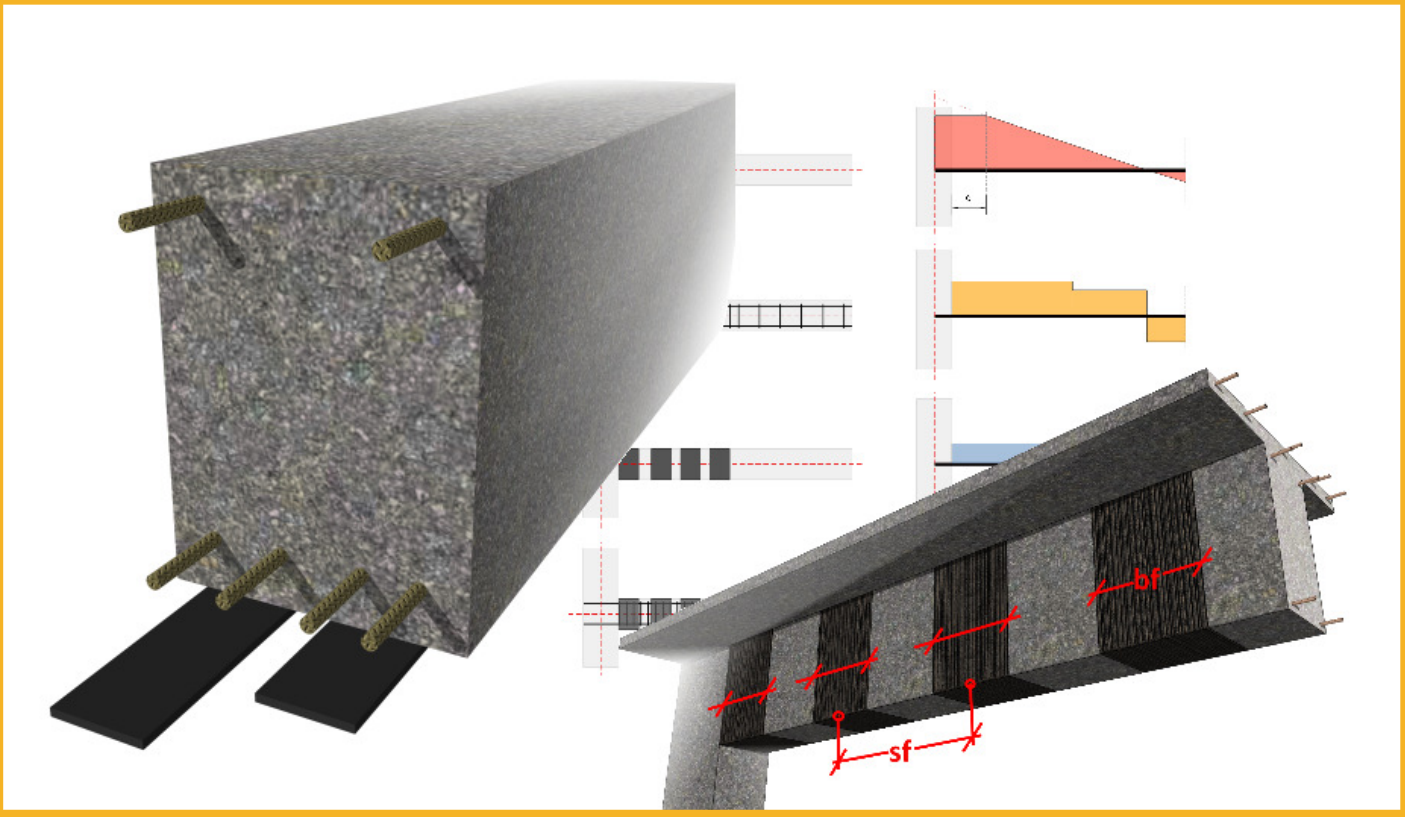


USER GUIDE

Sika® CarboDur® calculation software based on ACI 440.2R-08.

DECEMBER, 2015 / 2.0 / SIKA SERVICES AG /

DOCUMENT FOR THAILAND

BUILDING TRUST

TABLE OF CONTENTS

1 INTRODUCTION

The aim of this software is to assist the user in calculating the CFRP dimensions required to provide (a) flexural strengthening, (b) shear strengthening and (c) column confinement. These three topics are discussed in the next sections, which present the theoretical basis of the calculations.

The calculation procedures employed in this program are based on the ACI 440.2R-08*: "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures.*

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

- ACI 318-14 318-14: 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 440.2R-08, 9.2)

These limits are imposed to guard again 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 must 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:

$$(\emptyset R_n)_{existing} \geq (1.1S_{DL} + 0.75S_{LL})_{new} \qquad (2.1.a)$$

In those cases where the deign 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:

$$(\emptyset R_n)_{existing} \geq (1.1S_{DL} + S_{LL})_{new} \qquad (2.1.b)$$

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 endurance (ACI 440.2R-08, 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.

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.

$$(R_n)_{existing,t=0} \geq (S_{DL} + S_{LL})_{new} \qquad (2.1.c)$$

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 440.2R-08, 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.

$$f_{fu} = C_E f^*_{fu} \quad (2.1.d)$$

$$\varepsilon_{fu} = C_E \varepsilon^*_{fu} \quad (2.1.e)$$

$$E_f = \frac{f_{fu}}{\varepsilon_{fu}} \quad (2.1.f)$$

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
Exterior exposure	Carbon	0.85
(Bridges, piers, unenclosed parking garages…)	Glass	0.65
Aggressive environment	Carbon	0.85
(Chemical plants, wastewater treatment plants…)	Glass	0.50

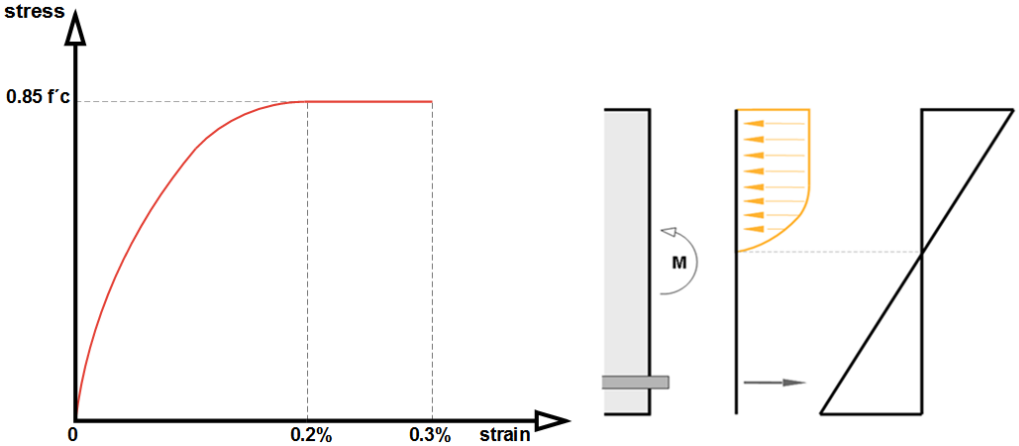
2.2 FLEXURAL STRENGTHENING

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 318-14** and **ACI 440-2R.08, 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:

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

$f_c = 0.85 f'c$ for 2‰ ≤ ε_c ≤ 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)

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

2.2.1 Serviceability (ACI 440.2R-08, 10.02.8)

Reinforced concrete members:

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

$$f_{s,s} \leq 0.80\, f_y$$

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

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

Prestressed concrete members:

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

$$f_{ps,s} \leq 0.82\, f_{py}$$
$$f_{ps,s} \leq 0.74\, f_{pu}$$

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

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

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).

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

2.2.2 Creep rupture and fatigue stress limits (ACI 440.2R-08, 10.02.9)

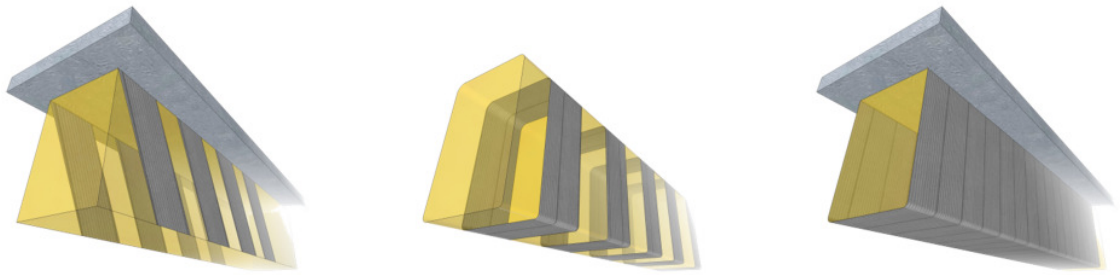
To avoid creep-rupture of the externally bonded or NSM reinforcement under sustained stresses or failure due to cyclic stresses and fatigue of the FRP reinforcement, the stress level in the FRP will be limited to the following values:

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

2.3 SHEAR STRENGTHENING

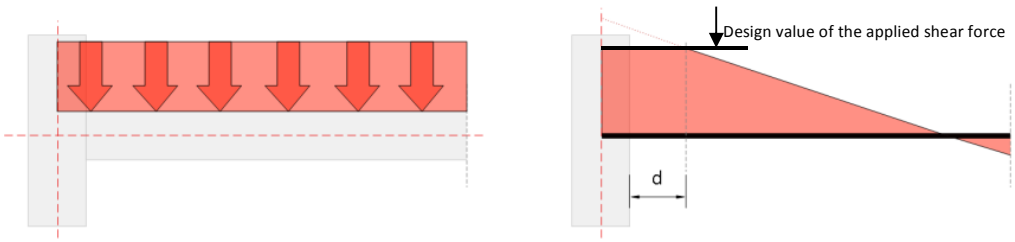
Shear strengthening of RC members using FRP may be provided through bonding the external reinforcement with the principal fiber direction as parallel as practically possible to that of maximum principal tensile stresses, so that the effectiveness of the FRP is maximized. For the most common case of structural 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.

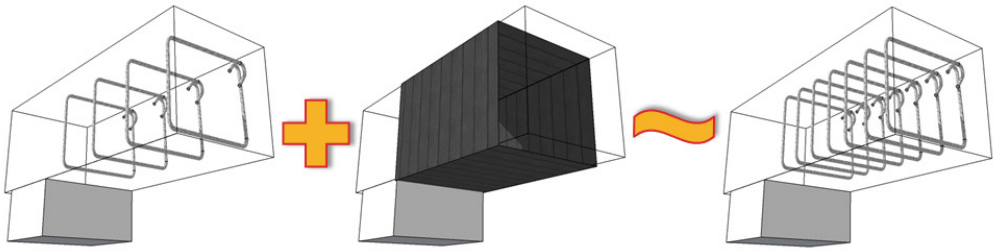


Closed jackets or properly anchored strips are always preferable compared with open jackets, as in the latter case CFRP premature debonding is usually expected; hence the effectiveness of the CFRP is reduced. 2-sided configuration provides the least effective performance due to the risk of debonding.

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 318-14.



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}.

