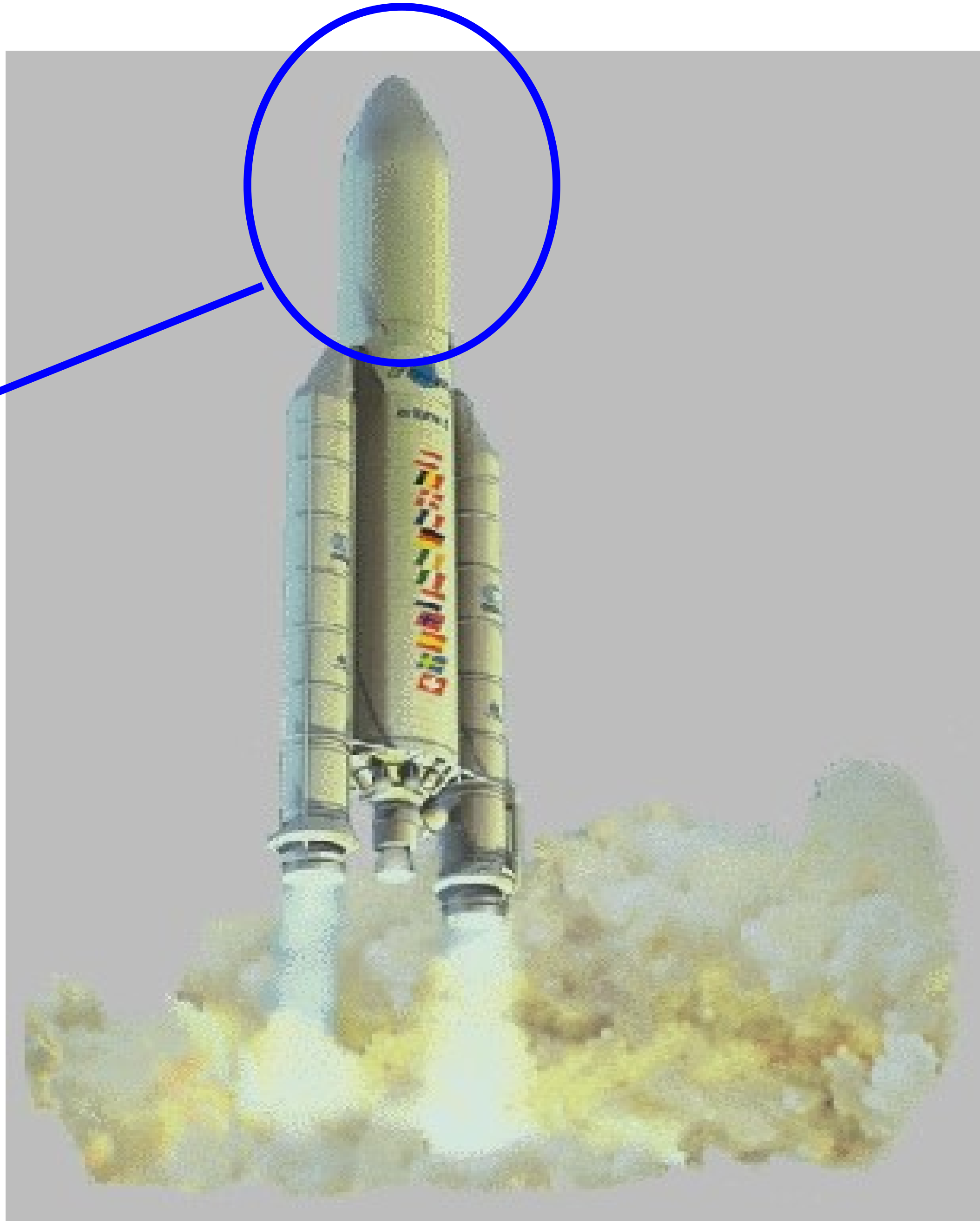




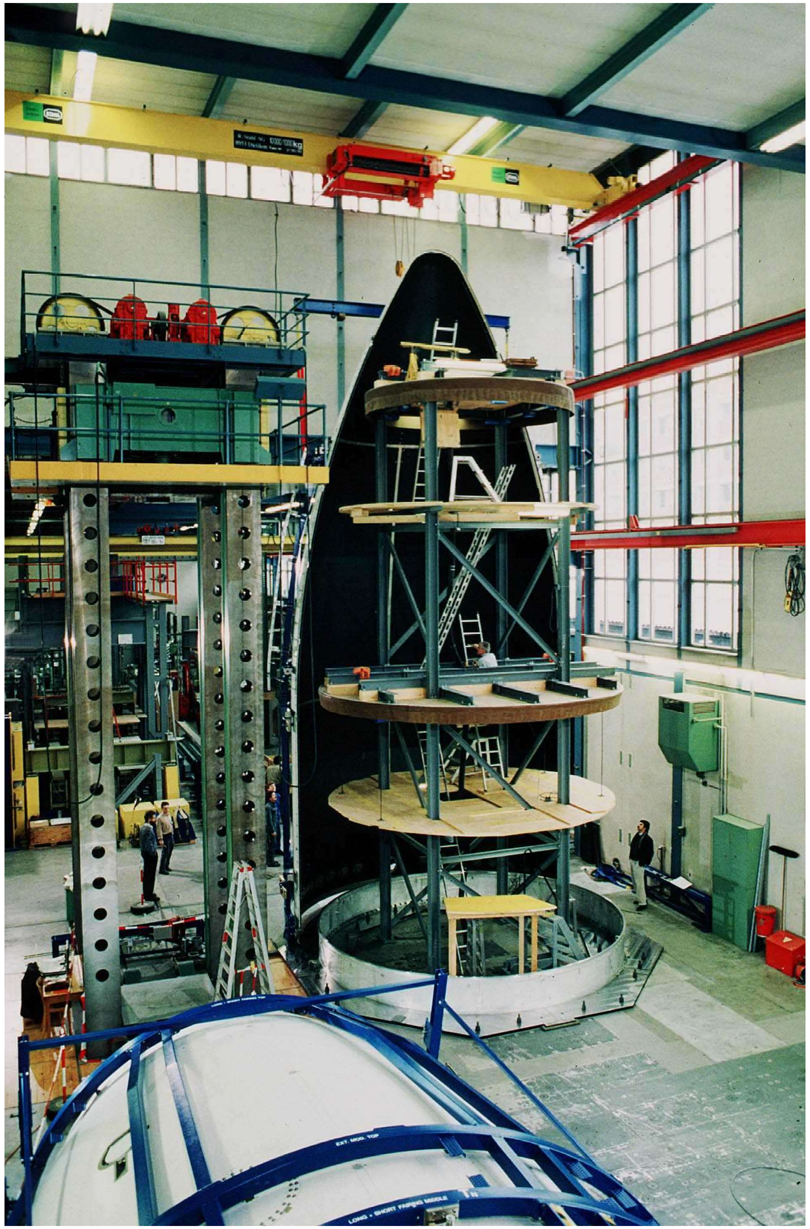
approved since 1974

# Ariane V

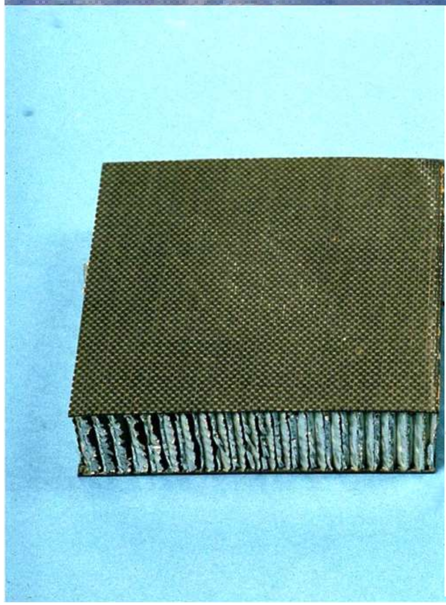
