USER MANUAL SIKA® CARBODUR® SOFTWARE
BASED ON ACI PRC-440.2-23

OCTOBER 2025 V. 1.0 / SIKA SERVICES TH

DOCUMENT FOR THAILAND

BUILDING TRUST

TABLE OF CONTENTS

1 INTRODUCTION

This software assists consultants in designing CFRP for flexural strengthening, shear strengthening, and column confinement. The next sections detail the theoretical background for these calculations.

This program uses calculation procedures from the **ACI PRC-440.2-23**, *"Design and Construction of Externally Bonded Fiber-Reinforced Polymer (FRP) Systems for Strengthening Concrete Structures"*.

Additional and auxiliary calculation methods are taken from the following codes:

- ACI 318: Building code requirements for structural concrete.
- Eurocode 2: Design of concrete structures.

2 THEORETICAL BACKGROUND

2.1 GENERAL DESIGN CONSIDERATIONS

2.1.1 STRENGTHENING LIMITS (ACI PRC-440.2-23, §9.2)

These limits are imposed to guard against collapse of the structure, should bond or other failure of the CFRP system ocurr due to vandalism, damage or other causes.

Due to this, the un-strengthened structural element should be able to resist a certain level of load. In the event that the FRP is damaged, the structure must be still capable to carry a certain level of load without collapse.

This minimum combination of loads is described as:

$$(\phi R_n)_{existing} \geq (1.1S_{DL} + 0.75S_{LL})_{new} \qquad (9.2)$$

In those cases where the design live load acting on the member is expected to be present for a sustained period of time (e.g. warehouses, libraries, stack areas, etc.) this fact must be taken into account. Therefore, the minimum combination of loads to be resisted by the unstrengthened member must be:

$$(\phi R_n)_{existing} \geq (1.1S_{DL} + S_{LL})_{new} \qquad (9.2b)$$

Additional limitations must be considered for each specific type of strengthening (flexural, shear or column confinement), as indicated in the corresponding section of this guide.

2.1.2 STRUCTURAL FIRE RESISTANCE (ACI PRC-440.2-23, §9.2.1)

Fire is an accidental situation that involves exceptional design conditions of the structure and the acting loads.

In case of fire, unprotected CFRP is expected to be lost due to the high temperatures. Hence, the unstrengthened member is subjected to reduced design loads, as defined by the local regulations and guidelines.

The software includes a simplified check of the nominal resistance of the un-strengthened member in case of fire at T=0.

The combination of actions used by the software for the verification of an un-strengthened member resistance is based on the combination of unfactored service loads provided in the ACI CODE-562.

$$\varphi_{ex} R \geq (0.9 \; or \; 1.2)S_{DL} + 0.5S_{LL} + 0.2S_{SL} \qquad (9.2.1)$$

Where:

- **R** is the nominal resistance of the member at anelevated temperature without FRP;
- **ϕ_{ex}** is 1.0;
- **S_{DL}** are the deal loads caculated for the strengthened structure;
- **S_{LL}** are the live loads caculated for the strengthened structure;

- **S_{SL}** are the snow loads caculated for the strengthened structure;

The dead load factor of 0.9 is applied when the dead load effect mitigates the total load effect; otherwise, the dead load factor of 1.2 is used. For cases where the design live load has a high likelihood of being present for a sustained period of time,a live load factor of 1.0 should be used in place of 0.5

Under this situation, if the CFRP is no longer required in case of fire; hence no fire protection will be necessary for it. However, a certain protection for the RC member may be required to achieve a necessary fire rating (to be calculated according to the existing codes such as ACI 216R or through testing).

2.1.3 REDUCTION FACTORS FOR FRP (ACI PRC-440.2-23, §9.4)

Because long-term exposure to various types of environments may reduce the tensile properties, creep rupture and fatigue endurance of FRP laminates, the material properties used in design equations should be reduced based on the environmental exposure condition.

$$f_{fu} = C_E f_{fu}^* \quad (9.4a)$$

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \quad (9.4b)$$

$$E_f = \frac{f_{fu}}{\varepsilon_{fu}} = \frac{f_{fu}^*}{\varepsilon_{fu}^*} \quad (9.4c)$$

Where the environmental reduction factor (C_E) can be obtained from the following table:

EXPOSURE CONDITIONS	FIBER TYPE	C_E
Interior exposure	Carbon	0.95
	Glass	0.75
	Basalt	0.75
	Aramid	0.85
Exterior exposure	Carbon	0.85
(Bridges, piers, unenclosed parking garages…)	Glass	0.65
	Basalt	0.65
	Aramid	0.75
Aggressive environment	Carbon	0.85
(Chemical plants, wastewater treatment plants…)	Glass	0.50
	Basalt	0.50
	Aramid	0.70

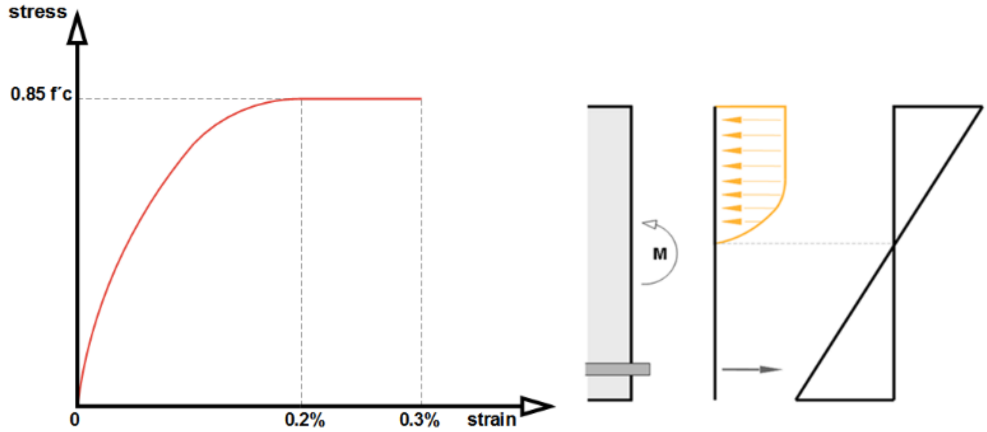
2.2 FLEXURAL STRENGTHENING

Reinforced concrete elements, such as beams, slabs and columns, may be strengthened in flexure, through the use of FRP composites epoxy-bonded to their tension zones, with the direction of fibers parallel to that of high tensile stresses (member axis).

The calculation of the FRP strengthening for flexural strengthening follows the principles exposed in **ACI 318** and **ACI PRC-440.2-23, Section 10** with the following modifications:

a) The compression stress block for the concrete used in the calculation is not based on a simplified rectangular stress block (Whitney stress block). Instead, a parabola-rectangle stress block is taken into account, as this model allows the calculation of concrete sections to be independent of the complexity of its geometry.

Forces equilibrium is carried out by using a parabola-rectangle stress block, as provided by Eurocode 2 (Fig. 2-8).



Concrete stress is determined according to the following equations:

$f_c = 0.85f'_c\,(1-(1-\frac{\varepsilon_c}{0{,}002})^2)$ for $0 \le \varepsilon_c \le 2‰$

$f_c = 0.85f'c$ for $2‰ \le \varepsilon_c \le 3‰$

b) In case of post-tensioned Sika® CarboDur® S plates, the maximum effective strain for the CFRP laminate will be limited to 1.26% (value experimentally validated for the Sika® CarboStress system)

$$\varepsilon_{fd,postensioned} \le 1.26\%$$

2.2.1 SERVICEABILITY (ACI PRC-440.2-23, §10.2.8)

Reinforced concrete members:

The stress in the steel reinforcement under service load must be limited to 80% of the yield strength.

$f_{s,s} \le 0.80\ f_y$ (10.2.8a)

The compressive stress in concrete under service load should be limited to 0.60 f´c.

$f_{c,s} \le 0.60\ f'_c$ (10.2.8b)

Prestressed concrete members:

The prestressed steel should be prevented from yielding under service loads. Hence, the following limits apply:

$f_{ps,s} \le 0.82\ f_{py}$ (10.3.1.4a)

$f_{ps,s} \le 0.74\ f_{pu}$ (10.3.1.4b)

The compressive stress in concrete under service load should be limited to 0.45 f´c.

$f_{c,s} \le 0.45\ f'_c$

Post-tensioned CFRP laminates:

The effective strain for the CFRP laminate under service loads will be limited to 0.92% (value experimentally validated for the Sika® CarboStress system).

$$\varepsilon_{fe,postensioned} \le 0.92\%$$

2.2.2 CREEP RUPTURE AND FATIGUE STRESS LIMITS (ACI PRC-440.2-23, §10.2.9)

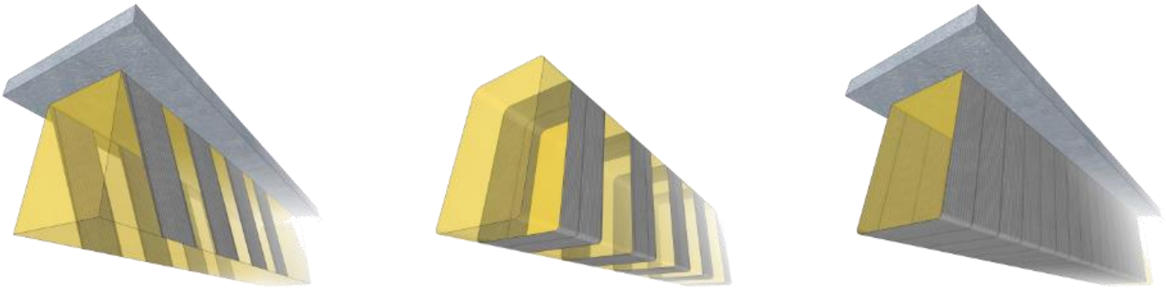
To avoid creep-rupture of the externally bonded or NSM reinforcement under sustained stresses or failure due to cyclic stresses and fatigue of the FRP reinforcement, the stress level in the FRP will be limited to the following values:

- CFRP: 0.55 f_{fu}
- GFRP: 0.20 f_{fu}

2.3 SHEAR STRENGTHENING

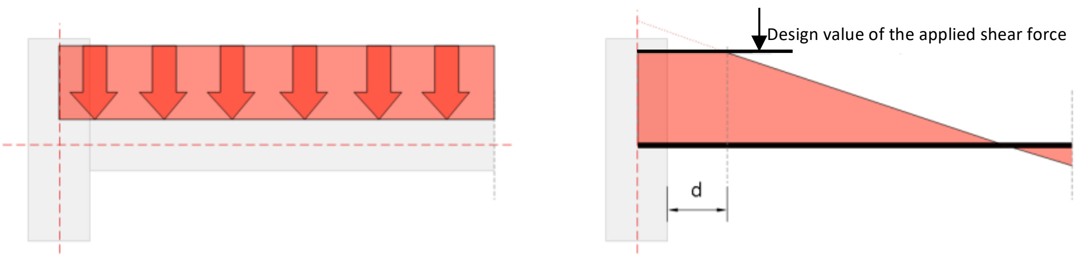
Shear strengthening of RC members using FRP may be provided through bonding the external reinforcement with the principal fiber direction as parallel as practically possible to that of maximum principal tensile stresses, so that the effectiveness of the FRP is maximized. For the most common case of structural members subjected to lateral loads, the maximum principal stress trajectories in the shear-critical zones form an angle with the member axis that may be taken roughly equal to 45°, which is possible in those situations where the FRP is displayed at both sides of the beam.