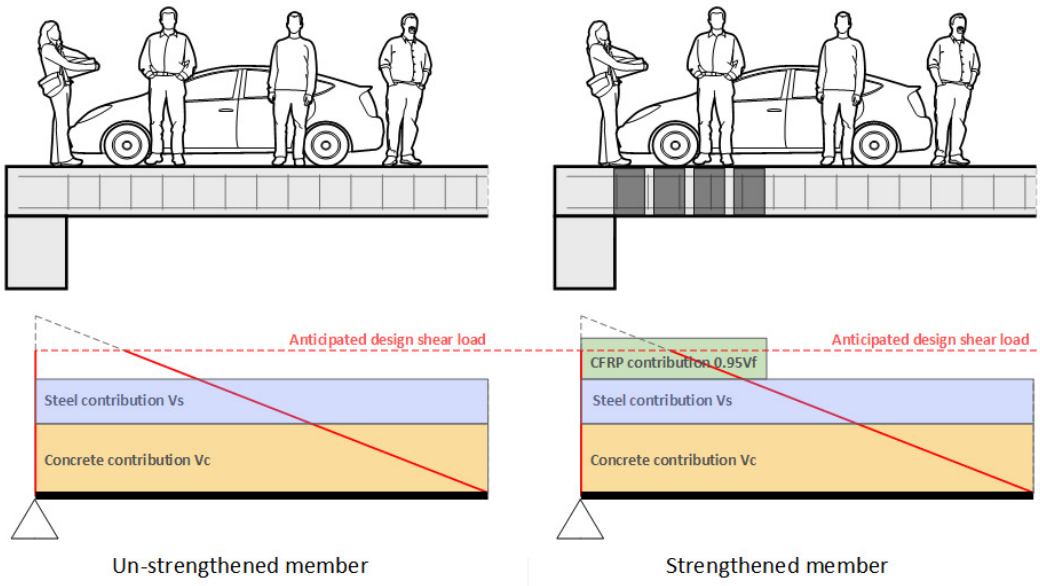


The effective strain depends on the degree of CFRP debonding when the shear capacity of the RC is reached; on in other words, on the type of anchorage (properly anchored CFRP, e.g. closed jackets, versus poorly anchored FRP, i.e. open jackets).

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

$$V_n = V_c + V_s + 0.95\, V_f$$

where V_f, the contribution of FRP to the member's shear capacity, is calculated according to ACI440 2R-08, section 11.4.



2.3.1 Strengthening limits (ACI 440.2R-08, 11.4.3)

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:

$$V_s + V_f \leq 0.66\sqrt{f'_c}\, b_w\, d$$

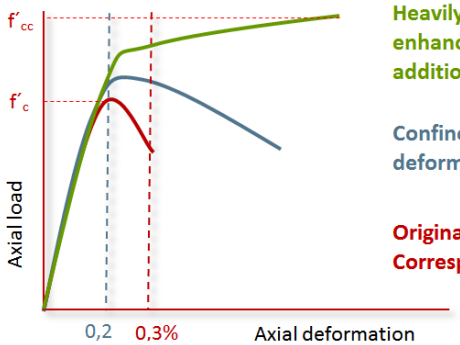
2.4 COLUMN CONFINEMENT

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.

In the case of circular columns, these goals can be achieved by applying external FRP jackets, either continuously over the surface, or discontinuously as strips. In the case of rectangular columns, confinement can be provided with rectangular-shaped reinforcement, with corners rounded before application. Note that rectangular confining reinforcement, although possible, 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 and rebar buckling.

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



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.

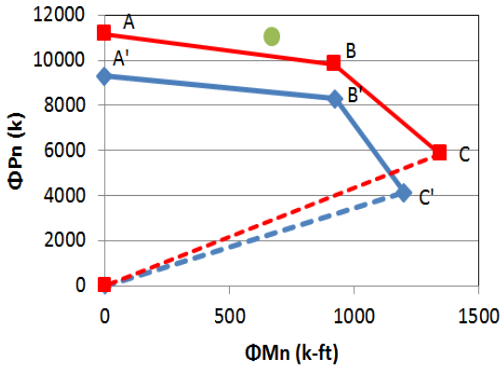
Confined concrete. The enhanced peak stress remains at ~0.2% deformation. The ductility is significantly increased.

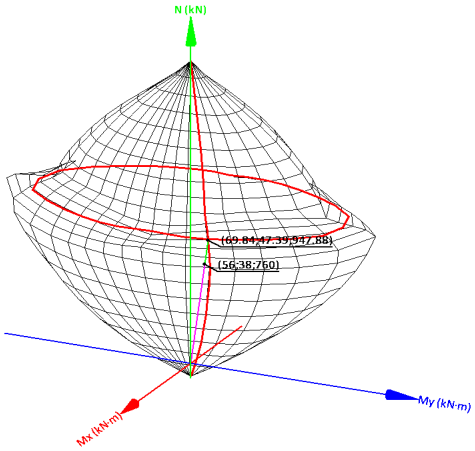
Original concrete. Peak Stress Corresponding to 0,2% deformation, ultimate strain 0,3%.

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-08, 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 440.2R-08, 12.2 (left).





2.4.1 Serviceability (ACI 440.2R-08, 12.1.3)

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 $0.60f_y$.

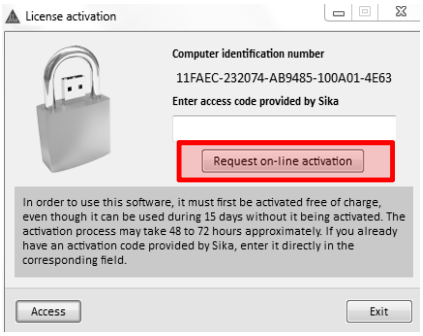
3 USE OF SIKA® CARBODUR® SOFTWARE

3.1 INSTALLATION AND ACTIVATION

Unzip the compressed folder and run the installation file "*Install Sika Carbodur.exe*". Once done, the software is fully available for evaluation purposes for 15 days.

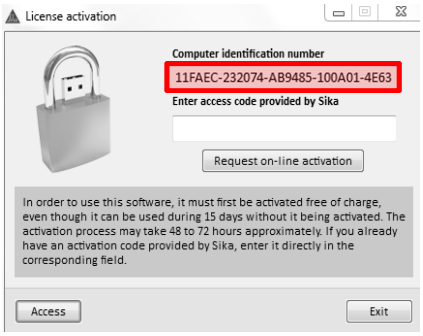
The user can access the software freely within the evaluation period by selecting the "Access" option located in the bottom-left corner:

In order to proceed to the definitive activation of the free license, select the “Request on-line activation” option and fill the activation form. Your software will be activated remotely by your local Sika company within the next 48h-72h.



After this, the software will not display the activation box any longer.

In case your software´s license is not activated within the following 72 hours, send an e-mail to rataporn.r@th.sika.com including your contact information (name, company, phone number, city and country) and the Computer Identification Number displayed on top.



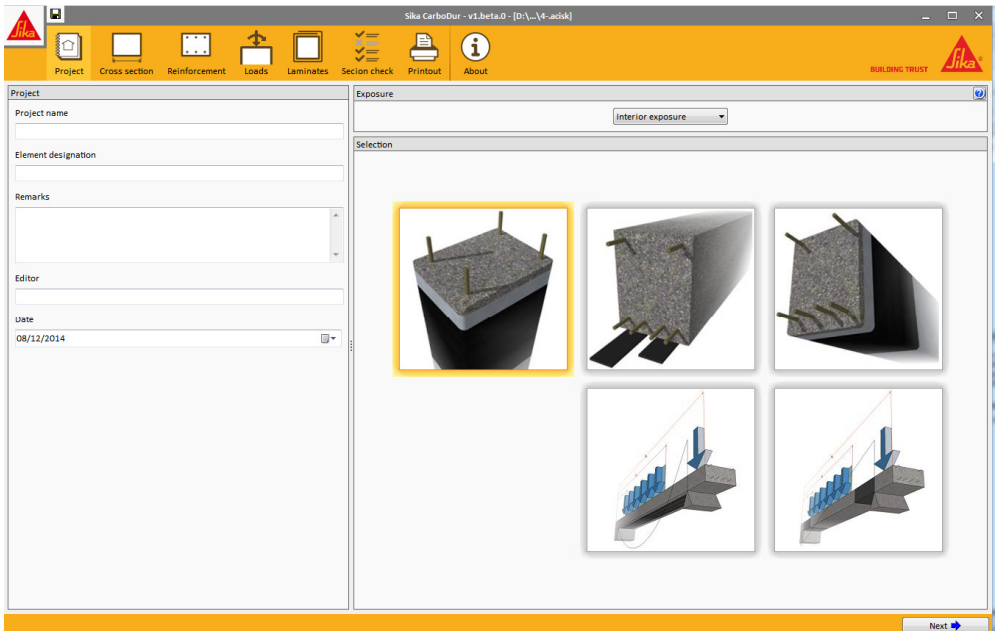
3.2 INTRODUCTION

The software package **Sika® CarboDur®** is a user friendly, simple and reliable design tool for the selection of required CFRP dimensions to provide flexural strengthening, shear strengthening or confinement for reinforced concrete sections and beams (reinforced or prestressed).

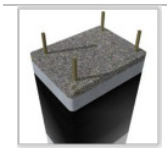
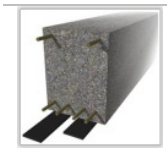
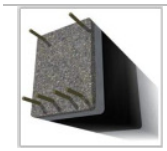
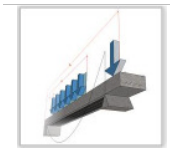
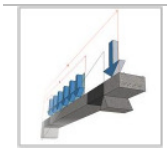
When the program starts, the user is requested to select language, country and unit system. By selecting the country, the software database is adapted to the available Sika® strengthening product range for that specific territory.

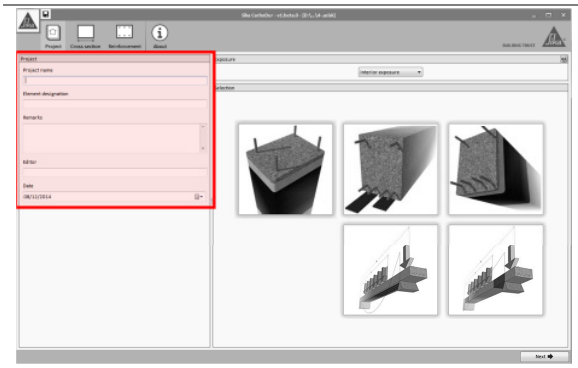
3.3 PRELIMINARY INFORMATION

In the main screen, the user is requested to select one specific kind of calculation, and to enter the general information concerning the project:



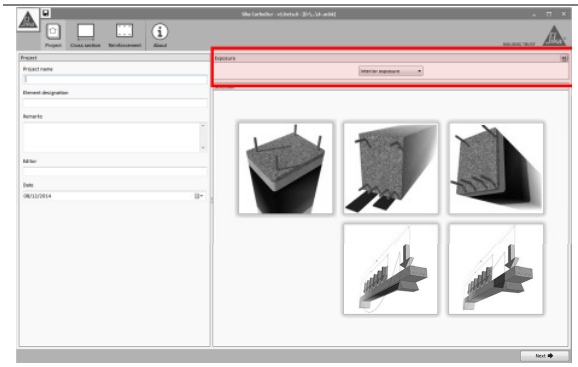
The selection of the type of strengthening is done by selecting one of the main drawings shown in the main screen:

	**Column strengthening by means of CFRP confinement.** Calculation will comprise the mechanical enhancement of a RC member under axial loads. The dimensioning of the SikaWrap® confinement will take into account either pure axial load or a combination of axial load + bending (X axis, Y axis or both).
	**Flexural strengthening of the critical section in a beam.** Calculation includes the dimensioning of the necessary FRP, based on the anticipated bending moments acting on the critical section of a RC / Prestressed beam.
	**Shear strengthening of the critical section in a beam/rectangular column.** Calculation includes the dimensioning of the necessary FRP, based on the anticipated shear forces acting on the critical section of a RC beam / rectangular column. The evaluation of the resistance of the unstrengthened section in case of fire is also included.
	**Flexural strengthening of beam** Software determines the distribution of the anticipated bending moments for the RC/Prestressed member, and calculates the necessary FRP sections and its arrangement along the beam.
	**Shear strengthening of beam** Software determines the distribution of the anticipated shear forces for the RC/Prestressed member, and calculates the necessary FRP sections and its arrangement along the beam.