## Live load cover

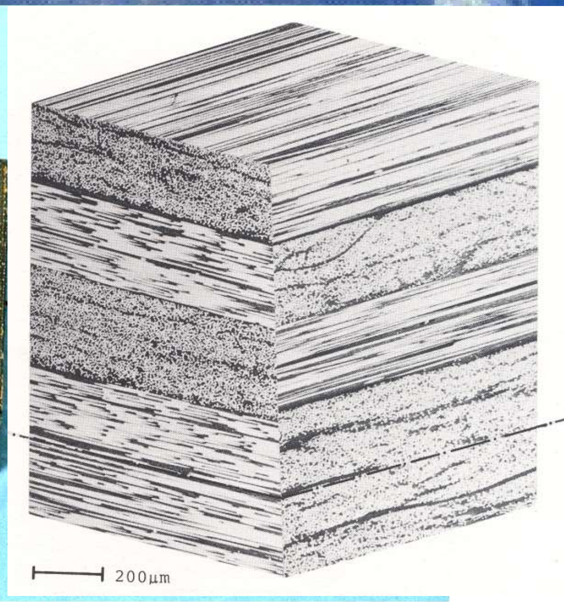


- H = 12,7 m
- D = 5,4 m
- 200°C, 110 km, 3 min
- Total mass = 1680 kg

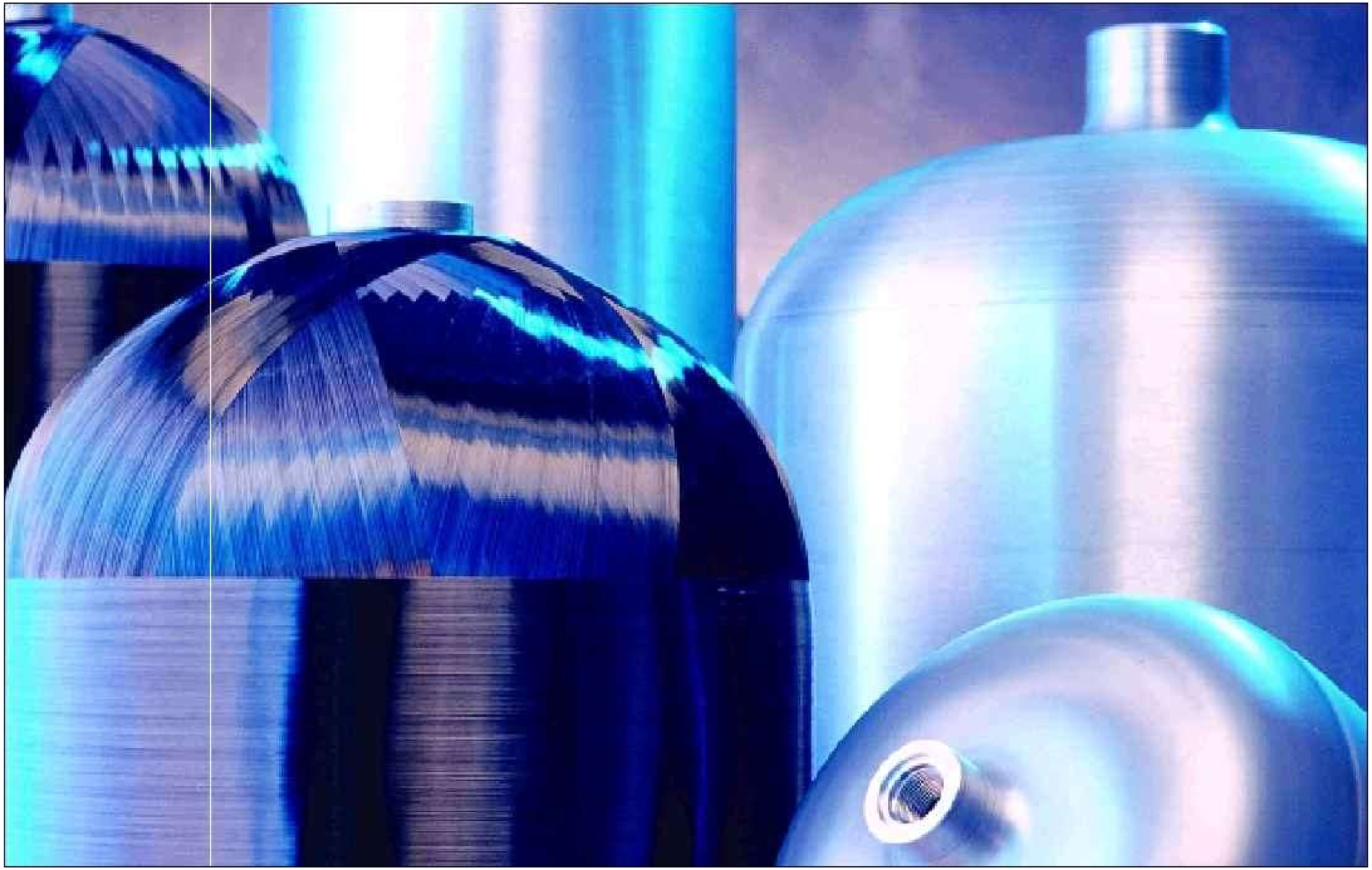