However, in case of complete Wrapping or U-Wrapping schemes, it is normally more practical to attach the external CFRP reinforcement with the principal fiber direction perpendicular to the member axis.

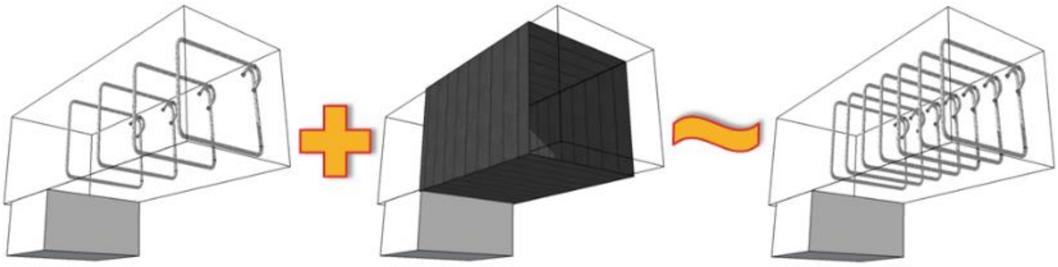


Closed jackets or properly anchored strips are always preferable compared with open jackets, as in the latter case CFRP premature debonding is usually expected; hence the effectiveness of the CFRP is reduced. 2-sided configuration provides the least effective performance due to the risk of debonding.

For members subjected to predominantly uniformly distributed loading the design shear force need not to be checked at a distance less than *d* from the face of the support, as indicated in ACI 318.



The external FRP reinforcement may be treated in analogy to the internal steel (accepting that the CFRP carries only normal stresses in the principal CFRP material direction), assuming that at the ultimate limit state in shear (concrete diagonal tension) the CFRP develops an effective strain in the principal material direction, ε_{fe}, which is in general, less than the tensile failure strain, ε_{fu}.



The effective strain depends on the degree of CFRP debonding when the shear capacity of the RC is reached; on in other words, on the type of anchorage (properly anchored CFRP, e.g. closed jackets, versus poorly anchored FRP, i.e. open jackets).

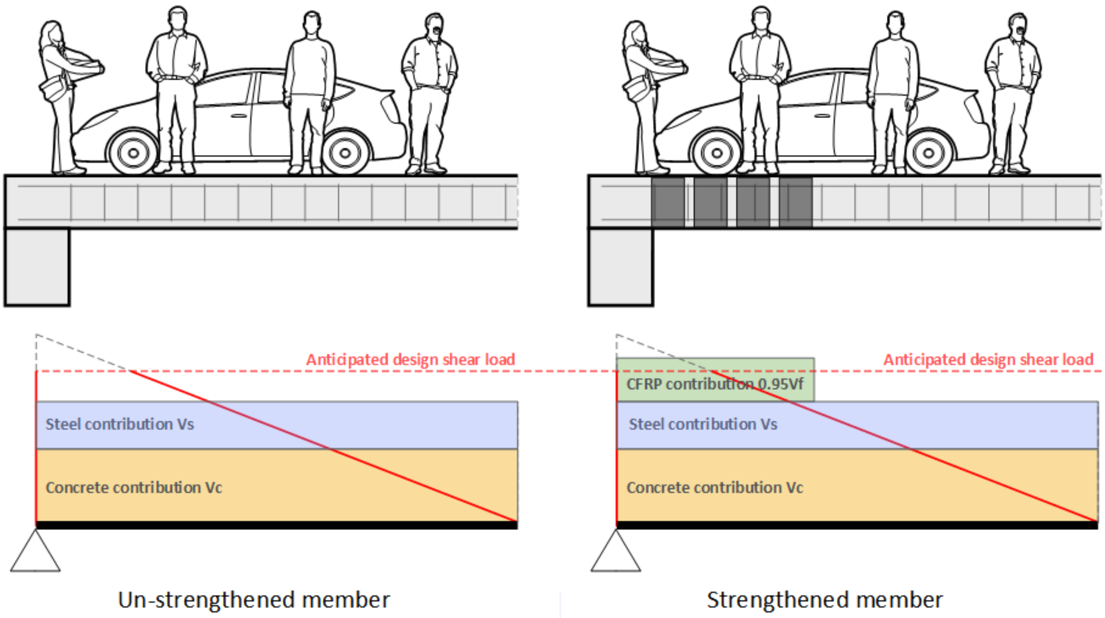
Hence, the shear capacity of a strengthened element may be assessed as follows:

$$\phi V_n = \phi\left(V_c + V_s + \psi V_f\right) \qquad (11.3b)$$

where V_f, the contribution of FRP to the member's shear capacity, is calculated according to ACI PRC-440.2-23, section 11.4 and **ψ** depends on the strengthening scheme:

ψ = 0.85 for three-side and two-opposite-sides schemes

ψ = 0.95 for Compelteley wrapped schemes



The contribution of the FRP V_f can be evaluated:

$$V_f = \frac{A_{fv} f_{fe}(\sin(\alpha)+\cos(\alpha))d_{fv}}{s_f}$$

(11.4a)

where:

- **A_{fv}** is the total cross section of FRP applies;
- **d_{fv}** is the effective depth of FRP shear reinforcement;
- **s_f** is the center-to-center spacing of FRP strips;
- **α** is the angle of application of FRP reinforcement direction relative to longitudinal axis of member;
- **f_{fe}** is the effective effective stress in the FRP. **$f_{fe} = E_{fe}\,\varepsilon_{fe}$** (11.4d);
- **ε_{fe}** depends on the type of application (complete wrapping, U-Wrap or s sides)

U-wraps may be anchored using carbon fiber anchors detailed in accordance with 14.1.4.

This anchors need to fulfill all the geometrical limitation, such as spacing, length, hole dimensions angle of spread, etc. If all the limitations are fulfilled the maximum U-wrap strain used for design should be that given by Eq. (11.4.1.1) and ψf = 0.85.

2.3.1 STRENGTHENING LIMITS

In addition to the existing strengthening limits, the sum of the shear strengths provided by the shear reinforcement (steel and FRP) should be limited, based on the criterion given for steel alone (ACI 318) as follows:

$$V_s + V_f \leq 0.66 \sqrt{f'_c}\, b_w\, d \qquad \text{(SI)} \qquad (11.4.3)$$

2.4 COLUMN CONFINEMENT

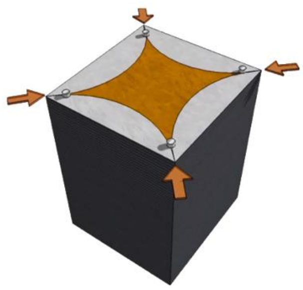
The main objectives of confinement are:

a. to enhance concrete strength and deformation capacities,
b. to provide lateral support to the longitudinal reinforcement and
c. to prevent the concrete cover from spalling.

For circular columns, these goals can be achieved by applying external FRP jackets. For rectangular columns, confinement can be provided with rectangular-shaped reinforcement, with corners rounded before application. Note that rectangular confining reinforcement is less effective as the confinement action is mostly located at the corners and a significant jacket thickness needs to be used between corners to restrain lateral dilation.

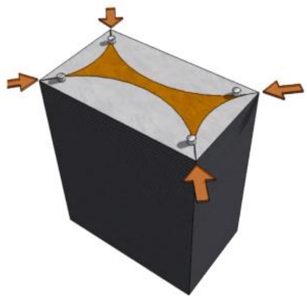
Circular columns

The concrete section effectively confined by the externally bonded FRP jacket equals the net section of the structural member.



Square/rectangular columns

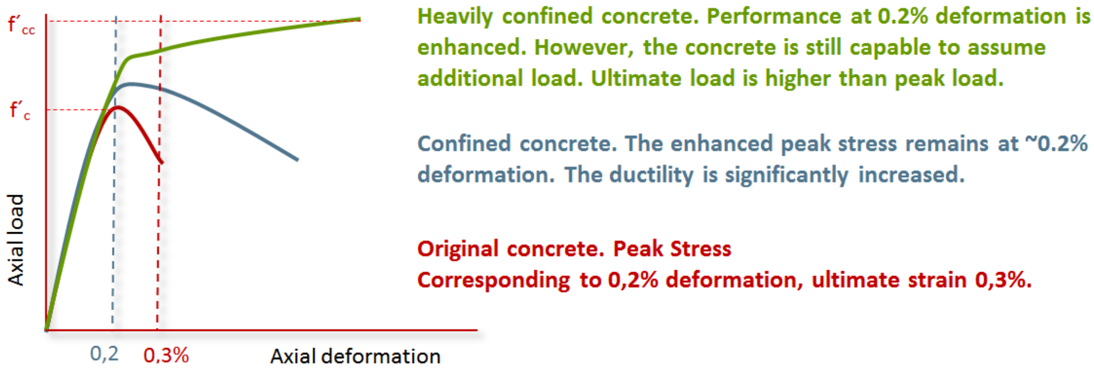
Confinement is concentrated at the corners rather than around the entire perimeter and thus the level of confinement varies throughout the cross-section, with much of the section having low levels of confinement



Long-shaped rectangular columns

The efficiency decreases further with columns that exhibit long-shaped cross-sections. The benefit provided by the confinement in case of 2:1 aspect ratios or greater is almost negligible.

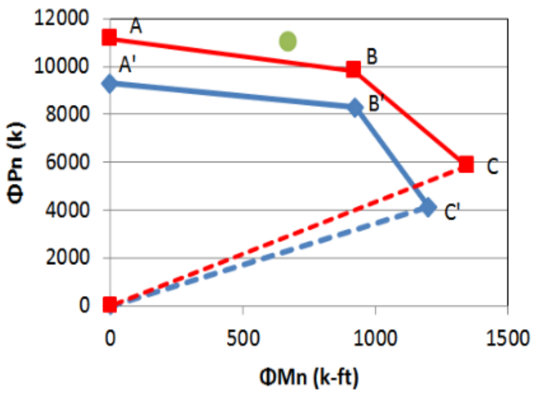
The stress-strain response of CFRP-confined concrete is illustrated schematically as follows:

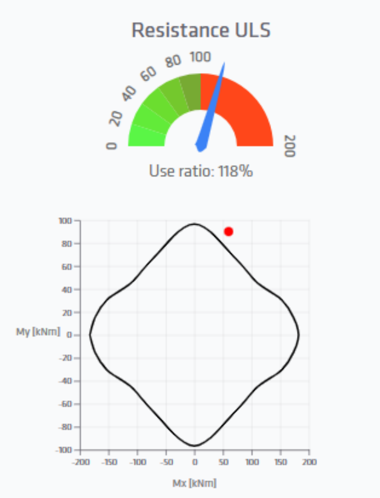


The figure displays a nearly bilinear response with a sharp softening and a transition zone at a stress level that is near the strength of unconfined concrete, f'_c. After this stress the tangent stiffness changes, until the concrete reaches its ultimate strength f'_{cc} when the jacket reaches tensile strain at failure ε_{fe}.

