SIKA SOLUTIONS FOR STRUCTURAL STRENGTHENING WITH CFRP

LUIS ALMELA
SIKA EUROPE MANAGEMENT AG
OCTOBER 2022

BUILDING TRUST

WHAT WE DO
BUILDING TRUST

SIKA AT A GLANCE

27,000	EMPLOYEES
101	COUNTRIES
300+	PLANTS WORLDWIDE
4	NEW & EXPANDED PLANTS IN 2021
99	NEW PATENTS IN 2021
7+[1]	ACQUISITION IN 2021
9.25 BN	NET SALES IN 2021 (IN CHF)

Sika is a specialty chemicals company with a leading position in the development and production of systems and products for sealing, bonding, damping, reinforcing, and protecting in the building sector and motor vehicle industry.

FOCUS ON ATTRACTIVE MARKETS:
CROSS-SELLING, LIFE-CYCLE MANAGEMENT, ONE BRAND

Concrete

Waterproofing

Roofing

Building Finishing

Flooring & Coating

Sealing & Bonding

Engineered Refurbishment

Industry

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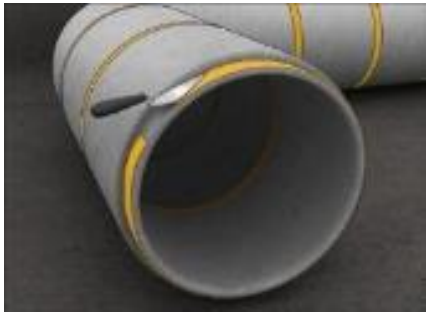
REFURBISHMENT (ENGINEERED)
APPLICATION FIELDS

Cementitious Grouts

Resin Grouts

Structural Strengthening

Sika® CarboDur®
SikaWrap®



Rigid Bonding

Sikadur®

Anchoring

Mortar Admixtures

Concrete Repair

Concrete Protection

CONTENTS

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STRUCTURAL STRENGTHENING- DEFINITION

SOLUTIONS TO INCREASE THE **LOAD BEARING CAPACITY** OF AN EXISTING STRUCTURE OF REINFORCED CONCRETE.

DIFFERENT SYSTEMS FOR **FLEXURAL, SHEAR AND CONFINEMENT**

ADVANTAGEUS ALTERNATIVE TO TRADITIONAL SOLUTIONS IN MOST OF THE CASES.

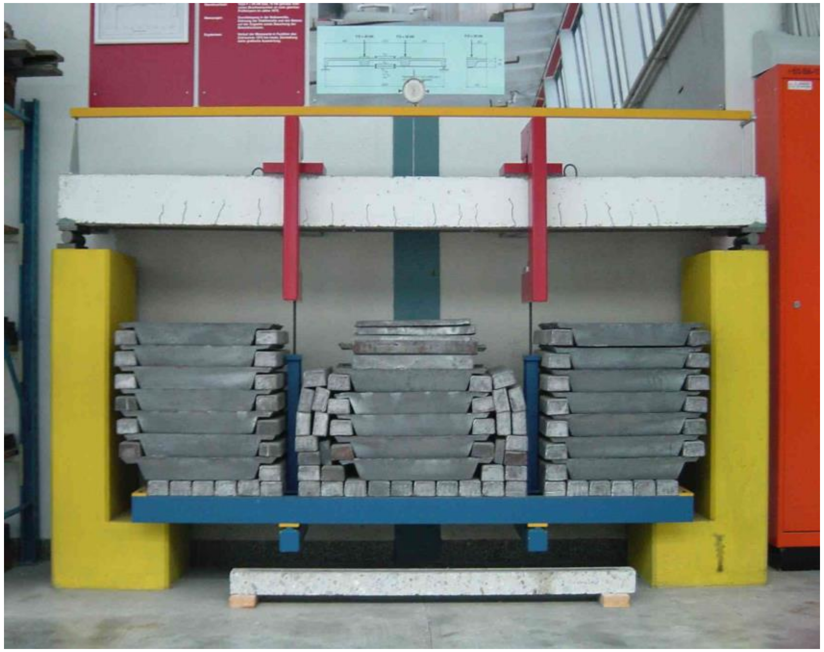
STRENGTHENING SYSTEMS ARE BASED ON COMPOSITE TECHNOLOGY, MOSTLY WITH **CARBON FIBRE** REINFORCED POLIMERS (CFRP)

STRUCTURAL STRENGTHENING- TRADITIONAL SOLUTIONS

DEVELOPMENT OF THE SIKA FRP SYSTEMS

SIKADUR®30: LONG-TERM DURABILITY

1967: Sikadur®range developed as steel plate bonding for Structural Strengthening

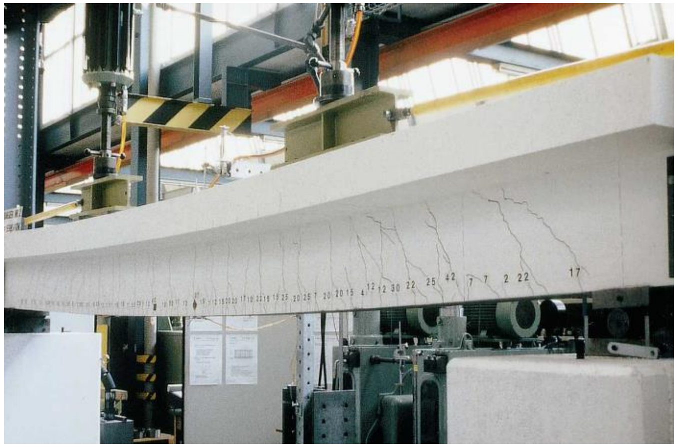


1970 Long Term Test at EMPA
Sikadur® -30 (not finished yet)

Steel: long-term durability is critical as resulting of the risk of corrosion. From 90s, steel plates were progressively substituted by CFRP systems.

SIKA FRP PRODUCT RANGE
CFRP RANGE DEVELOPMENT

1982: Tests of Carbon Fiber Reinforced Polymer (CFRP) Plates for Structural Strengthening of Reinforced Concrete



Cyclic Load Test

>50 test beams

Climatic Test (heat+humidity)

1989 PhD Thesis H.-P. Kaiser, EMPA, Switzerland

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SIKA FRP PRODUCT RANGE
FIRST APPLICATION OF SIKA CFRP SYSTEMS

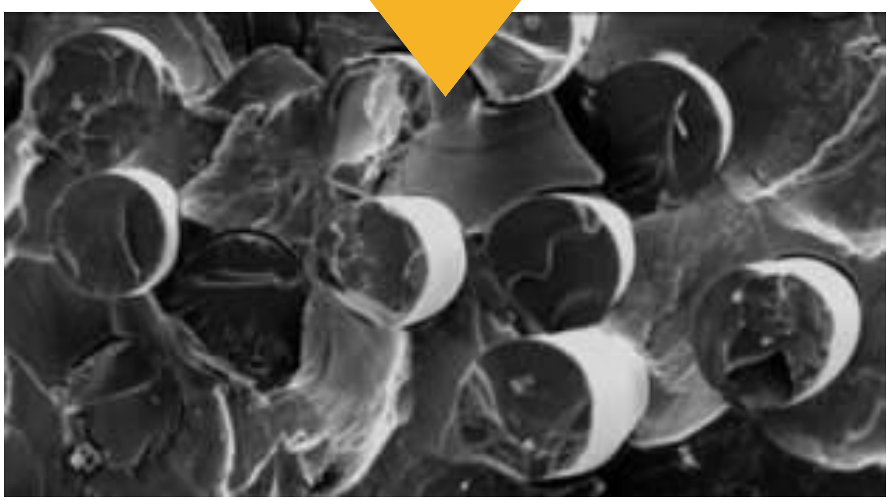
1991: First Application of Sika CFRP systems for Structural Strengthening of a bridge

Ibach Bridge, Zurich (Switzerland)

INTRODUCION
WHAT IS THE CFRP?