The area located on the left comprises the information concerning the project (name, element designation, remarks, editor and date), which will be included in the subsequent printout documents.

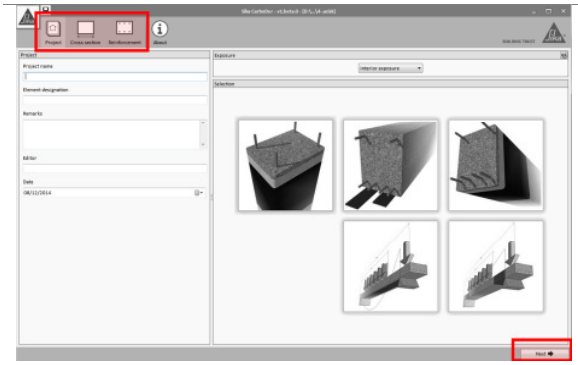
The length of the text string to enter can be restricted due to this.



The exposure conditions must be defined by the user. Three options are available, as indicated in ACI 440.2R-08, Table 9.1.:

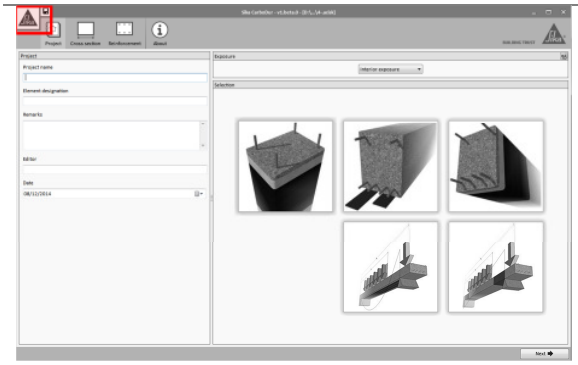
- Interior exposure
- Exterior exposure (bridges, piers, unenclosed parking areas, etc.)
- Aggressive environment (chemical plants, water treatment plants, etc.)

The exposure conditions will determine the reduction factor for the FRP system and therefore, the design material properties.



Regardless of the type of strengthening selected, the calculation process is organized into successive stages, which are shown in the icons situated at the top of the screen. The type and quantity of stages vary as a function of the selected strengthening method and the data introduced by the user.

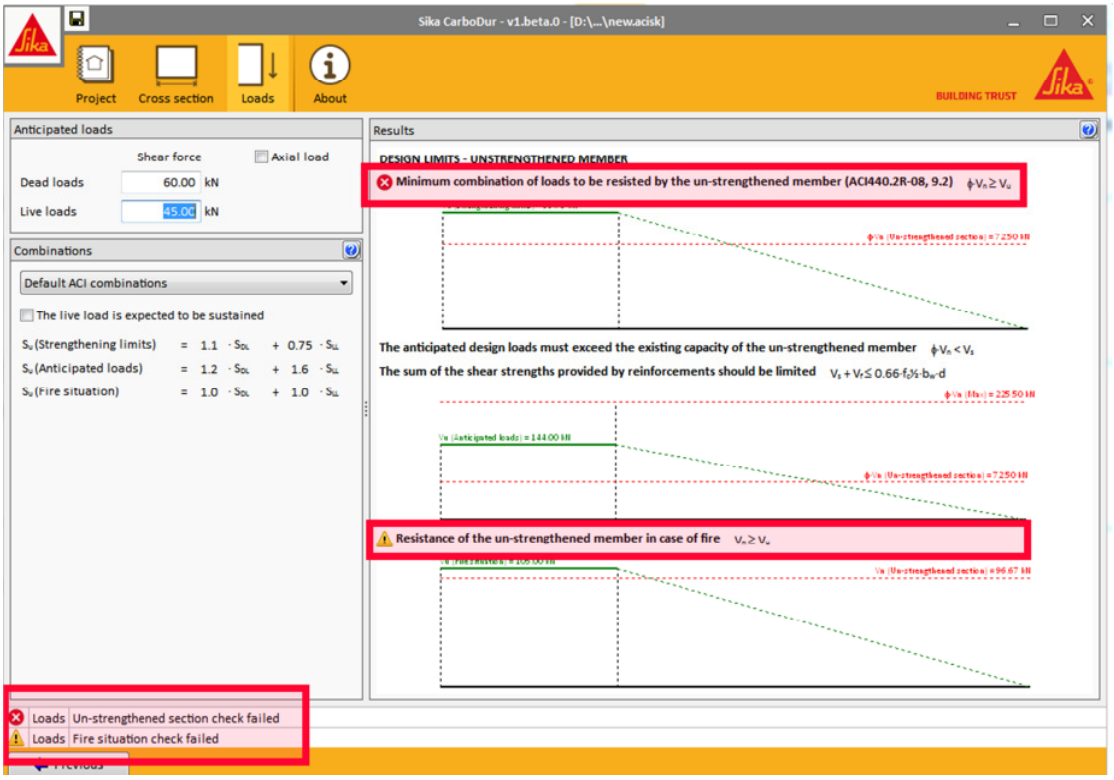
Alternatively, the user can move forwards/backwards to different stages by clicking the button(s) shown on the bottom-right or bottom-left (“next” & “previous”).



Throughout the calculation process, the user can open/save the corresponding project file pressing the Sika logo in the top-left corner. Alternatively, the small icon showing a floppy disk allows the instant saving of the file.

Throughout the calculation process, some conditions may not meet the certain limitations and/or some logical parameters.

This information will be shown in the main screen, as well as at the bottom:



This symbol indicates that the condition is not satisfied. However, the user is allowed to complete the calculation, and this situation will be indicated in the printout document.

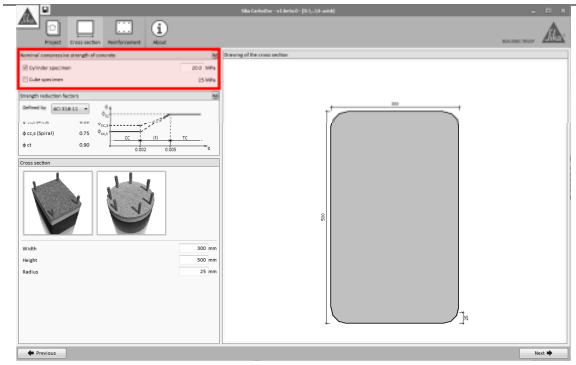
This symbol indicates that some critical or logical condition is not satisfied. The calculation cannot be done unless it is corrected.

For certain drawings, this group of symbols will allow the user to zoom in/out the image and export them into common file formats (CAD, Bitmap, EMF, etc.)

3.4 COLUMN CONFINEMENT

This module comprises the calculation of the necessary FRP confinement for a rectangular or circular RC section subjected to axial or axial+bending forces. FRP jackets enhance the strength of the structural member in terms of improved peak load resistance and ductility.

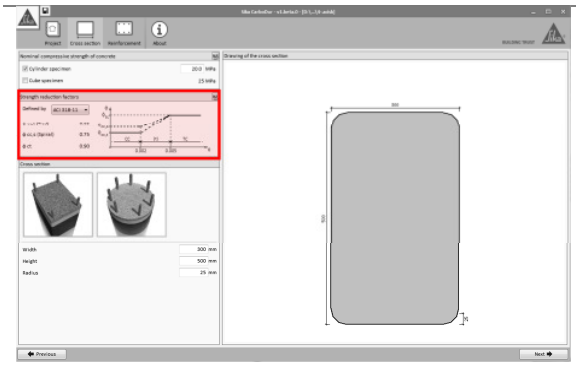
3.4.1 Cross section



The compressive strength of the concrete (f'_c) must be defined by the user.

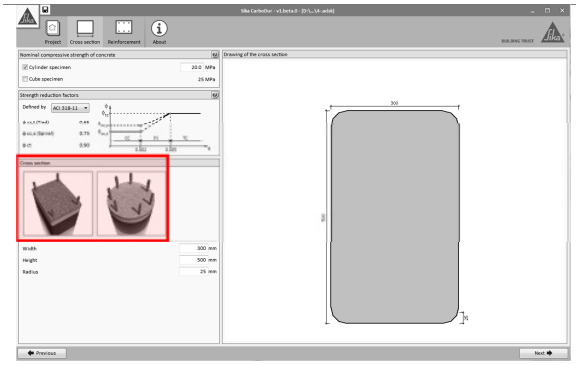
The strength is commonly based on cylinders, as indicated by ACI 318. However, the software allows entering strengths obtained from cube specimens, and proceeds to transform them into the equivalent cylinder strength (EN-1992-1-1).

Please note that the results provided in the printout documents will correspond to cylinder strength (ACI 318).



Design strength provided by a member shall be taken as the nominal strength in accordance to ACI 318 and ACI 440.2R-08, multiplied by the strength reduction factor Φ.

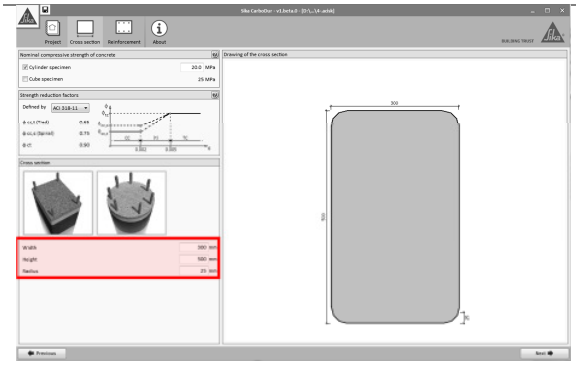
The reduction factors follow ACI 318 for compression-controlled and tension-controlled section as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary.