The determination of the design strength of the confined column is done according to ACI 440.2R-17, Chapter 12.

Please note that the software allows the calculation of columns subjected to axial loads and bending moment exerted in two different directions. Due to this, full 2D and 3D interaction diagrams (right) are used instead of the simplified 3-point diagram as indicated in ACI PRC-440.2-23, §12.2.





2.4.1 STRENGTHENING LIMITS

Refer to section 0.

2.4.2 SERVICEABILITY (ACI PRC-440.2-23, §12.2)

To ensure that radial cracking will not occur under service loads, the compressive stress in the concrete must remain below $0.65f'_c$.

In addition, the service stress in the longitudinal steel should not exceed $0.60f_y$.

3 USE OF SIKA® CARBODUR® CALCULATION SOFTWARE

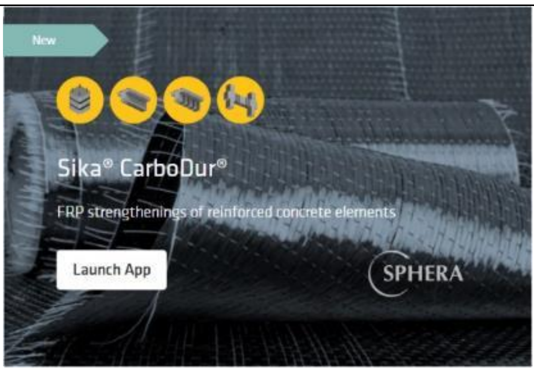
3.1 INTRODUCTION

Sika® CarboDur® Calculation Software is an advanced solution for FRP design and assessment on reinforced concrete structures. Following the most used and reliable FRP design guidelines worldwide, this powerful tool enables engineers to efficiently identify optimal FRP products that meet specific structural requirements. The software streamlines the design process, ensuring reliability, compliance, and enhanced project performance.

The software gives the possibility of access from any PC, laptop, tablet with an active internet connection. It is compatible with all web browsers, and it offers an interface designed for modern use and ease of navigation.

3.2 REGISTRATION

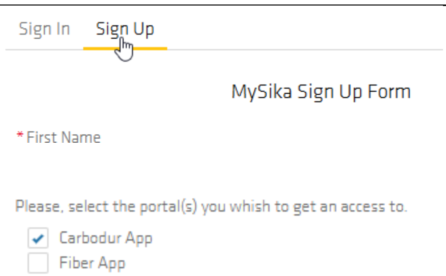
Being a cloud-based software, before start using the software, it is necessary to complete a registration process and to setup the access credentials.



The software is accessible at:
https://software.sika.com/structural

From this page click “Launch App”

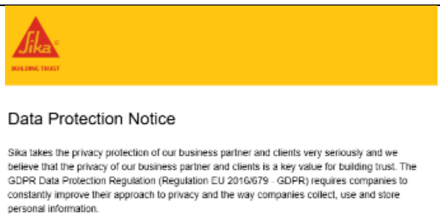
NOTE: The language of the page can be changed by selecting the language button located in the top yellow bar.



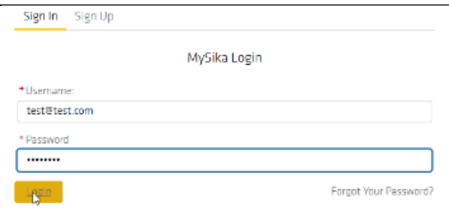
Click “Sign up” and complete the form with your name, surname, email, company, language, city, and country.

Choose whether to access only the CarboDur® Software or both the CarboDur® Software and SikaFiber software.

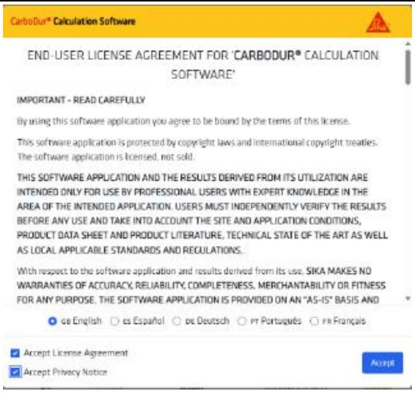
Read and accept the Privacy Notice and Submit



Check your inbox for two emails: one to set your portal password, and one with the Sika Data Protection Notice.



Once the password is set, it is possible to login and start to use the software

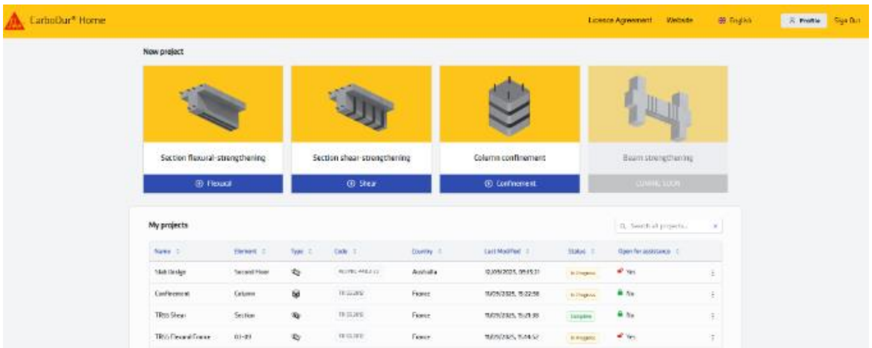


At the first login the user will be required to accept the EULA (End-user Licence Agreement) and the privacy notice

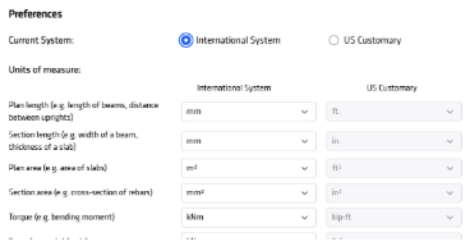
NOTE*: This popup will appear at each login, but only if the "My projects" section is empty. Once the user creates any projects, the popup will no longer be displayed. The End User License Agreement (EULA) always remains accessible via the "License Agreement" link in the top yellow bar.*

3.3 HOME PAGE

Home page offers an overview displaying the icons for creating a new project, the list of existing projects, the access to preferences, etc

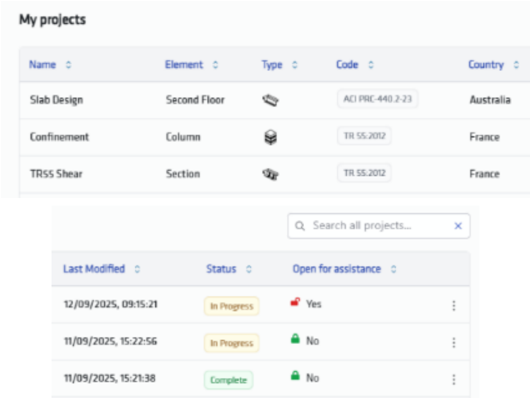


The yellow bar at the top allows you to view the License Agreement (EULA), go to **sika.com webpage**, switch languages of the software, edit your profile or log out.



Accessing the profile and Preferences opens a window where the selection between SI (International System) and US Customary Units measurement units can be done.

***NOTE**: Every single units of measure can be customized*



The "**My Projects**" section appears in the centre of the home page, showing a list of your projects. The columns in these table can be easily rearranged clicking on the symbols.

The columns of the table represents:

- Name: name assigned to the project
- Element: name or position of the element designed
  Type of design: confinement, flexural, shear, beam
  Design code: (ACI 440, TR 55, CNR-DT 200 SIA 166)
- Country: It shows the country product catalogue used for that specific design
- Date of last modification
- Status or the project: It shows if the project is complete or still in progress
- Open for assistance: It shows if the project is locked or unlocked (see below)

Projects are private and locked by default; only the owner has access.

To request support from Sika on a specific project, open it and use the "Open the project for assistance" slider. Click "Copy Current URL" to share direct access with others. When finished, turn off the slider.

__NOTE__: Access to projects opened for assistance is restricted __ONLY__ to members of the Sika organization. Any shared link will not be accessible to external users.

The "**New Projects**" section enables users to create new projects by selecting the appropriate button, based on the required type of FRP strengthening.

<u>Flexural strengthening of the critical section in a beam.</u>

The Flexural module includes the dimensioning of the necessary FRP, based on the anticipated bending moments acting on the critical section of a RC / Prestressed beam, subjected to both positive and negative bending moments, including scenarios involving also axial loads

<u>Shear strengthening of the critical section in a beam/column.</u>

The calculation determines the required FRP based on anticipated shear forces at the critical section of an RC beam or column. Axial loads on the section can also be considered in the design.

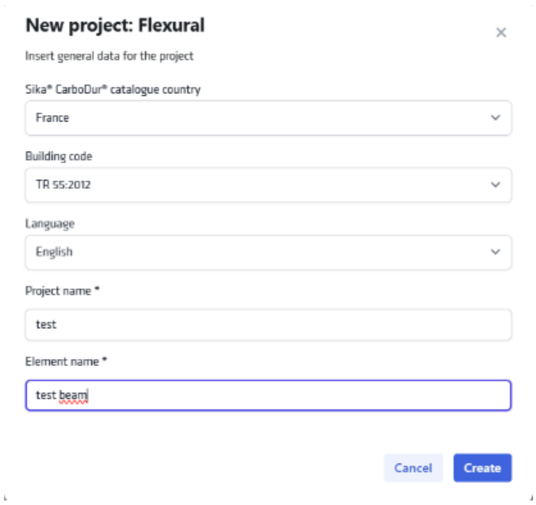
<u>Column strengthening by means of CFRP confinement.</u>

The Confinement module will comprise of the mechanical enhancement of a RC member under axial loads and bending moments. It allows the design of structural strengthening through confinement for reinforced concrete (RC) sections subjected to biaxial bending moments, using SikaWrap® FRP systems. This module facilitates the analysis of columns subjected simultaneously to axial loads and bending moments acting in two orthogonal directions.

<u>Flexural/Shear strengthening of beam</u>

Software determines the distribution of the anticipated bending moments/shear forces for the RC/prestressed member, and calculates the necessary FRP flexural and shear sections and the arrangement along the beam.