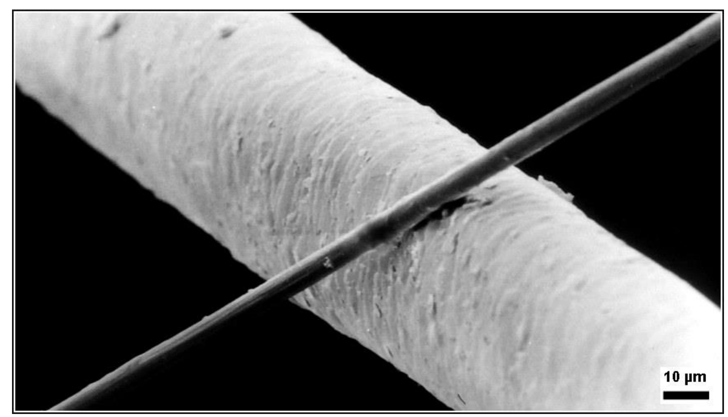
CARBON FIBERS

EPOXY RESIN



Human hair
(D=0,08mm)

Carbon fibre
(D=0,007mm)



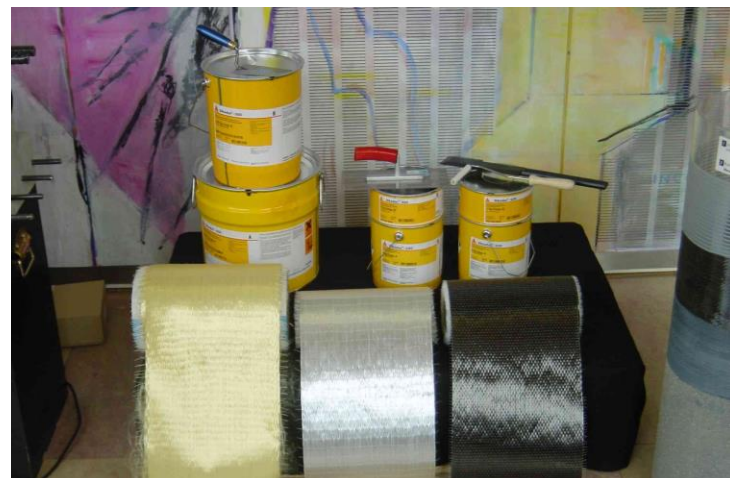
SIKA FRP PRODUCT RANGE
MAIN FRP STRENGTHENING MATERIALS

PREFABRICATED SYSTEMS

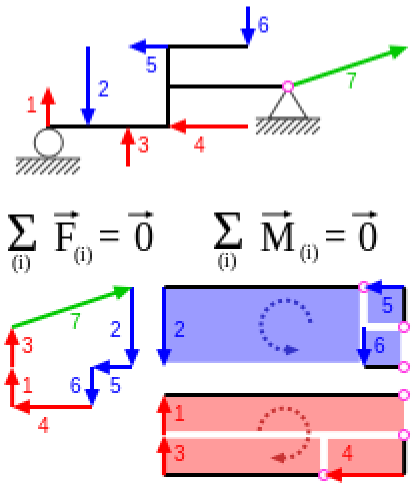
- Sika Carbodur® CFRP plates/ - Grids
- Sika CarboShear L- links
- Sika CarboDur® range for NSM applications
- Sika CarboStress® post-tensioned CFRP system
- Sikadur® structural adhesives

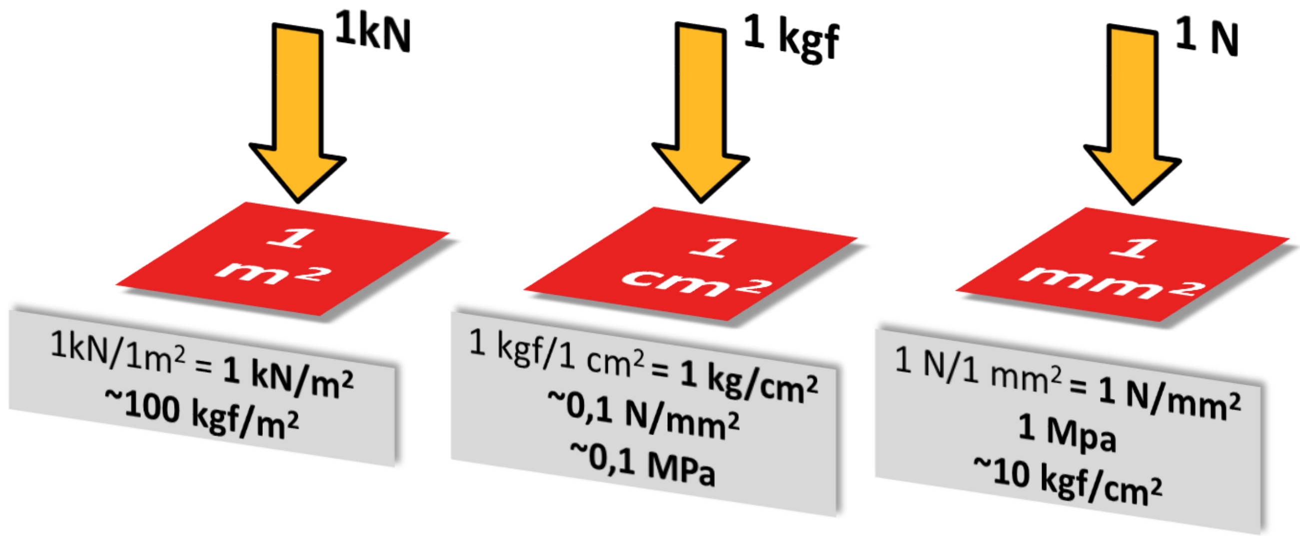
MANUAL APPLICATION SYSTEMS

- SikaWrap® fabrics
- SikaWrap® FX anchorages
- SikaWrap® Grid FRP meshes
- Sikadur® structural adhesives



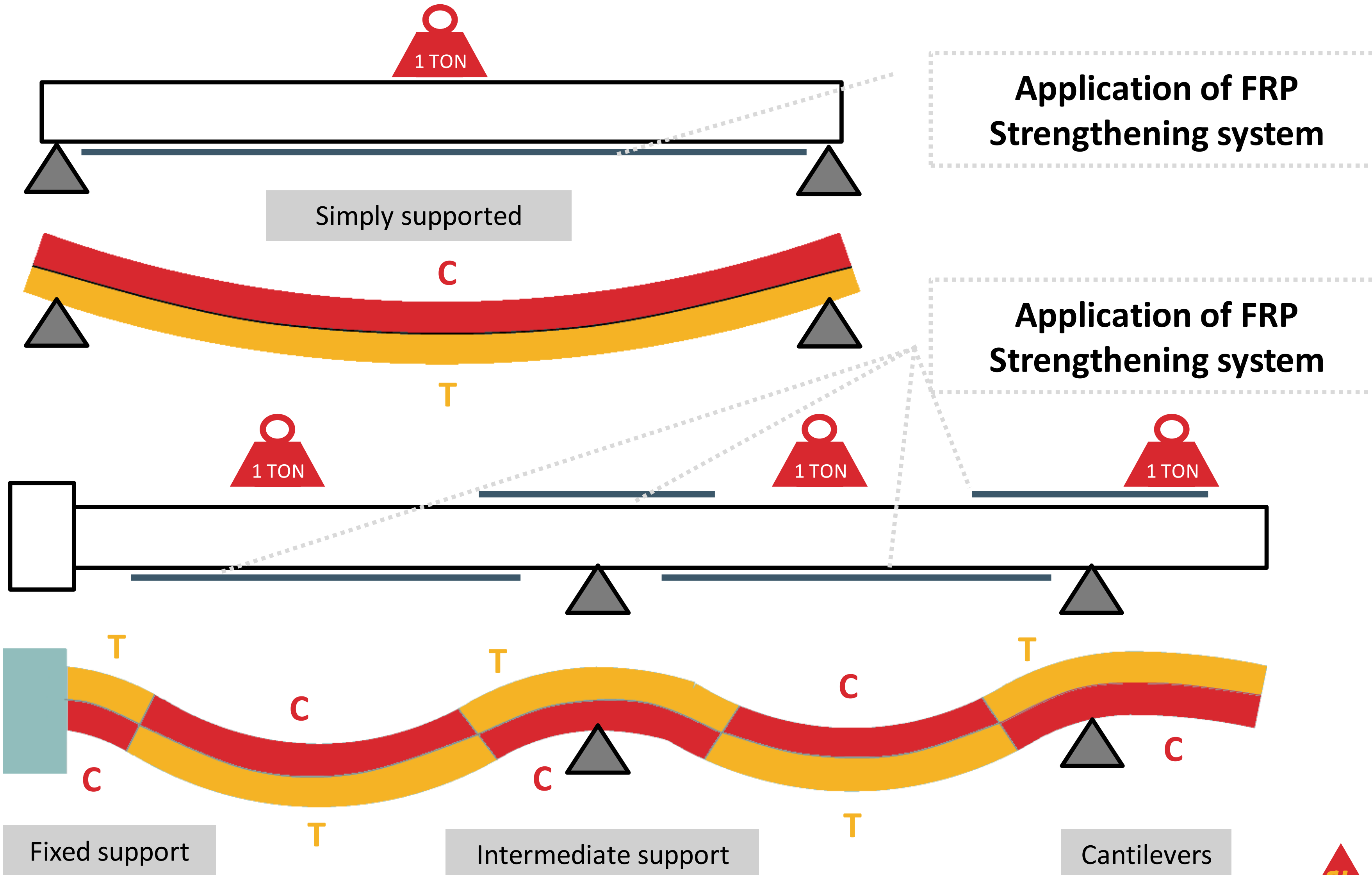
Prefabricated systems represent ≈80% of the current applications in Europe, as they are usually considered as a safer system (lower safety factors and less restrictions regarding the unevenness of the concrete surface,) and higher efficiency during the installation process.