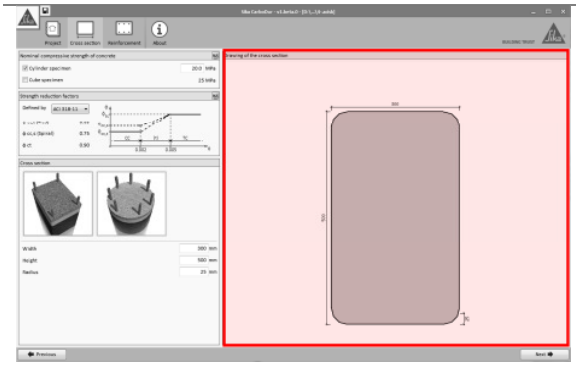
The drawings on the left area are used to select the cross-section of the member.

The rectangular section comprises some geometrical limits, such as:

- The aspect ratio of the section cannot exceed 2:1
- The largest side cannot exceed 900mm.
- The corner must be rounded with a minimum radius of 13mm.

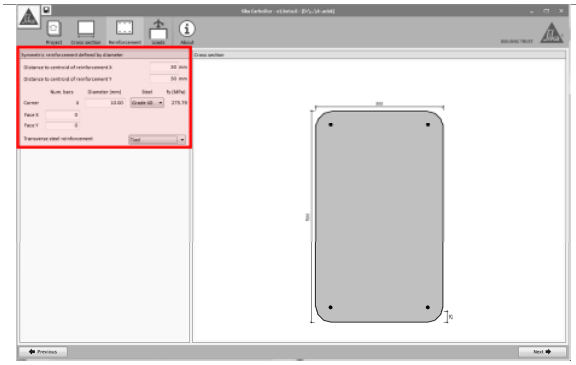


The dimensions of the cross section are entered in the boxes situated below the selection drawings.



Finally, the main screen shows the final display of the cross section as defined by the user.

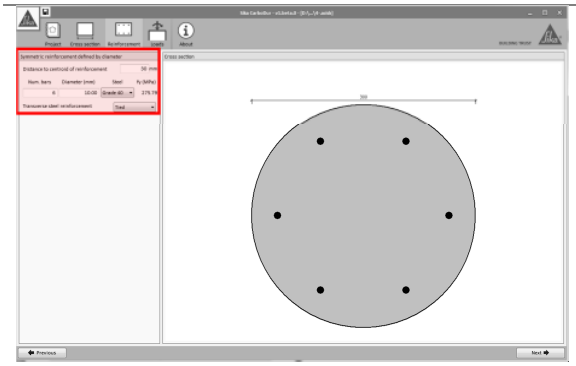
3.4.2 Reinforcement



For rectangular sections, the reinforcement is defined by the steel located in the corners. Additionally, intermediate steel bars can be displayed along the horizontal and vertical sides of the section.

The kind of steel can be indicated either by selecting one of the existing grades, or user-defined.

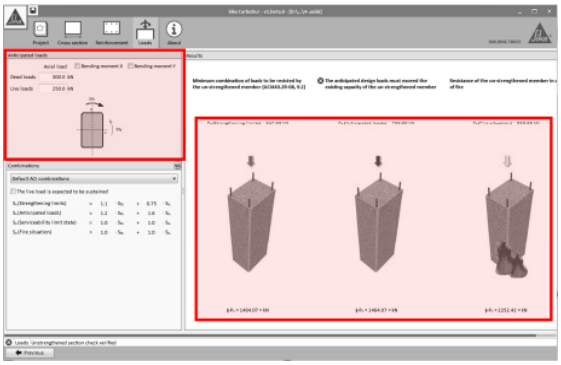
The transverse steel type (spiral/tied) also need to be be declared, as the reduction factors are directly related to this (ACI 318).



In case of circular columns, the vertical bars are distributed homogeneously around the perimeter.

Please note that concrete cover is not entered, but the “mechanical cover”, which is taken from the centroid of the reinforcement.

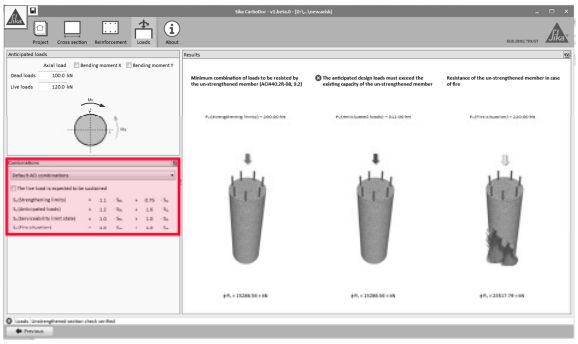
3.4.3 Loads



Pure axial loads are requested as default. Optionally, the user can activate the options corresponding to “Bending Moment X / Y”, which allow to enter additional bending moments acting in 1 or 2 different directions.

If simply “Axial load” is entered, some schematic drawings will be displayed on the main screen, indicating the three initial conditions that are being evaluated automatically by the software for the existing, unreinforced member.

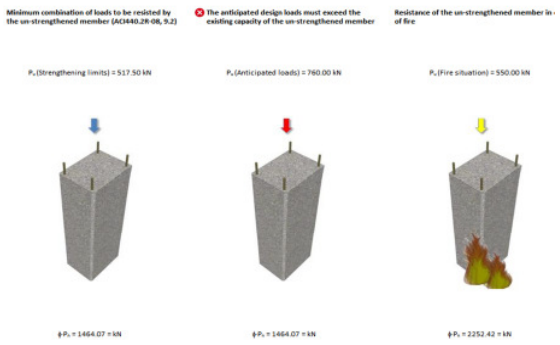
The information displayed on each figure indicates the different combinations of loads (declared by the user) to be examined. The figure at the bottom shows the max/min value to meet.



The different combinations of loads are indicated on the left hand side of the screen, showing the default combination factors as indicated in ACI 318 and ACI 440.2R-08.

- **Strengthening limits** concerns the minimum load to be assumed by the RC member in case that the CFRP system is damaged. This value is altered if the live load is expected to be sustained. Please checkon page 4 for additional information.
- **Anticipated loads** indicate the design load to be expected after the FRP strengthening.
- **Serviceability Limit State** shows the combination of service loads.
- **Fire situation** indicates the load level in case of a fire scenario.

The combination factors for each case can be adjusted manually by the user if necessary.

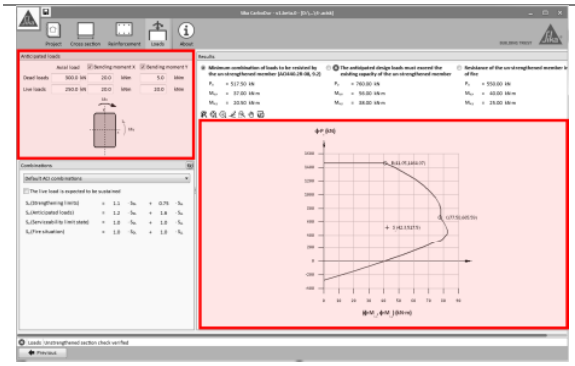


The first drawing (left) verifies if the existing member is able to support a reduced combination of the loads (top) entered by the user. The admissible load level is indicated at the bottom. This condition must be fulfilled to continue with the calculation.

The scheme in the center verifies that the requested loads (top) exceed the strength of the existing, unreinforced member (bottom). This condition must be obviously verified to continue with the calculation.

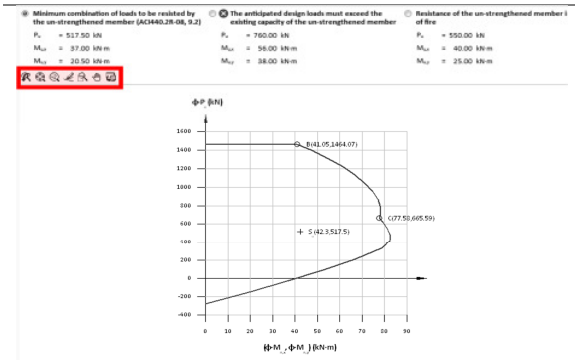
The right picture verifies if the acting load in case of fire can be initially carried by the unreinforced element (considering that the unprotected FRP is damaged due to the high temperatures). Otherwise the software will allow the calculation, but the printout document will remind the user of need for FRP protection.

Refer to section 2.1.2 for additional information.



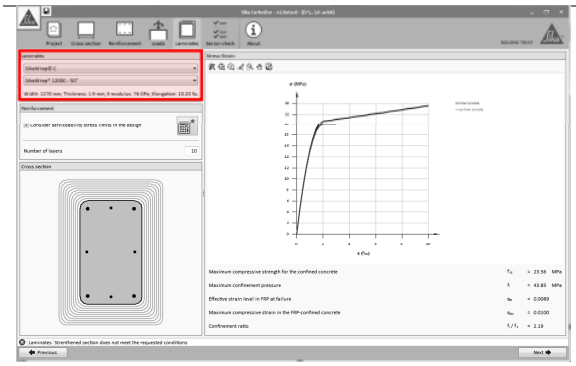
In case of a combination of axial load and bending moments, the software will display a 2D P-M interaction diagram showing the limit boundaries for the different situations as exposed below.

The 3 verifications are indicated on the top area of the main screen. The 3 interaction diagrams can be switched by clicking the selection buttons beside the different checks on top.



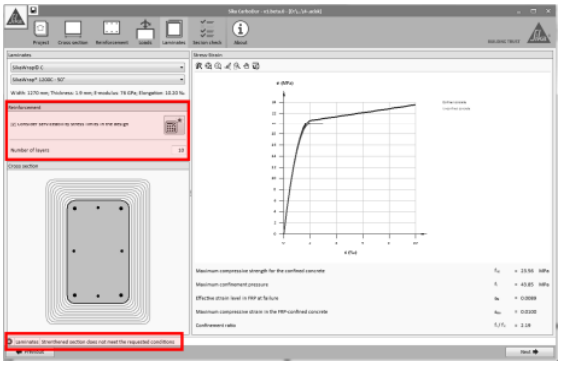
The user can zoom, pan and export the interaction diagrams into common formats (CAD, EMF, bitmap…) by clicking the different option buttons shown on the screen.

3.4.4 Laminates



The selection of the Sika® product range is done by means of the drop boxes displayed on the upper left corner.

Additionally, some simplified information concerning the selected system is shown inmediately below.

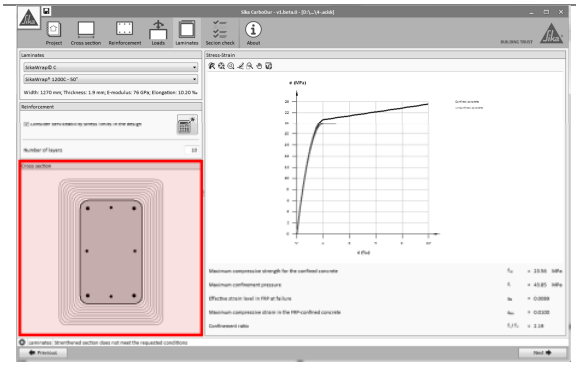


The calculation is done when the Calculator icon is clicked, showing the necessary number of plies corresponding to the selected SikaWrap® laminate.

