STRUCTURAL STRENGTHENING

DECEMBER 2019, TEL AVIV
TM REFURBISHMENT EMEA
LUIS ALMELA, SIKA EUROPE MANAGEMENT

BUILDING TRUST

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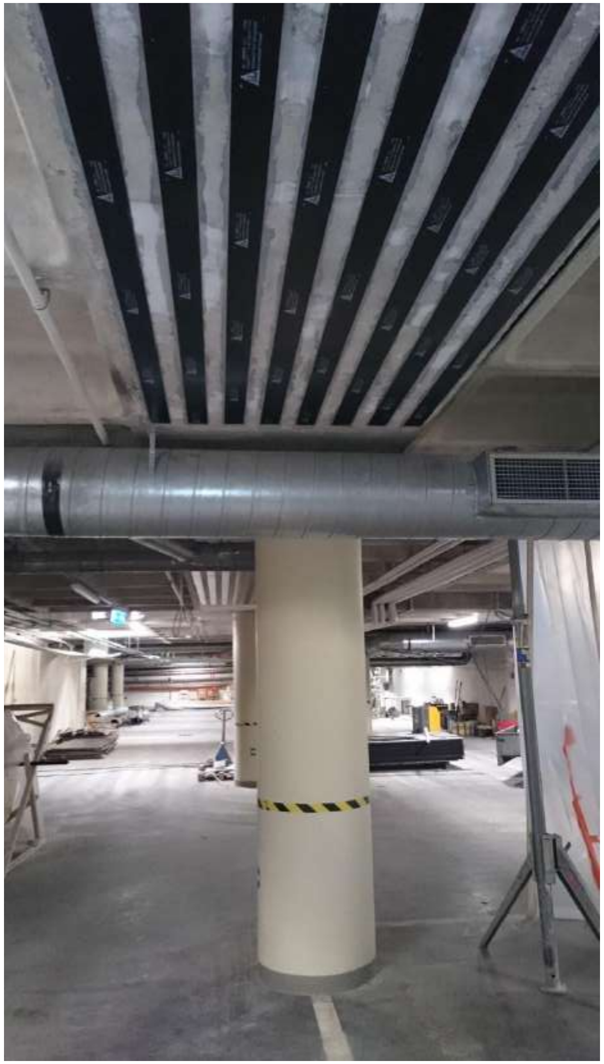


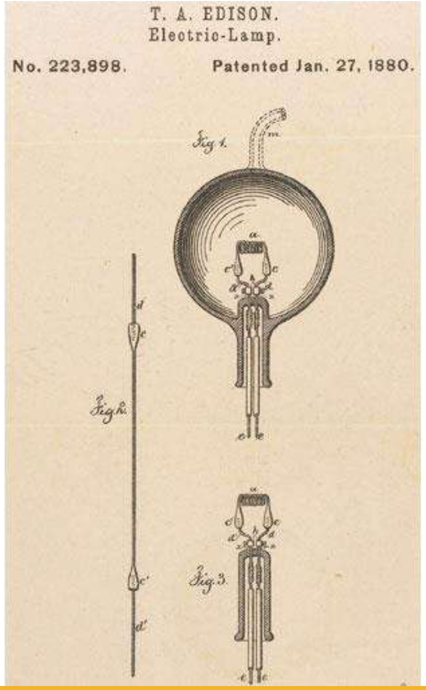
1. INTRODUCTION
DESIGN OF FRP REINFORCEMENTS

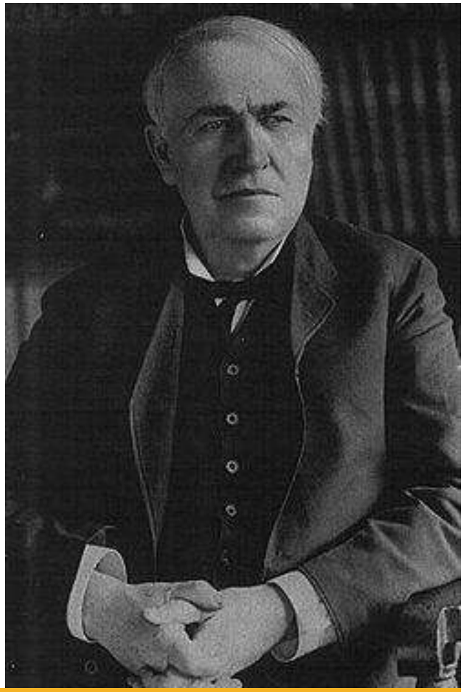
INTRODUCTION

INTRODUCTION

THE ORIGINS OF THE CARBON FIBER

“I haven’t failed 999 times, I’ve found 999 ways not to make the electric light bulb.”





In 1879, Thomas Edison baked cotton threads or bamboo slivers at high temperatures carbonizing them into an all-carbon fiber filament used in the first incandescent light bulb to be heated by electricity.

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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.

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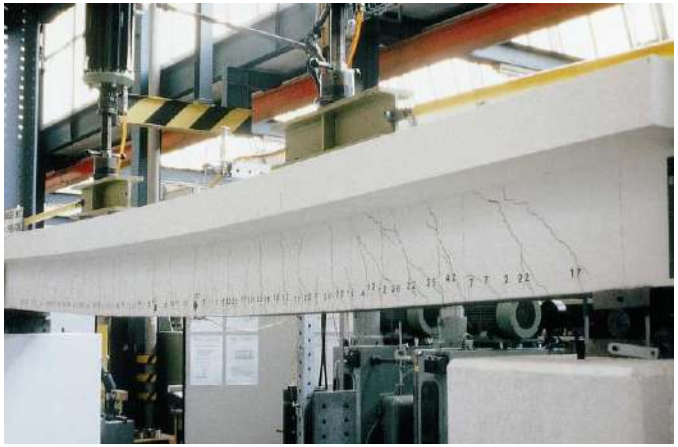
SIKA FRP PRODUCT RANGE

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

SIKA FRP PRODUCT RANGE
FIRST APPLICATION OF SIKA CFRP SYSTEMS

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

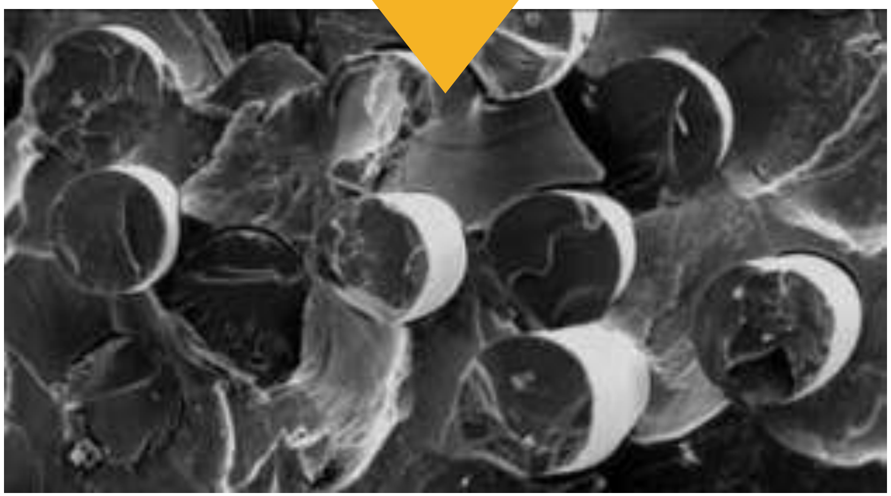
Ibach Bridge, Zurich (Switzerland)

INTRODUCION

WHAT IS THE CFRP?

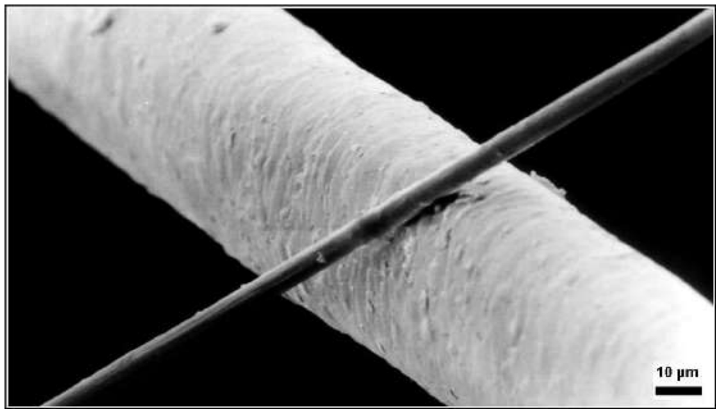
CARBON FIBERS

EPOXY RESIN



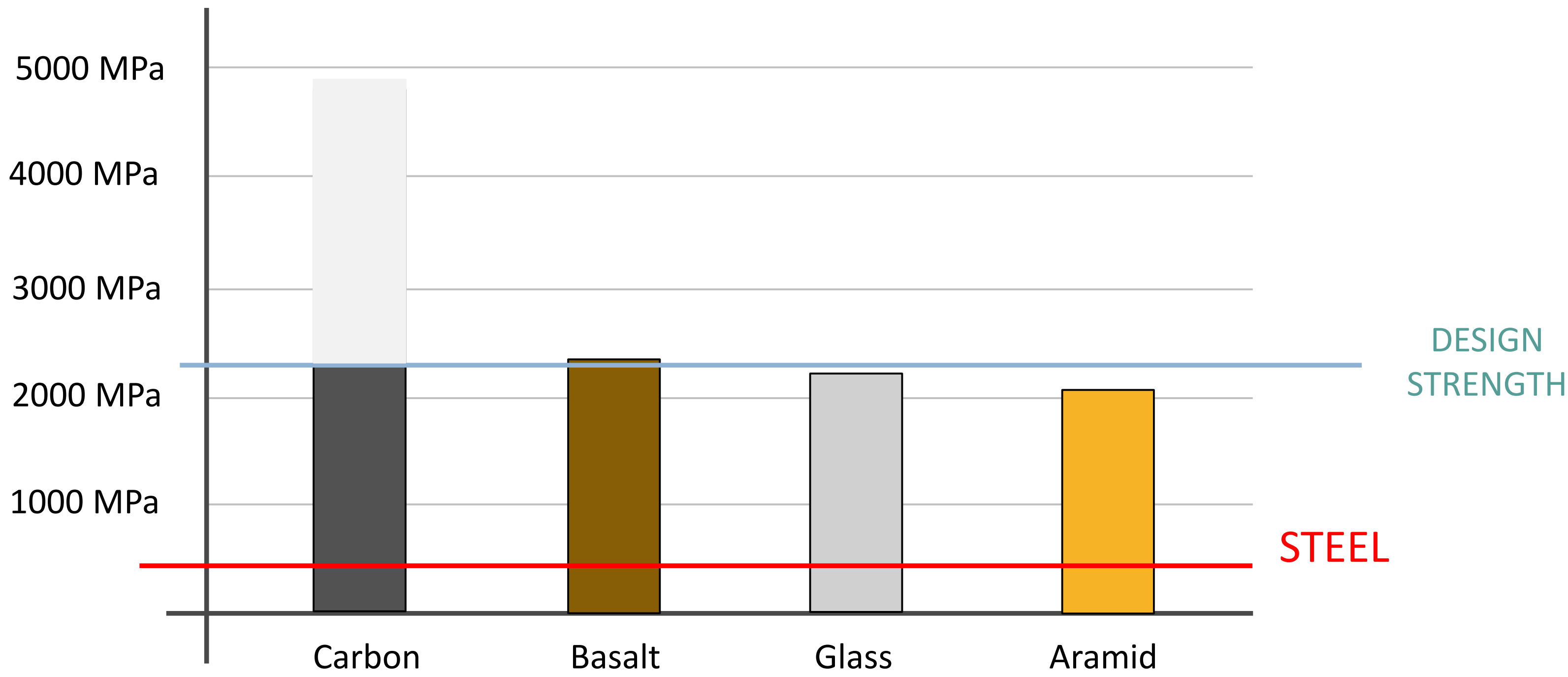
Human hair
(D=0,08mm)

Carbon fibre
(D=0,007mm)



FRP STRENGTH
FIBERS COMPARISON

ULTIMATE STRENGTH



SIKA FRP PRODUCT RANGE
MAIN FRP STRENGTHENING MATERIALS

PREFABRICATED SYSTEMS

Sika Carbodur® CFRP plates
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.

SIKA FRP PRODUCT RANGE
MAIN TRM SYSTEMS

GLASS FIBER SYSTEMS

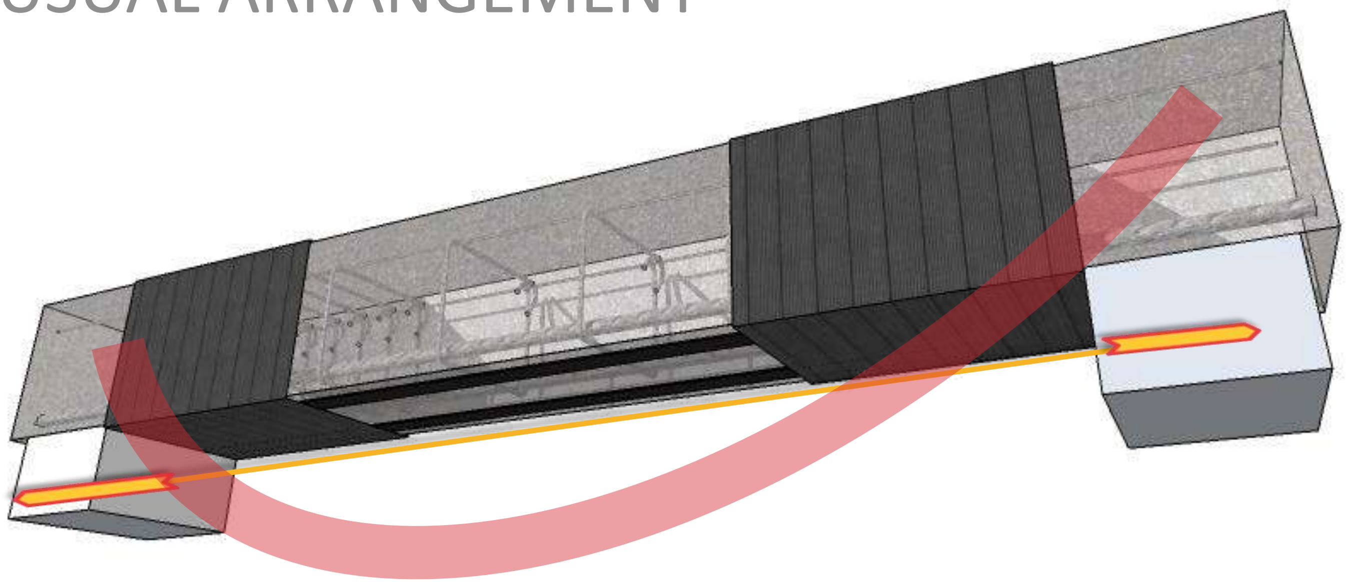
CARBON FIBER SYSTEMS

2. EXISTING PRODUCT RANGE AND INNOVATION IN CFRP MATERIALS

CARBON FIBER REINFORCED POLIMERS SOLUTIONS

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 CARBOHEATER II

APLICACIÓN EN "ESTACIÓN NORTE" (MADRID)

Sika España, 2018

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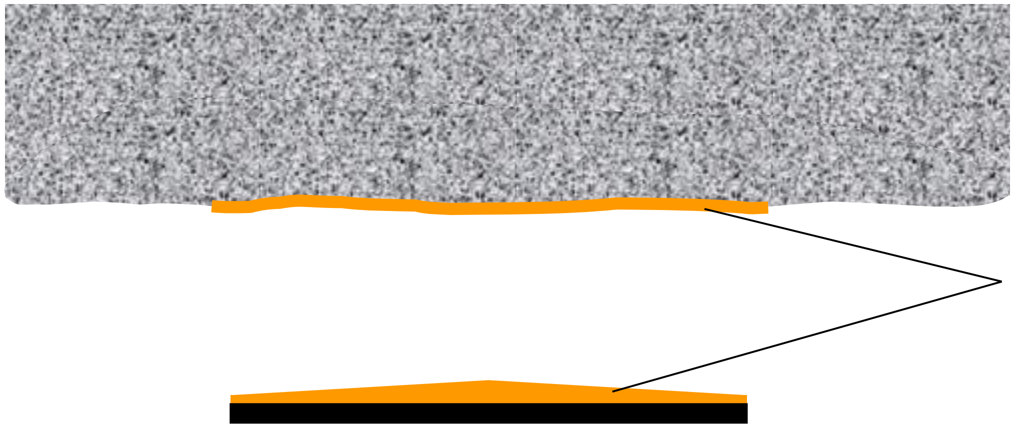
SIKA CARBODUR®

INSTALLATION PROCESS



Sikadur®-30

Priming
Putty
Structural adhesive

CarboDur® Laminate

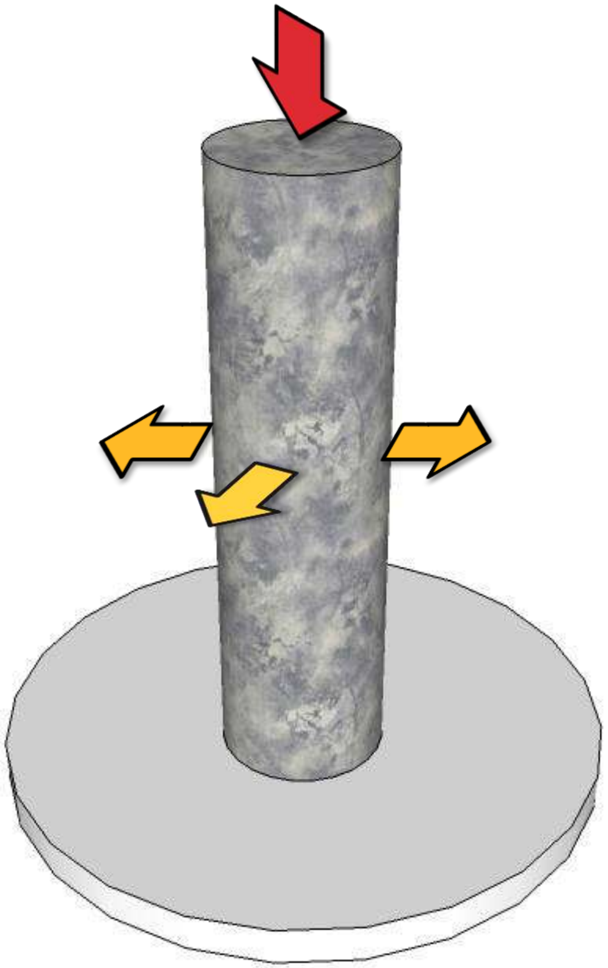
Simple
Fast
Safe

COLUMN CONFINEMENT

POISSON´S EFFECT

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.

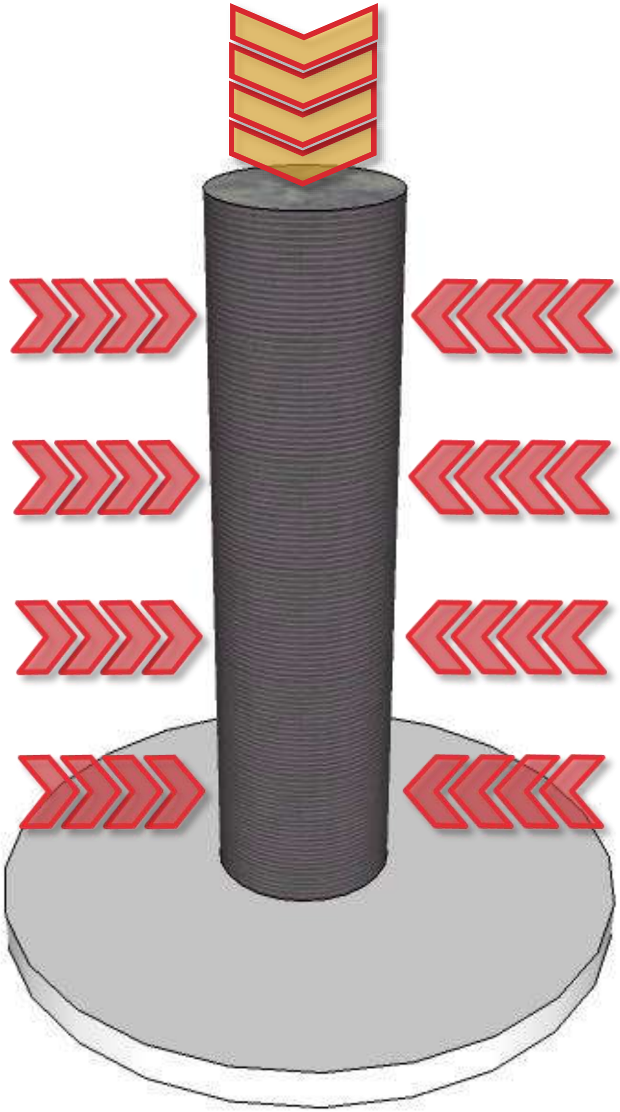


Hence, if the transversal expansion is restricted, the final strength increases…

COLUMN CONFINEMENT

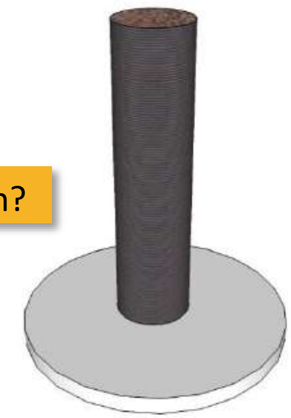
POISSON´S EFFECT

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?