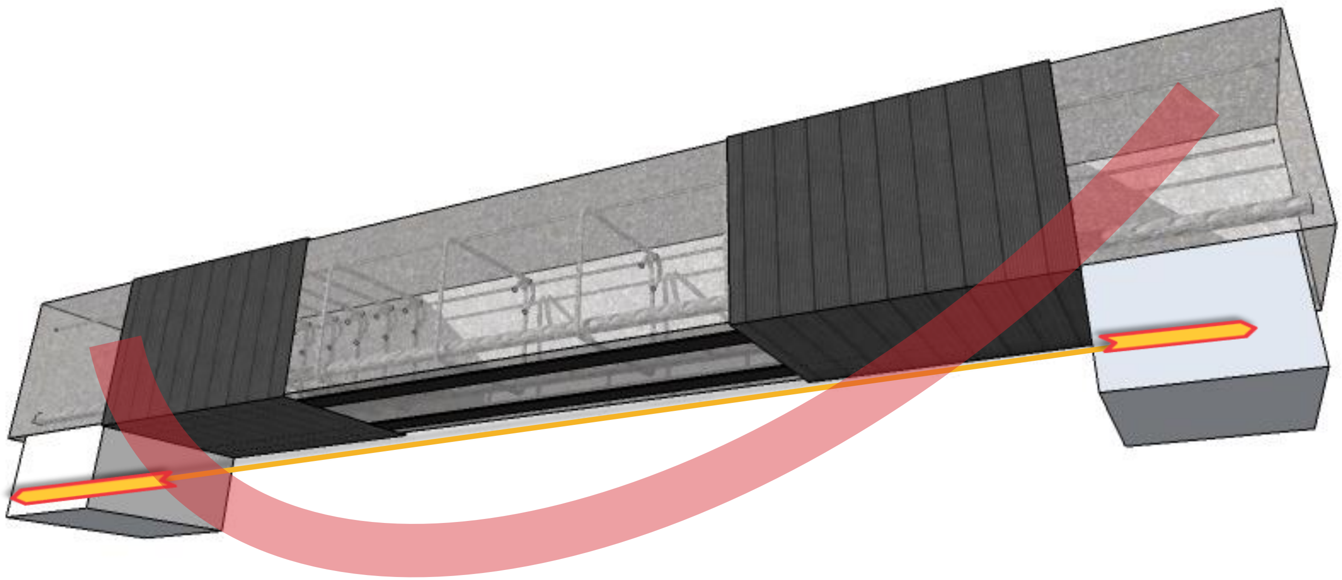
1. BASIS OF CFRP DESIGN

MAIN TYPES OF STRENGTHENING
FLEXURAL



CFRP STRENGTHENING OF BEAMS

USUAL ARRANGEMENT



A complete strengthening comprises the shear and flexural reinforcement of the member.

Bending

Carbon fiber laminates only work under tension. Hence, it´s necessary to determine the position of the tensile stresses along the element.

The CFRP laminates are displayed longitudinally along the concrete´s surface.

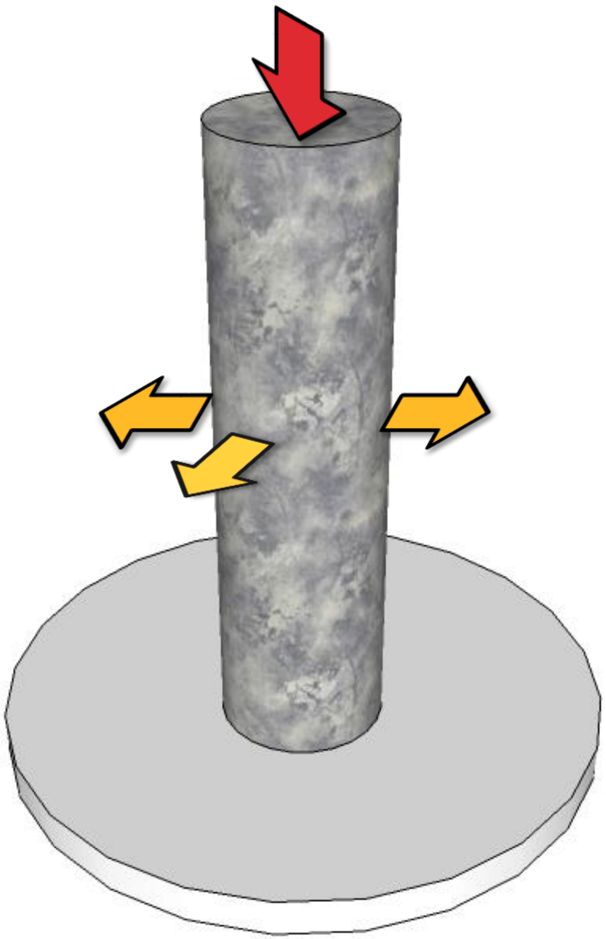
Shear

External CFRP stirrups are displayed at the beam´s ends. The wrapping scheme can be either complete (full wrapping) or partial (U-wrapping or lateral display).

SIKA AT WORK
NARROWS BRIDGE

- Carbon fiber laminate. Application to the deck soffit was efficient, particularly with the long lengths involved (up to 55 meters).
- Date: April 2001
- Location: Perth, wa
- Contractor: structural systems, wa

MAIN TYPES OF STRENGTHENING
CONFINEMENT



Due to the Poisson´s effect, the concrete is transversally expanded when compressed.