NOTE: This module will be released soon



When starting a new project, the user must select the country catalogue, the design guideline, the language, the project name and the element name or position.

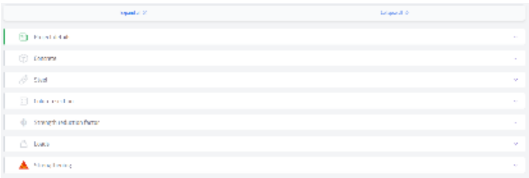
The country catalogue restricts FRP strengthening products to those listed within that specific catalogue/country.

The country catalogue and design guideline cannot be modified after the project is created.

***NOTE**: Be sure that the chosen FRP design guideline is consistent with the general concrete design code.*

General Concrete Building Code	***FRP Design Guideline***
ACI 318	*ACI 440 PRC-440.2-23*
Eurocode 2	*TR 55*
NTC 2018	*CNR-DT 200 R1/2013*
SIA 262	*SIA 166*

3.4 GENERAL INFORMATION



Each project, when opened, displays an interface consisting of panels that can be expanded or collapsed.

At the top, there are two buttons (“Expand all” and “Collapse all”) that allow the user to expand or collapse all panels simultaneously.

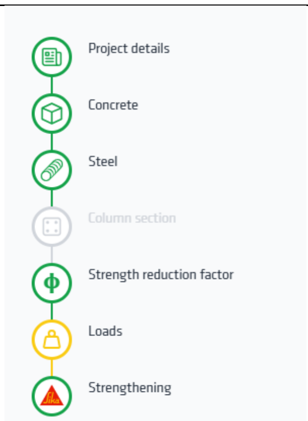
Each panel features a coloured icon, where the colour indicates the progress status of the individual project section.

See below for the explanation of the colours

The side bar is always displayed.

The top of the sidebar shows the project title, the current design element, last save date, FRP guideline used for this specific project and chosen product catalogue.

***NOTE**: The country catalogue restricts FRP strengthening products to those listed within that specific catalogue/country.*



The central part of the sidebar displays all icons, each representing different section of the project.

Green means that panel is complete

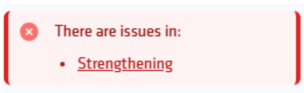
Grey means that panel has not been opened yet

Yellow means there’s a warning in that panel

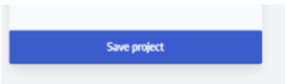
Red means there is an issue or some data are missing in that panel

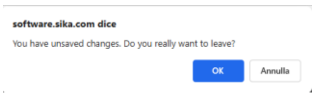
***NOTE**: In this way the user has always a complete overview of the full project parts*

50



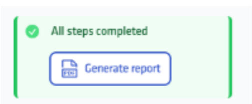
If there are any problems or warnings, they'll appear beneath the icons so users can easily review them.



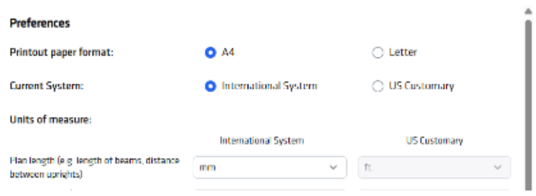


The lower part of the sidebar features a button labelled “Save project.” This button remains grey when the project has been saved and turns blue if there are any unsaved changes requiring the user to save the project.

***NOTE**: Most web browsers display a popup warning about unsaved changes if you try to refresh, go back, or close the browser window.*



When all sections are completed and all the sidebar icons display green, a button will appear at the bottom of the sidebar, allowing the user to generate the print-out report



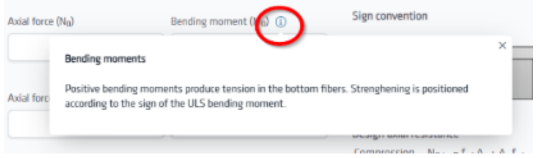
Users are able to specify the desired paper size for printouts. The document can be printed in either A4 or Letter size.

The selection can be made prior to clicking the "**Generate report**" button by accessing your profile in the upper right corner of the page **Profile** and on the prefrences **Preferences**.

A full printout in PDF is generated after the project is completed.

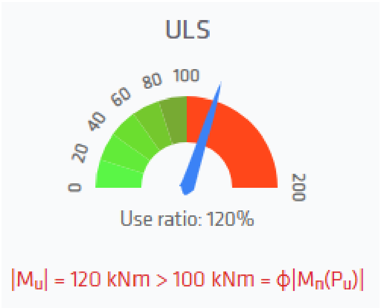
Print out contains:

- Design data
- Element data
- Loads
- Strengthening details
- Results



In many parts of the software this symbol ⓘ is displayed.

Clicking on it will allow the user to access additional and useful information

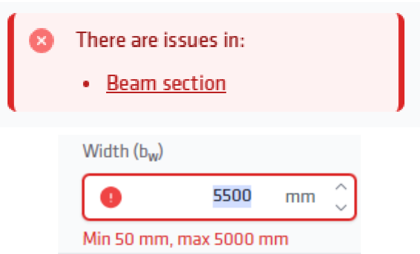


In "Loads" and "Strengthening" panels these indicators called "**Use ratio**" are shown.

These indicators represent the usage ratio for a specific load combination or verification. They are defined as the ratio of the design condition to the resistant condition.

The use ratio indicator in the left picture displays the proportion of the design ULS bending moment (**M_u**) to the ULS resistant bending moment (**ϕM_n**).

Use ratio= M_u / ϕM_n



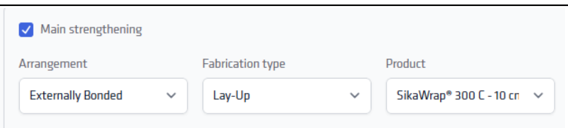
Some conditions or logical parameters may not satisfy certain limitations during calculation.

This information will be displayed on the main screen and in the lateral bar too.

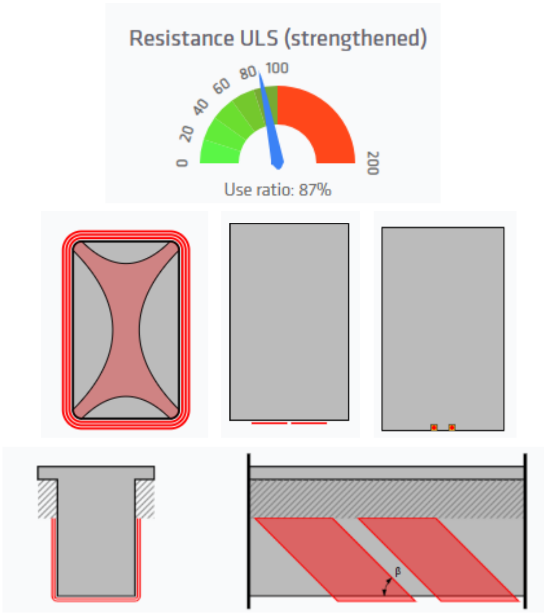
***NOTE**:*

⚠ *This symbol indicates that the condition is not satisfied. However, the user is allowed to complete the calculation.*

⊗ *This symbol indicates that some critical or logical condition is not satisfied. The calculation cannot be completed unless it is corrected.*



The software, across all modules (Flexural, Shear, Confinement, Beam) and for all supported design guidelines (TR 55, ACI 440, CNR-DT 200, SIA 166), applies a **verification approach** rather than a **design approach**.



Once the geometry and loading conditions are defined, the user can select, using some dropdown menus:

- The strengthening arrangement (Externally Bonded or Near-Surface Mounted),
- The fabrication type (Wet Lay-Up or Prefabricated),
- the specific product (from the available products listed in the Country Catalogue),
- and the geometry of the strengthening system (width, number of layers, position).

Based on these inputs, the **use ratio** indicator is updated in real time, providing immediate feedback on whether the design satisfies the selected verification criteria.

The layout of the chosen strengthening products is always displayed graphically in the screen.

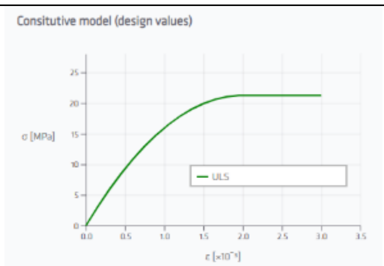
***NOTE**: This approach provides the user with full flexibility in defining the strengthening system, including the choice of products, positioning, number of strips, number of layers, spacing, and inclination. The adequacy of the configuration is always verified by monitoring the section status through the use ratio indicator.*

3.5 COLUMN CONFINEMENT

The Confinement module will comprise of the mechanical enhancement of a RC member under axial loads and bending moments. It allows the design of structural strengthening through confinement for reinforced concrete (RC) sections subjected to biaxial bending moments, using SikaWrap® FRP systems. This module facilitates the analysis of columns subjected simultaneously to axial loads and bending moments acting in two orthogonal directions.

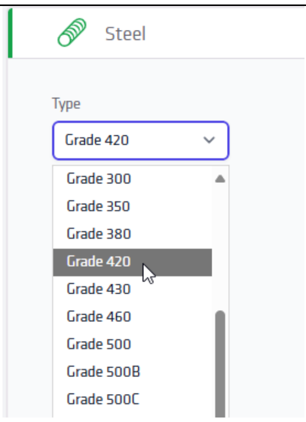
3.5.1 CONCRETE

In this panel, the the user selects the compressive strength of concrete (**f'$_c$**). The strength is commonly based on cylinders, as indicated by ACI 318.

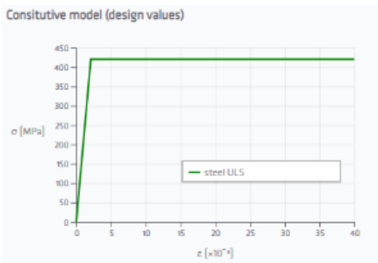


Stress-strain constitutive model (design values) are visualized.

3.5.2 STEEL

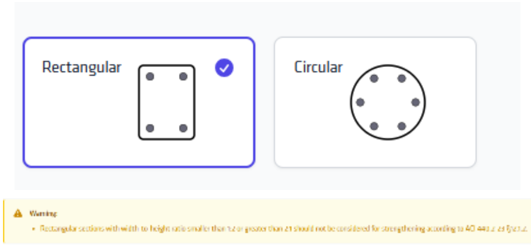


In this panel, the tensile strength of the steel (**f$_y$**) is specified by the user. This value can be selected from a dropdown menu, which contains a list of the most used steel types all around the world, or, if "user defined" is chosen, it may be entered manually.



Stress-strain constitutive model (design values) are visualized.