**Ariane V**: **Static Tests at EMPA, Switzerland**





# Pressure vessel  (700 ... 2130bar)

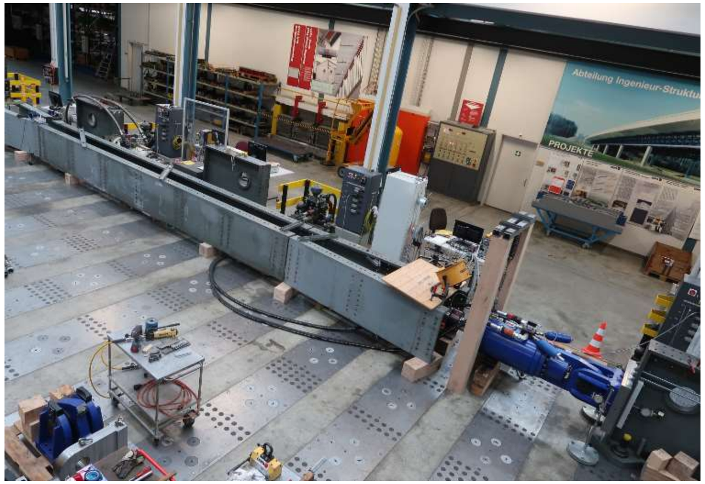


# Future Challenges

# Visions and Dreams

# CFRP hangers for network