SikaWrap®

STRUCTURAL STRENGTHENING

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SIKAWRAP® FABRICS
DRY APPLICATION

SIKA AT WORK
SEISMIC RETROFITTING OF A MALL

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SIKAWRAP® FABRICS

DRY APPLICATION

Sikadur®-330

Priming

Adhesive
Saturant

SikaWrap®

SIKAWRAP® FABRICS
WET APPLICATION

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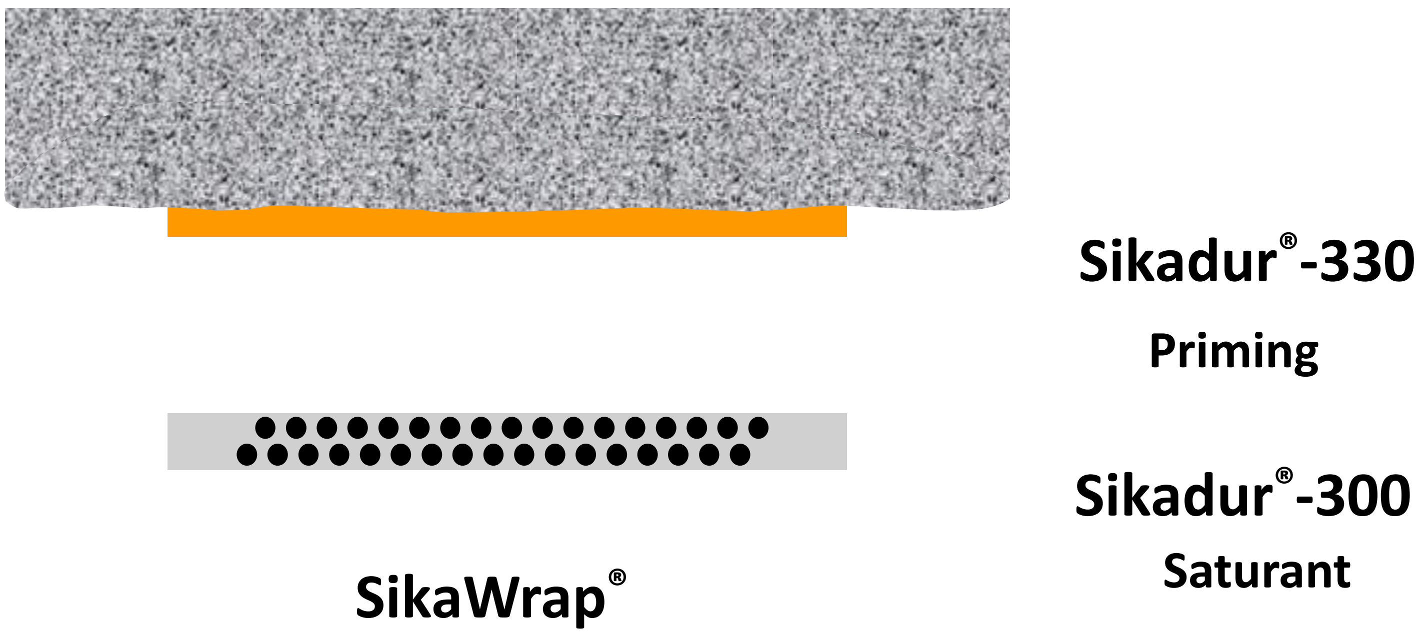
SIKAWRAP® FABRICS

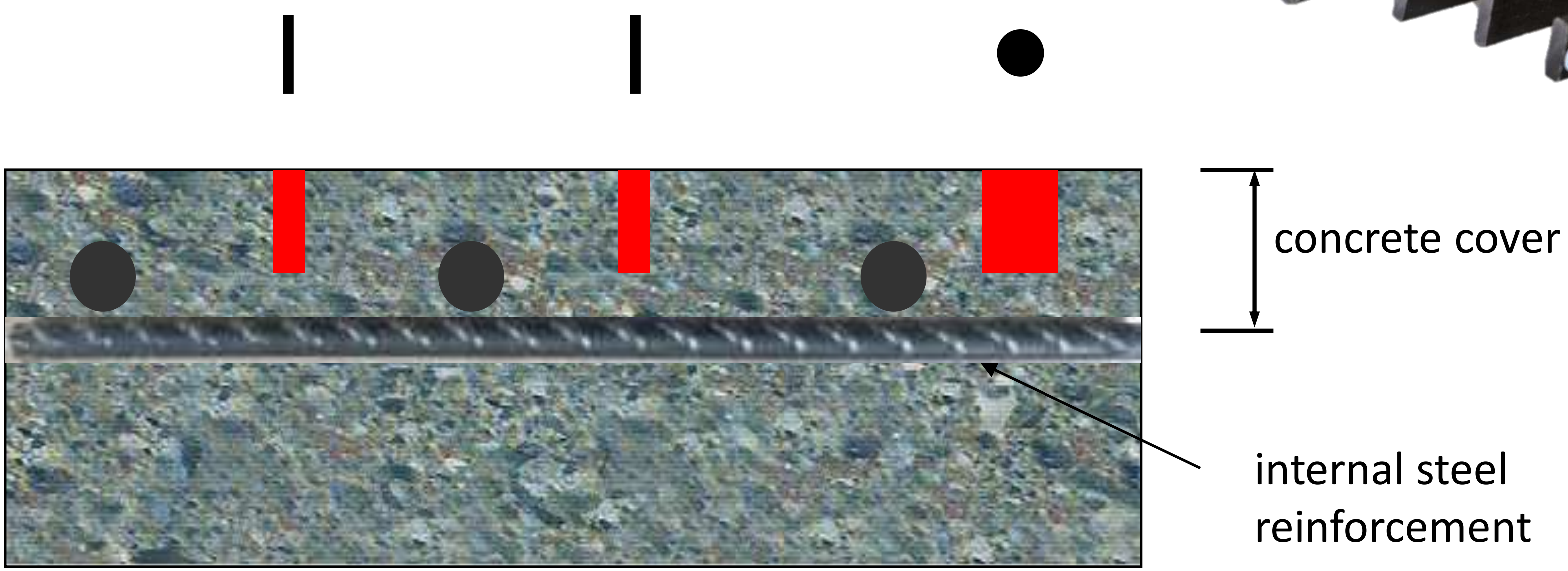
WET APPLICATION



NEAR SURFACE MOUNTED

USUAL ARRANGEMENT

1. Cut groove in concrete cover of internal reinforcement
2. Fill with Sikadur®-30/330/300 adhesive
3. Place CarboDur® S plate / CarboDur® BC rod



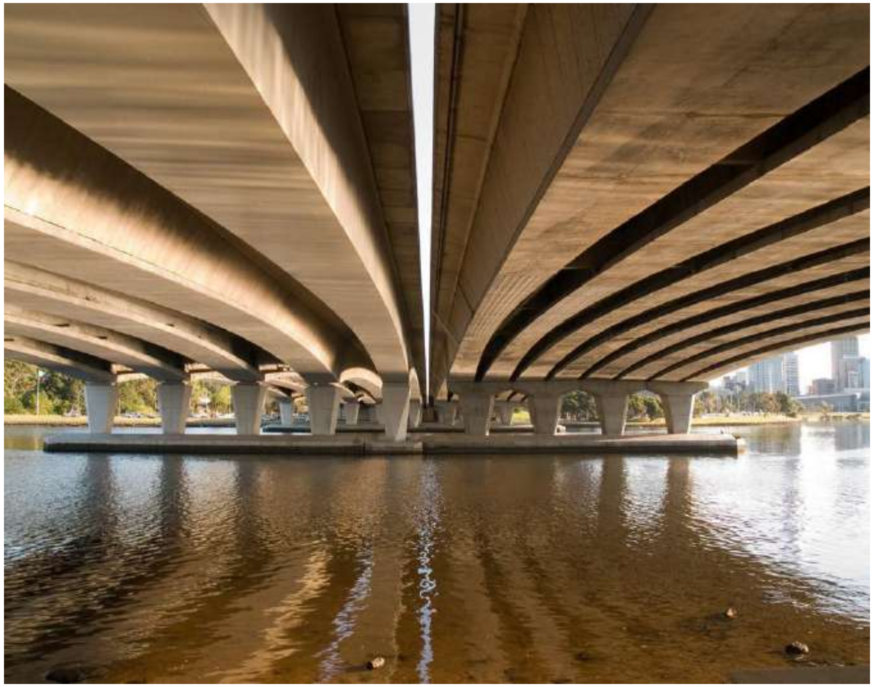
NEAR SURFACE MOUNTED

USUAL ARRANGEMENT

OTHER STRENGTHENING METHODS: DRAWBACKS

SIKA AT WORK
NARROWS BRIDGE

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



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TRM (TEXTILE REINFORCED MOTAR) SOLUTIONS

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SIKA PRODUCT RANGE

MAIN TRM SYSTEMS

GLASS FIBER SYSTEMS

- MASONRY STRENGTHENING
- SEISMIC RETROFITTING


SIKA TRM SYSTEM
TEXTILE REINFORCED MORTAR SYSTEM
© Copyright Sika Services AG 2015 - All rights reserved
BUILDING TRUST
Sika

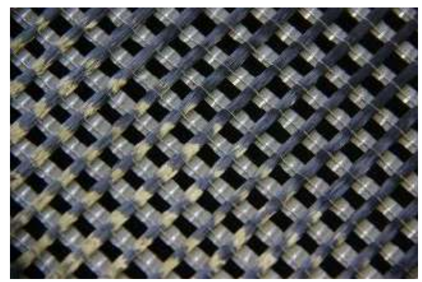
SIKA AT WORK

UFFICI GALLERY

SIKA FRP PRODUCT RANGE
MAIN TRM SYSTEMS

CARBON FIBER SYSTEMS

- REINF. CONCRETE STRENGTHENING
- MASONRY STRENGTHENING
- SEISMIC RETROFITTING



SIKA AT WORK
BURIED WATER TANK IN ALSACE, FRANCE

SIKA AT WORK

WASTE WATER TREATMENT PLANT IN SOUESMES, FRANCE

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INNOVATION IN STRUCTURAL STRENGTHENING SOLUTIONS
SIKA CARBOHEATER 2

SPECIFICATION SELLING PUSHING SPECIALTIES
NEW SIKA CARBOHEATER

- CarboHeater machine: heating of CarboDur plates and Sikadur adhesive by introducing a current to the carbon fibres

- Main applications:
  - Curing of resin in cold conditions
  - Faster time to service (full curing in 1-2h)
  - Elevation of adhesive Tg (Sikadur®-30 LP)

SIKA® CARBOHEATER 2
MAIN USES

- CarboDur® Projects with:
  - Time constraints
  - Low ambient temperatures
  - High service or ambient temperatures

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SIKA CARBOHEATER II

APLICACIÓN EN "ESTACIÓN NORTE" (MADRID)

Sika España, 2018

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Sika

SIKA AT WORK

PRÍNCIPE PÍO TRAIN STATION MADRID, SPAIN

INNOVATION IN STRUCTURAL STRENGTHENING SOLUTIONS

SIKAWRAP FX-50

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FRP STRENGTHENING METHOD BASED ON CFRP STRINGS

MULTI-PURPOSE SYSTEM

Mechanical performance (dry fiber):

Weight:	≥ 50 g/m
Fibre cross section:	≥ 28 mm^2
E-modulus:	240 Gpa.

Mechanical performance (laminated string):

Ultimate strength (mean value):	~ 70 kN/cord
Design strength (flexural strengthening):	~50 kN/cord
Design strength (shear strengthening):	~25 kN/cord

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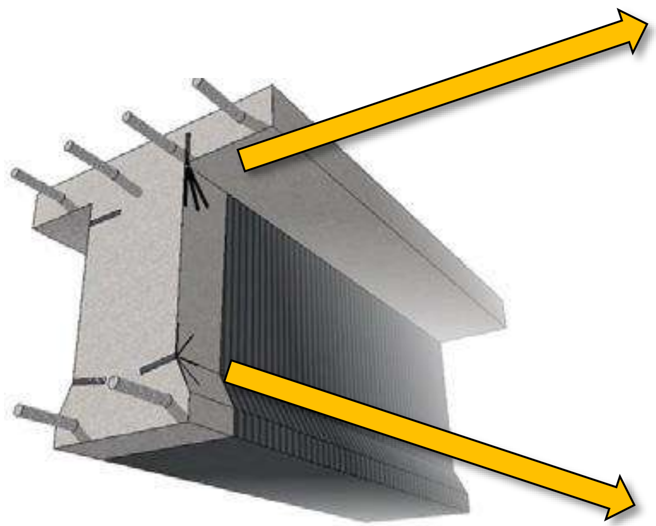
ENHANCEMENT OF EXISTING FRP TECHNIQUES

USE AS FRP ANCHORAGE

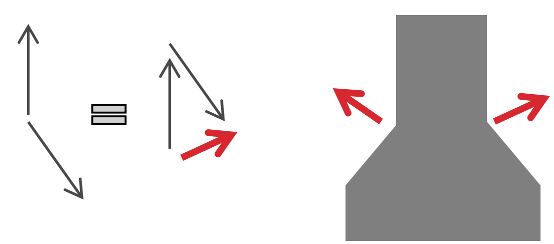


End-anchorage

- Increased end-anchorage performance, enabling the user of a higher effective stress level for the external wrapping with fabrics.
- Enhancement of the effective depth (according to the design code)

Anchorage at inner angles

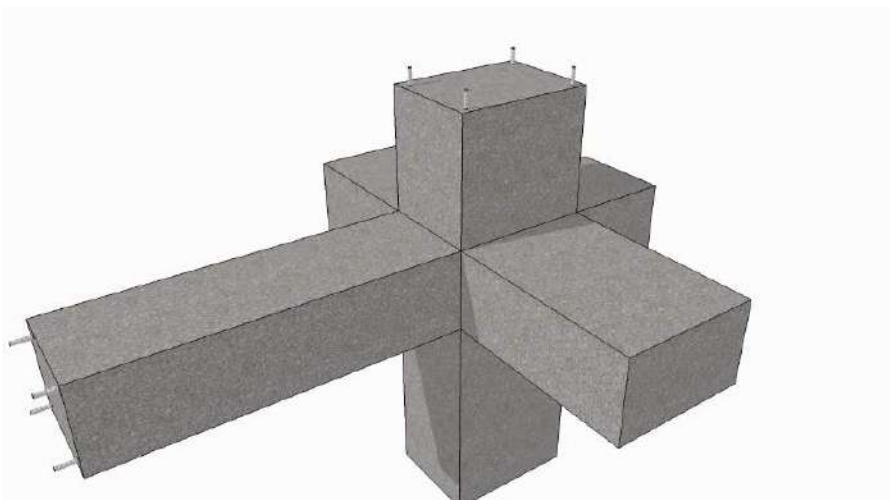
- Reduction of the debonding risk due to the pull-out forces
- Enhancement of the effective depth (according to the design code)

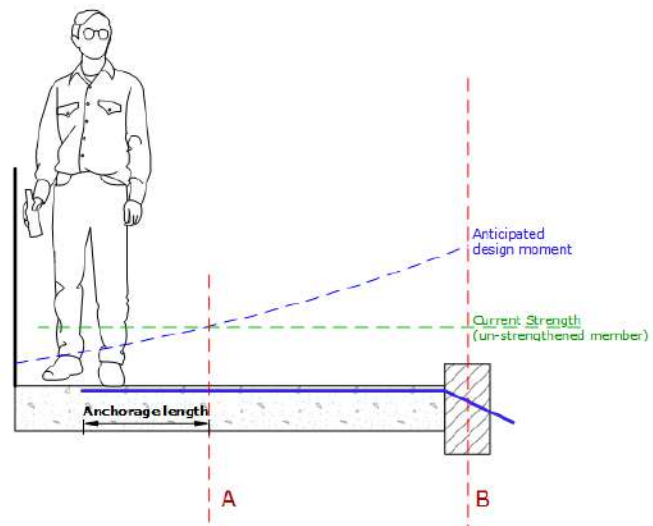


FRP STRING AS STRENGTHENING METHOD

Flexural strengthening in cantilevered structures

- In those cases where the continuity of the CFRP strengthening is not feasible due to the existence of intermediate structural members or walls, the CFRP exhibits an extraordinary anchorage capacity, being able to transfer the net design to its end-anchorage simply by introducing its end into a 20mm hole.
- Specially important is the capacity of the CFRP cord to be bended into the inclined hole, as it´s not possible to provide a horizontal drilling.





3. DESIGN INTERNATIONAL GUIDELINES

SIKAWRAP® & SIKA CARBODUR®

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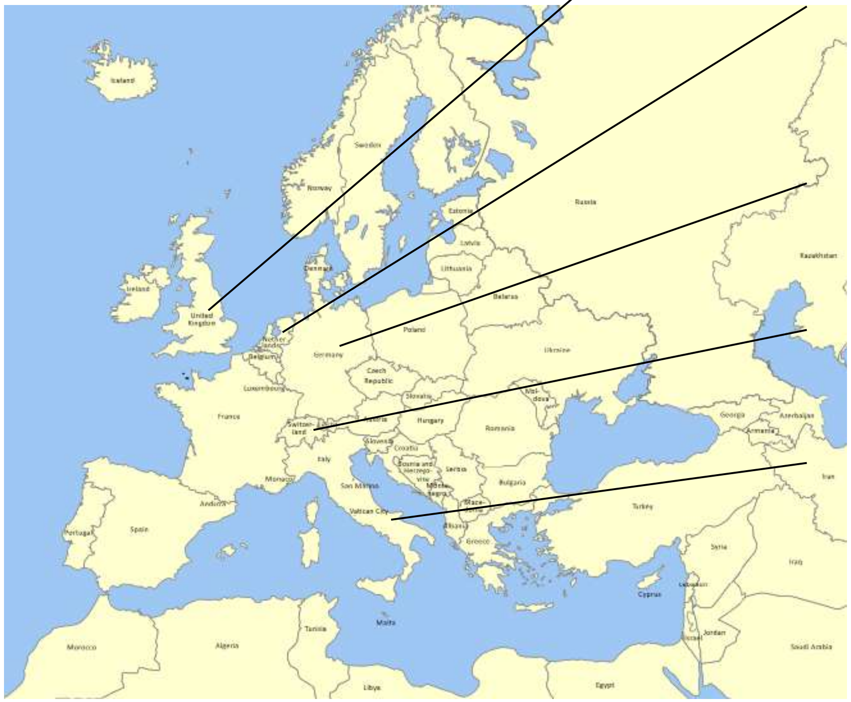
DESIGN GUIDELINES

LOCAL EUROPEAN GUIDELINES



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

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

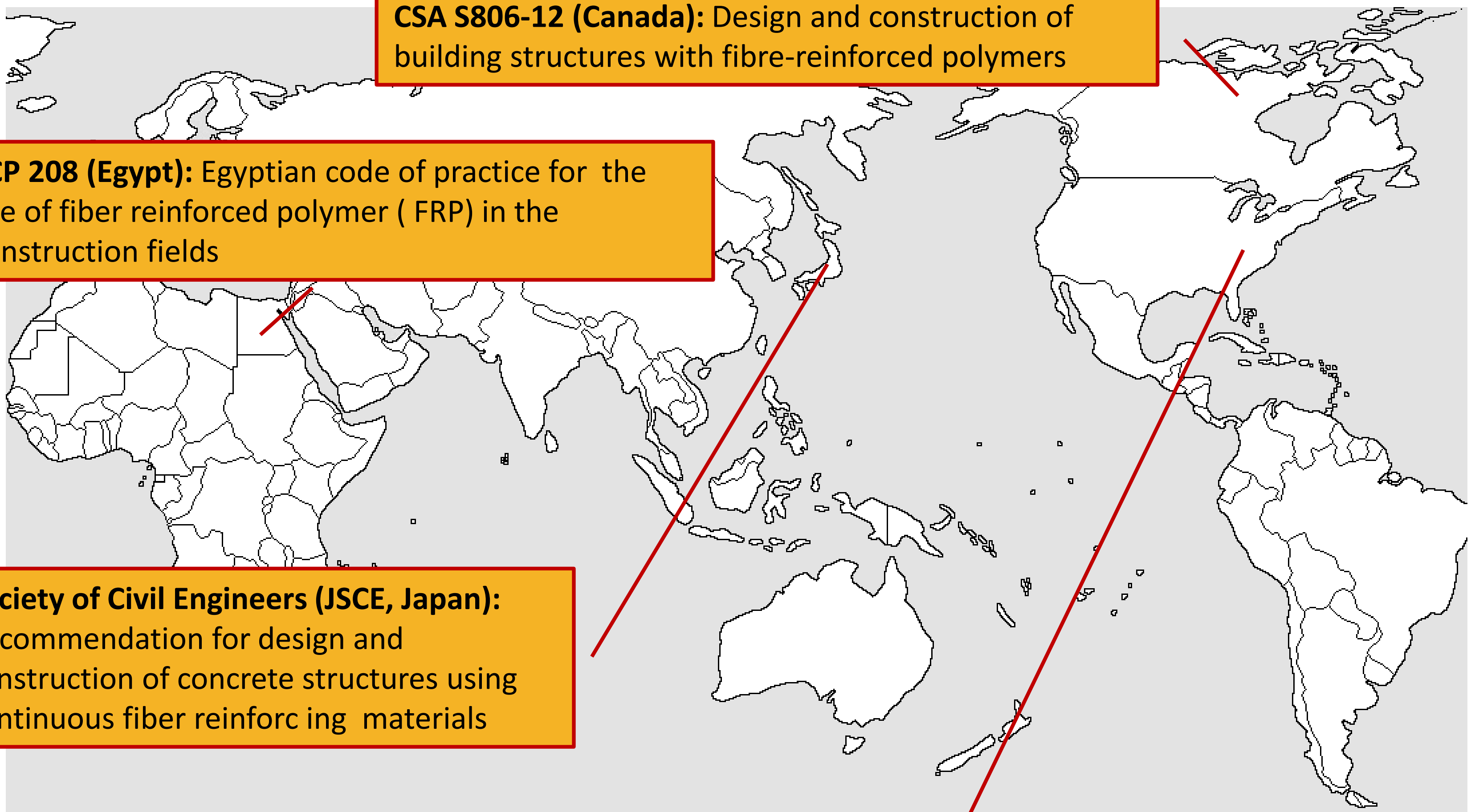
DAfStb Heft 591 (Germany): Strengthening of concrete elements by means of extrenally bonded reinforcements.

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.

DESIGN GUIDELINES

OTHER COUNTRIES



CSA S806-12 (Canada): Design and construction of building structures with fibre-reinforced polymers

ECP 208 (Egypt): Egyptian code of practice for the use of fiber reinforced polymer (FRP) in the construction fields

Society of Civil Engineers (JSCE, Japan): Recommendation for design and construction of concrete structures using continuous fiber reinforc ing materials

American Concrete Institute, ACI 440.2R. (USA): Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures.

GUIDELINES

FUTURE OF THE FRP DESIGN GUIDELINES

Current situation:

EUROCODE 2

+ fib Bulletin 14, or

+ CUR-91 (Netherlands)
+TR55 (UK)
+CNR-DT 200 (Italy)

ACI 318-14

+ ACI440.2R

~ 2020: FRP design to be integrated into EC2: no longer FRP guidelines in Europe.