3.5.3 COLUMN SECTION

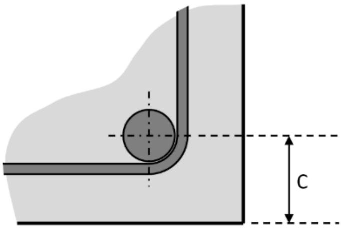


It is possible to select rectangular or circular concrete section

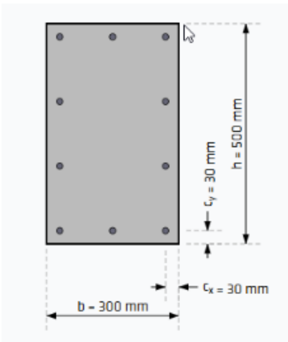
In case of rectangular, width and height need to be selected.

In case of circular section, just the diameter of the section

***NOTE**: ACI 440, for rectangular sections, specifies a precise geometric limitation for the width-to-height ratio B/H (or H/B) to a maximum value of 2. Software will display a warning if this limitation is not met.*



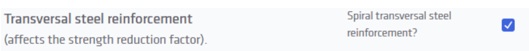
Mechanical covering is the distance from the centre of the longitudinal rebar to the outer edge of the concrete, calculated as the sum of the concrete cover, stirrup diameter, and half the longitudinal bar diameter.



<u>For rectangular section</u>, reinforcing bars are defined in 3 groups:

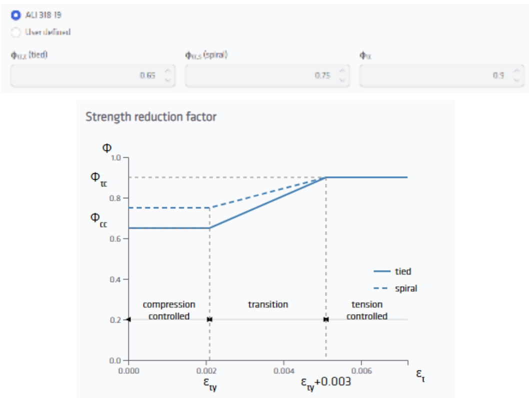
- **Corner bars**: bars at the 4 corners of the section
- **Horizontal bars**: additional bars located on the horizontal sides
- **Vertical bars**: additional bars located on the vertical sides

<u>For a circular section</u>, reinforcing bars are defined as the total number of bars evenly placed around the perimeter.



When spiral transverse steel is used, the appropriate flag should be selected by the user. This will affect the reduction factors (ACI 318).

3.5.4 STRENGTH REDUCTION FACTOR

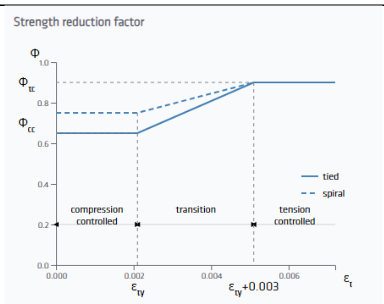


In the Strength reduction factor panel the values of $\phi_{cc,t}$ (tied), $\phi_{cc,s}$ (spiral) and ϕ_{tc} are shown.

Design strength provided by a member shall be taken as the nominal strength of the member in accordance to ACI 318 and ACI PRC-440.2R-23, multiplied by the strength reduction factor ϕ.

The reduction factors follow ACI 318 for compression-controlled and tension-controlled section as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary

On the right of the panel the diagram of the Strength reductin factor is shown

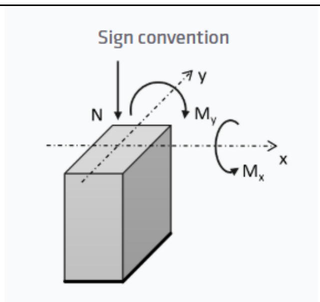


On the right of the panel the diagram of the Strength reductin factor is shown

3.5.5 LOADS

Axial force (P_{SLU}) 500 kN
Bending moment ($M_{x,SLU}$) 45 kNm
Bending moment ($M_{y,SLU}$) 30 kNm

Each load combination is specified by an axial load value and two bending moment values acting simultaneously in two perpendicular directions.



Each load can be assigned as positive or negative according to the convention shown in the figure on the left. It is possible to analyse conditions of combined bending and compression (biaxial bending), tension and bending, or pure axial force.

Design axial resistance

Compression $P_{n,c} = 0.8\ (f_y\ A_s + 0.85\ f'_c\ (A_g\text{-}A_s)) = 2694.3$ kN
Tension $P_{n,t} = f_y\ A_s = 190$ kN

Limit states

	ULS	Accidental damage	Fire (t=0)
$\phi_{cc}P_{n,c}$	1751.3 kN	1751.3 kN	2694.3 kN
$\phi_{tc}P_{n,t}$	171 kN	171 kN	190 kN

In this table the limit values of the axial load, in compression and in tension, for ULS, Stengthening limits and Fire (t=0) are showed

Ultimate limit state (ULS) loads
Combination loads for strength checks.

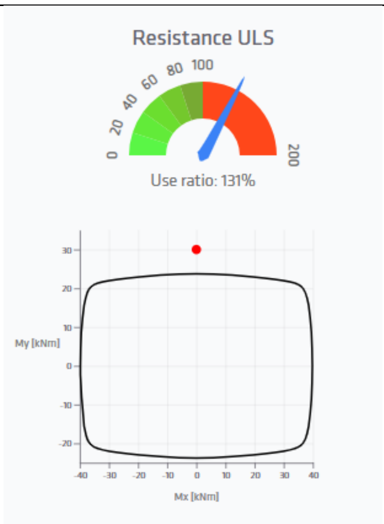
This represents the unfactoreed values of the axial load (**P_{SLU}**) and the two bending moments (**$M_{x,SLU}$** and **$M_{y,SLU}$**), for the ULS loads combination

Serviceability limit state (SLS) loads
Combination loads for SLS and fire.

This represents the unfactoreed values of the axial load (**P_{SLS}**) and the two bending moments (**$M_{x,SLS}$** and **$M_{y,SLS}$**), for the characteristic combination of actions in serviceability conditions and for fire at T=0

Strengthening limit loads
Combination of loads for FRP strengthening limit

This preliminary verification is required (see section 2.1.1). It represents the unfactoreed values of the axial load (**P_{dam}**) and the two design bending moments (**$M_{x,dam}$** and **$M_{y,dam}$**) acting in serviceability limit state.

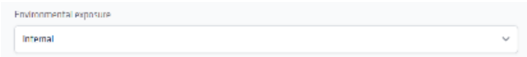


For each combination, the use ratio (see section 3.4) is displayed.

Below, a graphic visualization of the interaction diagram of the section, in the plane Mx-My, shows the diagram and the position of the combination (red point).

***NOTE**: Use ratio > 100% means that the combination is out of the interaction diagram.*

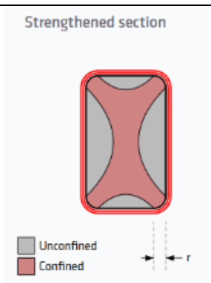
3.5.6 STRENGTHENING



The user has to select the relevant long-term exposure to environmental conditions using a dropdown menu. This will affect the determination of the reduction factor to be applied in the design equations.

Define the following parameters:

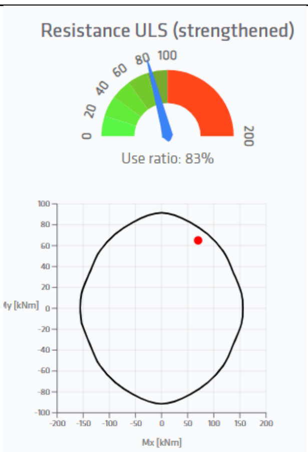
- **SikaWrap® fabric**: select from the products available in the Country Catalogue.
- **Number of layers**: specify the required number of fabric layers.
- **Fillet radius**: define the corner radius for the columns.



The software provides a visual representation of the applied strengthening and the effect of confinement.

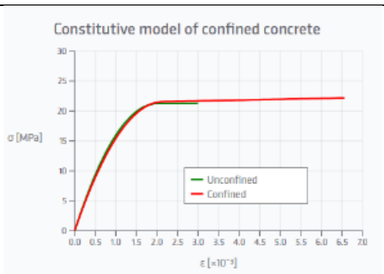
The confined area of the concrete is highlighted in red.

As the height-to-width (or width-to-height) ratio increases, the confined zone becomes smaller, resulting in reduced confinement efficiency.



The software shows the use ratio indicator for the strengthened section in ULS combination. Use ratio <100% means that verification is ok and with the chosen strengthening system and FRP quantity the section is OK.

A graphic visualization of the interaction diagram for the strengthened section , in the plane Mx-My, shows the diagram and the position of the combination (red point).



A comparison between the stress-strain diagrams for unconfined and confined concrete is displayed

Product details

Product	SikaWrap® Hex 103 C - 25"
Type of fibers	C
Width (w_f)	635 mm
Single layer thickness (t_f)	1 mm
Elastic modulus (E_f)	71.7 GPa
Ultimate strain (ε_{fu}^*)	14.5 ‰
Strength (f_{fu}^*)	1040 MPa
Environmental reduction factor (C_E)	0.95

For the chosen SikaWrap® system, all the relevant physical and mechanical properties are displayed.

3.5.7 PRINTOUT

A full printout in PDF is generated after the project is completed.

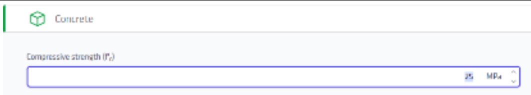
Print out contains:

- Design data
- Element data
- Loads
- Strengthening details
- Results

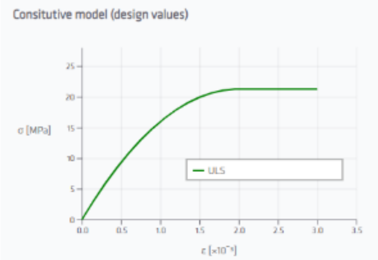
3.6 SECTION FLEXURAL STRENGTHENING

The Flexural module includes the dimensioning of the necessary FRP, based on the anticipated bending moments acting on the critical section of a RC / Prestressed beam, subjected to both positive and negative bending moments, including scenarios involving also axial loads.

3.6.1 CONCRETE

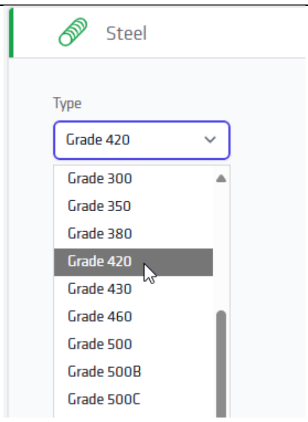


In this panel, the the user selects the compressive strength of concrete (**f'c**). The strength is commonly based on cylinders, as indicated by ACI 318.

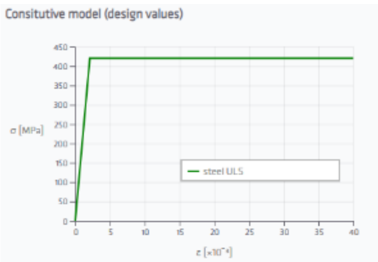


Stress-strain constitutive model (design values) are visualized.