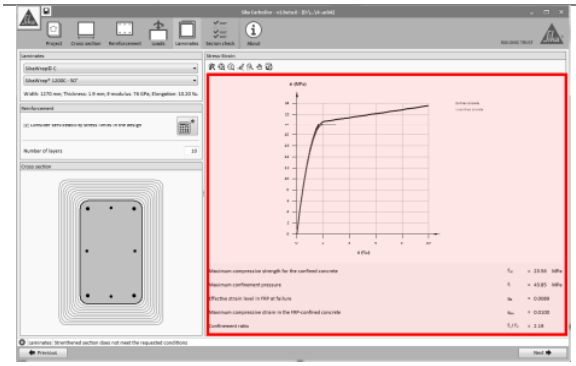
The option displayed on the left (Serviceability limits) will take automatically into account the limits concerning the stresses of the different materials (Refer to page 9 for additional information).

Please note that, in some cases, it may be necessary to use high-density fabrics and/or a significant quantity of layers to meet this limitation.

In case this option is disabled, the calculation will be based on the ultimate limit state of the member. However, the software will display a warning message indicating this fact.



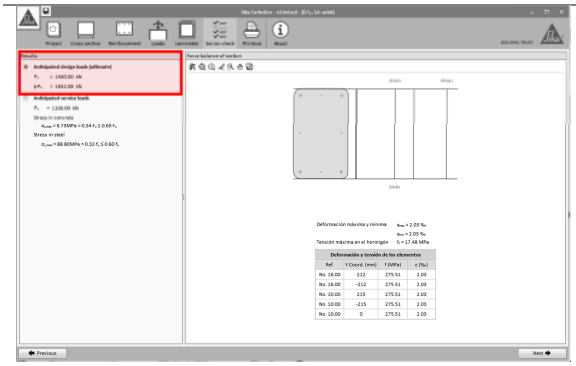
A schematic drawing on the left shows the necessary number of SikaWrap® fabrics.



The main screen displays the stress-strain model corresponding to the un-confined and confined concrete. Axial strain is shown in the horizontal axis and the stress is displayed in the vertical axis.

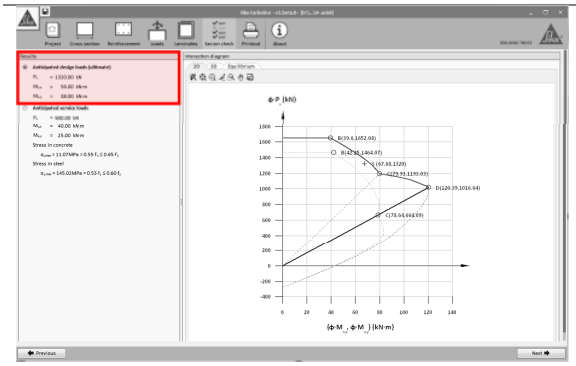
The figures displayed at the bottom indicate additional information regarding the most relevant parameters of the calculation.

3.4.5 Section check

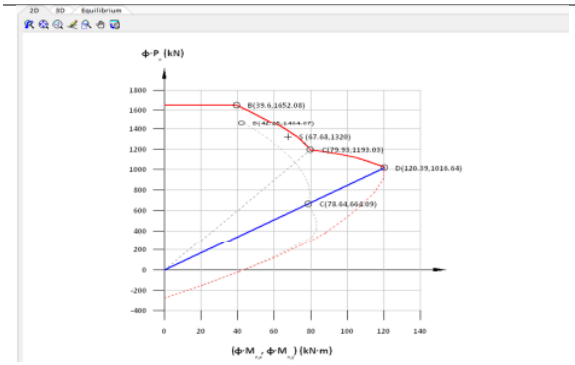


This section allows the user to know the resulting stress-strain states for the section under the combination of design (factored) loads or service loads.

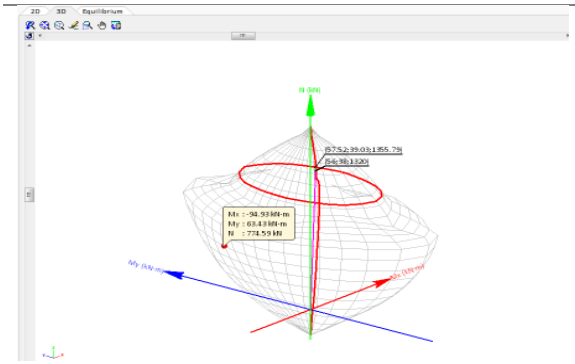
The information is displayed graphically and numerically on the main screen.



In the case that axial loads and bending moments act simultaneously (eccentricity larger than 0.1h), the information concerning the performance of the strengthened member under design loads will be substituted by an interaction diagram.



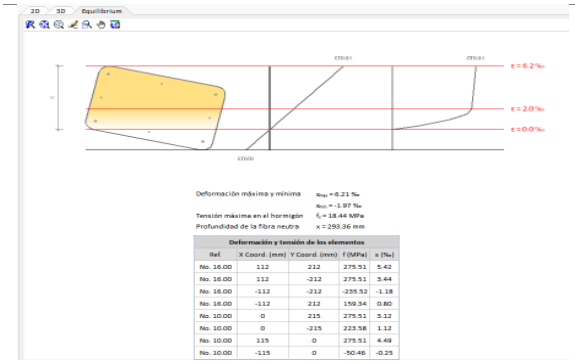
The 2D option shows simultaneously the ultimate strength of the un-strengthened (dashed) and strengthened (solid red) members, as well as the balance lines and the most relevant figures of the 2D profiles. The actual combination of design loads is shown in the same diagram as a cross symbol.



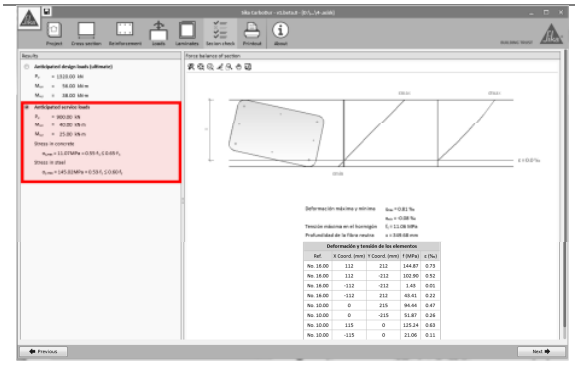
The 3D option displays the ultimate strength of the strengthened member, as well as the position corresponding to the combination of design loads.

The user can obtain information regarding different combinations of moments and axial loads by positioning the pointer in any of the vertex of the grid´s surface.

The 3D model can be rotated and zoomed, as well as exported to diverse graphic formats.

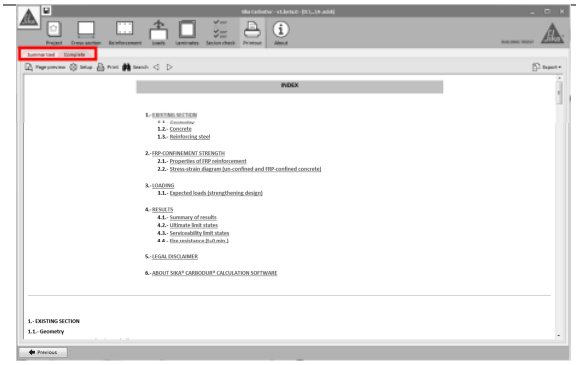


The tab named as “equilibrium” shows the stress-strain profile of the section under the combination of design loads.



In the same way, the option corresponding to “anticipated service loads” shows the stress-strain profile of the strengthened section under the service loads.

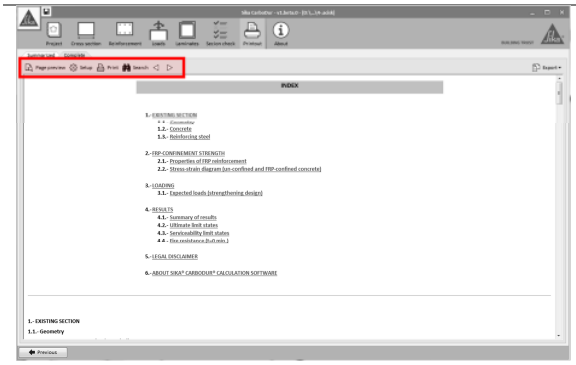
3.4.6 Printout



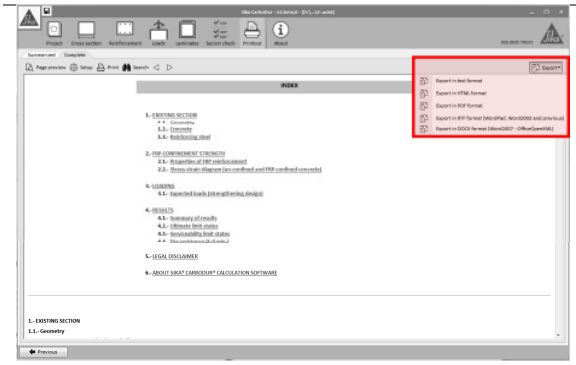
Two different types of printout documents can be printed or exported.

The summarized document includes a summarized information about the initial state, design loads and necessary FRP reinforcement (type and quantity).

The complete option additionally comprises all the intermediate calculations and verifications.



The icon situated on the upper-left corner allows to preview, print, configure and search information throughout the document.

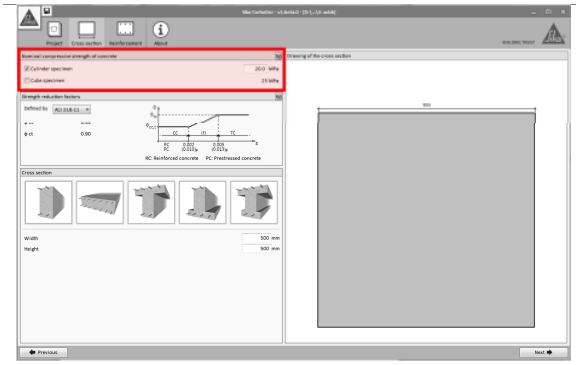


The icon located on the upper-right corner enables to export the document into different formats, such as:

- Text document.
- PDF document
- DOCX document
- RTF document
- HTML document.

3.5 FLEXURAL STRENGTHENING (SINGLE SECTION)

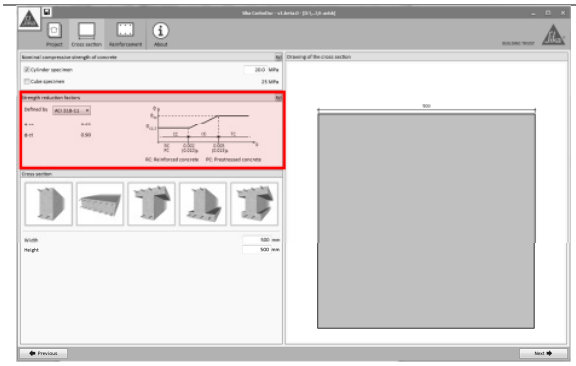
3.5.1 Cross section



The compressive strength of the concrete (f'_c) must be defined by the user.