TECHNICAL REPORT 55, THIRD EDITION (2014)

EUROCODE 2

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).

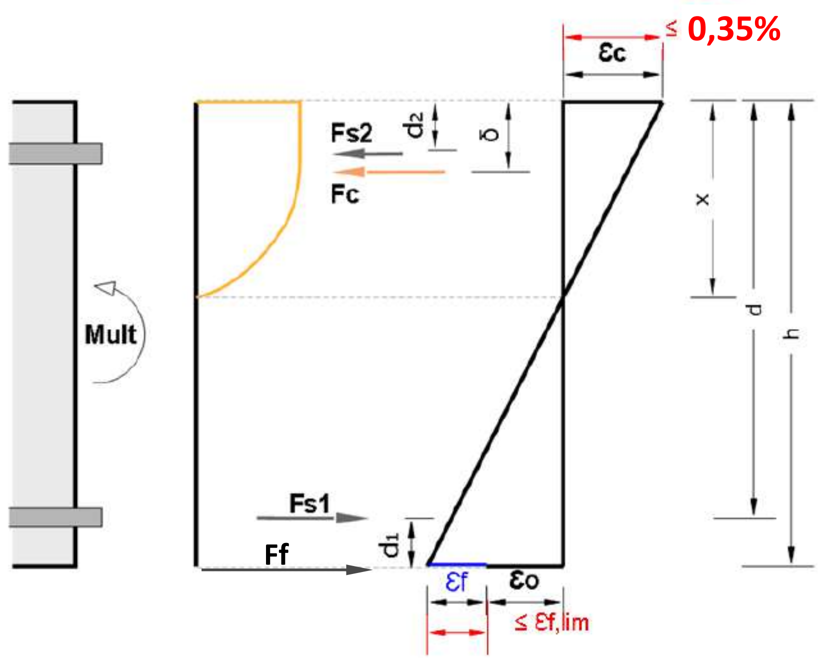
FLEXURAL STRENGTHENING

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)

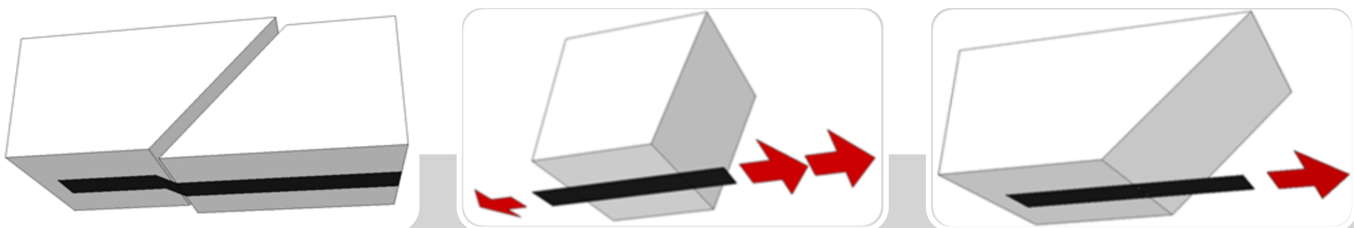


FLEXURAL STRENGTHENING

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.

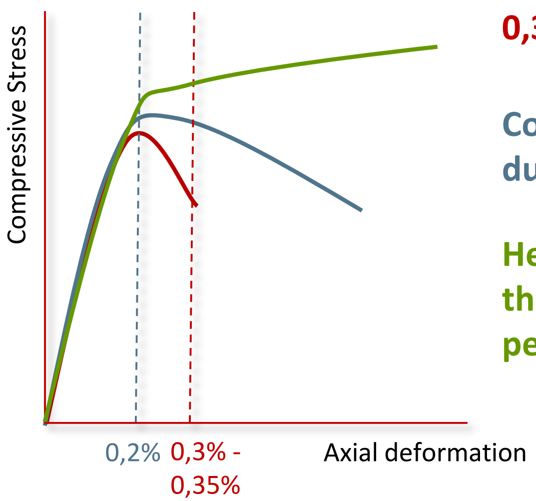
COLUMN CONFINEMENT

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:

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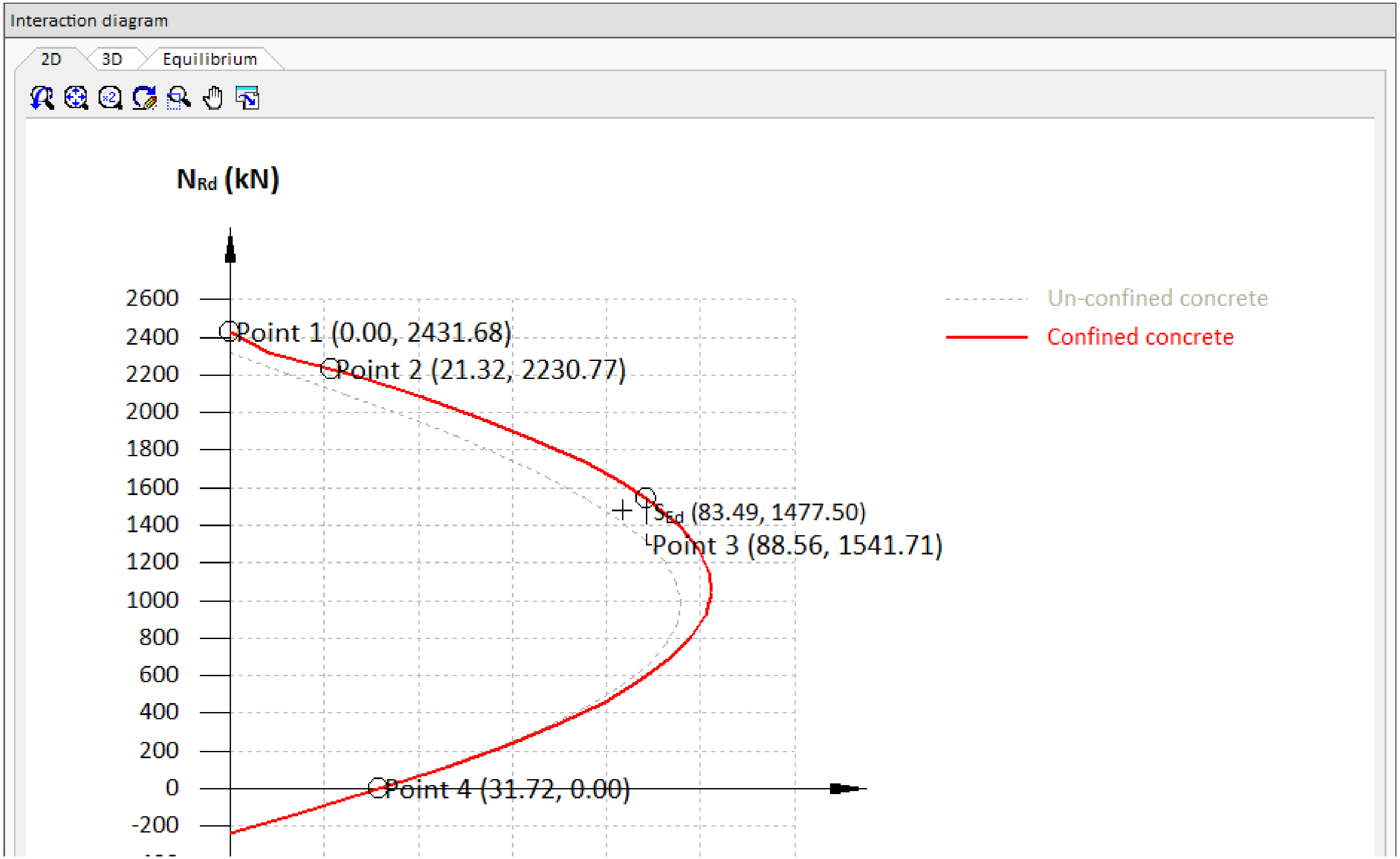
COLUMN CONFINEMENT

AXIAL LOADS + BENDING MOMENT



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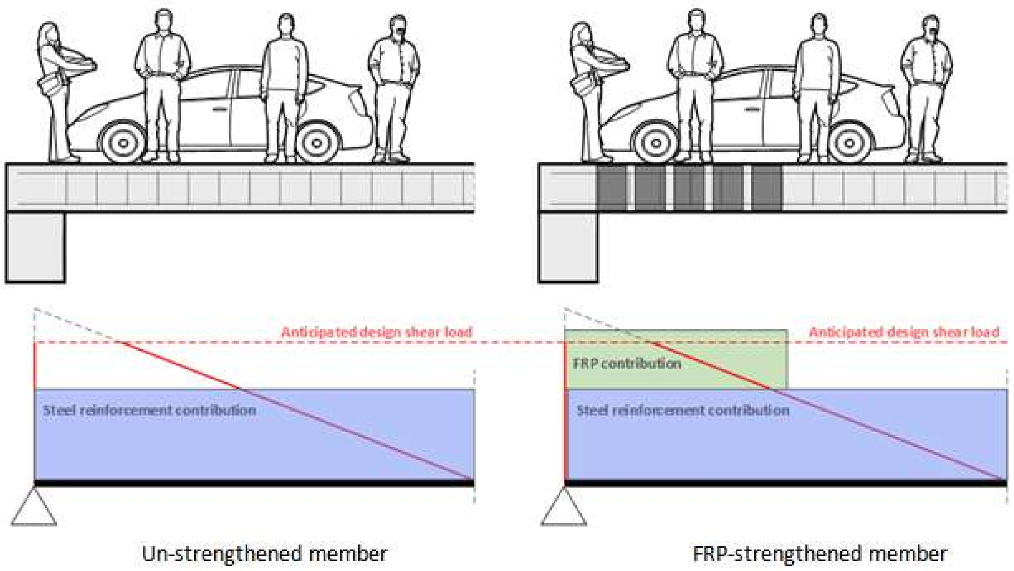
SHEAR STRENGTHENING

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).



ACI 318 AND ACI 440.2R

GUIDELINES
ACI 318-11

- **ACI 318-11** Building Code Requirements for Structural Concrete
  - Covers the materials, design and construction of structural concrete
    - For example:
      - Contract documents
      - Concrete quality
      - Formwork
      - Construction joints
      - Analysis and design
      - Provisions for seismic design
      - Etc, etc.
  - Also covers strength evaluation of existing concrete structures

GUIDELINES
440.2R-08

- ACI 440.2R-08 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening <u>Concrete</u> Structures
  - General information on the history and use of FRP strengthening systems
  - Recommendations on the engineering, construction and inspection of FRP systems
  - For strengthening of masonry:
    - ACI 440.7R-10 Guide for the Design and Construction of Externally Bonded Fiber-Reinforced Polymer Systems for Strengthening Unreinforced Masonry Structures

DESIGN PHILOSOPHY IN ACI 440.2R-08

- Design is based on:
  - Traditional reinforced concrete design principles, from ACI 318.
    - Plane sections before bending remain plane after bending
      - Strain is directly proportional to the distance from the neutral axis depth
      - The section is already strained at the time of FRP installation
        - Strain compatibility between concrete substrate and FRP must be maintained.
    - Maximum useable concrete strain = 0.003
    - $f_s = E_s \varepsilon_s \leq f_y$
    - Tensile strength of concrete shall be ignored.

DESIGN PHILOSOPHY IN ACI 440.2R-08

- Strengthening limits are imposed
  - To guard against collapse of structure should failure of FRP occur
  - Unstrengthened member must be able to resist a certain level of load
    - Loss of bond, damage, vandalism

$$(\emptyset R_n)_{exising} \geq (1.1 S_{DL} + 0.75 S_{LL})_{new} \qquad (9\text{-}1)$$

- Fire

$$R_{n\theta} \geq S_{DL} + S_{LL} \qquad (9\text{-}2)$$

- where

$R_{n\theta}$ = nominal strength of a member subjected to elevated temperature associated with a fire

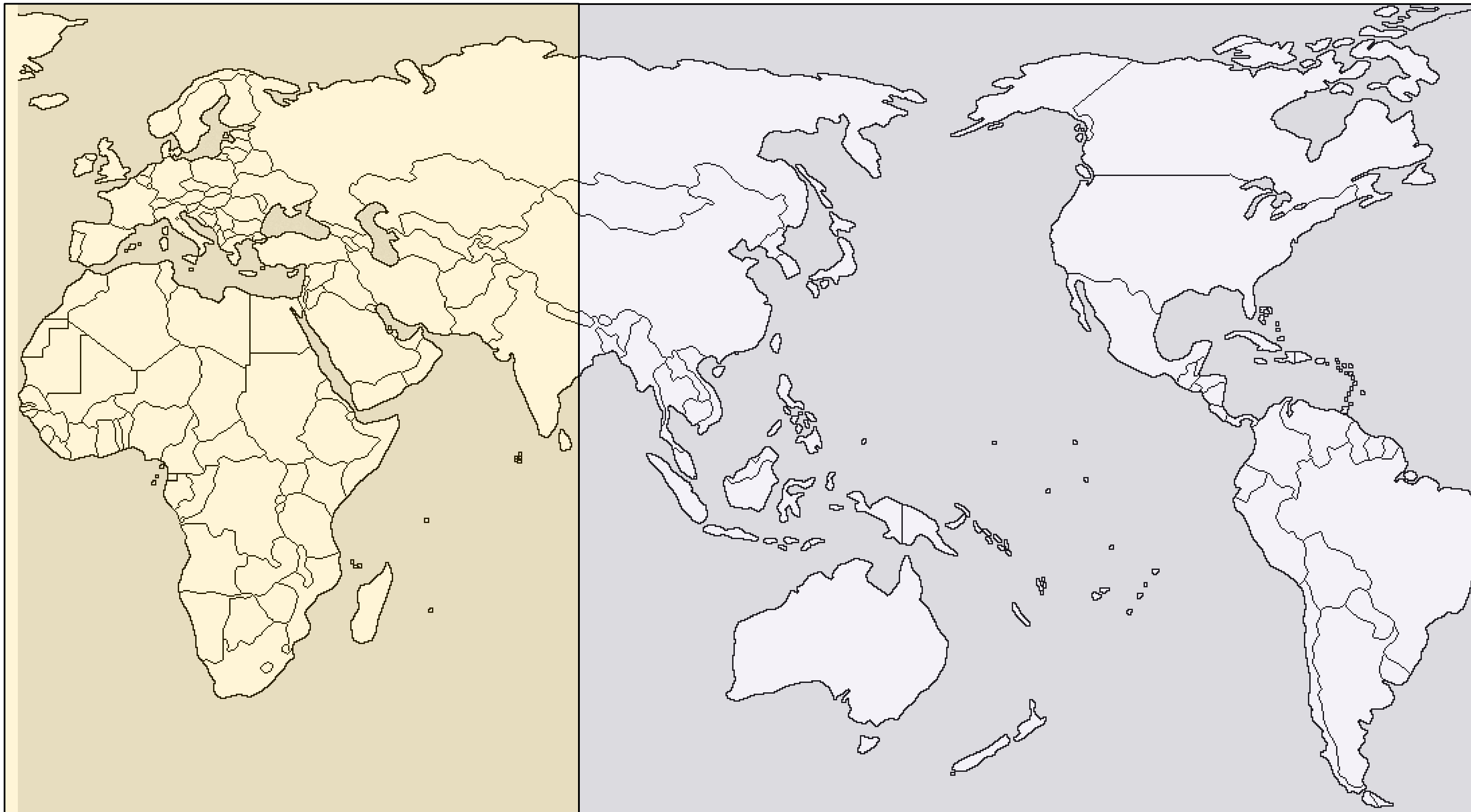
FAILURE MODES

- The following flexural failure modes should be investigated:
  1. Crushing of the concrete prior to steel yielding
  2. Yielding of the steel followed by concrete crushing
  3. Yielding of the steel followed by FRP rupture
  4. Shear / tension delamination in concrete cover
  5. FRP debonding from substrate

The desired modes of failure are modes 2 and 3

DESIGN GUIDELINES

WORLDWIDE DISTRIBUTION (SIMPLIFICATION)



Eurocode-2 based guidelines:
FIB Bulletin 14 (2001 !!!!)
TR55 (2014)

ACI 440.2R: Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures

5. FIRE SCENARIO

REACTION TO FIRE AND FIRE RESISTANCE UNDER EUROCODE 2 APPROACH

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.

The fire protection for a structural member is therefore not directly oriented to the PROTECTION of the structure (e.g. the structure can collapse or be seriously damaged in case of fire, even when protected).

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.

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

STEP 1: NEED FOR CFRP

IN CASE OF FIRE?

NEED FOR CFRP STRENGTHENING

PERSISTENT AND TRANSIENT SITUATION

The design of a structure is focused in ensuring the necessary strength under the expected loads. For safety reasons, the different codes take into account additional safety coefficients.

Under those circumstances, an appropriate strengthening method must be displayed, so that the structural safety gap required the local regulation is achieved.

PERSISTENT AND TRANSIENT SITUATIONS	**Eurocode** (e.g. residential building)
Design loads	The expected loads are magnified by means of safety factors : ▪ x 1.5 for imposed loads ▪ x 1.35 for permanent loads
Ultimate Strengths	The material´s strengths are reduced by means of safety factors ▪ y_c= 1.5 for concrete ▪ y_s= 1.15 for steel

NEED FOR CFRP STRENGTHENING

FIRE SITUATION

DETERMINATION OF THE ANTICIPATED DESIGN **LOADS** UNDER A FIRE SCENARIO

General Rule (*Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire, section 4.3.1.*)

FIRE LOADS TAKEN AS THE SERVICE, UN-FACTORED LOADS (QUASI-PERMANENT COMBINATION OF LOADS AS USUAL)

Simplified rule (*Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire, section 2.4.2.)*

FIRE LOADS TAKEN AS A REDUCED RATIO OF THE DESIGN LOAD (e.g.. 70%)

DETERMINATION OF THE ANTICIPATED DESIGN **STRENGTHS** UNDER A FIRE SCENARIO

Characteristic strengths for concrete and steel to be used
(*Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design, section 2.3.)*

Materials safety factors:

- **$Y_{c,fi}$ = 1 for concrete**
- **$Y_{s,fi}$ = 1 for steel**

DESIGN STRENGTHS

EXAMPLE (BASED ON EUROCODE 1&2):

ULS, PERSISTENT&TRANSIENT

	CHARACTERISTIC STRENGTH	DESIGN STRENGTH
CONCRETE	25 MPa	25/1.50 = **16.6 MPa**
STEEL	500 MPa	500/1.15 = **434 MPa**

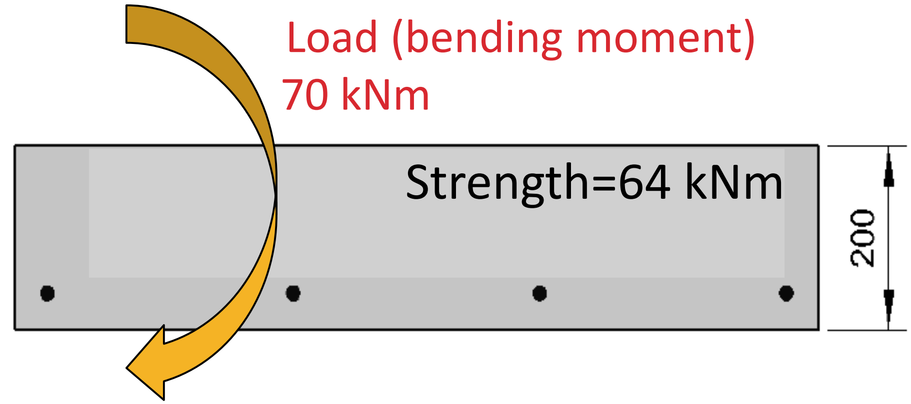
ULS, FIRE SITUATION

	CHARACTERISTIC STRENGTH	DESIGN STRENGTH
CONCRETE	25 MPa	25/1 = **25 MPa**
STEEL	500 MPa	500/1 = **500 MPa**

NORMAL VS. FIRE SITUATION

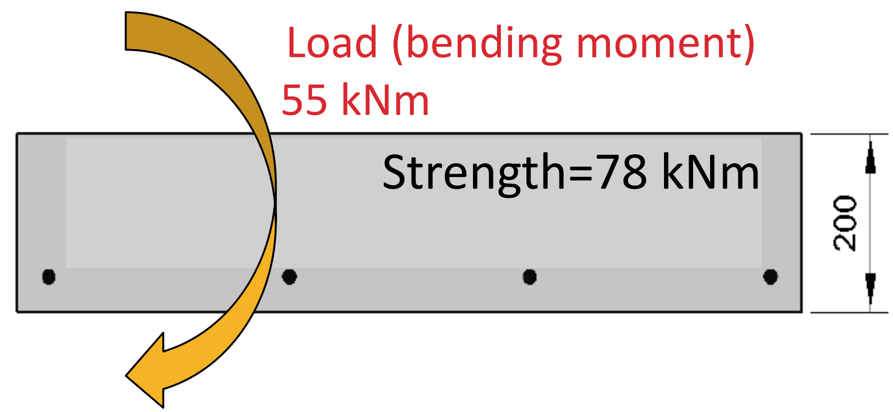
EXAMPLE:

NORMAL DESIGN SITUATION
(NO CFRP)



Design loads exceed the design strength : CFRP is necessary !!