3.6.2 STEEL

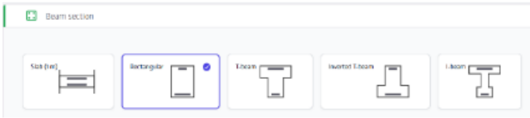


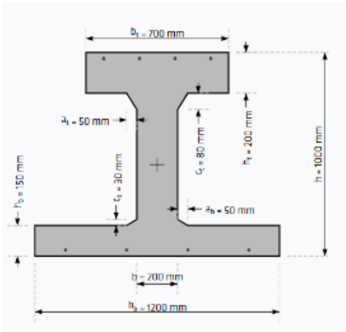
In this panel, the tensile strength of the steel (**f_y**) is specified by the user. This value can be selected from a dropdown menu, which contains a list of the most used steel types all around the world, or, if "user defined" is chosen, it may be entered manually.



Stress-strain constitutive model (design values) are visualized.

3.6.3 BEAM SECTION



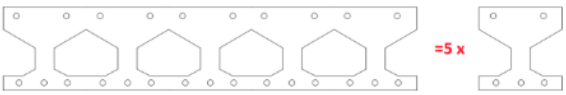


The user can select one of the following basic shapes for the element:

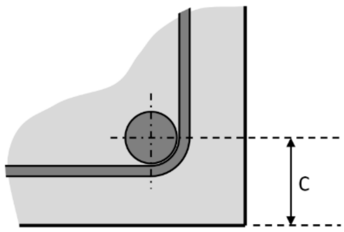
- Slab
- Rectangular
- T-beam
- Inverted T-beam
- I-beam

In case of slab section, the user needs to enter just the thickness of the slab.

Additionally, fillets (chamfers) can be displayed for certain shapes, providing the possibility of defining complex geometries.



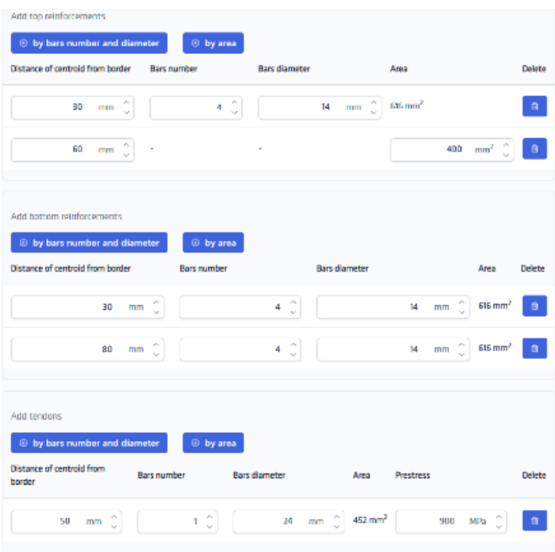
***NOTE**: by selecting a suitable geometry profile, the user can create parts of complex elements and geometries*



In this panel the internal steel reinforcement of the section needs to be defined.

Internal steel reinforcement are divided in **Top Reinforcements**, **Bottom Reinforcement** and, in case of prestressed concrete section, **Tendons**

For each type of internal steel reinforcement the first parameter to define the mechanical covering (Distance of centroid from the border). This represents the distance from the centre of the longitudinal rebars to the outer edge of the concrete, calculated as the sum of the concrete cover, stirrup diameter, and half the longitudinal bar diameter.



The definition of the top and bottom steel bars is determined separately for each layer, consisting of the following parameters:

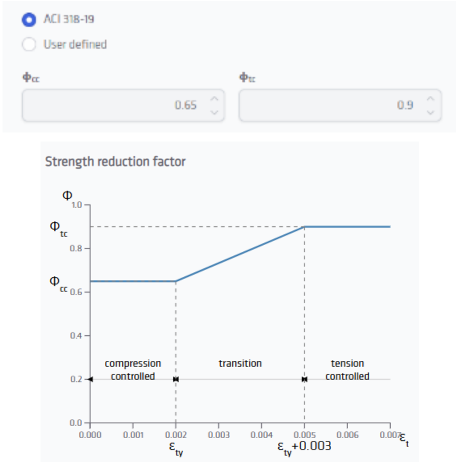
- Distance from the centroid to the concrete surface (see previous point).
- Steel section.

Each layer of steel section may be specified by providing the number of rebars, their diameter and position, or by assigning the total area of steel and its location.

The quantity of steel layers is not restricted.

***NOTE**: For prestressing steel, the user should confirm the mechanical properties of the steel and <u>specify the actual stress in the steel at the time of strengthening</u> (f_{se}). This value generally corresponds to the initial prestressing stress minus any prestressing losses up to the point of strengthening.*

3.6.4 STRENGTH REDUCTION FACTOR



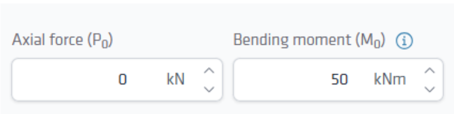
In the Strength reduction factor panel the values of ϕ_{cc} and ϕ_{tc} are shown.

Design strength provided by a member shall be taken as the nominal strength of the member in accordance to ACI 318 and ACI PRC-440.2R-23, multiplied by the strength reduction factor ϕ.

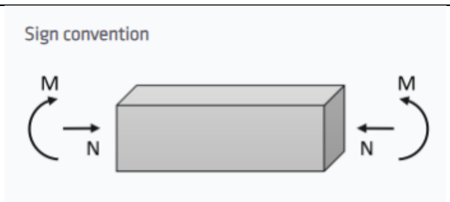
The reduction factors follow ACI 318 for compression-controlled and tension-controlled section as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary

On the right of the panel the diagram of the Strength reductin factor is shown.

3.6.5 LOADS



For the flexural strengthening design, it possible to consider an axial force acting on the section. This is helpful to design, for example, inclined beams or inclined roofs. Each load combination is specified by an axial load and a bending moment value.



Each load can be assigned as positive or negative according to the convention shown in the figure on the left. It is possible to analyse conditions of bending and compression, tension and bending, or pure bending moments.

Load cases (positive moments)

	Initial	ULS	Fire (t=0)	Accidental damage
ε_t	0.0198	0.0198	0.0198	0.0198
ϕ	0.90	0.90	1.00	0.90
$M_n(P_u)$	108.7 kNm	108.7 kNm	108.7 kNm	108.7 kNm
ϕM_n	97.8 kNm	97.8 kNm	108.7 kNm	97.8 kNm

Load cases (negative moments)

	Initial	ULS	Fire (t=0)	Accidental damage
ε_t	0.0198	0.0198	0.0198	0.0198
ϕ	0.90	0.90	1.00	0.90
$M_n(P_u)$	-108.7 kNm	-108.7 kNm	-108.7 kNm	-108.7 kNm
ϕM_n	-97.8 kNm	-97.8 kNm	-108.7 kNm	-97.8 kNm

In this table the limit values of the net tensile strain in extreme tension steel (ε_t), strength reduction factor (ϕ),the nominal flexural strength at a section (**M_n**) and the factorized moment (**ϕM_n**) are showed, both for positive and negative moments.

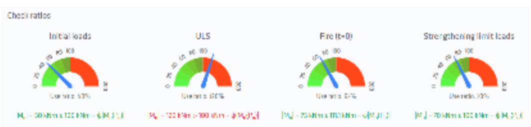
Initial loads

Combination loads at the time of the application of strengthening.

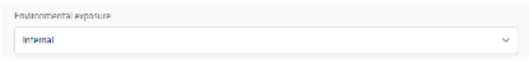
This represents the unfactored values of the axial load (**P_0**) and the bending moment (**M_0**) acting on the section, at the time of the application of the FRP strengthening system.

This Initial loads can be due to: the self-weight of the beam, the dead loads (either in whole or in part), live loads (when applicable).

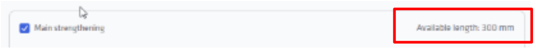
The software checks that those forces do not exceed the initial strength of the un-strengthened element. This condition must be fulfilled to continue with the calculation.

Ultimate limit state (ULS) loads Combination loads for strength checks.	This represents the unfactored values of the axial load ($\mathbf{P}_{ULS}$) and the bending moment ($\mathbf{M}_{ULS}$), for the Ultimate State Loading (ULS) loads combination
Serviceability loads Combination loads for serviceability limit state.	This represents the unfactored values of the axial load ($\mathbf{P}_{SLS}$) and the design bending moment ($\mathbf{M}_{SLS}$), for the combination of actions in service conditions
Fire loads Combination loads for fire limit state.	This represents the unfactored values of the axial load ($\mathbf{P}_{fi}$) and the bending moment ($\mathbf{M}_{fi}$) acting in case of a fire scenario. The software verifies if, in case of fire, the assigned loads can be initially assumed by the unreinforced element (considering that the unprotected FRP is damaged due to the high temperatures).
Strengthening limit loads Combination of loads for FRP strengthening limit	This preliminary verification is required (see section 2.1.1). It represents the unfactored values of the axial load ($\mathbf{P}_{damage}$) and the bending moment ($\mathbf{M}_{damage}$) acting in serviceability limit state.
Prestress steel? ☑ Statically indeterminate scheme? ☐ **Prestress loads** Statically indetererminate internal actions due to prestress	For prestressed concrete sections (where the “Prestressed Steel” option is selected in the Steel Panel), users must specify whether the static scheme is statically indeterminate. A **statically determinate beam** is one where the support reactions can be found using only the equations of static equilibrium. In this scenario, the values of axial load ($\mathbf{P}_{p}$) and bending moment ($\mathbf{M}_{p}$), due to prestressing steel, are automatically calculated by the software. A **statically indeterminate beam**, on the other hand, requires additional compatibility and deformation conditions to be solved, since it has more supports or restraints than necessary. In this scenario, the user is required to select the appropriate option and manually enter the values for axial load ($\mathbf{P}_{p}$) and bending moment ($\mathbf{M}_{p}$) attributable to prestressing steel.
 Errors: • Section fails for FRP Strengthening limit. This FRP Strengthening limit check can be disabled by the user.	For the Initial, ULS, Fire and Strengthening limit, , use ratio indicators for the unstrengthened section are shown (see section 3.4). If the use ratio for either the "Initial loads" or the "Strengthening limit loads" exceeds 100%, an error message will be displayed to notify the user that the preliminary verification has not been successful. ***NOTE***: *In this situation, strengthening can be designed; however, generating the printout report is not possible due to this error. The error appears in the Loads panel and is indicated by a red icon in the lateral bar (see section 3.4).*

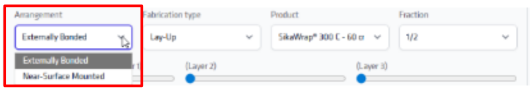
3.6.6 STRENGTHENING

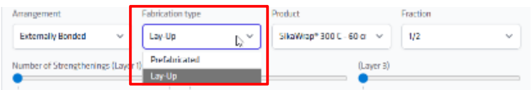


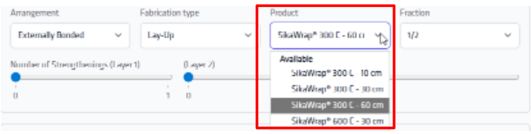
The user has to select the relevant long-term exposure to environmental conditions using a dropdown menu. This will affect the determination of the reduction factor to be applied in the design equations.