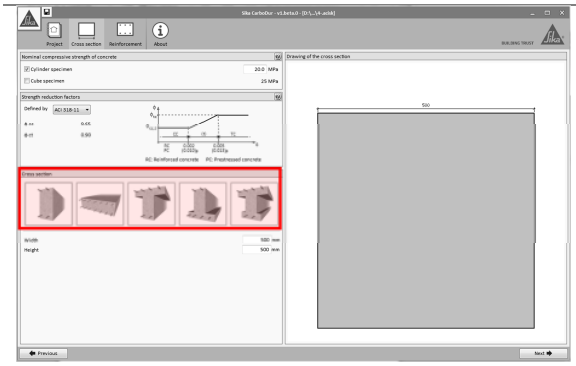
The strength is commonly based on cylinders, as indicated by ACI 318. However, the software allows entering strengths obtained from cube specimens, and proceeds to convert them into the equivalent cylinder strength (EN-1992-1-1).

Please note that the results provided in the printout documents will correspond to cylinder strength (ACI 318).



Design strength provided by a member shall be taken as the nominal strength of the member in accordance to ACI 318 and ACI 440.2R-08, multiplied by the strength reduction factor Φ.

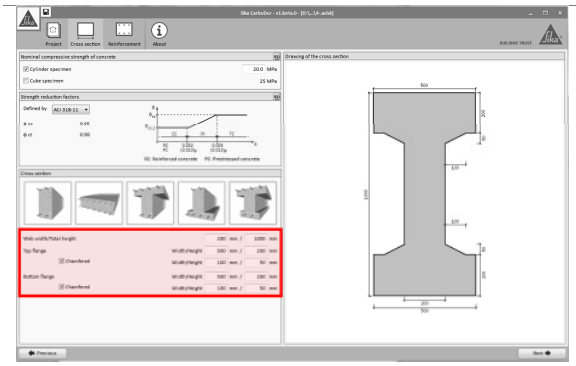
The reduction factors follow ACI 318 for compression-controlled and tension-controlled section as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary.



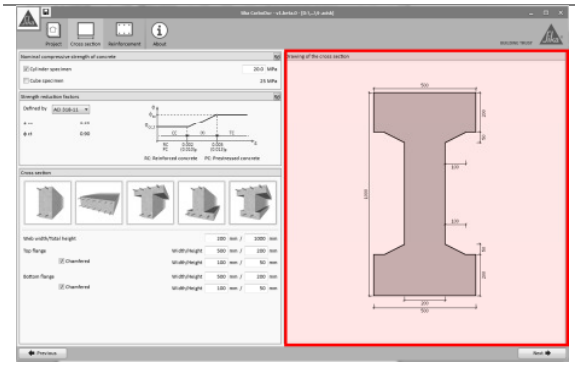
The user can select one of the following basic shapes for the element:

- Rectangular
- Slab
- T-beam
- Inverted T-beam
- Double-T beam

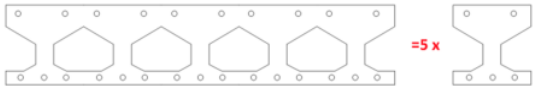
The selection of “slab” involves that the subsequent distribution of the steel bars and FRP laminates will be defined by its spacing instead of its quantity.



The main dimensions of the section are entered in the boxes shown beneath the schemes. Additionally, chamfers can be displayed for certain shapes, providing the possibility of defining complex geometries.

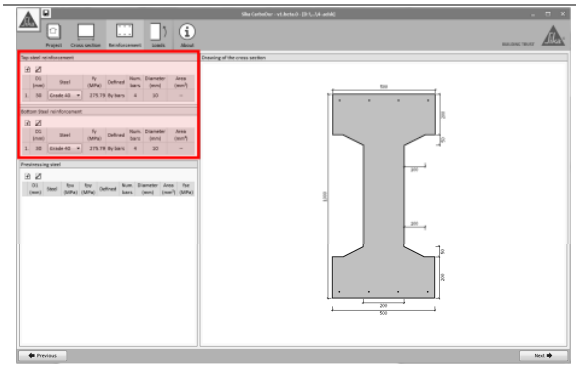


The final section and its dimensions are shown on the main screen.



Note that, by selecting a suitable geometry profile, the user can create parts of complex elements.

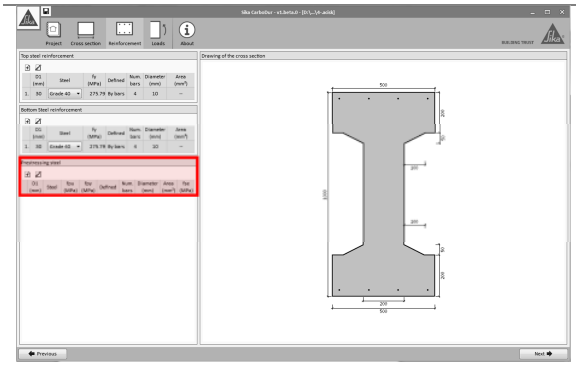
3.5.2 Reinforcement



The definition of the top and bottom steel bars is done individually for each layer, comprising the following parameters:

- Distance from the centroid to the concrete surface.
- Steel grade or yielding strength (user-defined)
- Steel section, defined by number and diameter in the entire section.

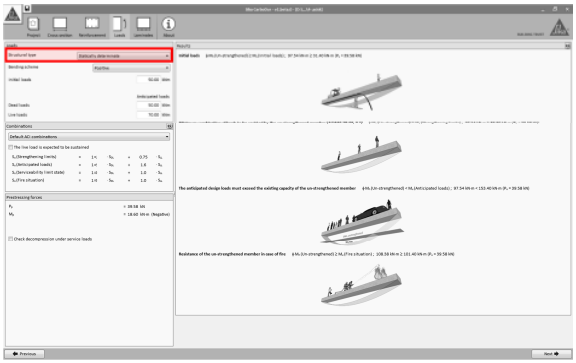
The quantity of steel layers is not restricted.
Note that, in case of slabs, the steel bars are not defined by its quantity, but by its spacing.



Additionally, bonded prestressed steel can be defined.

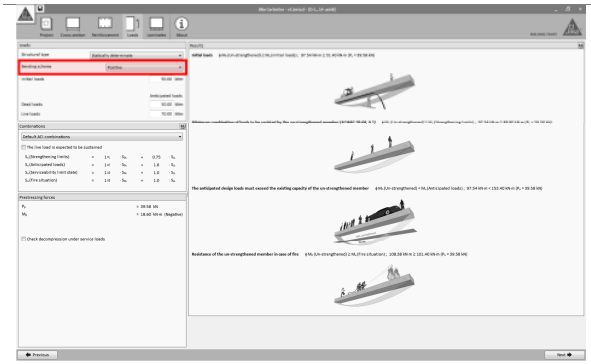
The user must verify the mechanical characteristics of the prestressing steel, and indicate the effective stress in the steel at the moment of strengthening (f_{se}), which corresponds to the original prestressing stress minus the corresponding stress relaxation at the moment of strengthening.

3.5.3 Loads

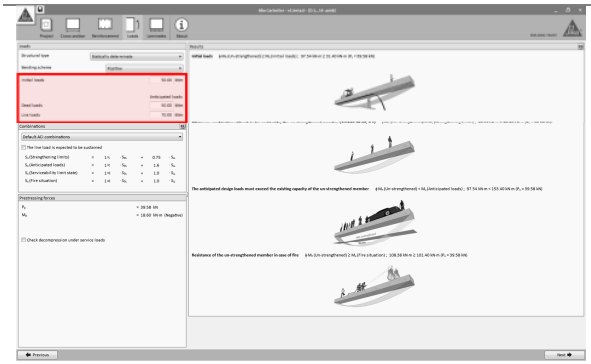


The user must indicate if the member is statically determinate or indeterminate.

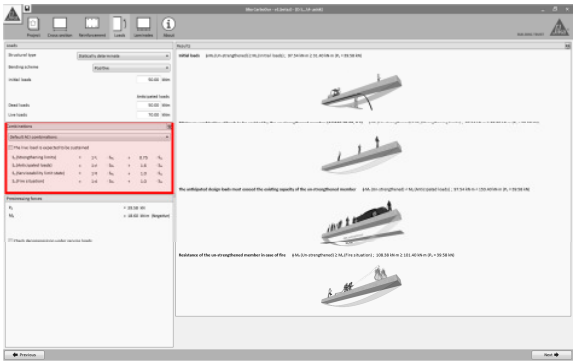
- In case of a statically determinate member, the software will provide automatically the prestressing force and moment exherted by the prestressing. Additionally, solutions based on post-tensioned Sika® CarboStress® systems will be available for the calculation.
- Otherwise, the user must enter manually the effective force and moment in the section for a prestressed beam. Only CFRP solutions based on bonded or NSM alternatives will be available in this case.



CFRP strengthening is feasible either for negative bending moment or positive bending moment. The kind of calculation must be chosen in the corresponding dropdown box.



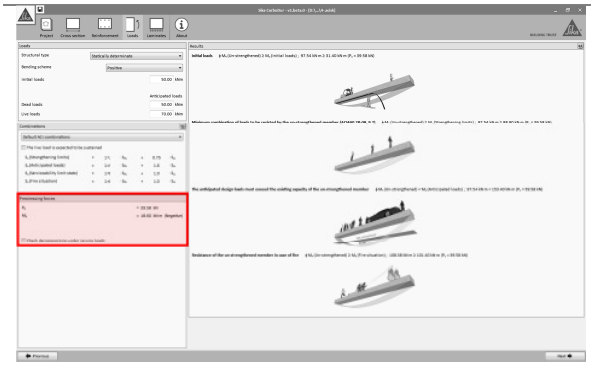
- The initial loads correspond to the acting, unfactored loads during the strengthening. Those loads will mainly correspond to dead loads for most of the situations.
- Dead loads and Live loads correspond to the anticipated service loads (unfactored) to be assumed by the strengthened element.



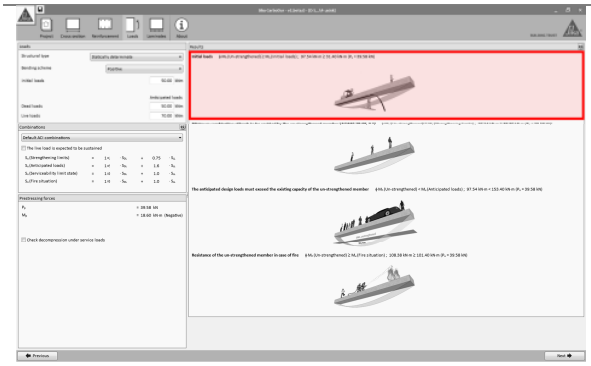
The different combinations of loads are indicated on the left side of the screen, showing the default combination factors as indicated in ACI 318 and ACI 440.2R-08.

- **Strengthening limits** concerns the minimum load to be assumed by the RC member in case that the CFRP system is damaged. This value is altered if the live load is expected to be sustained. Please check page 6 for additional information.
- **Anticipated loads** indicate the design load to be expected after the FRP strengthening.
- **Serviceability Limit State** shows the combination of service loads.
- **Fire situation** indicates the load level in case of a fire scenario.

The combination factors for each case can be adjusted manually by the user if necessary.