FIRE SITUATION, SAME SLAB
AND LOAD CONDITIONS

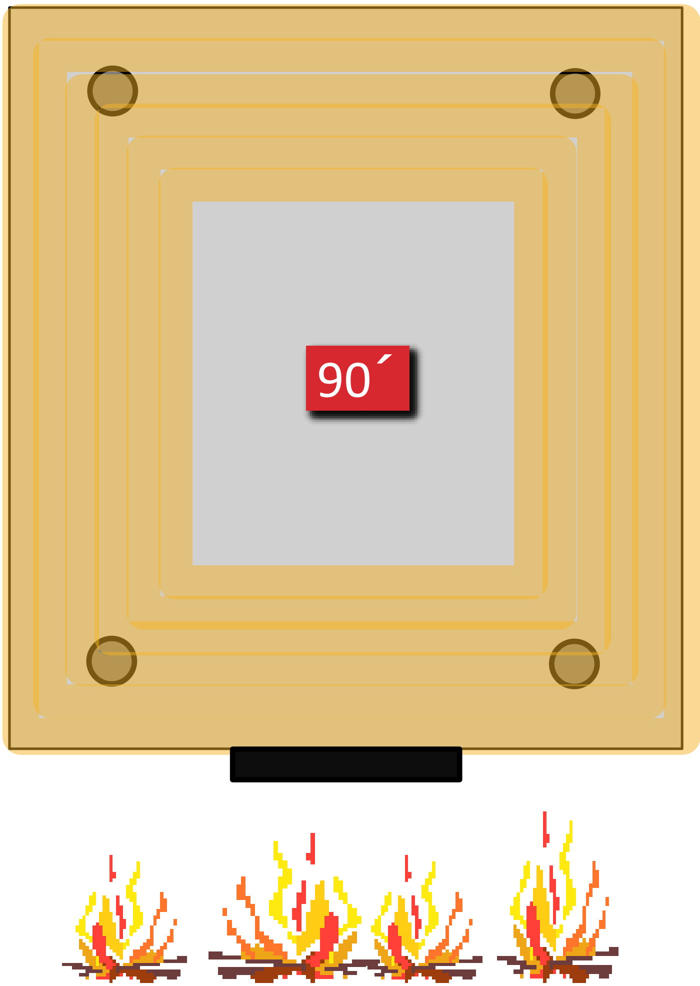


CFRP Strengthening? Why?

STRUCTURAL ANALYSIS

UNDER FIRE SITUATION

MECHANICAL PERFORMANCE
STRENGTHENED MEMBER, UNPROTECTED



When unprotected, the CFRP adhesive exceeds its maximum working temperature in a few minutes, and the laminate loses its adhesion

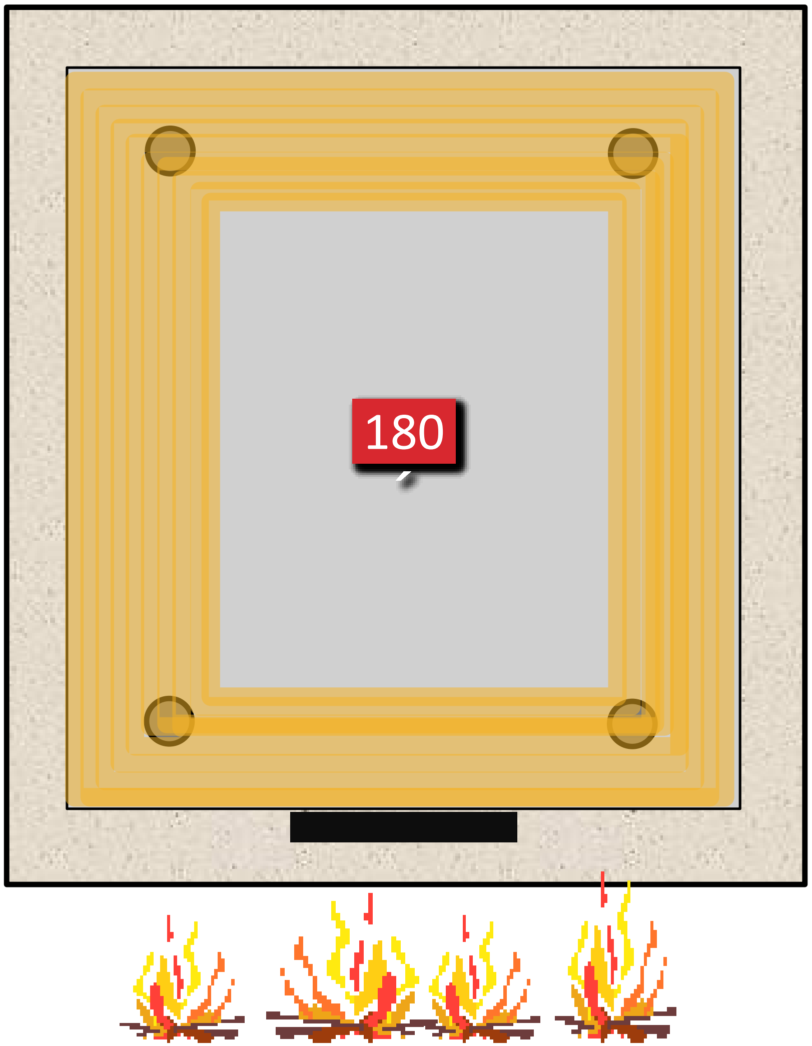
The member is heated progressively from the outside of the faces exposed to fire.

Both concrete and steel reduce its strength as the temperature increases.

If the remaining section is not able to support the existing loads during the fire, the element will collapse after XXX minutes. This is its FIRE RESISTANCE

MECHANICAL PERFORMANCE

STRENGTHENED MEMBER, PROTECTED



When the element is protected, the CFRP adhesive can stay under its working temperature for a reduced time, until the laminate loses its adhesion

The member is heated progressively from the outside of the faces exposed to fire. However, due to the insulation, the heating rate is slowed.

Both concrete and steel reduce its strength as the temperature increases.

If the remaining section is not able to support the existing loads during the fire, the element will collapse after XXX minutes. This is its FIRE RESISTANCE

MECHANICAL PERFORMANCE OF THE MATERIALS
IN CASE OF FIRE

1-Existing situation

$M_{rd,0}$ = 64,78 kNm (slab depth 200) ✓

Design load: 60 kNm

2-Strengthened slab

M_{rd} = 91,10 kNm (slab depth 200) ✓

2 x Carbodur S512

Design load: 90 kNm

3-Fire situation

Design load: 63 kNm

0’

	d1	Steel	fyk	Area			ds
1.	40 mm	B500	500 MPa		☑	4 ×	18 mm

Current strength: 76,10 kNm (200) ✓

30’

	d1	Steel	fyk	Area			ds
1.	30 mm	User	475 MPa		☑	4 ×	18 mm

Current strength: 72,56 kNm (190) ✓

60’

	d1	Steel	fyk	Area			ds
1.	18 mm	User	435 MPa		☑	4 ×	18 mm

Current strength: 66,81 kNm (178) ✓

90’

	d1	Steel	fyk	Area			ds
1.	11 mm	User	400 MPa		☑	4 ×	18 mm

Current strength: 61,74 kNm (171) ✗

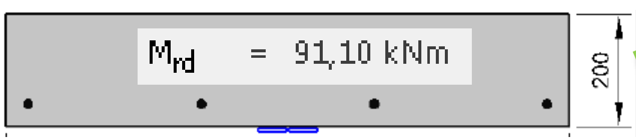
MECHANICAL PERFORMANCE OF THE MATERIALS

28 mm SikaCrete protective mortar

1-Existing situation

Design load: 60 kNm

2-Strengthened slab



2 x Carbodur S512

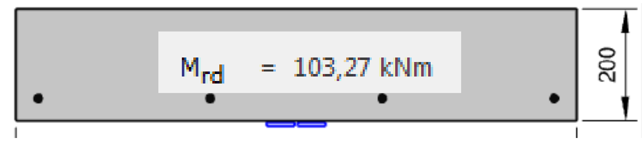
Design load: 90 kNm

3-Fire situation

Design load: 63 kNm

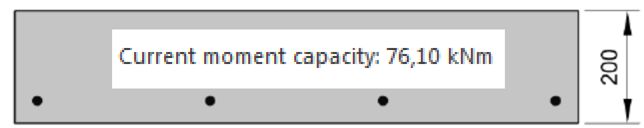
0-30'

	d1	Steel	fyk	Area			ds
1.	40 mm	B500	500 MPa		☑	4 ×	18 mm



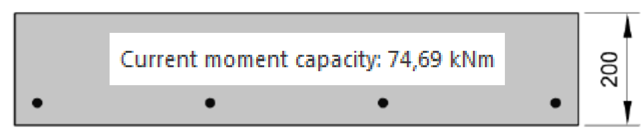
60-90'

	d1	Steel	fyk	Area			ds
1.	40 mm	B500	500 MPa		☑	4 ×	18 mm



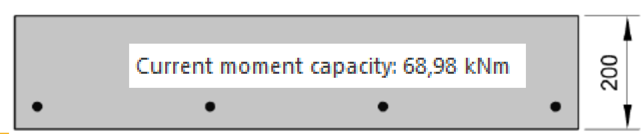
120'

	d1	Steel	fyk	Area			ds
1.	40 mm	B500	500 MPa		☑	4 ×	18 mm



240'

	d1	Steel	fyk	Area			ds
1.	40 mm	B500	500 MPa		☑	4 ×	18 mm



STEP 3 (FRP NECESSARY IN CASE OF FIRE)

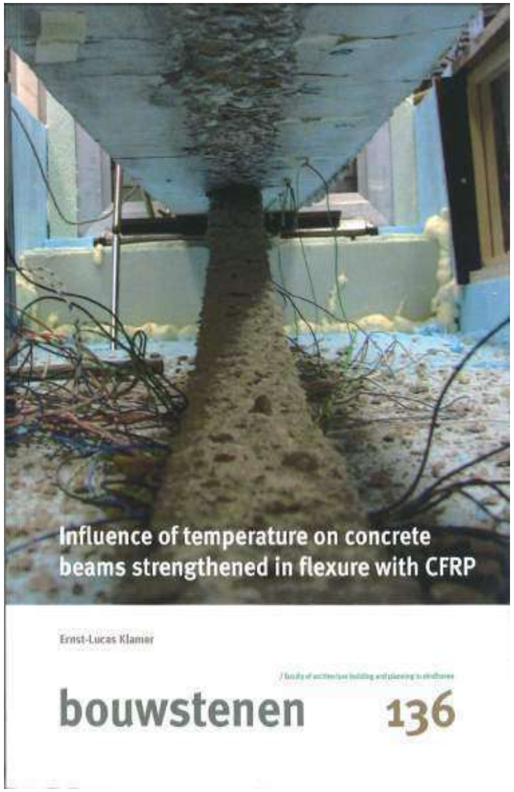
DETERMINATION OF THE FIRE PROTECTION

TEMPERATURE RESISTANCE
STRUCTURAL ADHESIVE

The temperature resistance for the CFRP materials is significantly high in certain cases.

However, the structural adhesives used for the adhesion/saturation usually exhibit low Tg (glass transition temperature), so they are the main target for the fire protection.

SikaDur 30LP: Tg=110ºC (120ºC curing temp.)



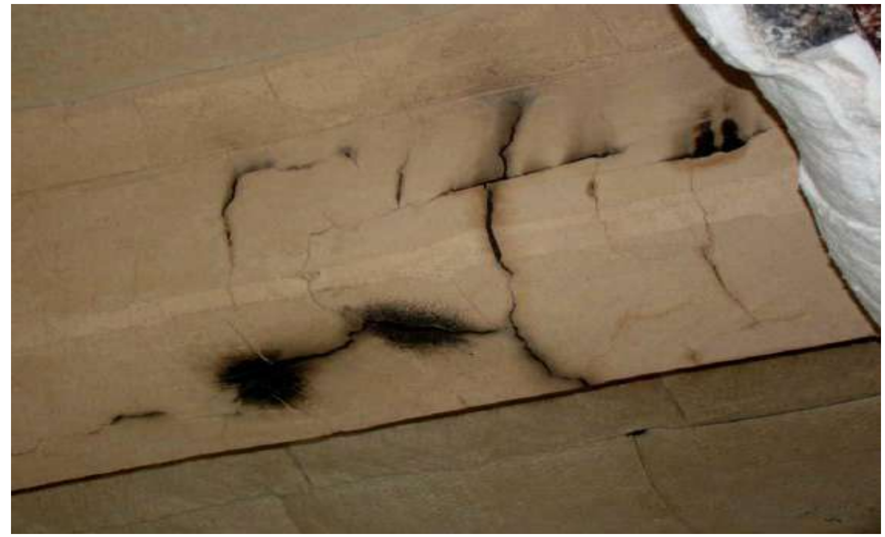
PhD Thesis 2009
Ernst-Lucas Klamer,
TU Eindhoven

SIKACRETE® PROTECTION MORTAR

Cement-based pre-bagged, dry mix fire protection mortar for wet sprayed application

SIKACRETE F FIRE PROTECTION
IS CFRP PROTECTED?

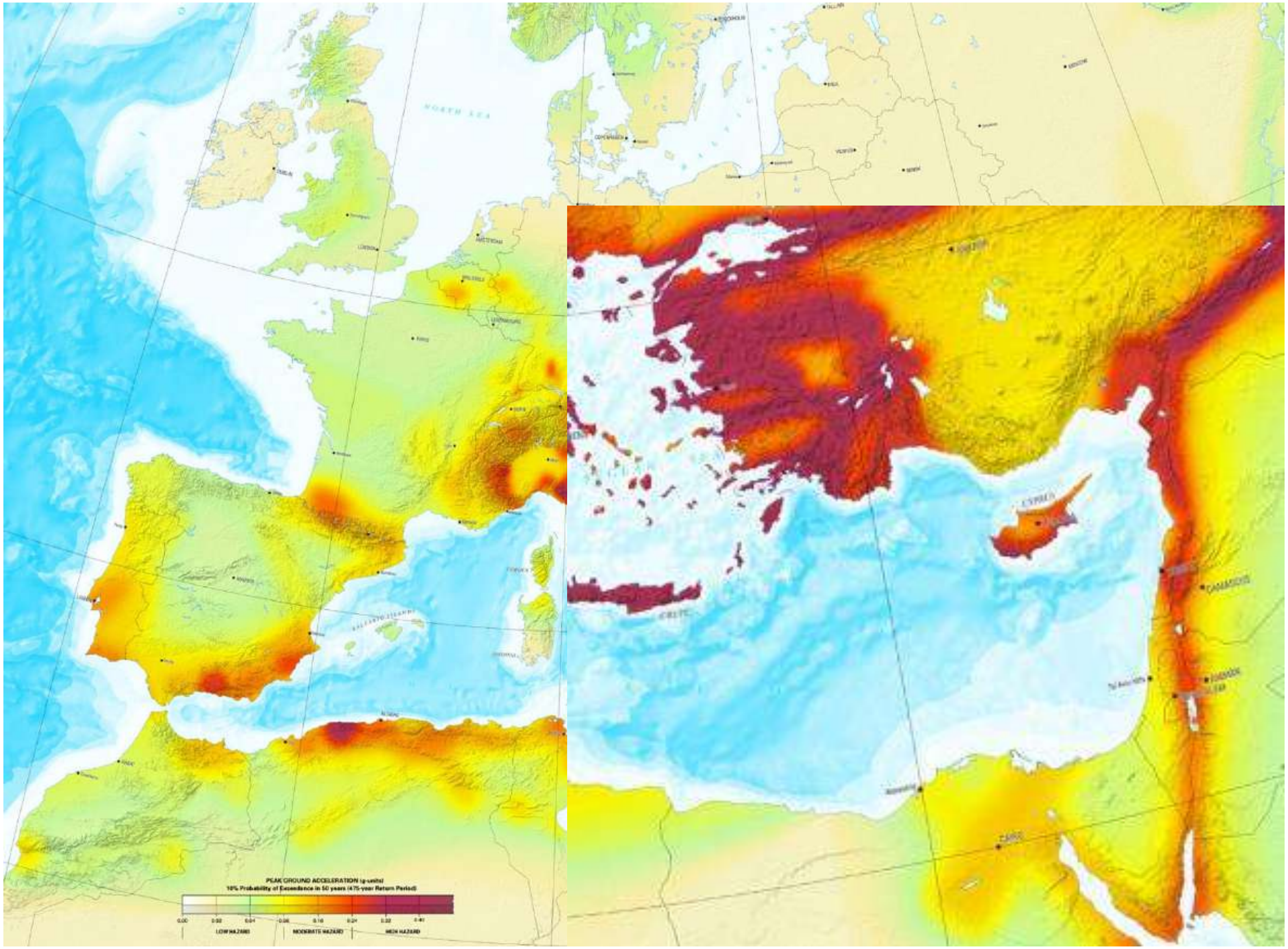
In case of fire, the CFRP reinforcement will easily be destroyed, even when protected:



In case of protection, the CFRP:
-Cannot be protected for more than 45 - 60 minutes, even when a significant thickness of Sikacrete 213F is applied.
-Even when protected, the CFRP must be replaced after a real fire scenario.

6. SEISMIC RETROFITTING

EARTHQUAKES
SEISMIC ACTIVITY

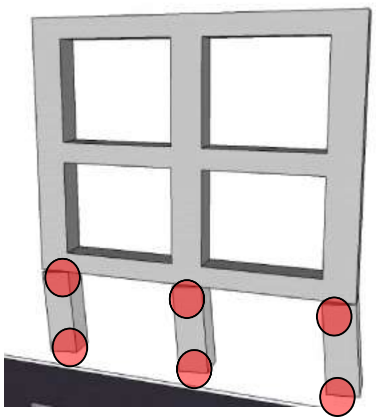


SEISMIC RETROFITTING
CONCRETE FRAMES

CONCRETE FRAMES FAILURE MODES

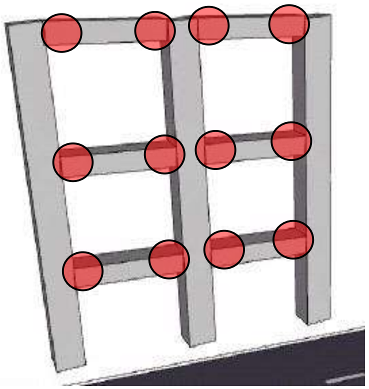
COLUMN-SWAY MECHANISM

Plastic hinges are generated at columns at the grou nd level (dangerous)




BEAM-SWAY MECHANISM

Plastic hinges are generated at beams ends in the different levels (desired target)




SEISMIC RETROFITTING
CONCRETE FRAMES

SEISMIC RETROFITTING
CONCRETE FRAMES

OTHER COLLAPSE MECHANISMS

FLEXURAL	BUCKLING
	

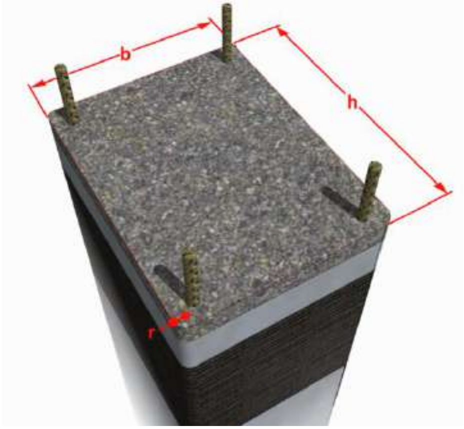
SEISMIC STRENGTHENING OF REINFORCED CONCRETE

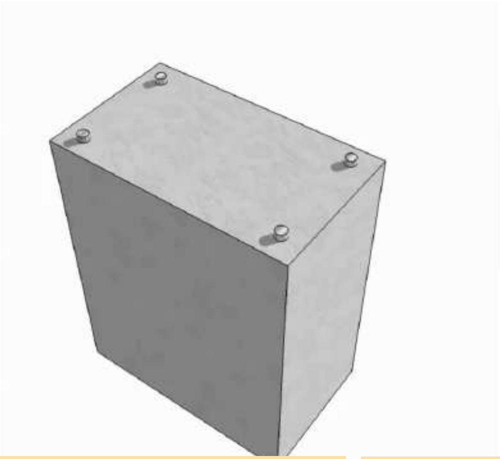
BASED ON ACI 440

SEISMIC STRENGTHENING

CONFINEMENT WITH CFRP - GENERAL CONSIDERATIONS

Confinement with FRP
Jacketing concrete structural members with FRP having the primary fibers oriented around the perimeter of the member provides confinement to plastic hinges, mitigates the splitting failure mode of poorly detailed lap splices, and prevents buckling of the main reinforcing bars.





In seismic , jacketing concrete structural members with FRP is not recommended for rectangular sections with aspect ratios *h*/*b* > 1.5, or face dimensions *b* or *h* exceeding 90 cm.