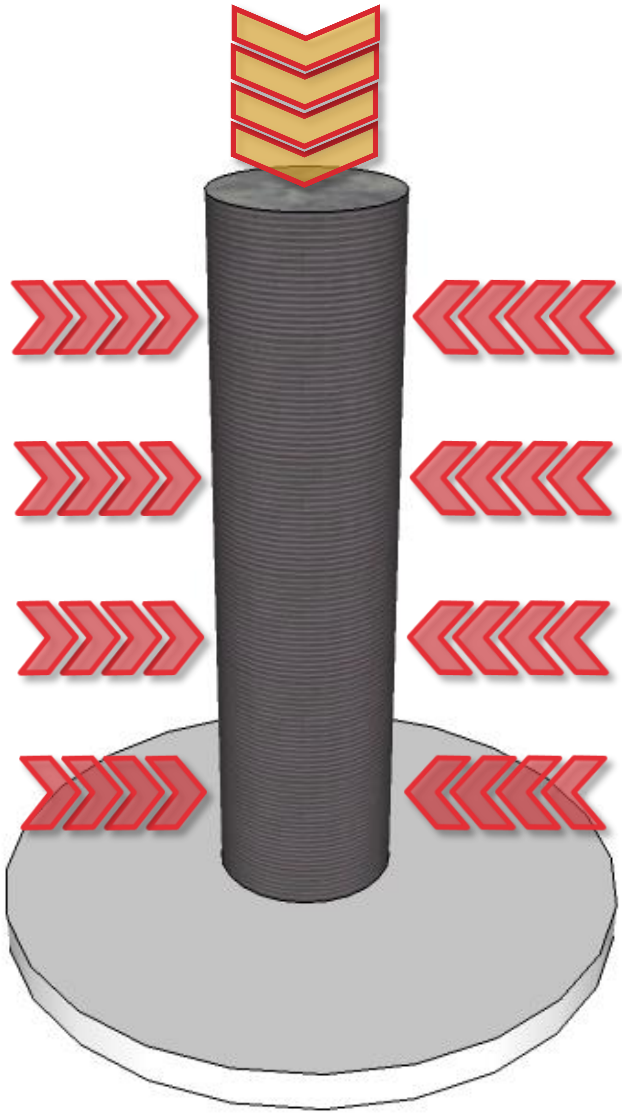
This expansion leads to the collapse of the column, as concrete has a very limited capacity for elongation.

Hence, if the transversal expansion is restricted, the final strength increases…

MAIN TYPES OF STRENGTHENING

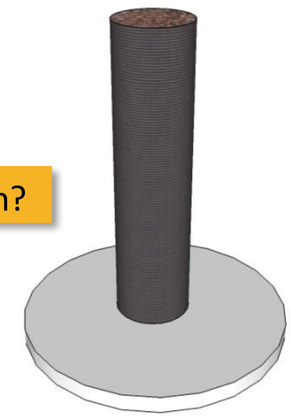
CONFINEMENT

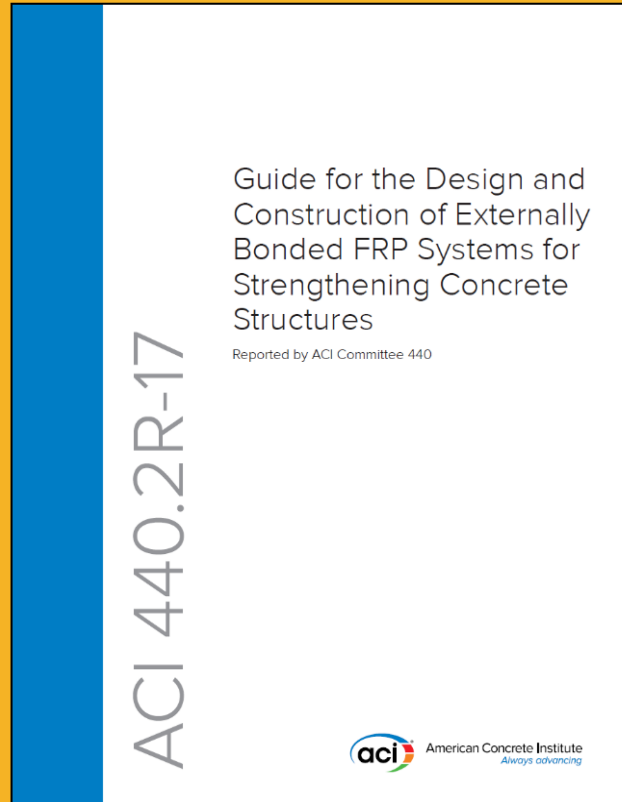
To avoid the lateral expansion, its necessary to ensure a confinement around the element, by using a rigid material with a high strength. This material must keep the geometry of the member when it tries to expand.

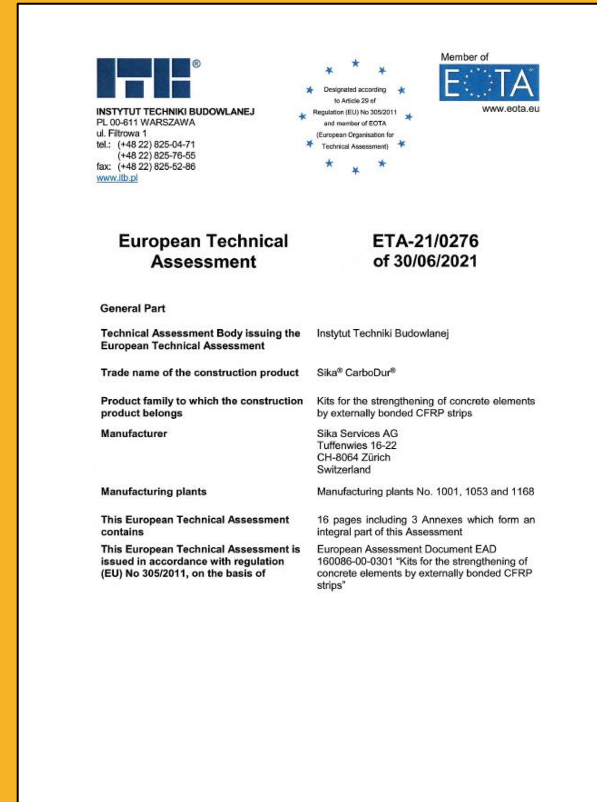


In case of strictly compressive loads alone (extremely unusual), the confinement allows surprising solutions:

Gravel column?






European Technical Assessment

ETA-21/0276 of 30/06/2021

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Member of EOTA
www.eota.eu

General Part

Technical Assessment Body issuing the European Technical Assessment	Instytut Techniki Budowlanej
Trade name of the construction product	Sika® CarboDur®
Product family to which the construction product belongs	Kits for the strengthening of concrete elements by externally bonded CFRP strips
Manufacturer	Sika Services AG Tuffenwies 16-22 CH-8064 Zürich Switzerland
Manufacturing plants	Manufacturing plants No. 1001, 1053 and 1168
This European Technical Assessment contains	16 pages including 3 Annexes which form an integral part of this Assessment
This European Technical Assessment is issued in accordance with regulation (EU) No 305/2011, on the basis of	European Assessment Document EAD 160086-00-0301 "Kits for the strengthening of concrete elements by externally bonded CFRP strips"

2. DESIGN INTERNATIONAL GUIDELINES & APPROVALS

DESIGN GUIDELINES
LOCAL EUROPEAN GUIDELINES

Concrete Society TR55 (UK): Design guidance for strengthening concrete structures using fiber composite materials.

CUR-91 (Netherlands): Strengthening of reinforced concrete structures with externally glued CFRP.

DAfStb Heft 591 (Germany): Strengthening of concrete elements by means of extrenally bonded reinforcements.

SIA 166 (Switzerland): Externally bonded reinforcement.

CNR-DT 200 (Italy): Guide for the design and construction of externally bonded FRP systems for strengthening existing structures.

SIKA® CARBODUR® EUROPEAN TECHNICAL ASSESSMENT

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European Technical Assessment | **ETA-21/0276 of 30/06/2021**

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For Sika® CarboDur® system, most of the European local approvals have been superseded by ***ETA-21/0276***

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3. TECHNICAL REPORT 55, THIRD EDITION

EUROCODE 2

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FRP STRENGTHENING LIMITS
TR55/EUROCODE2

Independently of any other mechanical limitation, the TR55 leads to certain restrictions before the design of the FRP:

SERVICEABILITY LIMITS

Reinforced Concrete Limits

The effective stress for the reinforcing steel under service loads (characteristic combination) will remain below 80% of its yield point.

$$f_y \leq 0.80\ f_{yk}$$

THE EXISTING MEMBER MUST EXHIBIT A MINIMUM STRENGTH

In the event that the FRP system is damaged, the structure will still be capable of resisting a reasonable level of load without collapse. The existing strength of the structure should be sufficient to resist a minimum level of load (frequent combination of service loads).