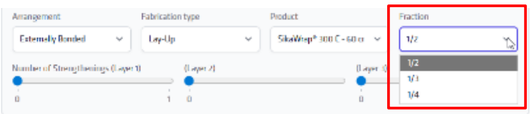


Typically, the strengthening system is located on the bottom side of the beam (on top for negative bending moments). This is called “**Main strengthening**” and the option is selected by default. The available width is displayed and it represents the maximum avaialble space to place the FRP strengthening system.





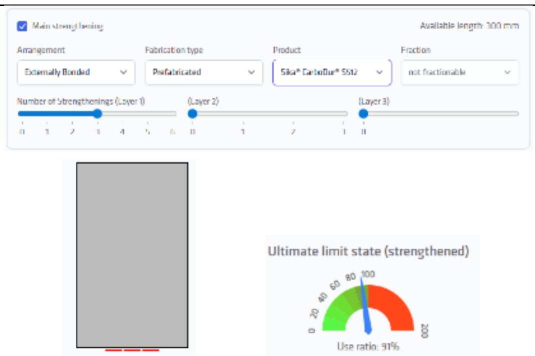




The user should define the following strengthening parameters:

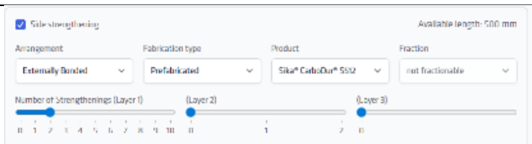
- **Arrangement**: Based on the chosen country catalogue, the user selects either an externally bonded system, a near surface mounted (NSM) system or Post-tensioned CFRP (Sika® CarboStress) for statically determinate beams, if locally available.
- **Fabrication type**: Based on the chosen country catalogue , the user selects either a Prefabricated system (Sika® CarboDur®) or a Lay-up system (SikaWrap®).
- **Product**: The user selects which product to use from a dropdown menu.
- **Fraction**: In certain Lay-up systems, it is possible to utilize a fraction of the fabric's original width. For example, when selecting SikaWrap®-300 C – 60 cm, users may opt to utilize the full width or choose from 1/2, 1/3, or 1/4 of the width. This results in corresponding fabric widths of 30 cm, 20 cm, or 15 cm.

NOTE: *The software checks the available width against the chosen fabric's width and only shows options that fit within the available width. In case the available width is 300 mm, it won’t be possible select the full 60 cm fabric width.*

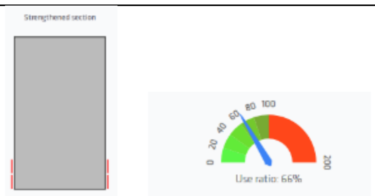


Number of strengthening layers: indicate the required number of fabric or plate strips and layers. If the width of the FRP matches the available section width, the software allows the addition of multiple strengthening strips. In the illustration, the user has chosen 3 strips of Sika® CarboDur® S512.

NOTE: *As already written, the user needs to select the appropriate product, number of strips and layer to get the use ratio (M_U / ϕM_n) below 100%*

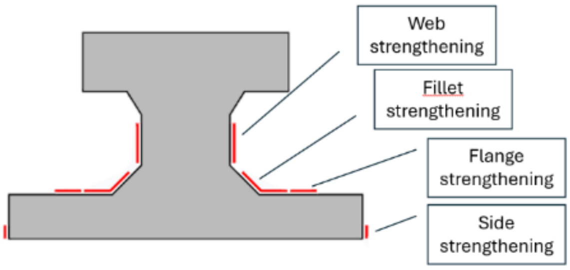


For rectangular, T-beam, inverted T-beam and I-beam sections, the software allows users to apply the strengthening system also to the beam's lateral sides (rectangular), called "**Side strengthening**." While the

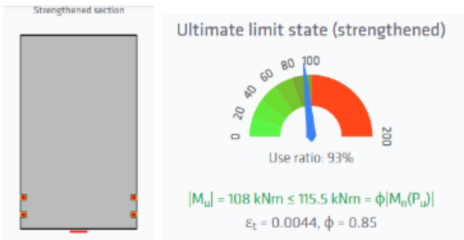


main application method is preferred, this option is useful when the soffit is inaccessible or insufficient for required strengthening, such as with narrow beams. Side strengthening can be used in addition to the main or as a replacement of it.

The choice of the strengthening follows the same logic of the main strengthening. User has to define the Arrangement, the Fabrication type, the Product, the fraction (if available) and the number of strips and layers.

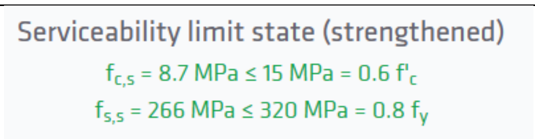


For I-beam sections, the software enables users to apply FRP strengthening to the vertical **Side**, the **Web**, the upper portion of the **Flange**, and the **Fillet**.

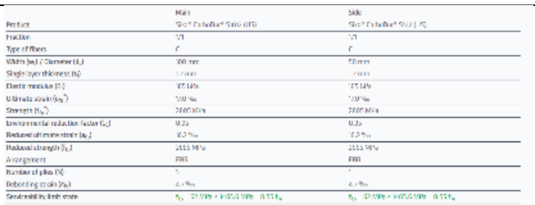


The software displays the reinforced section with the designed FRP systems and the use ratio indicator for the ULS combination. A ratio below 100% indicates that verification is successful and the section meets requirements with the selected strengthening system and FRP amount.

The values for the bending moment (M_U) and the factorized resistant bending moment (ϕM_n) are compared. The values of ε_t and the corrispondent ϕ are diplayed as well.



The software checks the characteristic serviceability limit state, by comparing concrete and steel stress levels to admissible values.



	Main	Side
Product	[illegible]	[illegible]
Fraction	[illegible]	[illegible]
Type of fibers	[illegible]	[illegible]
Width / Diameter	100 mm	50 mm
Single layer thickness	[illegible]	[illegible]
Elastic modulus	[illegible]	[illegible]
Ultimate strain	[illegible]	[illegible]
Strength	[illegible]	[illegible]
Environmental reduction factor	[illegible]	[illegible]
Reduced ultimate strain	[illegible]	[illegible]
Reduced strength	[illegible]	[illegible]
Arrangement	[illegible]	[illegible]
Number of plies	[illegible]	[illegible]
Debonding strain	[illegible]	[illegible]
Serviceability limit state	[illegible]	[illegible]

For the selected FRP systems (SikaWrap®, Sika® CarboDur®, etc.), all relevant physical and mechanical properties are provided, including the environmental reduction factor C_E and the debonding strain ε_{fd}.

3.6.7 PRINTOUT

A full printout in PDF is generated after the project is completed.

Print out contains:

- Design data
- Element data
- Loads
- Strengthening details
- Results

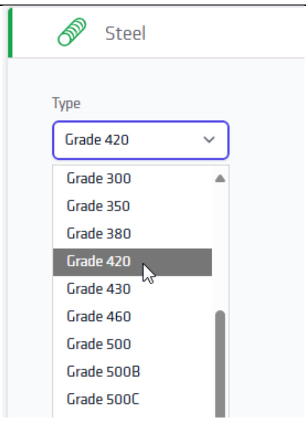
3.7 SECTION SHEAR STRENGTHENING

The Shear strengthening of the critical section in a beam/column calculation determines the required FRP based on anticipated shear forces at the critical section of an RC beam or column. Axial loads on the section can also be considered in the design.

3.7.1 CONCRETE

In this panel, the the user selects the compressive strength of concrete (**f'c**). The strength is commonly based on cylinders, as indicated by ACI 318.

3.7.2 STEEL

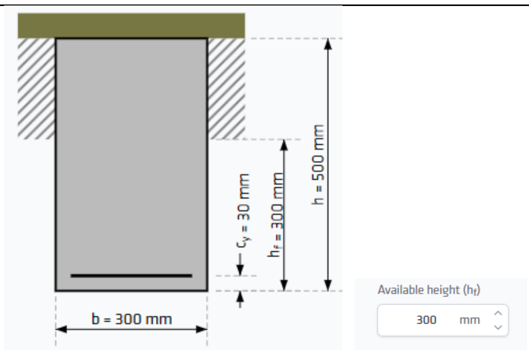


In this panel, the tensile strength of the steel (**f_y**) is specified by the user. This value can be selected from a dropdown menu, which contains a list of the most used steel types all around the world, or, if "user defined" is chosen, it may be entered manually.

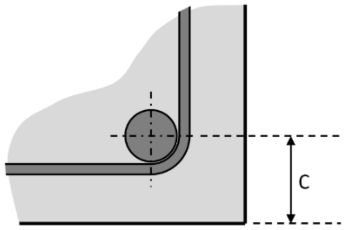
3.7.3 BEAM SECTION

The user can select one of the following basic shapes for the element:

- Rectangular
- Rectangular not accessible from top
- T-beam



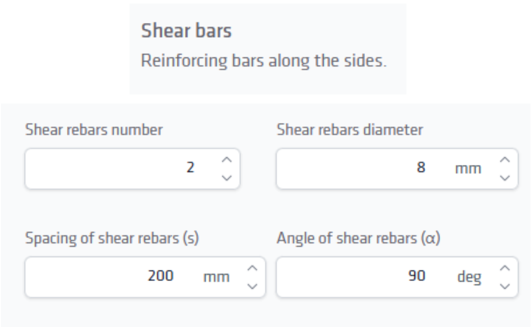
In the section "Rectangular not accessible from top" and for "T-Beam", it is necessary to specify the dimensions of the section (Width and Height) and the available height (**hf**), which indicates the space available on the vertical sides of the beam for installing the FRP shear strengthening system. This takes into account the presence of a slab that can limit the space for the application of the U-shaped SikaWrap® fabrics.



Mechanical covering (c_y) is the distance from the centre of the longitudinal rebar to the outer edge of the concrete, calculated as the sum of the concrete cover, stirrup diameter, and half the longitudinal bar diameter.