For sections with an aspect ratio > 1.5, the section can be modified to be circular or oval to enhance the effectiveness of the FRP jacket

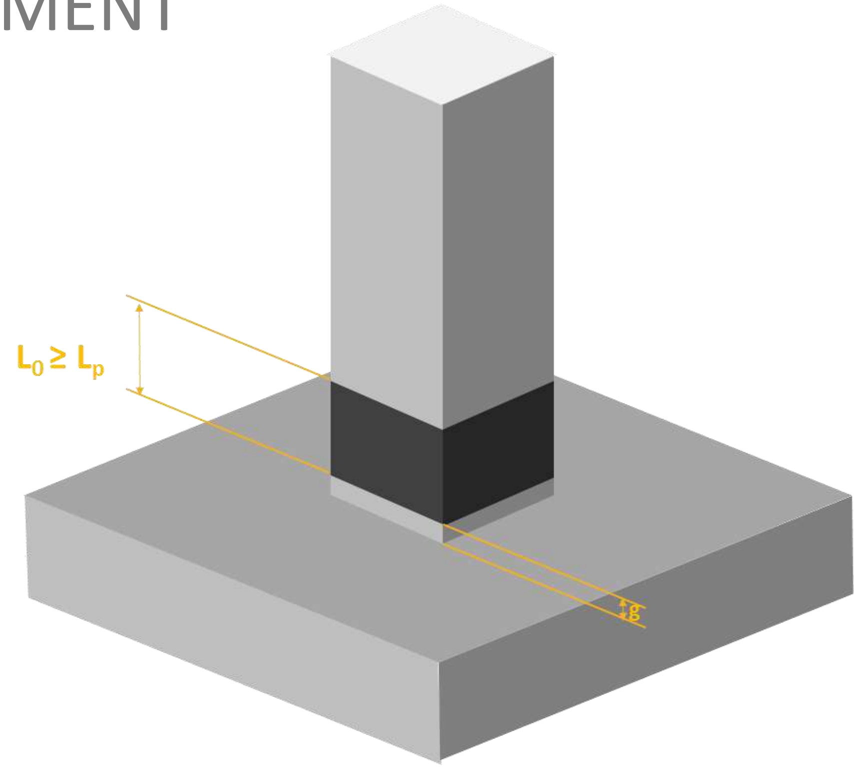
SEISMIC STRENGTHENING
PLASTIC HINGE REGION CONFINEMENT

FRP-jacketed reinforced concrete members achieve higher inelastic rotational capacity of the plastic hinge (Seible et al. 1997)

The design curvature ϕ_D for a confined reinforced concrete section at the plastic hinge can be calculated using:

$$\phi_D = \frac{\theta_p}{L_p} + \phi_{y,frp} \leq \phi_{u,frp}$$

Where:
Θp – plastic rotation demand (analytical procedures).
$\Phi_{y,frp}$ – curvature of the FRP-confined section at steel yielding.
$\Phi_{u,frp}$ – curvature of the FRP-confined section at ultimate capacity.
Lp – plastic hinge length



$$\phi_{y,frp} = \frac{\varepsilon_y}{d - c_{y,frp}}$$

ε_y - steel strain
$C_{y,frp}$ - depth of the neutral axis at steel yielding
d **- distance from the extreme compression fibers to the extreme tension steel.**

$$\phi_{u,frp} = \frac{\varepsilon_{ccu}}{c_{u,frp}}$$

ε_{ccu} - extreme compression fiber strain
$C_{u,frp}$ - depth of the neutral axis at ultimate

$$L_p = g + 0.044 f_y d_{b\ell} \quad \text{(SI)}$$

g - gap between the FRP jacket and adjacent members
$d_{b\ell}$ - diameter of the flexural steel rebar
f_y - yield stress of the flexural steel

Once the design curvature Φ_D has been established…

SEISMIC STRENGTHENING

LAP SPLICE CLAMPING

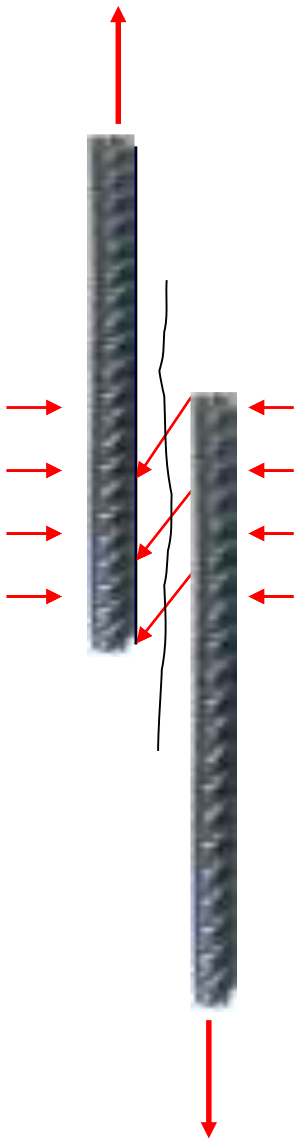
The capacity of lap splices can be improved by continuously confining the section over at least the length of the splice with externally bonded FRP

It is mandatory to continuously confining the section over at least the length of the splice with externally bonded FRP

The required thickness of the FRP jacket can be calculated as follows:

Circular sections: ntf = 1000 (D/Ef)
Rectangular sections: ntf = 1500 (D/Ef)

Where:
n - number of FRP plies
t_f - thickness per ply
D - diameter of a circular member or the greater dimension of rectangular sections (per Eq. (12.1.2a)
E_f - tensile modulus of the FRP jacket



SEISMIC STRENGTHENING

BUCKLING OF FLEXURAL STEEL BARS

Continuous or discrete FRP strips having the primary fibers oriented around the perimeter of the member can be used to prevent buckling of the flexural steel bars.

The amount of volumetric transverse reinforcement ratio should be at least:

$$\rho_f \geq \frac{0.0052\rho_\ell D}{d_{b\ell}} \frac{f_y}{f_{fe}}$$

Where:

ρ_ℓ - flexural reinforcement ratio;
D – diameter of a circular section or the diagonal length of a rectangular section
$d_{b\ell}$ - *diameter* of the flexural reinforcement
f_y -yield strength of the flexural reinforcement
ρ_f - volumetric transverse reinforcement ratio
f_{fe} is the effective design stress in the FRP jacket

BUILDING TRUST Sika®

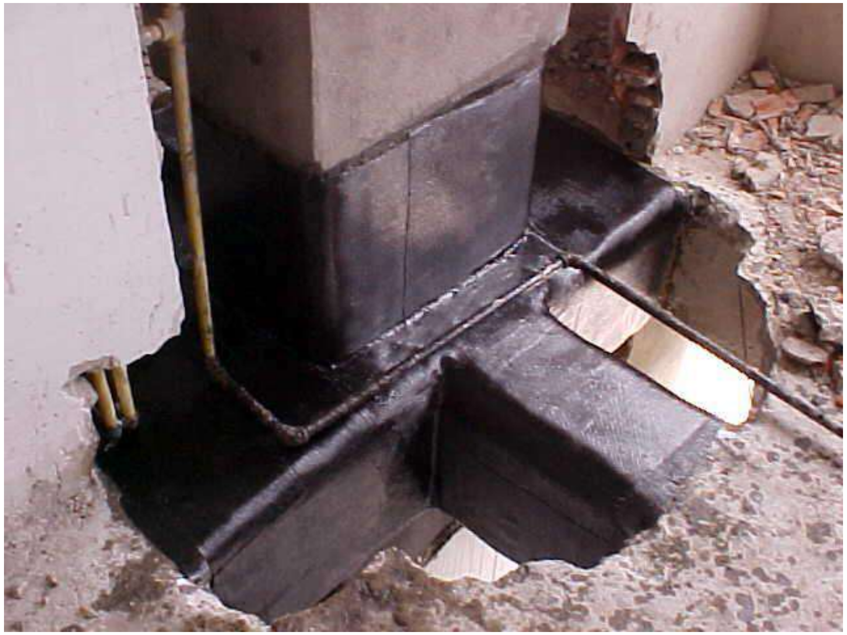
SEISMIC RETROFITTING

CONCRETE FRAMES

STRENGTHENING METHODS

Columns flexural reinforcement: and CFRP jackets for shear strengthening and to limit longitudinal steel rebars buckling.

Beam-Column joint retrofit to avoid fragile shear collapses

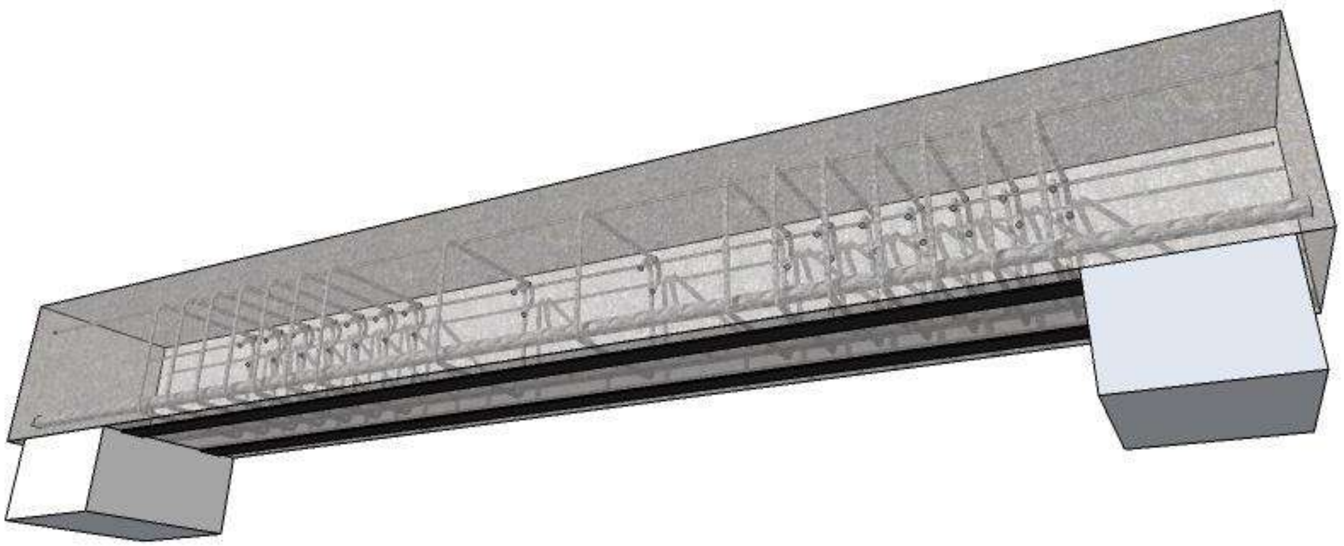


SEISMIC STRENGTHENING

FLEXURAL STRENGTHENING - GENERAL CONSIDERATIONS

The flexural capacity of reinforced concrete beams and columns in expected plastic hinge regions can be enhanced using FRP.

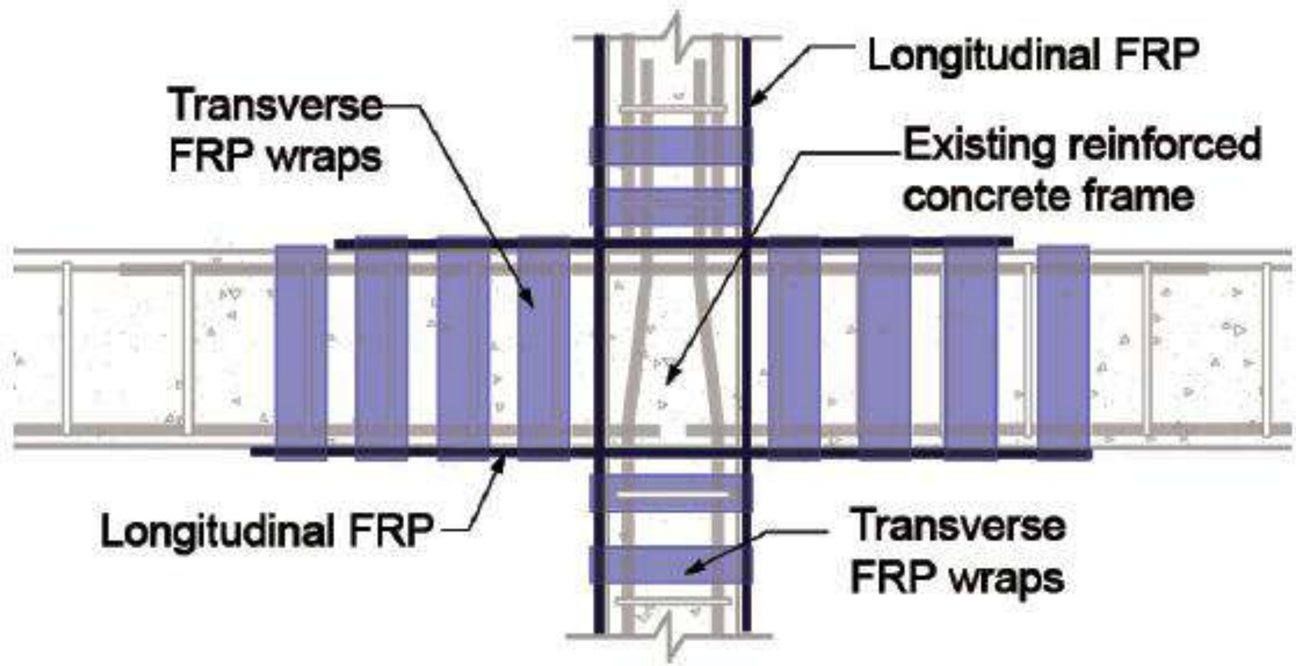
The flexural capacity of reinforced concrete beams and columns in expected plastic hinge regions can be enhanced using FRP only in cases where strengthening will eliminate inelastic deformations in the strengthened region and transfer inelastic deformations to other locations



SEISMIC STRENGTHENING

SHEAR STRENGTHENING - GENERAL CONSIDERATIONS

FRP shear strengthening can prevent brittle failures and promote the development of plastic hinges, resulting in an enhanced seismic behavior of concrete members.



Conceptual FRP strengthening detail (cross section elevation)

BUILDING TRUST

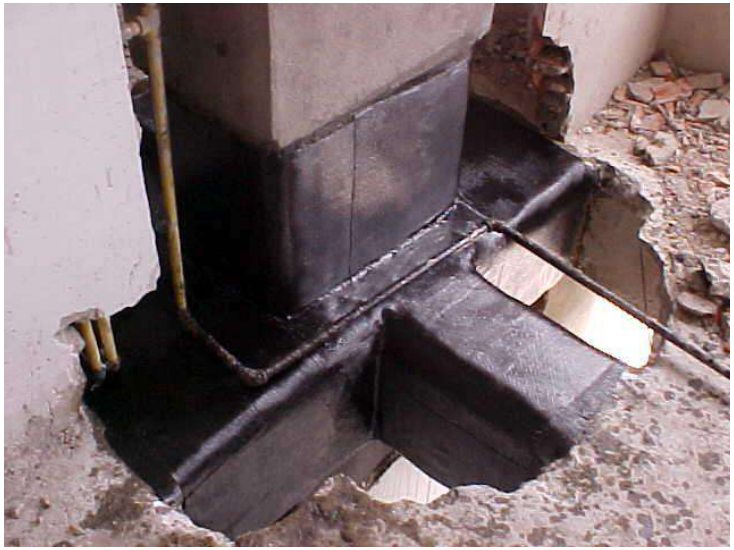
SEISMIC STRENGTHENING

BEAM-COLUMN JOINTS - GENERAL CONSIDERATIONS

Experimental tests done in structures designed to withstand only gravity loads show that unconfined beam-column joints frequently led to brittle failures and prevented structures from achieving higher global displacements before failure.

FRP systems can be effective for increasing the shear and energy dissipation capacity of unconfined joints.

FRP reinforcement in both directions is typically required at the joint to resist the cyclic loading effects of a seismic event



SEISMIC RETROFITTING OF MASONRY WALLS

SEISMIC STRENGTHENING OF MASONRY WALLS

INTRODUCTION

1 REGULATIONS OVERVIEW

- The calculation of seismic strengthening for shear walls may lead to complex calculations, as different guidelines/codes may be used simultaneously.
- The following examples showed this complexity, working with a combination of different ACI and European codes.
- Some of the most significant international codes are:

Concerning the design of masonry structures:
- Eurocode 6: Design of masonry structures.
- ACI 530/530.1-13: Building Code Requirements and Specification for Masonry Structures.

Concerning seismic evaluation and design of existing structures:
- Eurocode 8: Design of structures for earthquake resistance.
- ACI 530/530.1-13: Building Code Requirements and Specification for Masonry Structures.

SEISMIC STRENGTHENING OF MASONRY WALLS

INTRODUCTION

1 REGULATIONS OVERVIEW

Concerning the FRP strengthening of masonry walls:

- ACI 440.7R-10 Guide for the Design and Construction **of Externally Bonded Fiber-Reinforced Polymer Systems** for Strengthening Unreinforced Masonry Structures.

- ACI 549.4R-13 Guide to Design and Construction of **Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM)** Systems for Repair and Strengthening Concrete and Masonry Structures.

- CNR-DT 200 R1 (2013) Guide for the Design and Construction of **Externally Bonded FRP Systems** for Strengthening Existing Structures, from Italy.

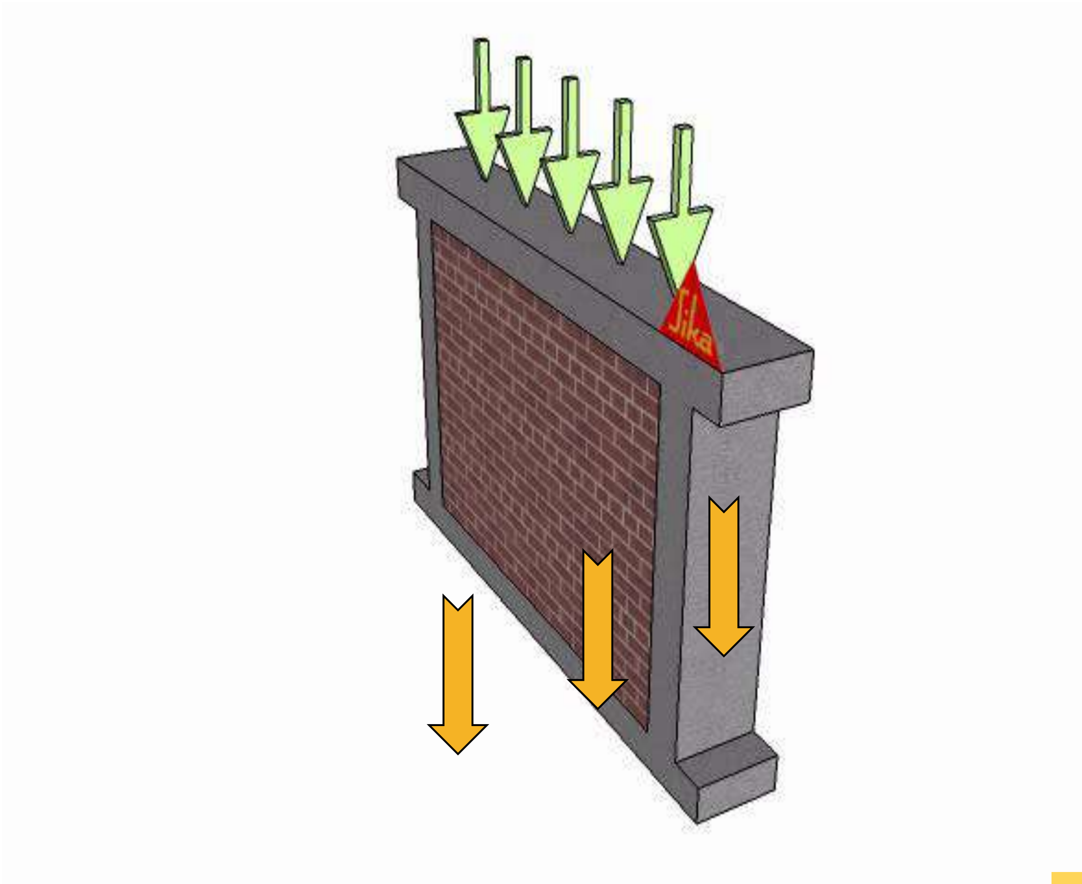
CASUISTIC

THE COLLAPSE OF THE WALL IN CASE OF HORIZONTAL FORCES CAN BE ORIGINATED BY THE RUPTURE OF THE WALL AS CONSEQUENCE OF ONE OF THE FOLLOWING MECHANISMS:

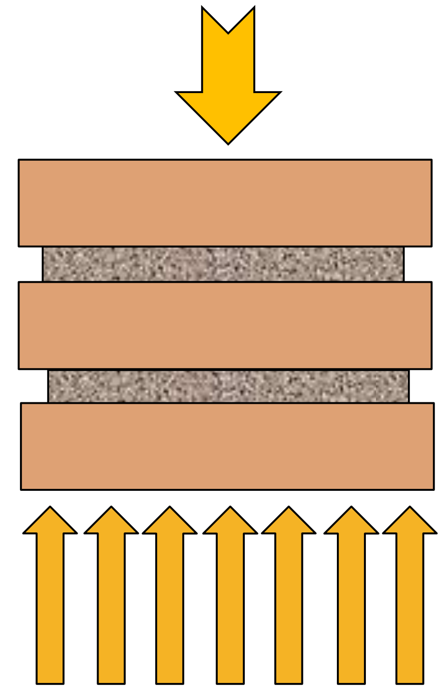
IN-PLANE SHEAR LOADS

IN PLANE LOADS

UN-REINFORCED WALLS



INITIAL (USUAL) STATE



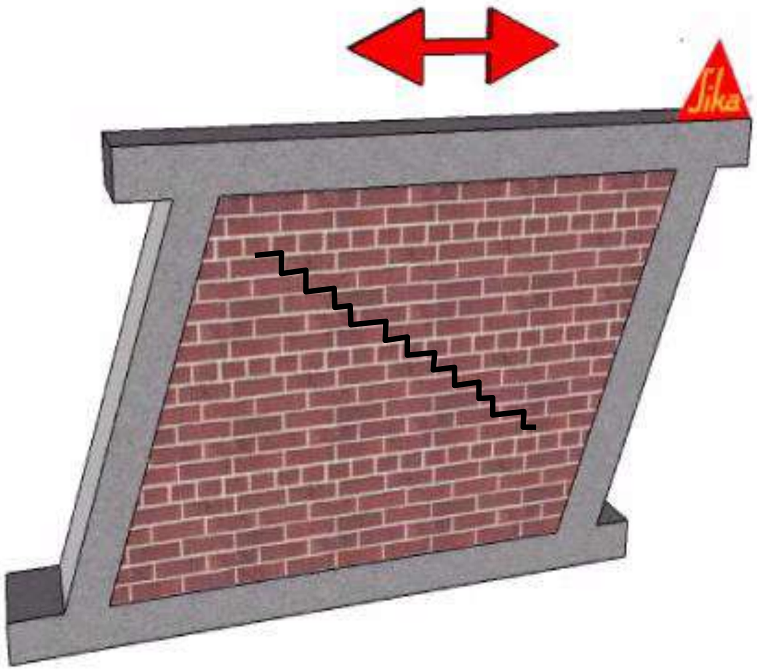
COMPRESSIVE FORCES

Masonry strains are due to in-plane compressions, therefore wall is working under suitable conditions.

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH

FAILURE MODE: SHEAR



The shear capacity of the unreinforced masonry is limited by the “design value” under shear forces, which can be determined according to Eurocode 6 as follows:

$$VRd = fvd\ t\ lc$$

Where:

- **fvd** is the design shear strength of the masonry.
- **t** is the width of the wall.
- **lc** is the length of the wall under compression.