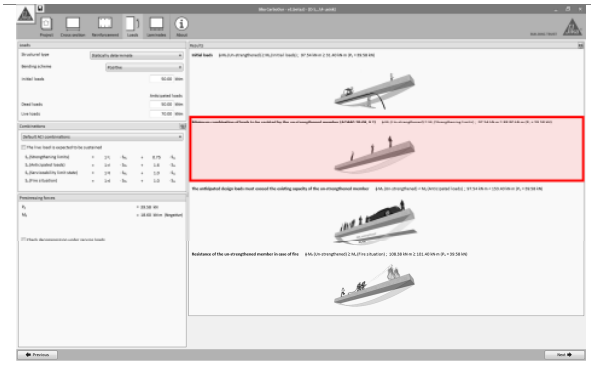


In case of prestressed members, the force and moment as resulting of the prestressing will be shown below the ACI combinations. For statically indeterminate members, the effective values must be manually entered by the user.

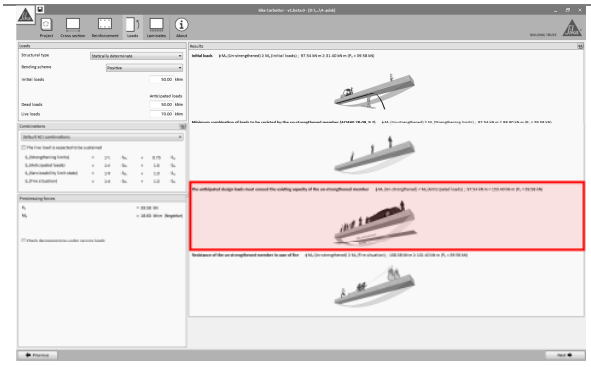


The main screen displays the preliminary checks concerning the performance of the unstrengthened member when compared to the anticipated loads entered by the user.

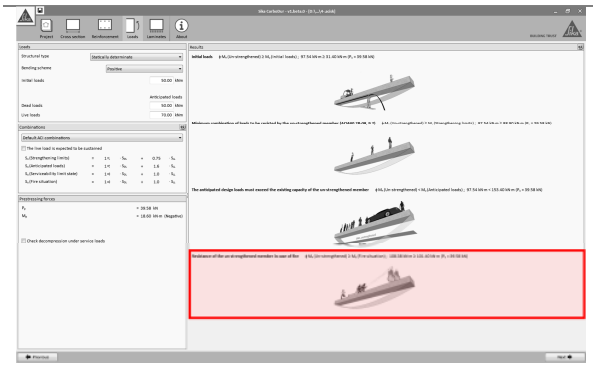
The first verification comprises the initial loads during strengthening. The software checks that those forces do not exceed the initial strength of the un-strengthened element. This condition must be fulfilled to continue with the calculation



The second condition verifies if the existing member is able to support a reduced combination of the loads entered by the user (Refer to page 4 for additional information). This condition must be fulfilled to continue with the calculation



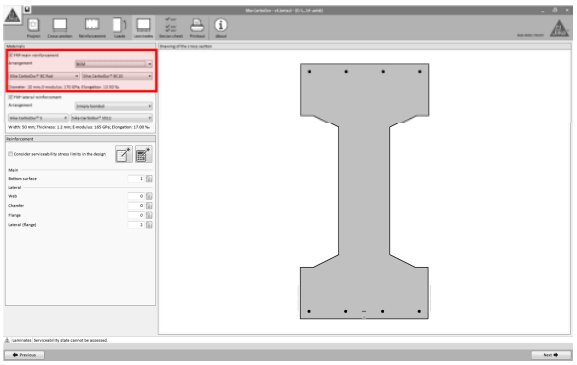
The 3rd scheme checks that the requested loads exceed the strength of the existing, unreinforced member. This condition must be obviously verified to continue with the calculation.



The last picture shows if the acting load in case of fire can be initially assumed by the unreinforced element (considering that the unprotected FRP is damaged due to the high temperatures). Otherwise the software will allow the calculation, but the printout document will remind the need of protection for the FRP.

Refer to section 2.1.2 for additional information.

3.5.4 Laminates



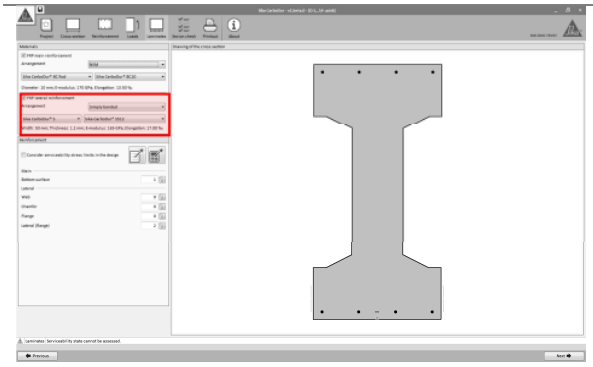
FRP main reinforcement:

The user must select the type of FRP to be displayed in the tensioned face of the element (main reinforcement). This face will correspond to the bottom surface in case of positive bending moments, and the surface on top in case of negative bending moments.

The first selection comprises the selection of the FRP display:

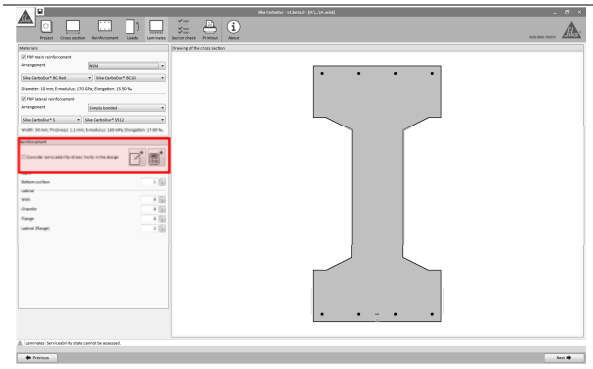
- Externally bonded application
- NSM (Near Surface Mounted) application
- Post-tensioned CFRP (Sika® CarboStress) for statically determinate beams.

Once the selection is done, the user is requested to select the FRP range (e.g. SikaWrap®, Sika CarboDur®, etc.) and the type of cross section to be used for the calculation.



FRP lateral reinforcement:

The second stage comprises the option to display additional FRP laminates on alternative locations (e.g. both sides of the beam, perimeter of the flanges, etc.). The selection follows the same principle and steps, those used for the main reinforcement.



The dimensioning of the FRP reinforcement can take into account the Serviceability stress limits by enabling the corresponding option (otherwise it will be based only on the Ultimate Limit State of the member).

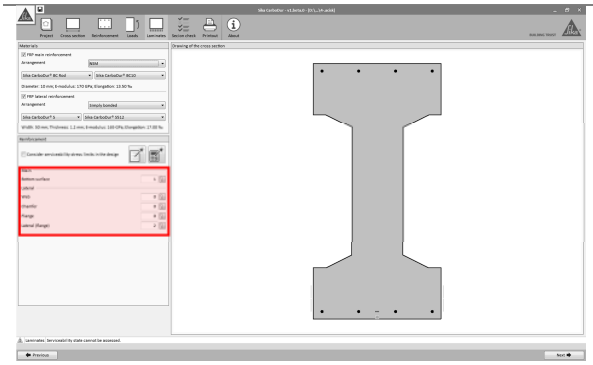
The calculation can be done in three different ways:

- **Automatic calculation**, by clicking the calculator icon. The software will automatically define the number of the necessary CFRP laminates, by means of the cross-sections selected previously by the user.

  The software will determine the necessary number of laminates as “Main reinforcement”. If the main

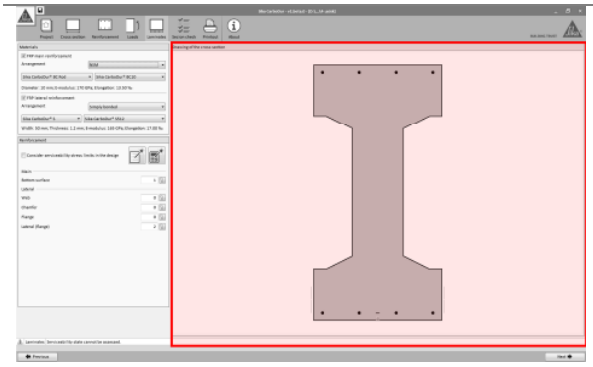
reinforcement is not enough to achieve the necessary strength, the software will automatically display additional FRP laminates as lateral reinforcement.

- **Semi-Automatic calculation**. By clicking the "paper list" icon, the software will show the different combinations of FRP sections to be displayed as "main reinforcement" that meet the requested strength. Those sections correspond to the Sika® product range selected by the user in the "main reinforcement" section.



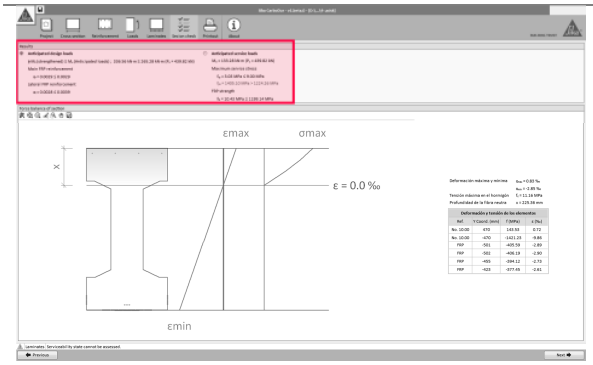
- **FRP arrangement defined by the user:** the user can define manually the number and type of FRP laminates to be displayed.

The locks shown beside the boxes are used to block the value in case of an automatic calculation. If the lock is blocked, that variable will be maintained unalterable in case of using the "Automatic Calculation".

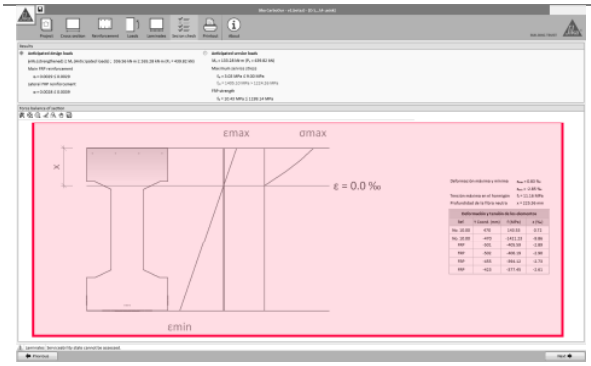


Finally, the main screen will show the necessary FRP arrangement as per the results of calculation.

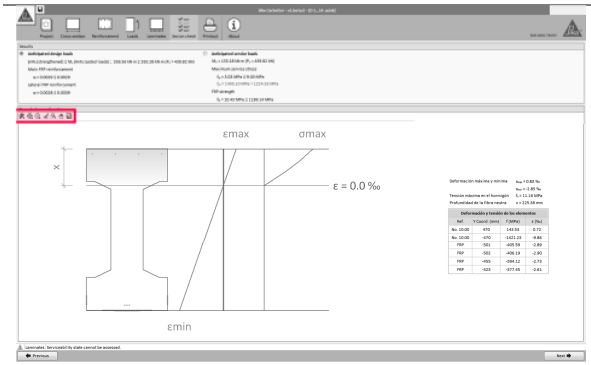
3.5.5 Section check



This section allows the user to know the resulting stress-strain states for the section under the combination of design (factored) loads or under service loads.