Use needs to define the longitudinalreinforcing bars on the lower part. Tese longitudinal bars are defined in two groups:

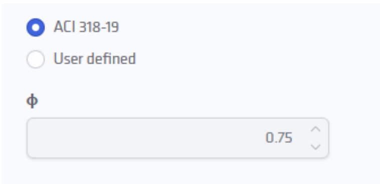
- **Corner bars**: bars at the two lower corners of the section
- **Horizontal bars**: additional bars located on the lower side



The definition of the internal shear reinforcement is determined defining the following parameters:

- **Shear rebars number**: This represents the number of arms of the internal stirrups (typically 2 for normal stirrups or 4 for double stirrups)
- **Shear rebars diameter**
- **Spacing of shear rebars**: This represents the spacing, centre-to-centre, of the stirrups
- **Angle of shear rebars**: is the angle of the stirrups with the axis of the beam. By default it is assumed 90° (vertical stirrups).

3.7.4 STRENGTH REDUCTION FACTOR

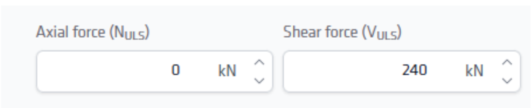


In the Strength reduction factor panel the values of ϕ is shown.

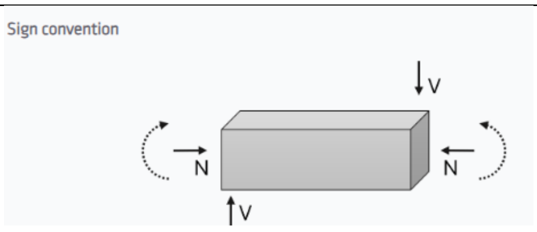
Design strength provided by a member shall be taken as the nominal strength of the member in accordance to ACI 318 and ACI PRC-440.2R-23, multiplied by the strength reduction factor ϕ.

The reduction factors follow ACI 318 for compression-controlled and tension-controlled section as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary.

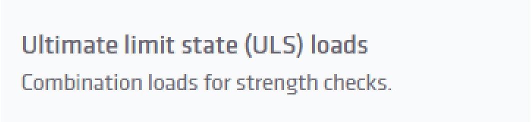
3.7.5 LOADS



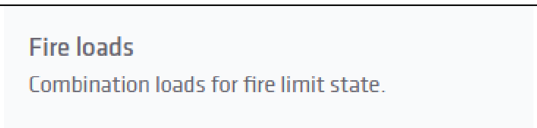
For the shear strengthening design, it possible to consider an axial force acting on the section. This is helpful to design shear strengthening, for example, for inclined beams or columns. Each load combination is specified by an axial load and a bending moment value.



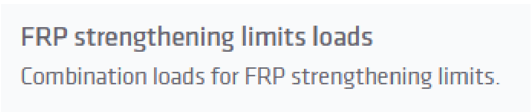
Each load can be assigned as positive or negative according to the convention shown in the figure on the left. It is possible to analyse conditions of shear-tension, shear-compression or pure shear.



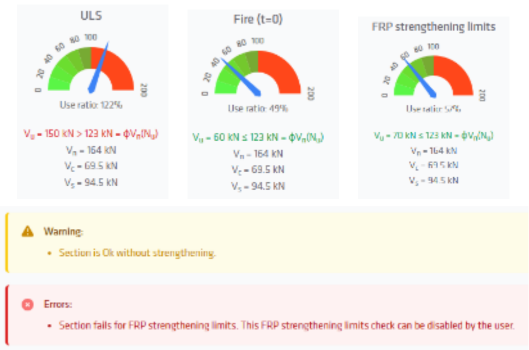
This represents the design values of the axial load (**N_{ULS}**) and the design shear force (**V_{ULS}**), for the Ultimate State Loading (ULS) loads combination



This represents the design values of the axial load (**N_{fi}**) and the design shear force (**V_{fi}**) acting in serviceability limit state (see section 2.1.2).



This preliminary verification is required (see section 0). It represents the design values of the axial load (**N_{damage}**) and the design shear force (**V_{damage}**) acting in serviceability limit state.

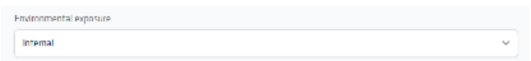


For the ULS , the Fire (t=0) and the FRP strengthening limits loads, use ratio indicators for the unstrengthened section are shown (see section 3.4).

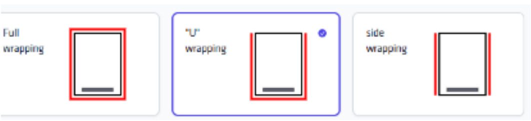
If the use ratio for either the "Fire loads" or the "FRP strengthening limits loads" exceeds 100%, an error message will be displayed to notify the user that the preliminary verification has not been successful.

NOTE*: In this situation, strengthening can be designed; however, generating the printout report is not possible due to this error. The error appears in the Loads panel and is indicated by a red icon in the lateral bar (see section 3.4).*

3.7.6 STRENGTHENING



The user has to select the relevant long-term exposure to environmental conditions using a dropdown menu. This will affect the determination of the reduction factor to be applied in the design equations.

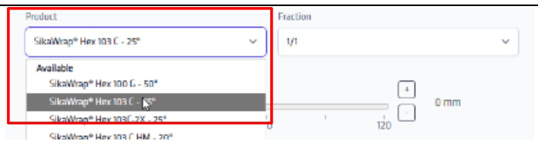


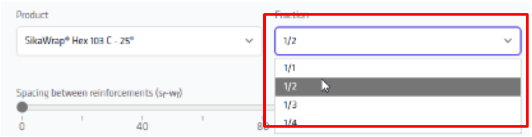
The possible FRP schemes are indicated in the upper-left corner of the panel Strengthening. The user must define the FRP wrapping scheme to be used in the calculation (refer to section 02.3.12.3).

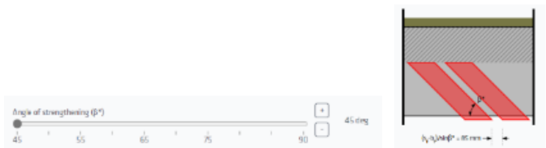
The available schemes are:

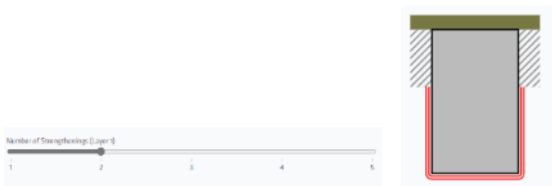
- **Full Wrapping** (SikaWrap® fabrics), in those cases where the 4 sides of a rectangular beam are accessible.
- **U-Wrapping** (SikaWrap® fabrics), valid for all the geometries.
- **2-sided configuration** (SikaWrap® fabrics or Sika® CarboDur® plates), valid for all the geometries.

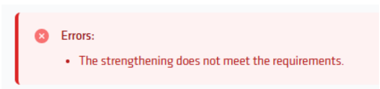
NOTE*: Availability of strengthening options may vary depending on the selected country catalogue and the* *section of the beam. For Rectangular not accessible from top and T-beam sections, “Full Wrapping” option won’t be available.*







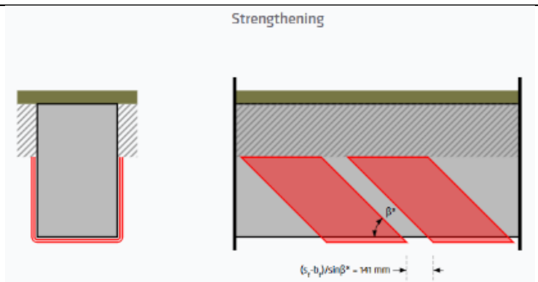




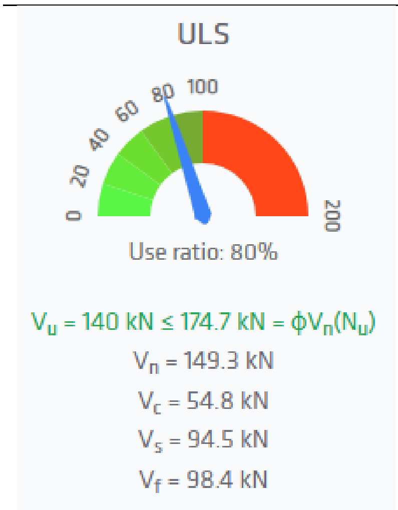
The user should define the following strengthening parameters:

- **Product**: The user selects which product to use from a dropdown menu
- **Fraction**: For some products, it is possible to utilize a fraction of the fabric's original width. For example, when selecting SikaWrap® XEX 103 C 25”, users may opt to utilize the full width or choose from 1/2, 1/3, or 1/4 of the width. This results in corresponding fabric widths of 12.5”, 8.33”, or 6.25”.
- **Spacing between strengthening**: User can decide to apply the shear strengthening either continuous or discrete. This slider sets the spacing between the strips. Moving the slider to the left (Spacing =0), the strengthening will be considered continuous. Spacing is measured perpendicular to the strips.
- **Angle of strengthening**: The software allows users to design the stripes at an angle as required. The slider enables users to select the inclination angle of the strips relative to the beam's axis.
- **Number of Strengthening Layers:** This slider allows users to choose the desired number of shear strengthening layers.
-

NOTE*: The software checks automatically the geometrical limits of the strengthening, according to the PRC ACI-440.2R-23. In case these limits are not fulfilled (see section 2.3) an error will be displayed .*



The software shows the reinforced section with FRP systems in two vertical views: one perpendicular and one parallel to the beam axis. This allows the user to view the number of layers, their arrangement, and the angle of the strips.



The Use ratio indicator for the ULS combination for the strengthened section , shows the final result of the calculation. A ratio below 100% indicates that verification is successful and the section meets requirements with the selected strengthening system and FRP amount.

Design shear force (**V_u**) is compared to the factorized strengthened resistant shear (**ϕV_n**).

For the strengthened section

$$\varphi V_n = \varphi\left(V_c + V_s + \psi_f V_f\right)$$

eq. 11.3b of PRC ACI-440.2R-23

$\psi_f V_f = 0.85$ for U-Wrap and s sides application

$\psi_f V_f = 0.95$ for completely wrapped application

Product details

Product	SikaWrap® Hex 100 G - 50"
Fraction	1/1
Type of fibers	G
Width (w_f)	1270 mm
Single layer thickness (t_f)	1 mm
Elastic modulus (E_f)	76 GPa
Ultimate strain (ε_{fu}^*)	18.2 ‰
Strength (f_{fu}^*)	1383 MPa
Environmental reduction factor (C_E)	0.75

For the selected FRP systems (SikaWrap®, Sika® CarboDur®, etc.), all relevant physical and mechanical properties are provided, including the environmental reduction factor **C_E**.

3.7.7 PRINTOUT

A full printout in PDF is generated after the project is completed.

Print out contains:

- Design data
- Element data
- Loads
- Strengthening details
- Results

4 LEGAL NOTE

SIKA SERVICES TH
TM Engineered Refurbishment
Tuffenwies 16
8048, Zurich
Switzerland
www.siks.com

Version given by
Antonino Montalbano
Phone: +39 335 5212 918
Mail: montalbano.antonino@it.sika.com