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH

FAILURE MODE: SHEAR

Joint sliding does not significantly reduce the axial load capacity of the wall.
It does, however, reduce the out-of-plane flexural load strength (dangerous)

IN PLANE LOADS-SHEAR

FRP STRENGTHENING

SIKAWRAP FABRICS

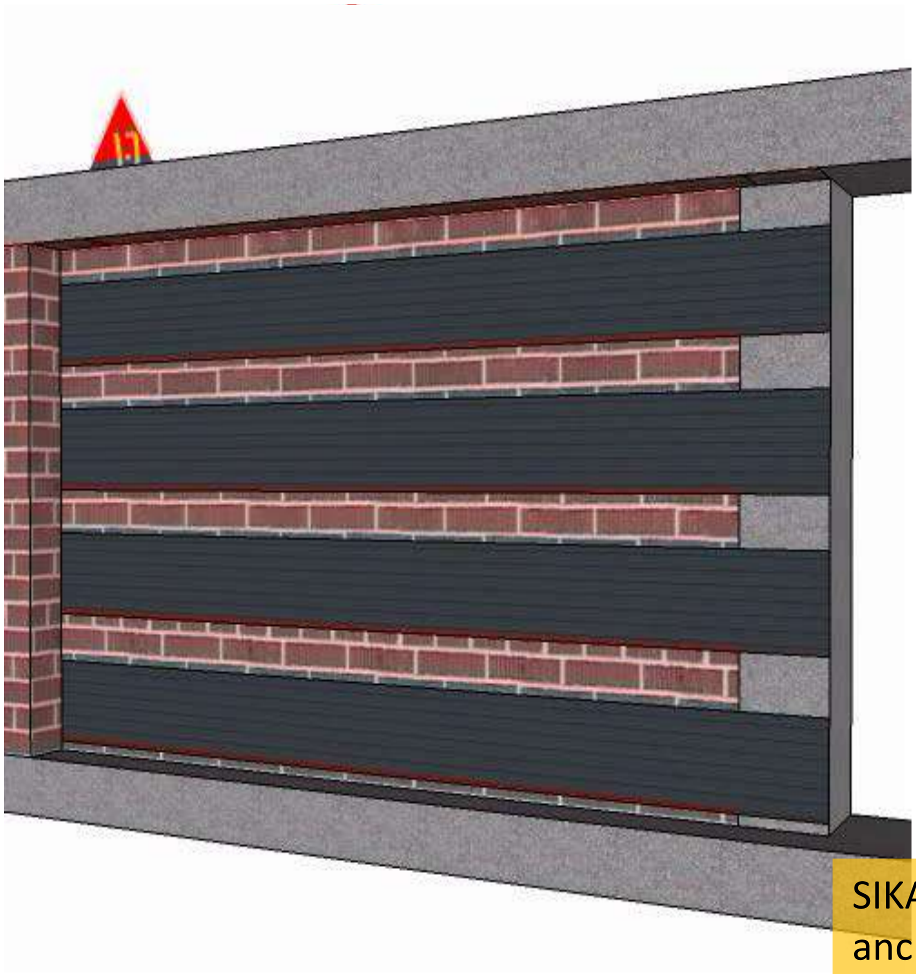
Overview

SIKAWRAP can also be applied in horizontal strips; spacing limits are the same as in CARBODUR option.

Fabric overlap on adjacent in-plane columns is still possible by extending plates over the concrete´s surface (effective length)

IN PLANE LOADS-SHEAR

FRP STRENGTHENING



SIKAWRAP FABRICS

Anchorage

SIKAWRAP can also be additionaly anchoraged using SIKAWRAP FX-50C through adjacent walls.

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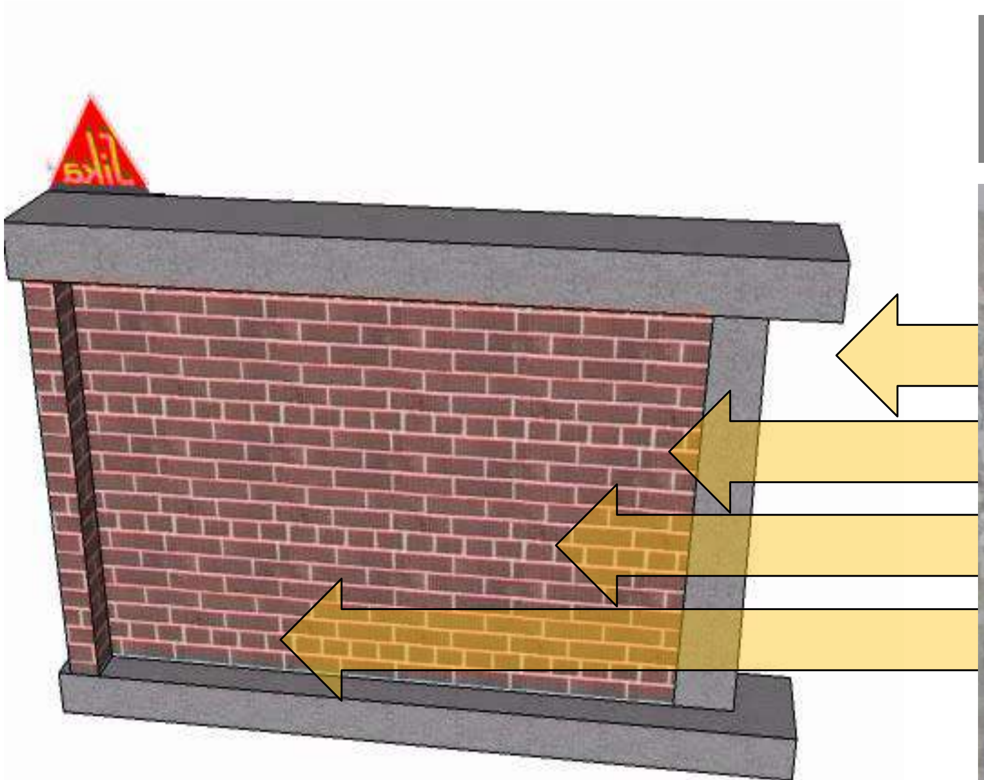
IN PLANE LOADS-SHEAR

FRP STRENGTHENING



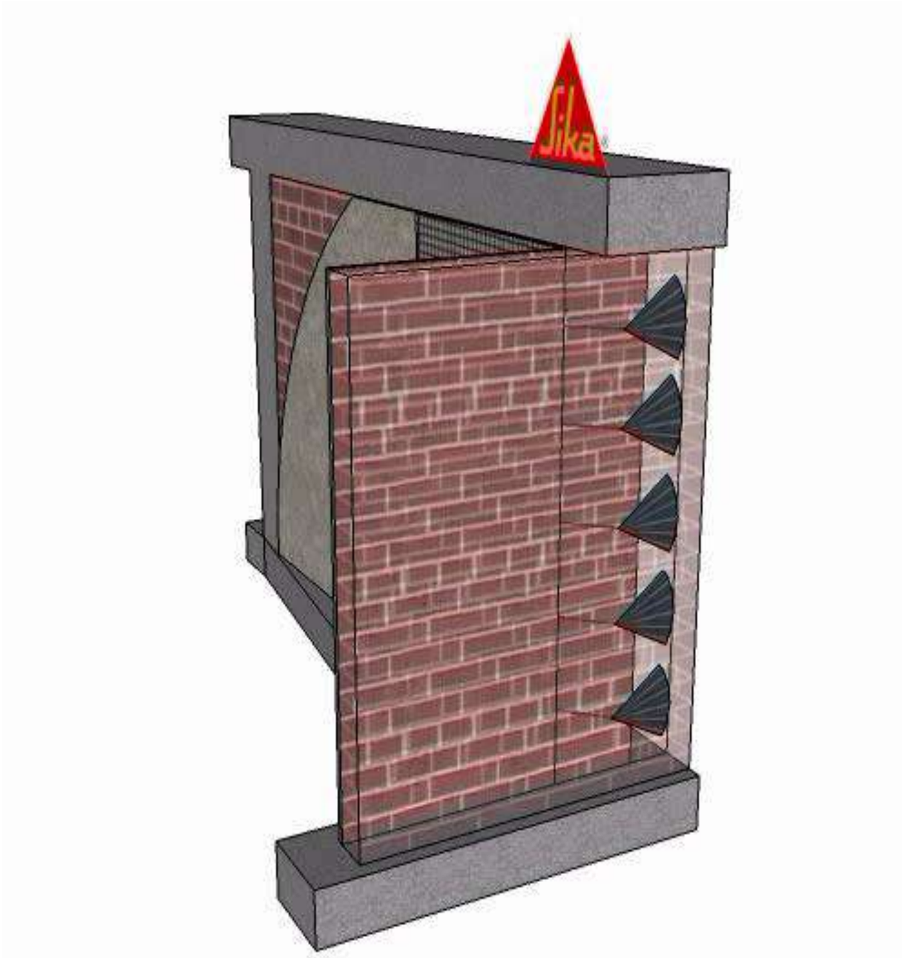
TEXTILE REINFORCED MORTAR (TRM

Anchorage

SIKAWRAP can also be additionaly anchoraged using SIKAWRAP FX-50C through adjacent wall

IN PLANE LOADS-SHEAR

FRP STRENGTHENING



X-FRAME CONFIGURATION

X-frame is an efficient alternative that can be achieved using TRM, SIKAWRAP, SIKA CARBODUR or NSM methods.

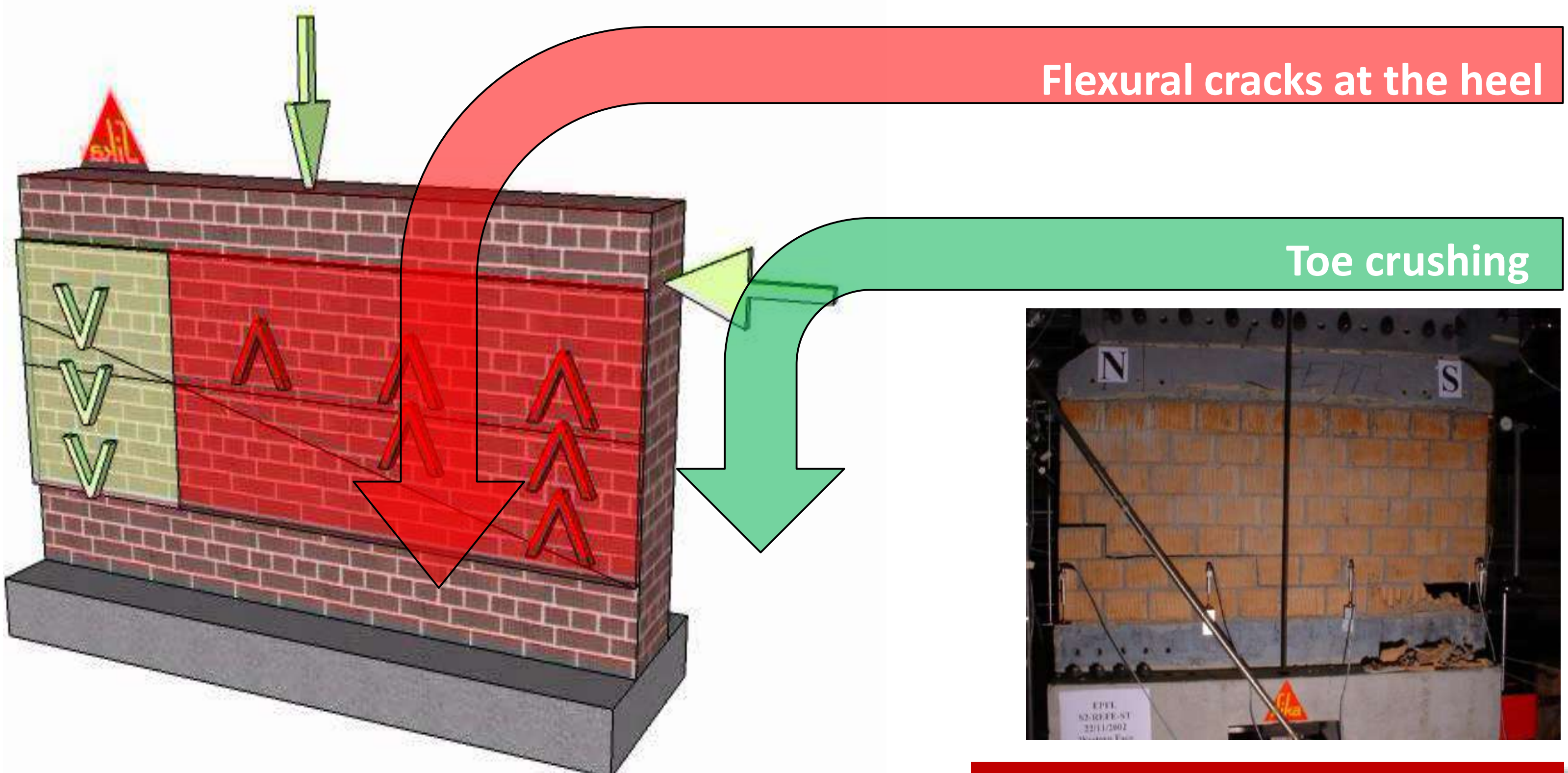
IN-PLANE FLEXURAL LOADS

SEISMIC RETROFITTING OF MASONRY PANELS

BUILDING TRUST

IN PLANE LOADS-FLEXURE

FRP STRENGTHENING



Failure mode

Flexure-controlled failure mode is characterized by the formation of flexural cracks and crushing of the toe

IN PLANE LOADS-FLEXURE

FRP STRENGTHENING

SIKAWRAP FABRICS

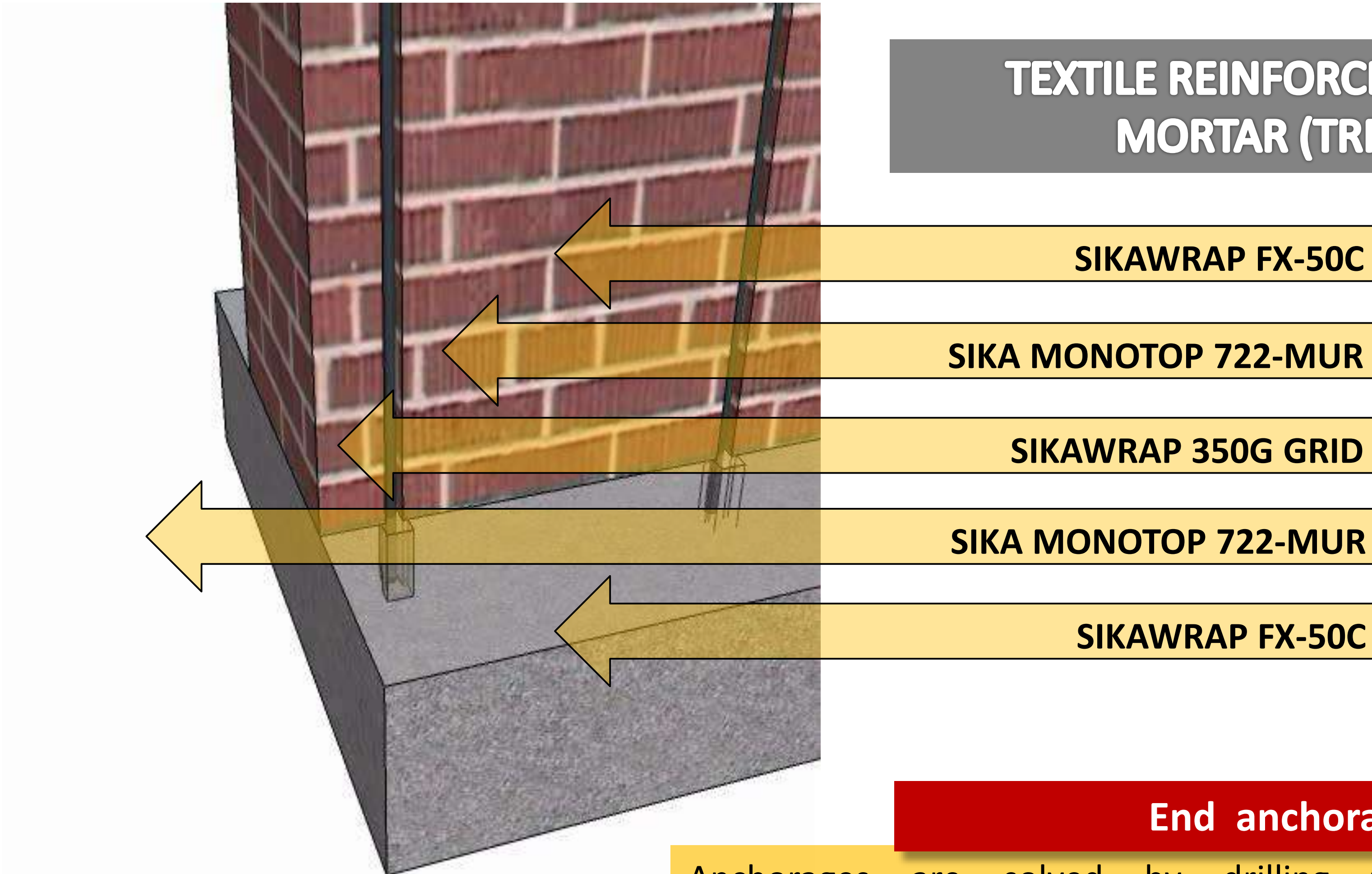
Alternative anchorage

SIKAWRAP FX-50C anchors can be installed into drilled holes, spreading the carbon fiber tows over SIKAWRAP ends.

IN PLANE LOADS-FLEXURE

FRP STRENGTHENING

TEXTILE REINFORCED MORTAR (TRM)



End anchorage

Anchorages are solved by drilling the slab/beam, and installing SIKAWRAP FX-50C

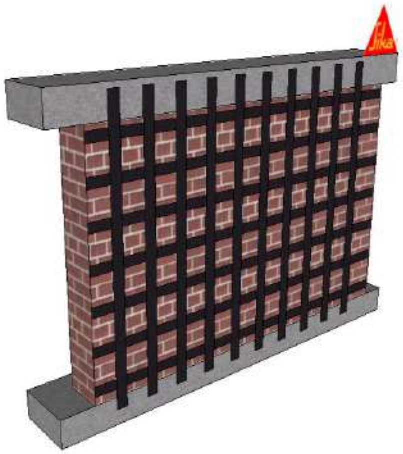
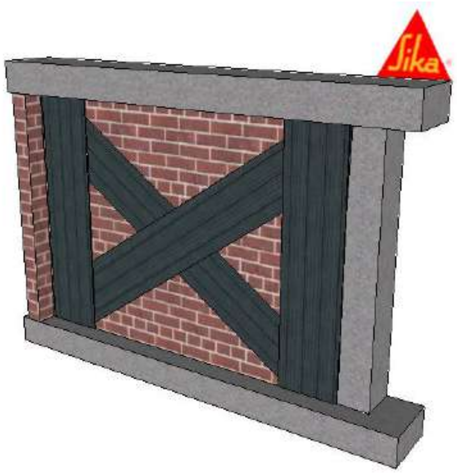
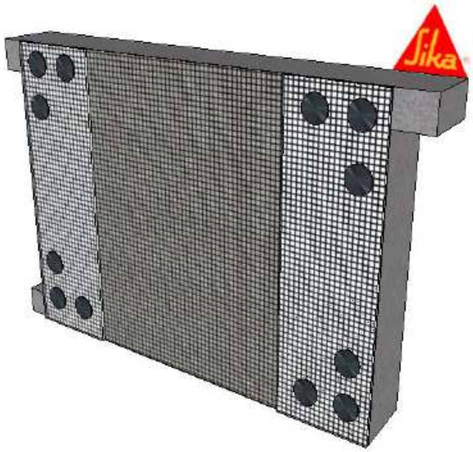
BUILDING TRUST

IN-PLANE LOADS: FLEXURE+SHEAR

SEISMIC RETROFITTING OF MASONRY PANELS

IN PLANE LOADS: FLEXURE + SHEAR

FRP STRENGTHENING

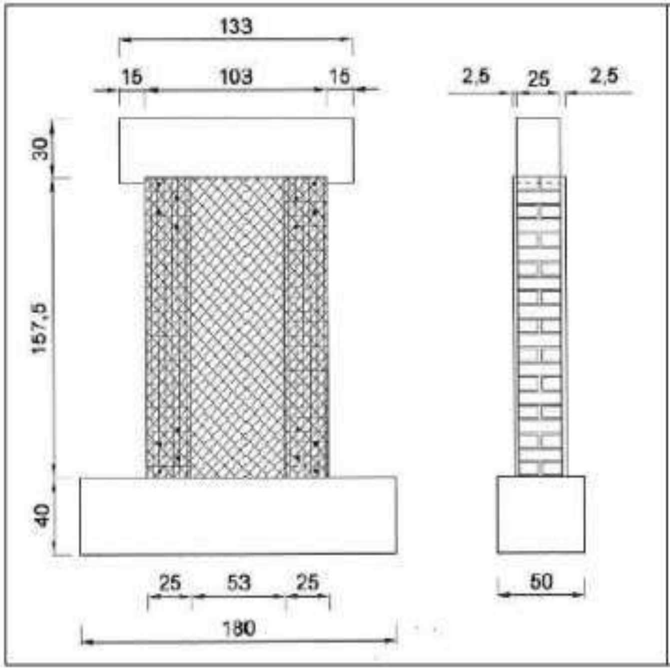




GRID CONFIGURATION	X-FRAME + VERTICAL STRIPS	TRM + LATERAL TRM STRIPS
NSM, SIKAWRAP and CARBODUR options can be combined. Vertical strips for flexural, horizontal strips for shear.	NSM, SIKAWRAP and CARBODUR options can be combined. Diagonal strips for shear, vertical strips for flexural.	SIKAWRAP 350G GRID and SIKAWRAP FX-50C. Lateral GRID strips for additional flexural resistance.