In the event that the FRP system is damaged, the structure will still be capable of resisting a reasonable level of load without collapse. The existing strength of the structure should be sufficient to resist a minimum level of load (quasi-permanent combination of service loads).

FLEXURAL STRENGTHENING

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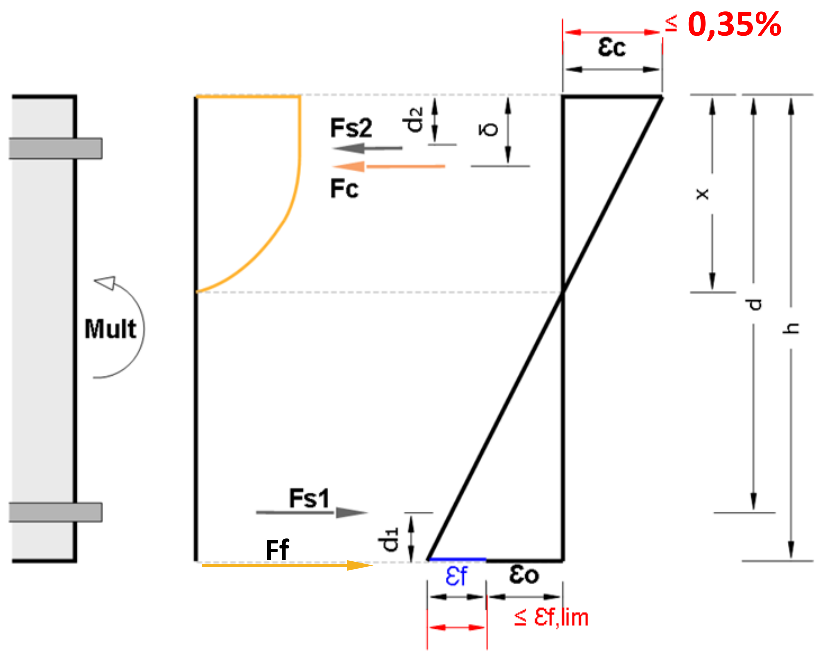
FLEXURAL STRENGTHENING

DESIGN OF THE FRP STRENGTHENING (1)

The calculation follows the standard mechanical principles in the EUROCODE 2 (forces equilibrium and compatibility of deformations in the section among the different materials), except for the following 2 issues:

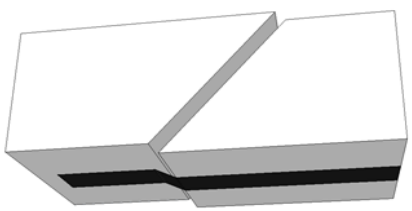
1) The section to calculate will exhibit an existing deformation prior to the strengthening, which must be considered for the design. This event may affect significantly the serviceability limits of the strengthened member.
2) The reduced FRP E-modulus will be taken into account (TR55 criteria)



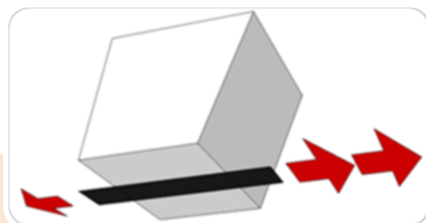
FLEXURAL STRENGTHENING
DESIGN OF THE FRP STRENGTHENING (2)

The ultimate strength of the strengthened member will be defined by one of the following limitations:

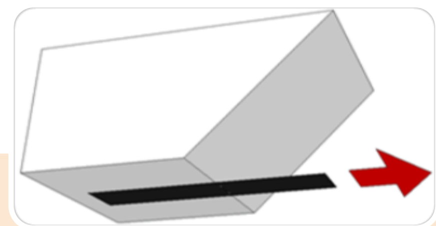
- Concrete crushing under compression (0,35% deformation for European codes).
- FRP rupture (not expected for systems based on CFRP, but possible in case of using GFRP laminates).
- Debonding of the FRP laminate from the substrate as a consequence of :



FRP separation induced by the presence of shear cracks



Debonding due to lap-shear forces along the span.



Debonding due to an insufficient anchorage length.

COLUMN CONFINEMENT

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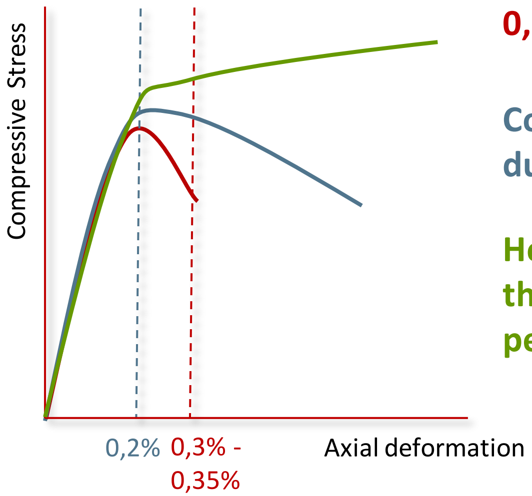
COLUMN CONFINEMENT

PERFORMANCE OF THE FRP CONFINEMENT

If the lateral expansion is constrained by means of a rigid material, the concrete will be able to take additional axial loads.

This can be represented graphically as follows:



Original concrete. Peak Stress corresponds to 0,2% deformation, ultimate strain 0,3%-0.35% (ACI/European codes).

Confined concrete. The enhanced peak stress remains at 0.2% deformation. The ductility is significantly increased

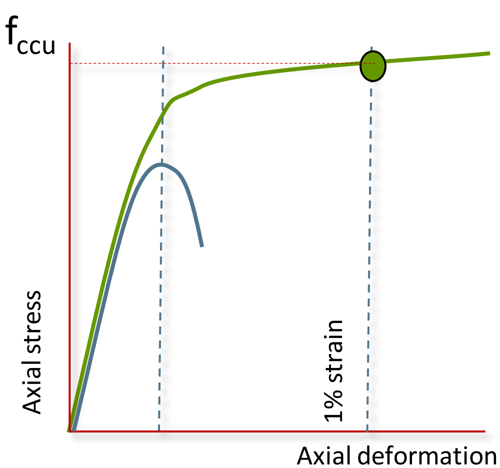
Heavily confined concrete. Performance at 0.2% deformation is enhanced. However, the concrete is still capable to assume additional load. Ultimate load is higher than peak load.

Hence, the performance of the confined concrete depends on the confinement force exerted by the CFRP jacket.

COLUMN CONFINEMENT
BASIS OF THE CALCULATION

TR55 & ACI44

Ascending secondary branch is mandatory
(~ $f_l/f_{c0} > 0,08$)
The strength of the confined concrete will correspond to a axial compressive strain of the concrete ≤1%



TR55

Teng et al. model (2009)

Maximum strength of the confined concrete for circular columns is defined as follows:

$$f_{ccu} = (1 + 5{,}25\,(\rho_k - 0{,}01)\rho_\varepsilon) \cdot f_{c0}$$

where ρ_k is the stiffness ratio and ρ_k is the strain ratio.