arch bridges

Fatigue experiments in 2020 on CFRP hangers



New bridge over the river Oder

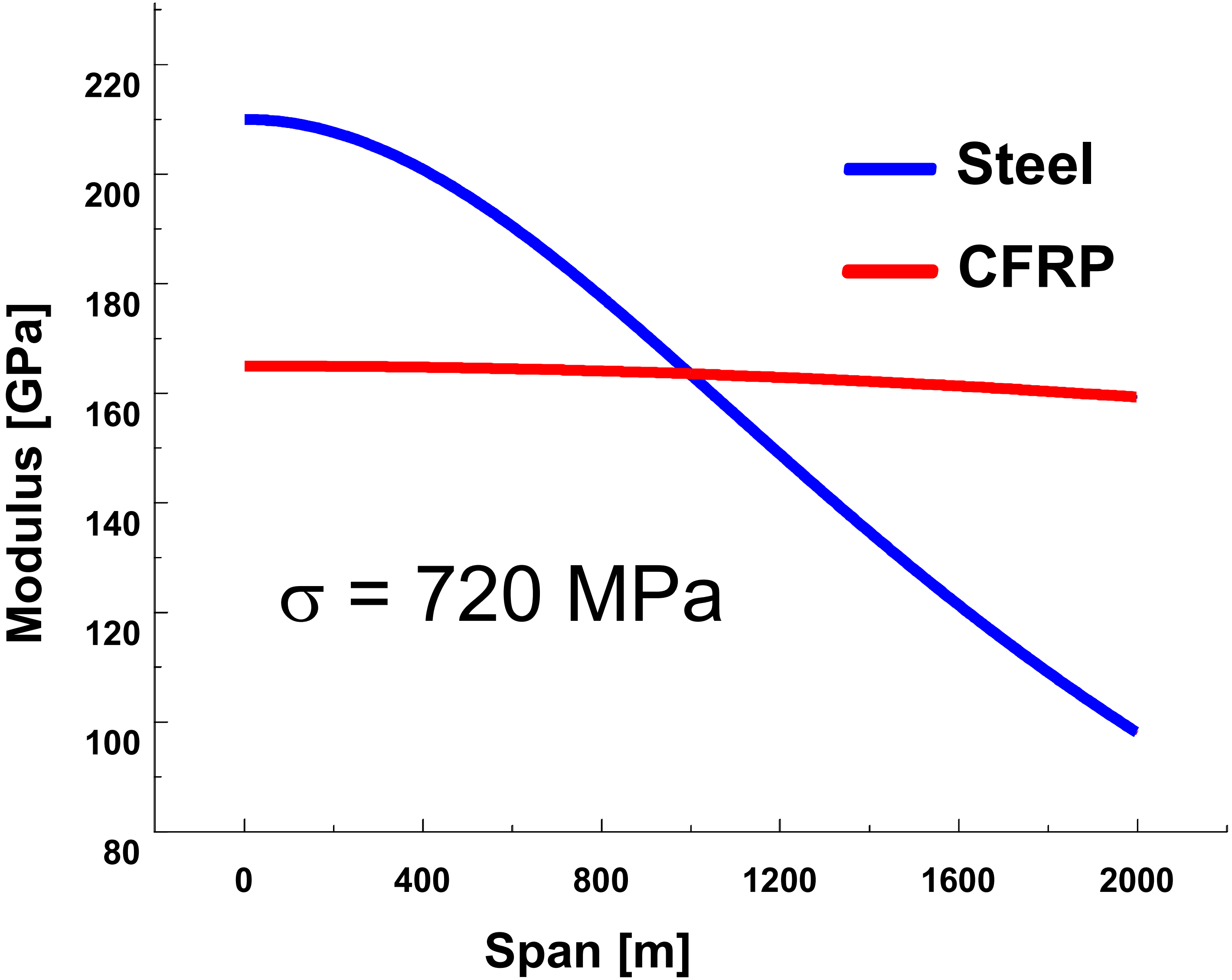
Picture from schlaich, bergermann, partner