IN PLANE LOADS: FLEXURE + SHEAR

FRP STRENGTHENING

IN-PLANE TESTS, TRM CONFIGURATION



MonoTop-722 Mur
SikaWrap-350G Grid
SikaWrap Anchor C

ZAG Slovenia, Prof. M. Tomazevic

IN PLANE LOADS: FLEXURE + SHEAR

FRP STRENGTHENING

BU CONTRACTORS

ZAG Slovenia
Prof. M. Tomazevic

Wall with Textile Reinforced Mortar
BM-S-3

SikaWrap®-350G Grid
Sika MonoTop®-722 Mur
SikaWrap® Anchor C

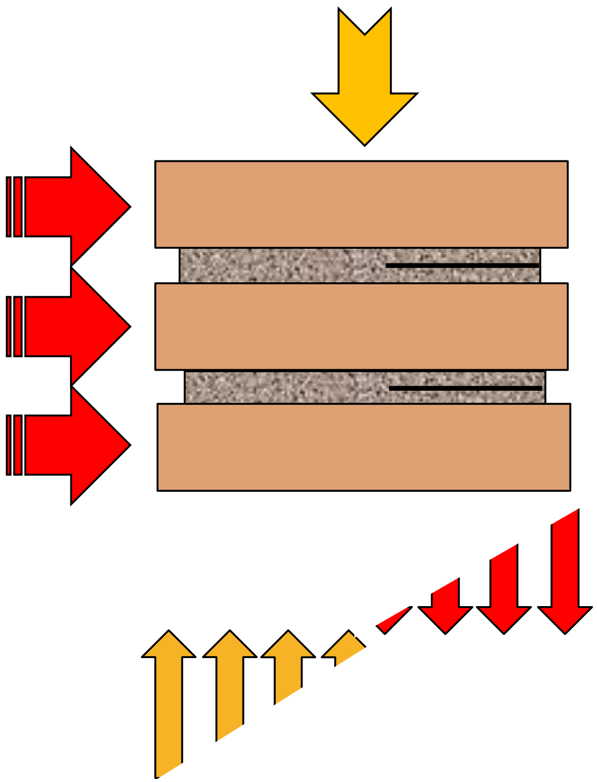
Innovation & Consistency | since 1910
Sika Services AG

OUT-OF-PLANE LOADS

SEISMIC RETROFITTING OF MASONRY PANELS

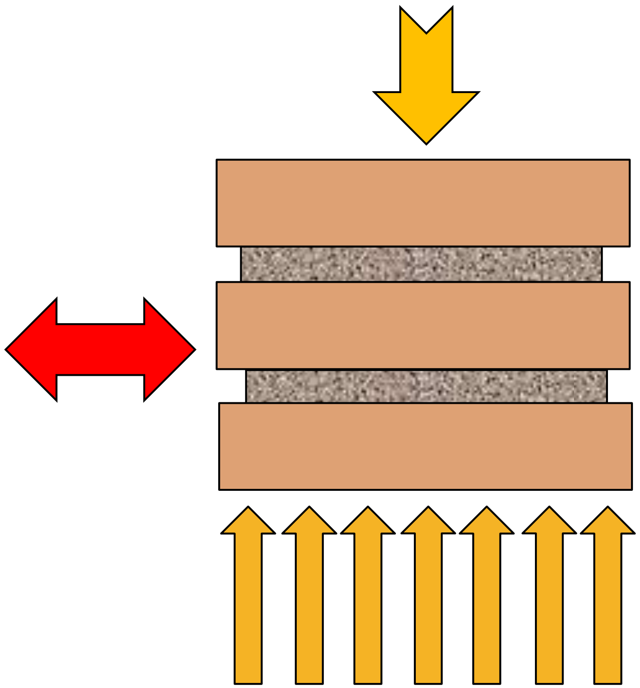
OUT-OF-PLANE LOADS: FLEXURE

FRP STRENGTHENING



Due to this forces, wall can develop tensional forces and flexural cracking (the contribution of masonry in tension is neglected)

“SEISMIC” ACCELERATION STATE

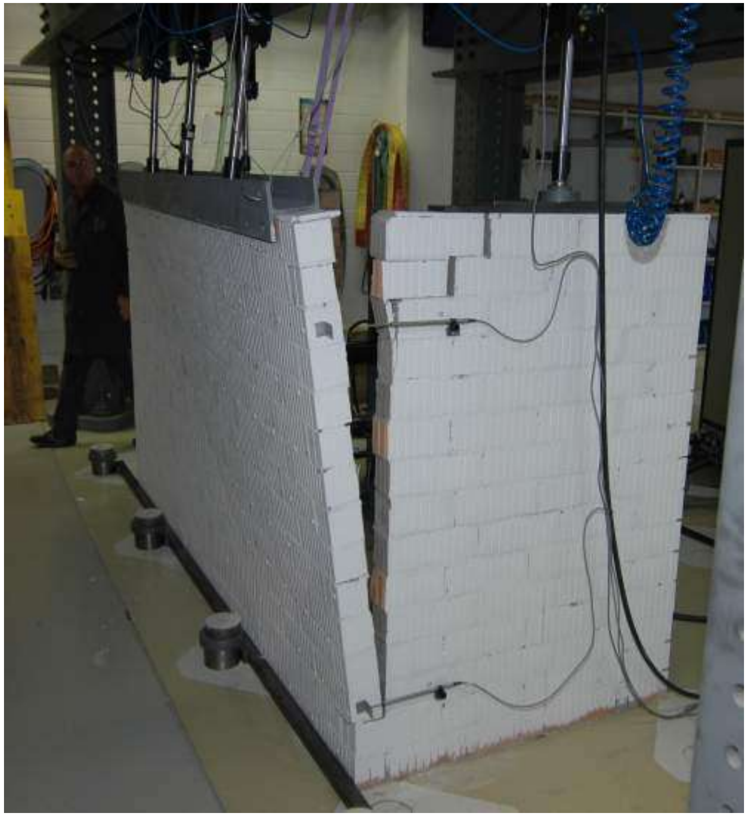


LATERAL ACCELERATION

Masonry vertical stress is altered due to an horizontal acceleration of the wall.

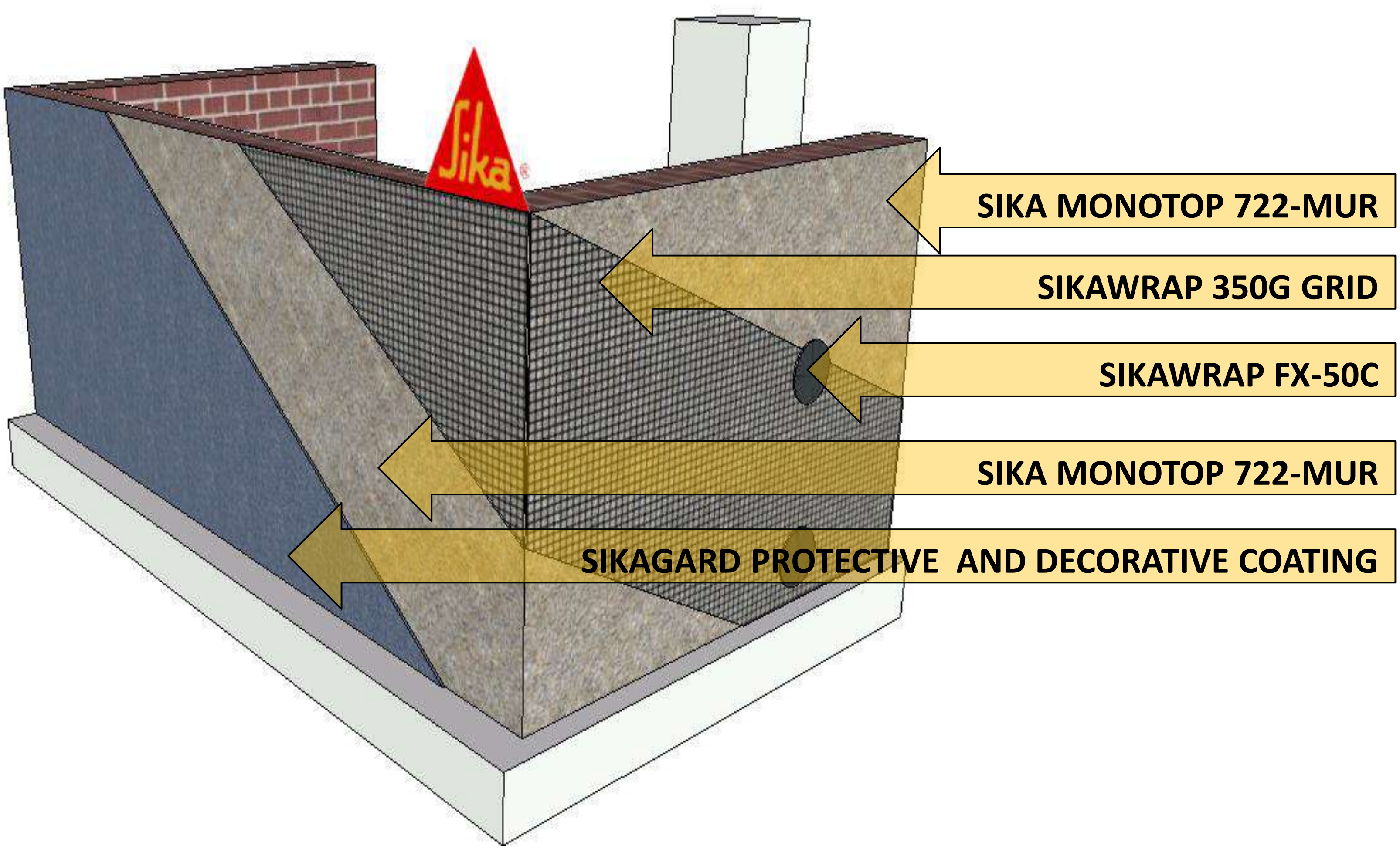
OUT-OF-PLANE LOADS: OVERTURNING

FRP STRENGTHENING



OUT-OF-PLANE LOADS

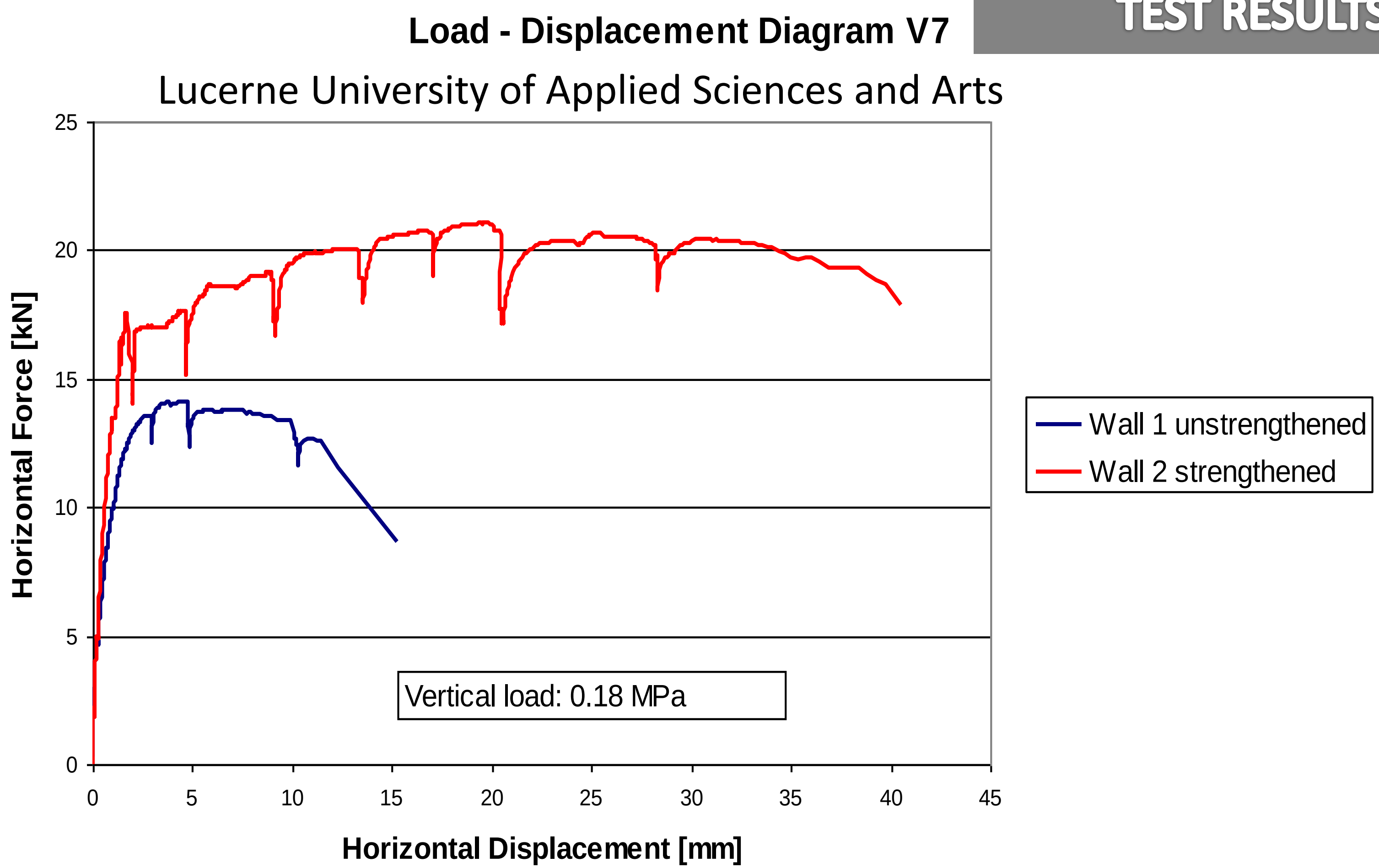
FRP STRENGTHENING BASED ON TRM



OUT-OF-PLANE LOADS: OVERTURNING

FRP STRENGTHENING BASED ON TRM

TEST RESULTS



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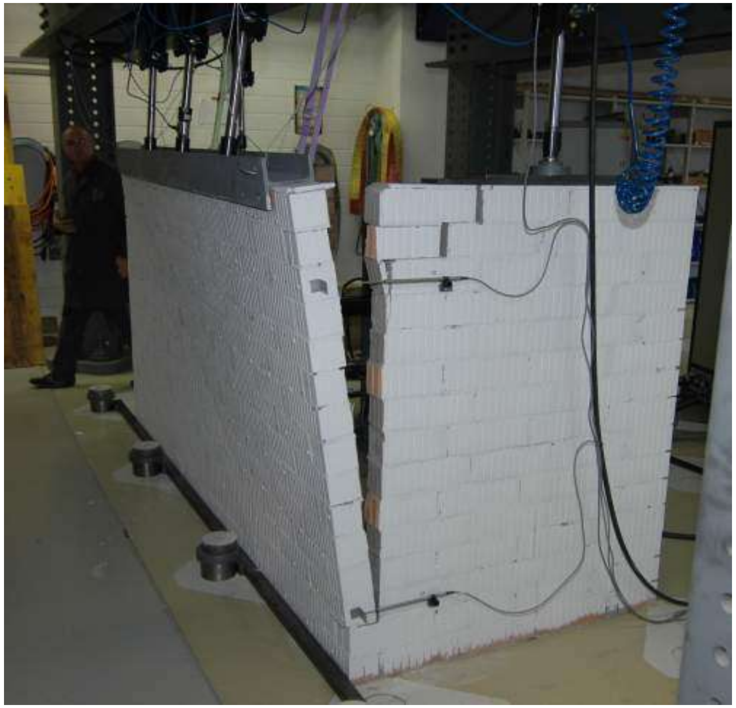
OUT-OF-PLANE LOADS: OVERTURNING

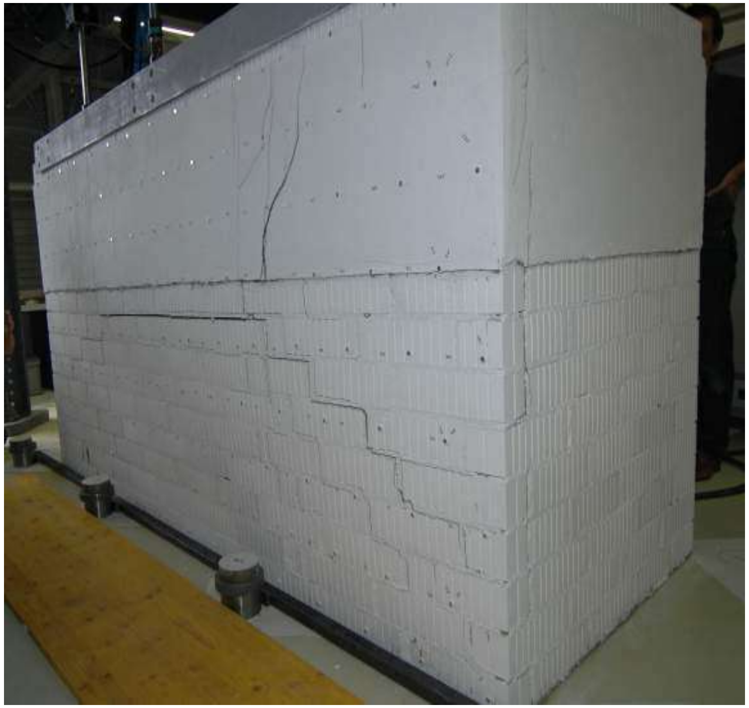
FRP STRENGTHENING BASED ON TRM

Reference wall



Wall collapses

Wall reinforced 50cm on top by using Sika Monotop 722 Mur and 1 layer of SikaWrap 350G Grid



Textile Reinforced Mortar still intact
Failure mechanism in unstrengthened part of wall

Test: Lucerne University of Applied Sciences and Arts

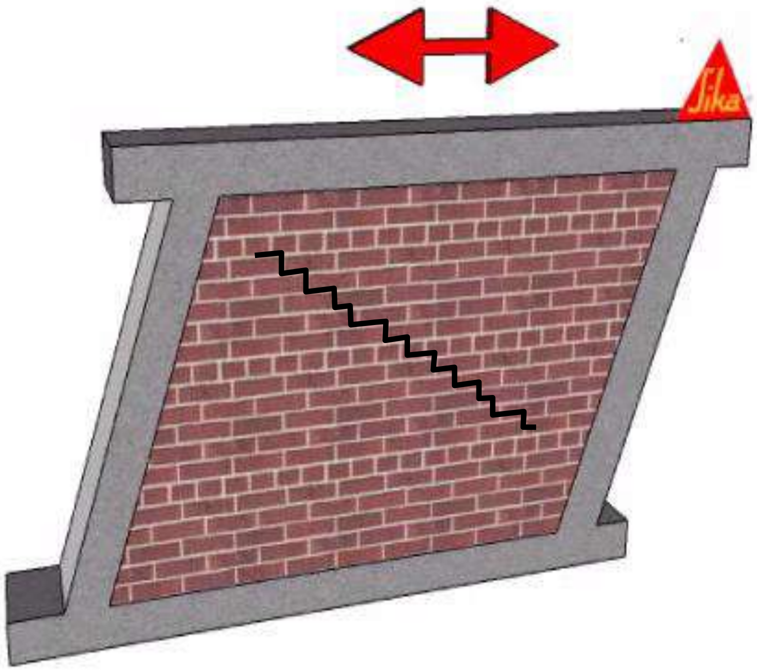
CASE STUDY

BUILDING TRUST

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH

FAILURE MODE: SHEAR



The shear capacity of the unreinforced masonry is limited by the "design value" under shear forces, which can be determined according to Eurocode 6 as follows:

$$VRd = fvd\ t\ lc$$

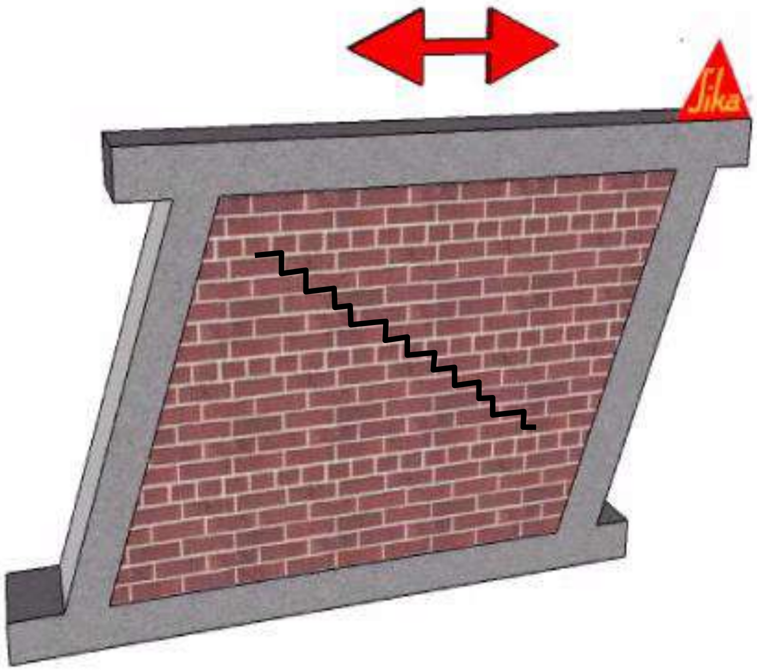
Where:

- **fvd** is the design shear strength of the masonry.
- **t** is the width of the wall.
- **lc** is the length of the wall under compression.

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH

FAILURE MODE: SHEAR



fvd is determined by dividing the characteristic shear strength of the masonry (**fvk**) by a safety factor (**ym**).

A secondary safety factor must be taken into account (**CFKL**) according to the existing knowledge about the structure (Eurocode 8).

Hence:

$$fvd = fvk\ ym\ CFKL = (fvko + 0{,}4\sigma)\ ym\ CFKL$$

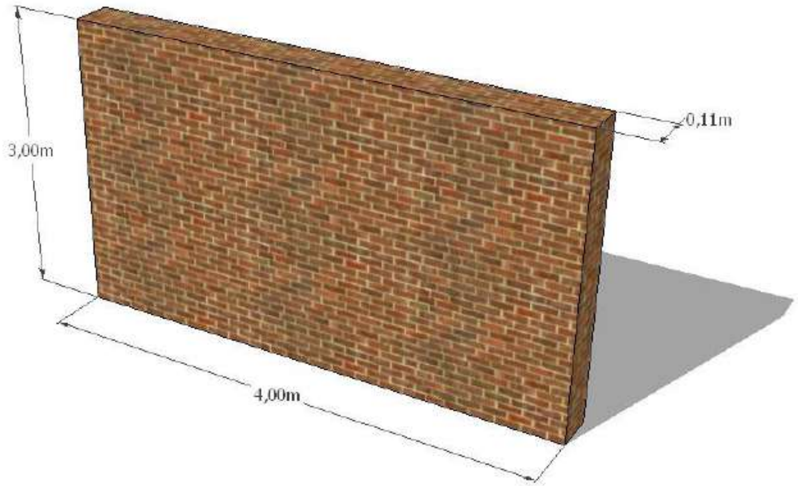
Where:

- **fvk** is the characteristic shear strength of the masonry.
- **fvko** is the initial characteristic shear strength of the masonry (no compression).
- **σ** is the average compressive stress corresponding to the compressed section of the wall (green area in the picture).

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH. CALCULATION EXAMPLE

- Solid bricks group 1, compressive strength 15MPa, mortar strength M10, Class CC1.
- Panel density: 1800 kg/m3
- Characteristic compressive strength: fk=6.20 Mpa.
- γm=max (1.5; 2/3 x 1.5)= 1.5 according to Eurocode 8, part 1.
- Knowledge level (Eurocode 8, part 3): KL1. Hence, knowledge factor CFKL1=1.35
- Design compressive strength fd=6.20MPa/(1.5 x 1.35)= 3.06MPa.
- Maximum compressive strain: 0,35%
- Parabola stress block, defined by the equation:
- $\sigma(x)$ = (1 − (1 − x (0.0035))2 · fd) , where **x** corresponds to the compressive strain (0 ≤ x ≤ 0.0035).
- Tensile strength of the masonry are neglected for the calculations.



IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH. CALCULATION EXAMPLE

The shear capacity of the strengthened wall can be evaluated as VRd, strengthened =VRd + VRd,TRM where VRd is the masonry contribution to shear strength: $VRd = f vd\ t\ lc$

and:

- **fvd** is the design shear strength of the masonry.
- **t** is the width of the wall (110mm).
- **lc** is the length of the wall under compression (2520mm).

Hence:

$f_{vd} = f vk\ \gamma m\ CFKL$

where :

- $\mathbf{f_{vk}}$ is the characteristic shear strength of the masonry, and equals $\min((f_{vko} + 0{,}4\sigma); 0.065 f_k))$,

where:

- $\mathbf{f_k}$ is the characteristic compressive strength of the masonry (6.20MPa).
- $\mathbf{f_{vko}}$ is the initial characteristic shear strength of the uncompressed masonry (0.20 MPa).
- **σ** is the average compressive stress corresponding to the compressed section of the wall

(310140N/ (110x2520mm)=1.18MPa).

$f_{vd} = 0.065 MPa \cdot 6.20\ 1.5 \cdot 1.35 = \mathbf{0.199}\ \boldsymbol{MPa.}$

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH. CALCULATION EXAMPLE

The contribution of the TRM (VRd,TRM) displayed on both sides of the wall, can be determined according to ACI549.2R-13:

VRd, TRM = 0.75 · 2 · n · Af · L · ffv

where:

- ffv is the design tensile strength of the mesh under shear forces (effective limited to **0,4%** by ACI549.2R-13, hence ffv=0.004 x 80000MPa = **320MPa**).
- Af is the area of the mesh reinforcement by unit width (Af=47.31mm2/1000mm=**0.04731mm2/mm).**
- N is the number of plies of mesh displayed in the face of the support (n=1).
- L is the length of the wall in the applied shear force (L=4m=4000mm).

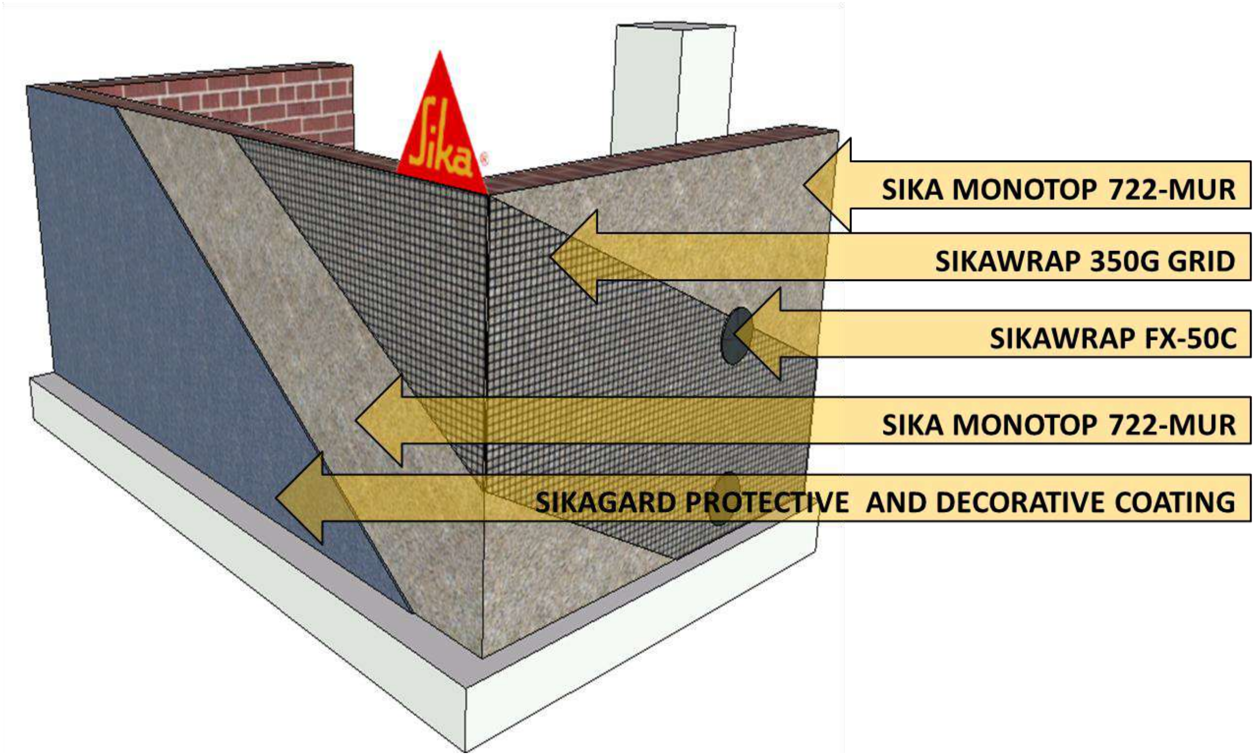
VRd, TRM = 0.75 · 2 · 1 · 0.04731 · 4000 · 320 = $\mathbf{90.83\ kN}$

Finally, the in-plane shear strength for the panel can be calculated as:

VRd, strengthened =VRd + VRd,TRM = 55.17kN + 90.83kN= 146kN

IN-PLANE SHEAR LOADS

INSUFFICIENT SHEAR STRENGTH. CALCULATION EXAMPLE



Finally, the in-plane shear strength for the panel can be calculated as:

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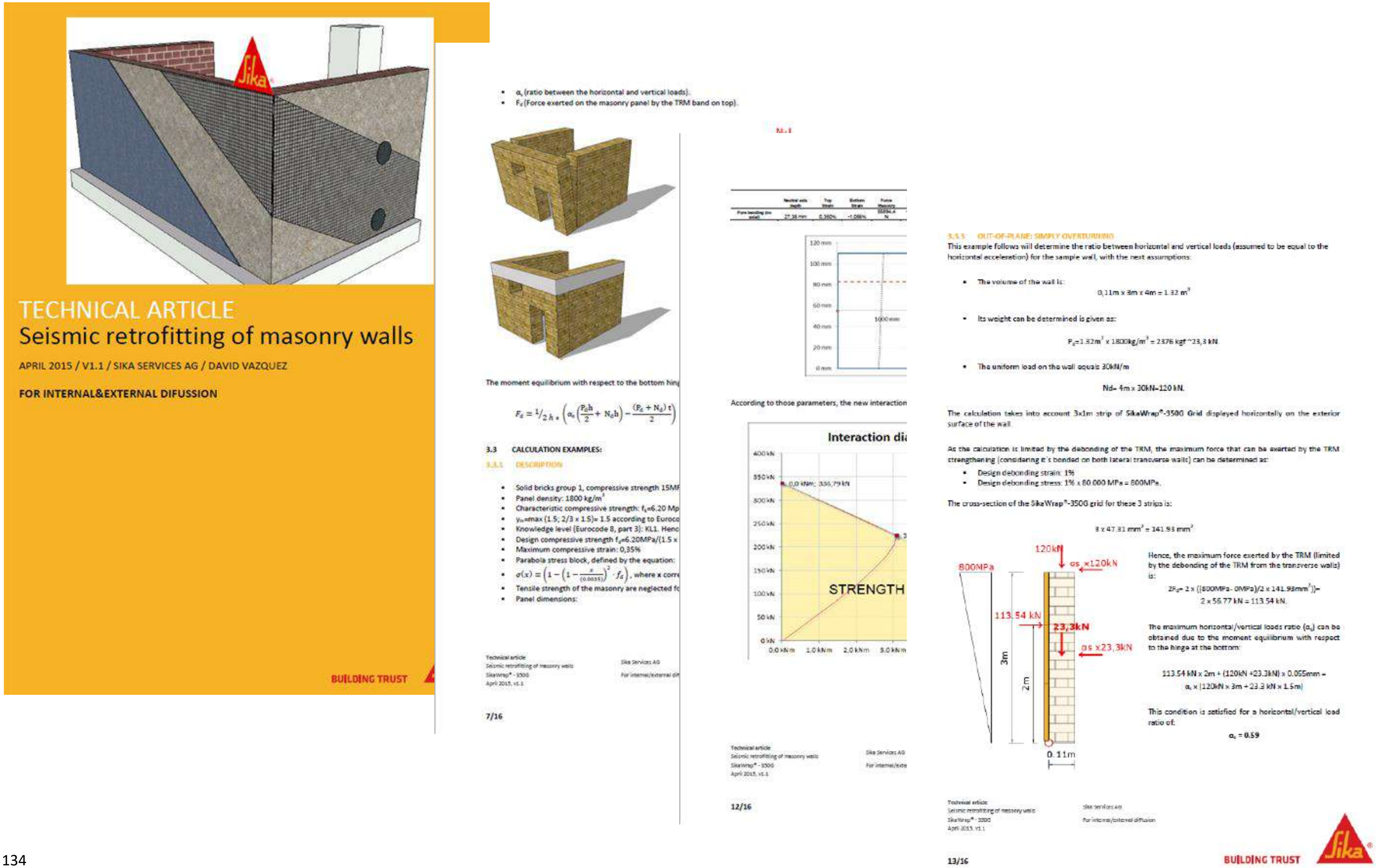
SEISMIC RETROFITTING OF MASONRY WALLS
GUIDELINE



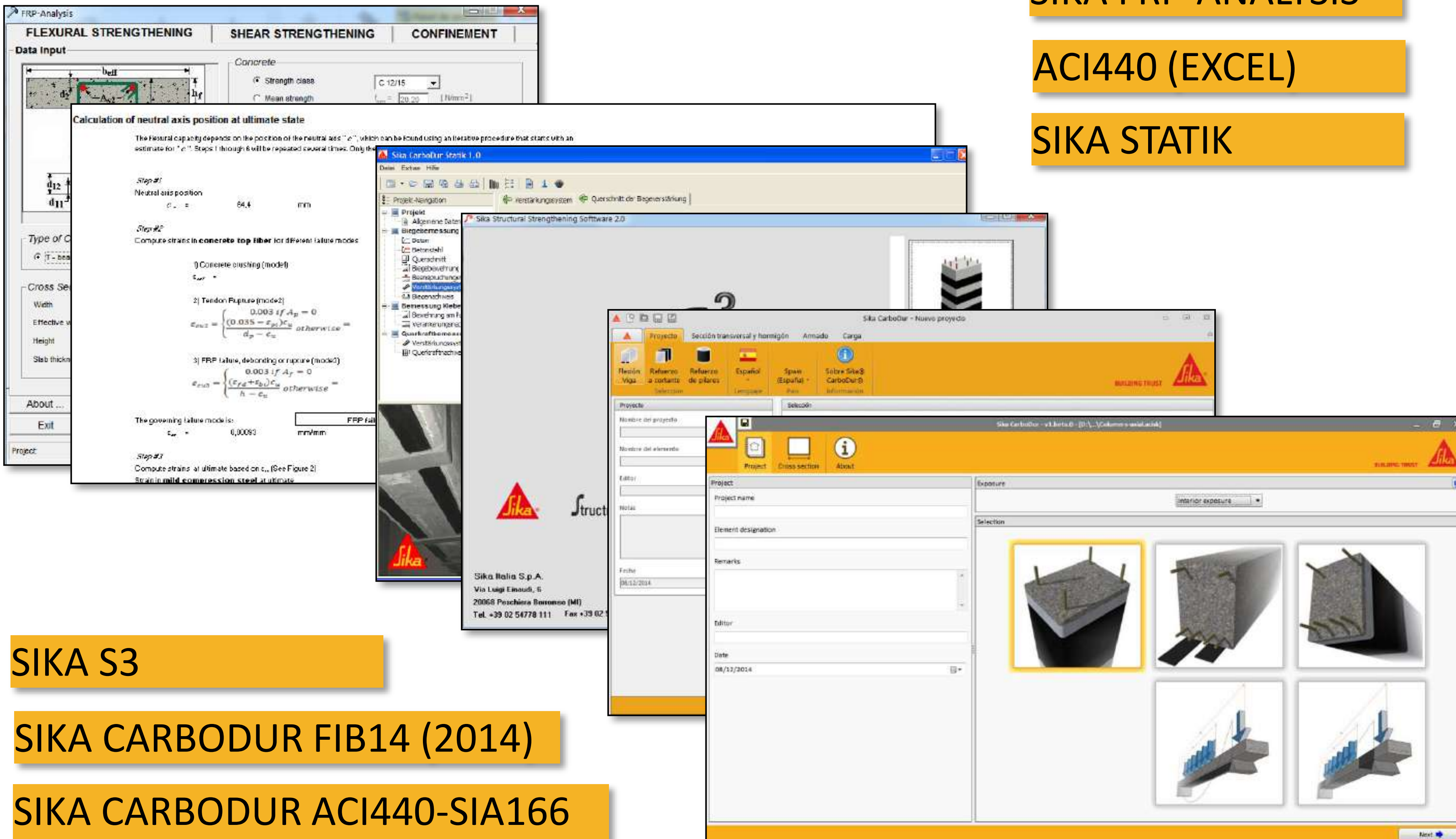
6. NEW SIKA CARBODUR® SOFTWARE AND CASE STUDY

SIKA® SOFTWARE FOR THE DESIGN OF FRP REINFORCEMENTS

SIKA FRP-ANALYSIS

ACI440 (EXCEL)

SIKA STATIK



SIKA S3

SIKA CARBODUR FIB14 (2014)

SIKA CARBODUR ACI440-SIA166 (2015), TR55 (2016) & CNR (2018)

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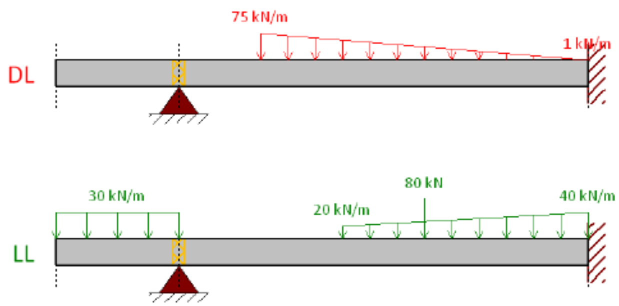
SIKA CARBODUR® SOFTWARE: KEY ADVANTAGES

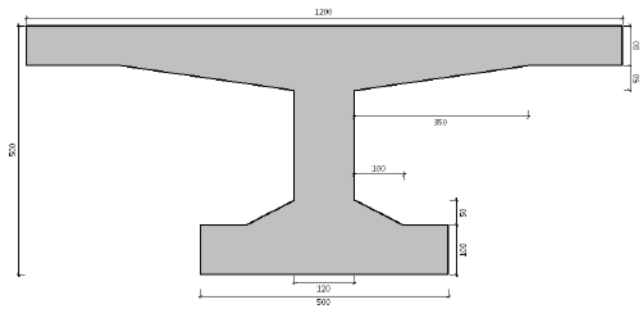
PROFESSIONAL

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

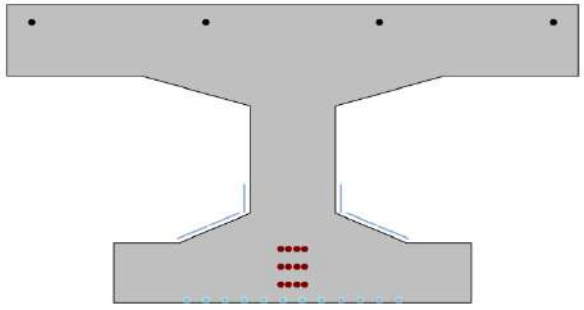
Strengthening of full structural members according its loads distribution. The design is not based on a single section



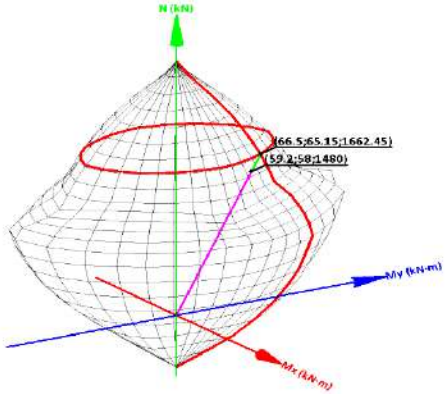
Calculation of complex geometries both for reinforced or prestressed concrete members.



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

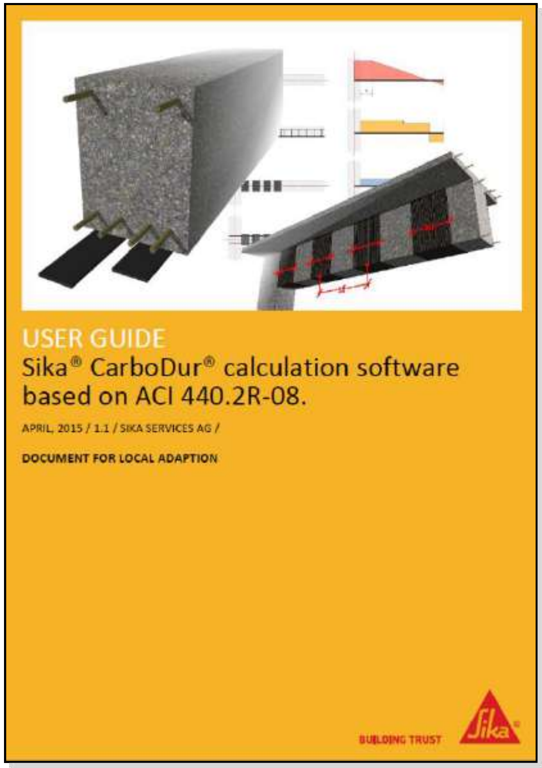


SIKA CARBODUR® SOFTWARE: KEY ADVANTAGES

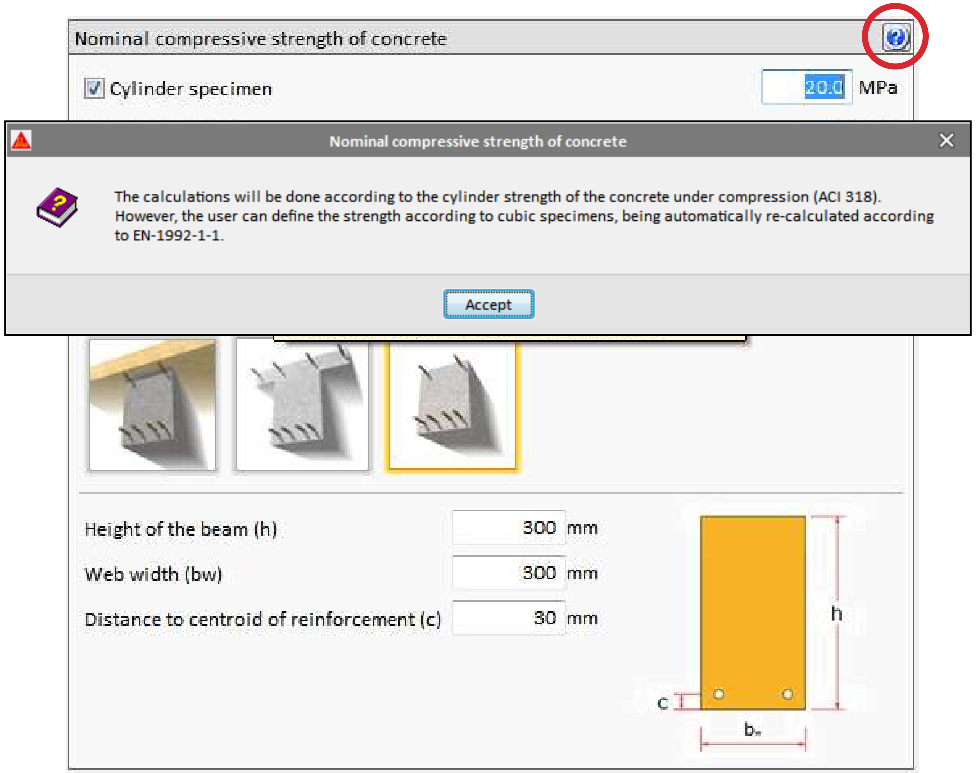
USER FRIENDLY

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

>40 pages user guide.



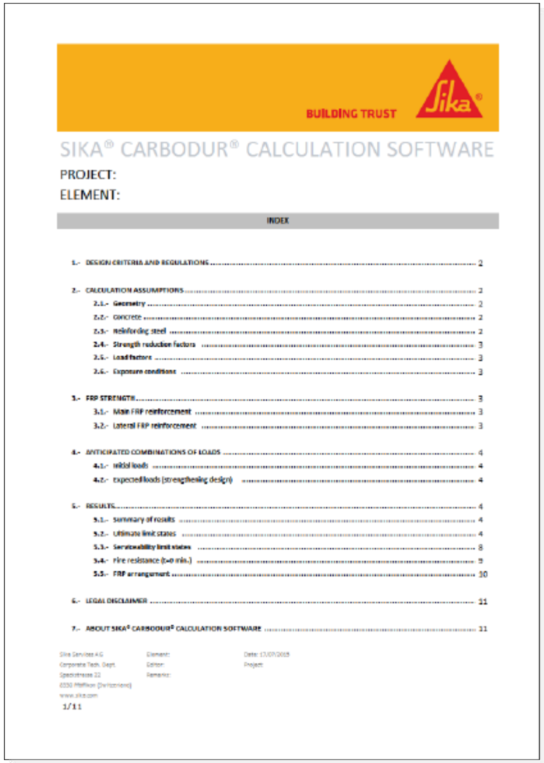
On-screen tooltips and help icons.



SIKA CARBODUR® SOFTWARE: KEY ADVANTAGES

NO MORE “BLACK BOXES”

The user <u>manages and controls the whole process</u>. Every assessment concerning the design of the FRP system can be done manually or automatically according to the user´s requirements.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SIKA® CARBODUR® CALCULATION SOFTWARE

PROJECT:

ELEMENT:

INDEX

1/11

The user can **verify the intermediate results** throughout the calculation process, enabling the verification of all the design parameters by means of the information displayed on the screen.

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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CASE STUDY

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¿ANY QUESTION?


obrigado
Dank U
Merci
mahalo
Köszi
спасибо
Grazie
Thank you
mauruuru
Takk
Gracias
Dziękuję
Děkuju
danke
Kiitos