Maximum axial deformation of the confined concrete is determined as follows:

$$\varepsilon_{cu} = 1{,}75 + 6{,}5\rho_k^{0{,}8}\rho_\varepsilon^{1{,}45}$$

TR 55 considers the effects of confinement stiffness and the jacket strain capacity to be separately (best accuracy)

SHEAR STRENGTHENING

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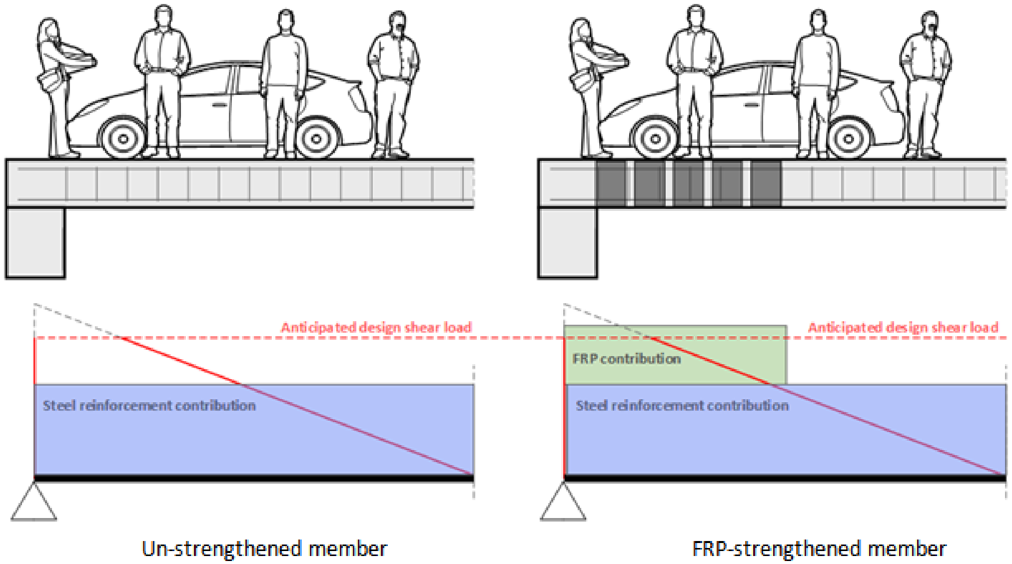
SHEAR STRENGTHENING
INTRODUCTION

Unlike the design of flexural strengthening, where standard mechanical criteria govern de calculations, the complexity of the shear mechanisms forced the development of design methods from experimental researches.

Independently from the calculation procedure used, the shear strength of the member is determined as the sum of the strengths provided by the steel and CFRP separately (and concrete in ACI-based codes).

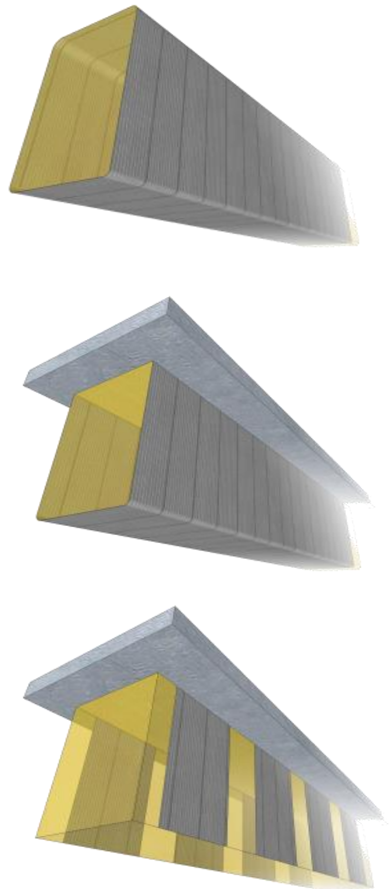


SHEAR STRENGTHENING
CFRP CONFIGURATIONS

However, certain criteria is common among the different design methods:

- The CFRP is dimensioning following similar procedures than those used for the calculation of internal steel stirrups.

- The CFRP can be displayed following 3 different configurations:
    - Full wrapping, providing the best performance.
    - “U” wrapping of the beam.
    - Bonded on both sides of the beam. This scheme provides the worst performance.



4. FIRE SCENARIO

REACTION TO FIRE AND FIRE RESISTANCE UNDER EUROCODE 2 APPROACH

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FIRE SITUATION

INTRODUCTION

2 parameters are related to the fire scenario. Their limits are defined by the local regulations (national/regional/city regulations) in each country.

1-Reaction to fire is the measurement of how a material or system will contribute to the fire development and spread, as well as the emission of smoke/flaming droplets.

According to their use, certain quantity and/or type of materials cannot be used for walls/floor/ceiling rendering.

Concrete and steel do not contribute to the fire development, and do not generate smoke. In case of an adequate kind of polymer used as saturator/adhesive, the reaction to fire of the strengthening system is moderate.

Fire reaction tests (ITB) of multi-layer CFRP Sika systems > Euroclass B

FIRE SITUATION
INTRODUCTION

2-Fire resistance of the structural member: The load bearing capacity of the member can be ensured for a specific period of time (30 to 240 minutes).

The fire resistance is expected to provide time to the building occupants for emergency evacuation before the structure collapses.

Hence, the requested time to resist is commonly proportional to the quantity of people to evacuate and the distance to the exit.

In many cases, outdoor structures (e.g. bridges) may not need a satisfy a certain fire resistance as the evacuation is feasible in a few minutes.

NEED FOR CFRP STRENGTHENING

ALTERNATIVES

CFRP IS NOT NECESSARY UNDER A FIRE SCENARIO

> 90% OF THE REAL CASES

OPTION A1

REQUESTED FIRE RESISTANCE (R30-R240) CAN BE FULFILLED WITH NO ADDITIONAL MEASURE OR PROTECTION.

OPTION A2

PROTECTION IS NECESSARY FOR THE **REINFORCED CONCRETE SECTION** TO MEET A CERTAIN FIRE RESISTANCE.

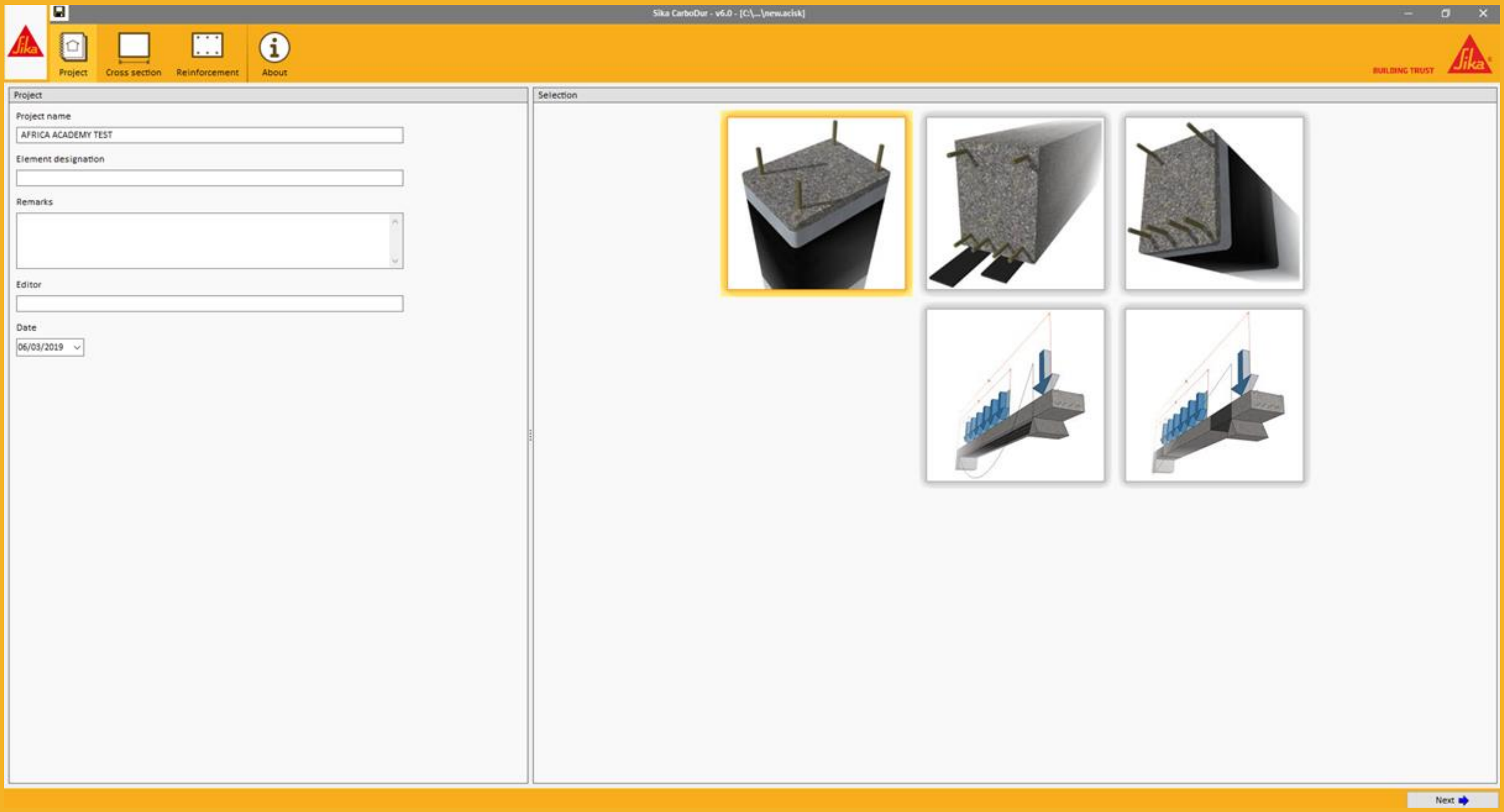
CFRP IS NECESSARY UNDER A FIRE SCENARIO

< 10% OF THE REAL CASES

OPTION B

PROTECTION IS NECESSARY FOR THE **CFRP AND THE REINFORCED CONCRETE SECTION** TO MEET A CERTAIN FIRE RESISTANCE.