DB

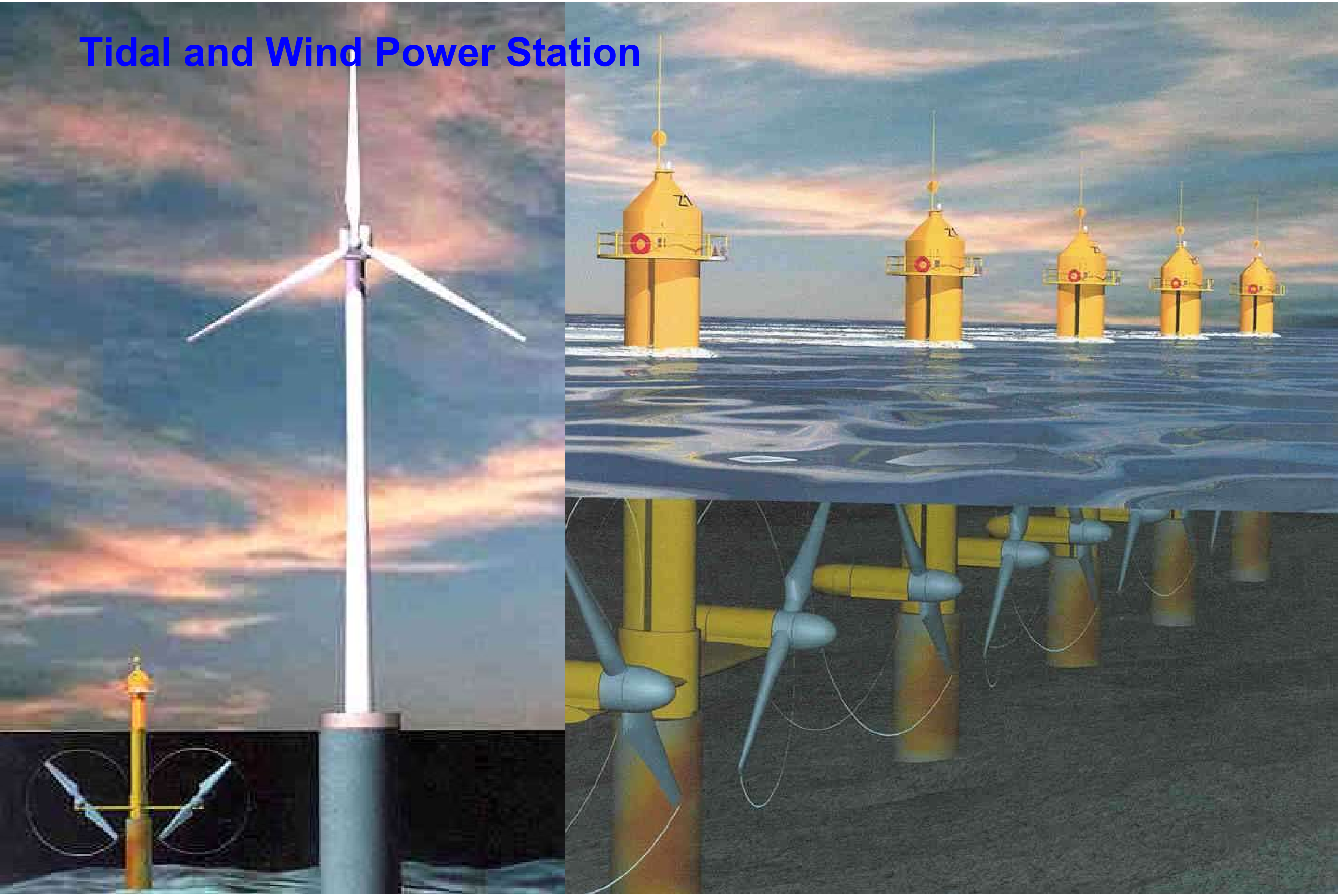
Carbo Link

sbp
schlaich
bergermann partner

# Relative equivalent Modulus



# Tidal and Wind Power Station



# Structural Health Monitoring

Wireless Monitoring Technology at Empa