THE NEED FOR CONCRETE PROTECTION AND THE RESULTING FIRE RESISTANCE MUST BE OBTAINED BY MEANS OF A CALCULATION FOLLOWING THE EUROCODE PROCEDURES.



4. SIKA CARBODUR® SOFTWARE

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SIKA® CARBODUR® SOFTWARE

- Sika® CarboDur® Software one of the most complete and powerful FRP strengthening software available.

- Free download from http://www.sika.com. Within 15 days from installation is necessary to require the activation of a **FREE** license

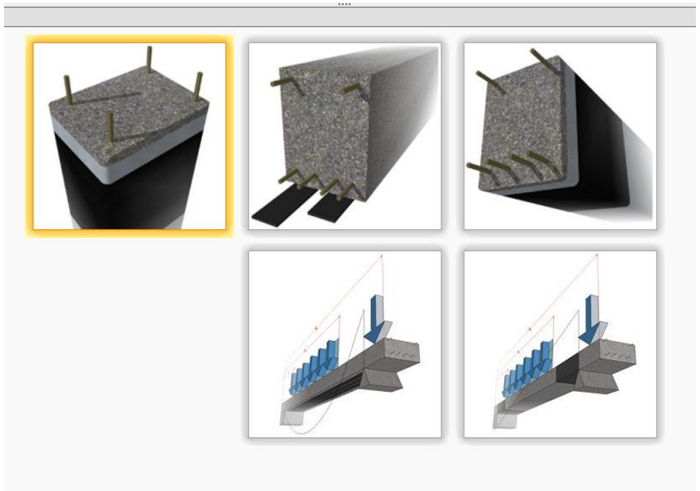
Single section **confinement** design

Single section **flexural** strengthening design

Single section **shear** strengthening design

Beam FRP **flexural** strengthening design

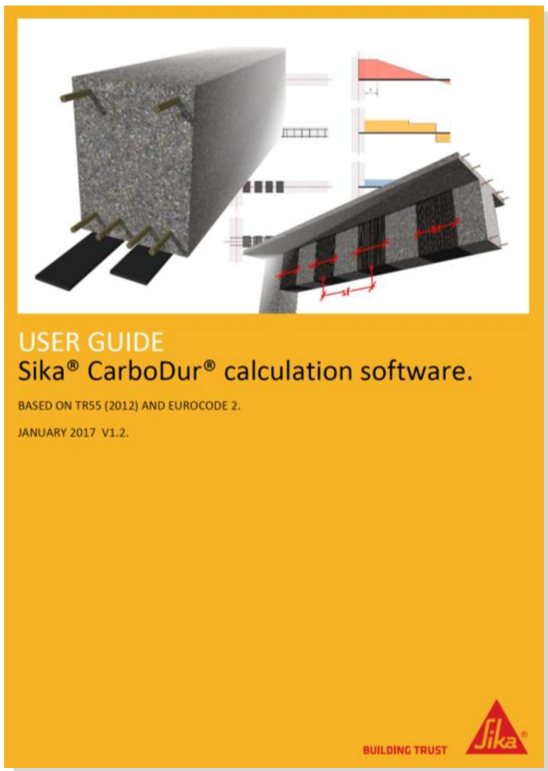
Beam FRP **shear** strengthening design



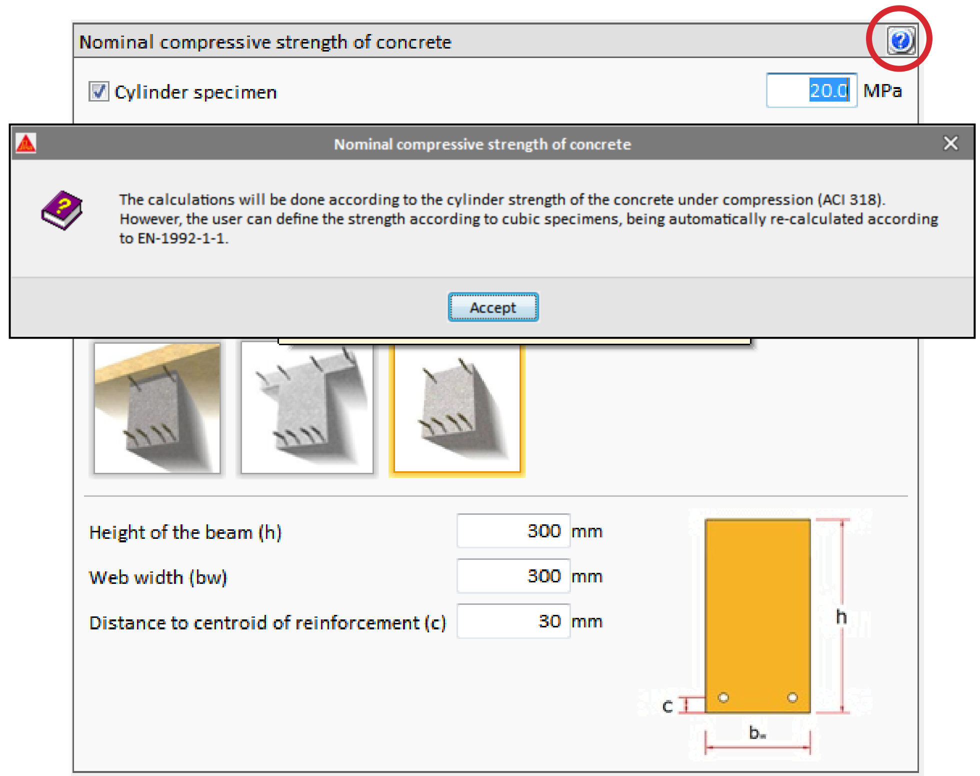
SIKA CARBODUR® SOFTWARE:
KEY ADVANTAGES: USER FRIENDLY

The software includes all the necessary information to facilitate its use to the engineer:

>40 pages user guide.



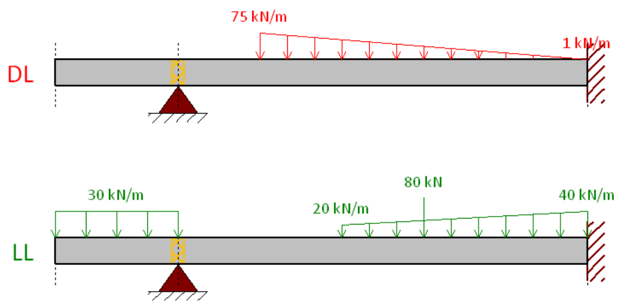
On-screen tooltips and help icons.



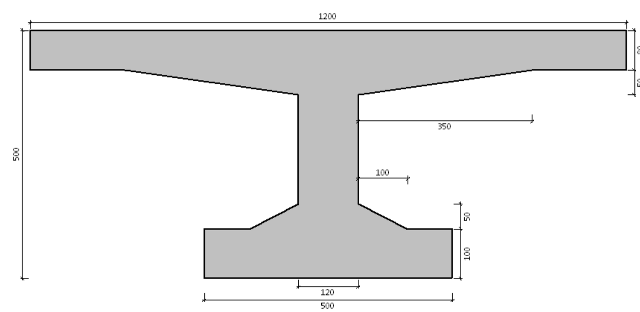
SIKA CARBODUR® SOFTWARE
KEY ADVANTAGES

Unlike simplistic excel sheets or calculation tools, **the Sika CarboDur® software comprises high-performance calculation possibilities for real situations**, for example:

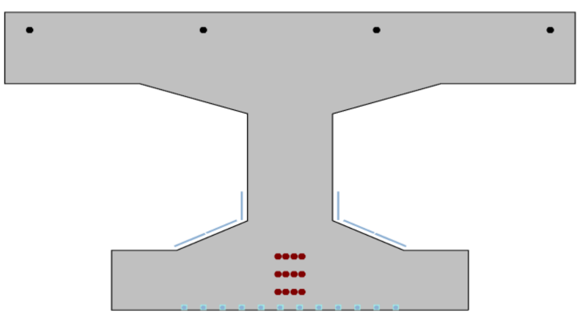
Strengthening of full structural members according its loads distribution. The design is not based on a single section



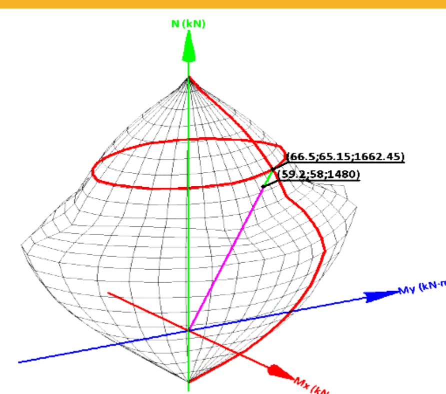
Calculation of complex geometries both for reinforced or prestressed concrete members.



Full FRP range of solutions (bonded, NSM, postensioned CFRP) according to the local availability

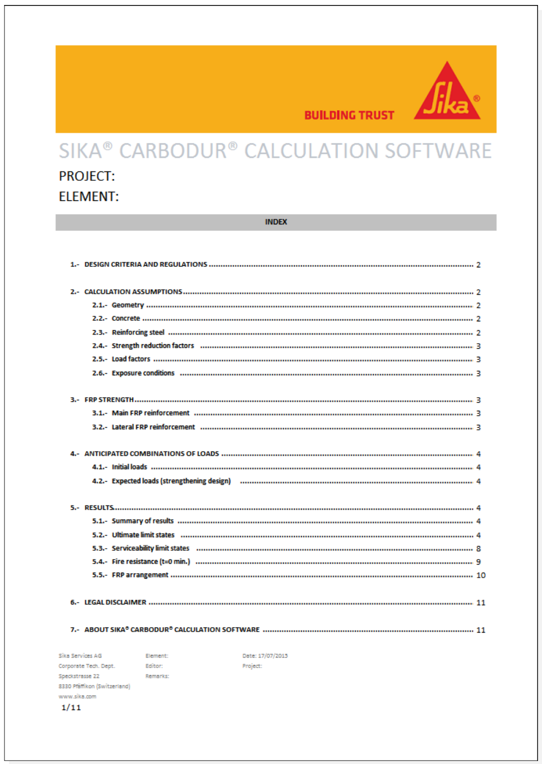


2D and 3D interaction diagrams for columns, allowing the calculation of elements exposed to axial + bending simultaneously



SIKA CARBODUR® SOFTWARE
NO MORE “BLACK BOXES”

The user <u>manages and controls the whole process</u>.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SIKA® CARBODUR® CALCULATION SOFTWARE

PROJECT:

ELEMENT:

INDEX

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Corporate Tech. Dept.
Speckstrasse 22
8330 Pfäffikon (Switzerland)
www.sika.com

Element:
Editor:
Remarks:

Date: 17/07/2015
Project:

1/11

The user can **verify the intermediate results** throughout the calculation process.

All the information concerning the design is finally shown in the calculation report, comprising the results and all the relevant data.

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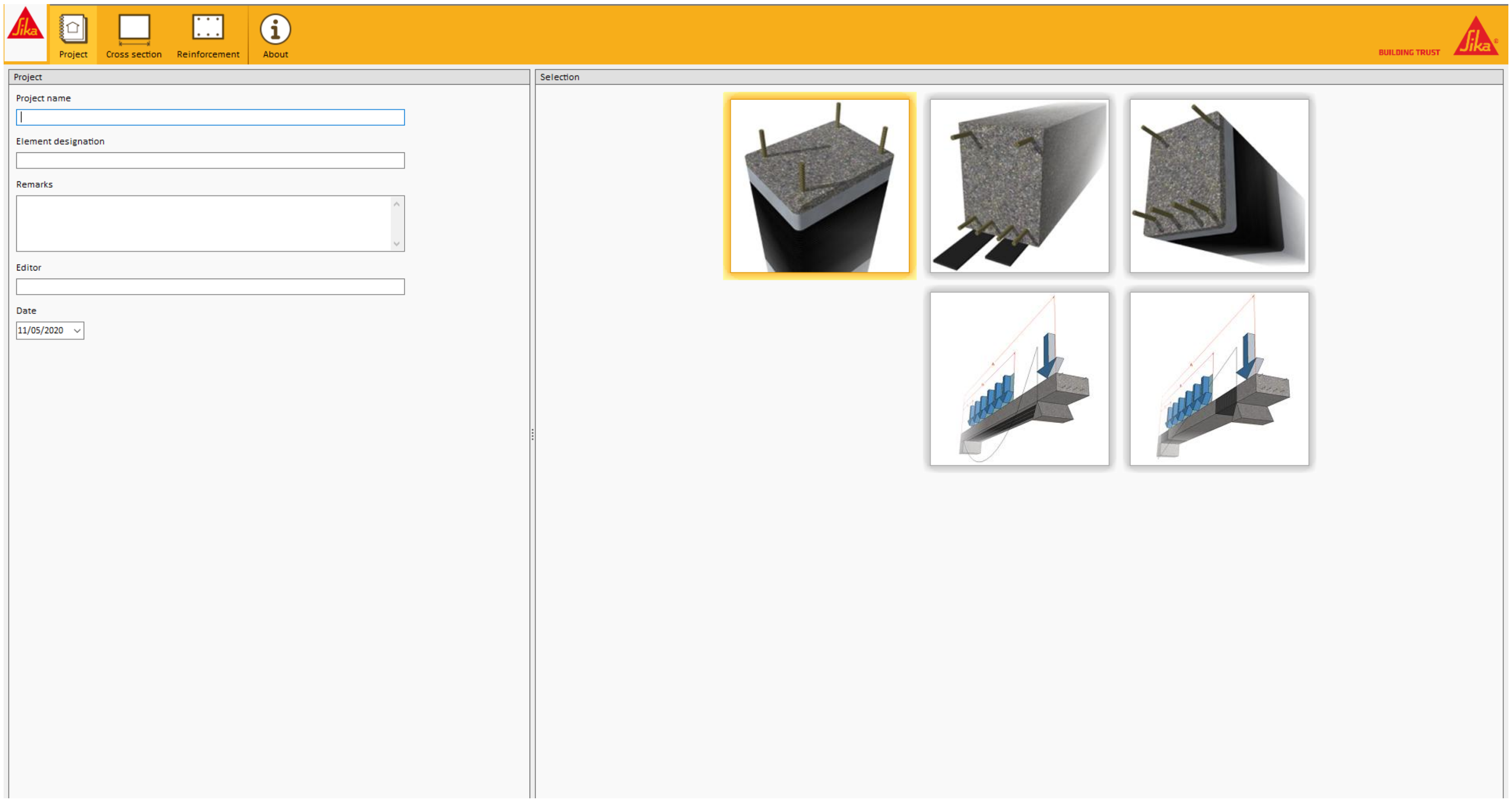
SIKA CARBODUR® SOFTWARE
DEMONSTRATION



THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS OR PROJECTS WE CAN HELP WITH PLEASE?

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