The information is displayed graphically and numerically on the main screen.



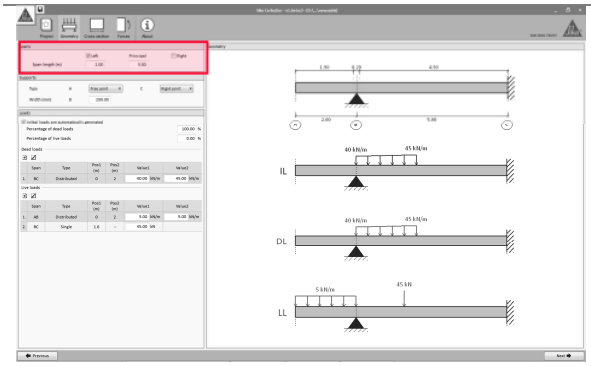
The graphic information can be moved, zoomed and exported to different format by means of the icons displayed on the left corner.

3.5.6 Printout

Refer to section 3.4.6.

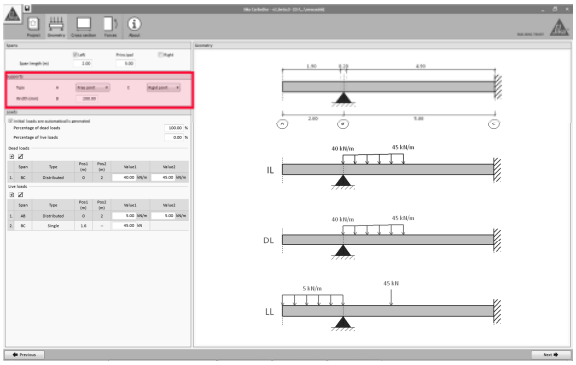
3.6 FLEXURAL STRENGTHENING (STRUCTURAL MEMBER)

3.6.1 Geometry



The calculations will be done for one single span (principal). However, additional left&rigth spans can be defined in order to take into account the influence of the loads and moments displayed on them.

This arrangement is done by selecting/unselecting the boxes located on the upper-left corner of the screen. Additionally, the lengths corresponding to the main and auxiliary spans must be declared.

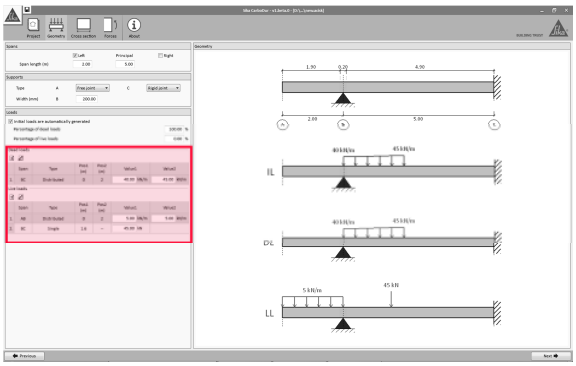


The second stage comprises the definition of the supports.

- Free Joint (Cantilever)
- Hinged Support
- Rigid Joint

The width corresponding to the supports at both sides of the principal span must be entered (in case they correspond to hinged joints)

Please note that the calculation of elements with prestressed steel and/or post-tensioned CFRP (Sika® CarboStress) is only allowed for simply-supported members comprising a single span.



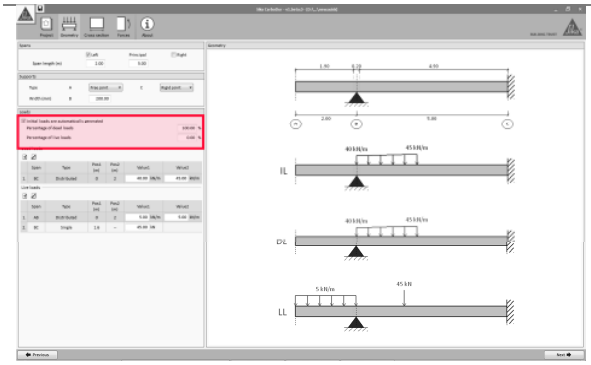
The arrangement of the un-factored dead and live loads along the element is done as follows:

- Span: the user must select the span where the loads will be displayed.
- Type of load

-Distributed (for rectangular, triangular and trapezoidal distributions; initial and final sections and the loading should be defined)

-Single load. Position and magnitude must be indicated.

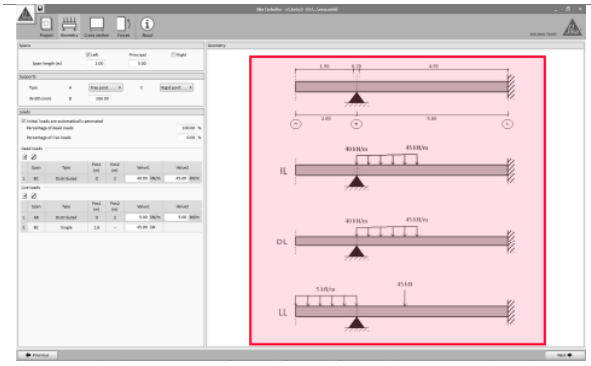
-Bending moment: Position and magnitude must be indicated.



The initial, un-factored loads acting during strengthening must also be defined.

The software provides a simplified option, which comprises a percentage of the live and dead loads as defined by the user (0% live loads and 100% dead load as usual).

Otherwise, the user must define manually the distribution and magnitude of the initial forces.



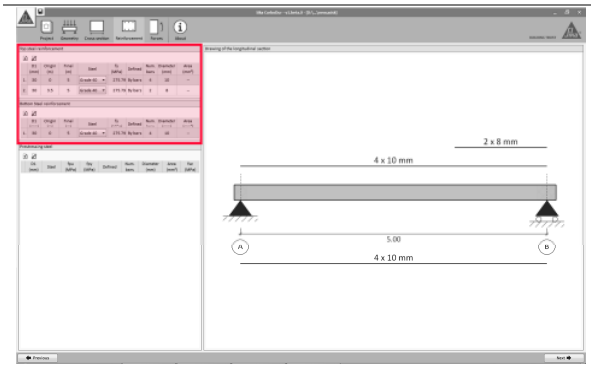
The schemes in the main screen display the arrangement of the loading as defined by the user, and are divided into:

- Geometry
- Initial loads(un-factored)
- Dead loads (un-factored)
- Live loads (un-factored)

3.6.2 Cross section

Refer to section 3.5.1.

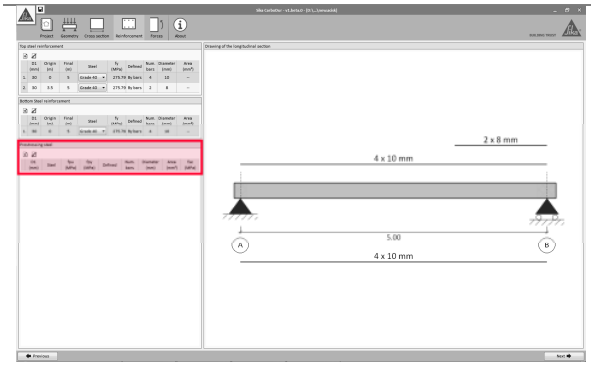
3.6.3 Reinforcement



The arrangement of the existing longitudinal steel reinforcement follows the same principles as the indicated in the section 3.5.2.

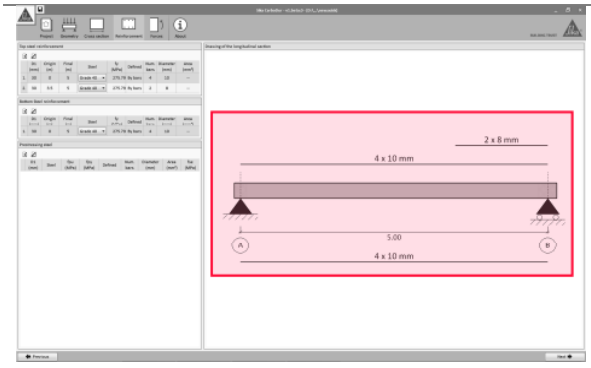
Unlike the steel definition for a single cross section, the user must declare the location and length of different steel bars, as well as its geometrical and mechanical values.

Please note that the steel is defined for the principal span, as the calculation of the existing strengths and the FRP reinforcement will not take into account the side spans, which must be evaluated independently if necessary.



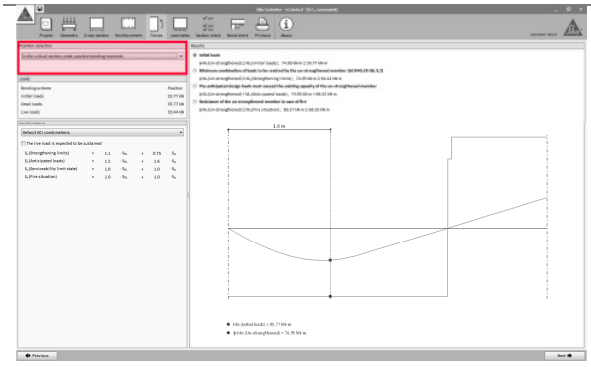
For elements based on simple supported beams comprising a single span, the use of prestressed steel is allowed by the software. The user must indicate the effective stress level in the prestressing steel, which corresponds to the original prestressing stress minus the corresponding stress relaxation at the moment of strengthening.

Please note that only bonded prestressing steel displayed horizontally along the span is valid for the calculation.



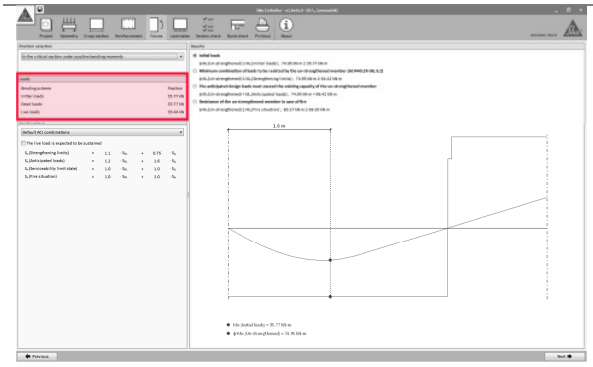
The main screen will display the steel arrangement as defined by the user.

3.6.4 Forces

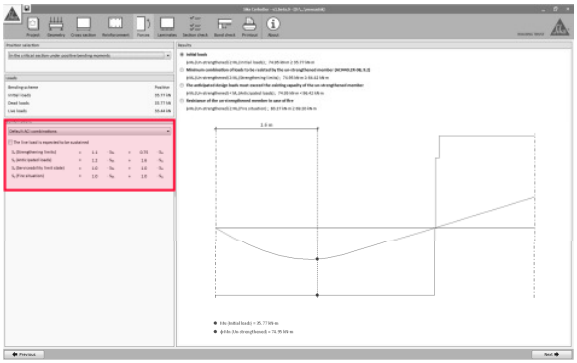


The calculation of the necessary FRP will be based on the critical section under positive or negative bending moments, as automatically determined by software.

The user can alternatively indicate a specific section for the calculation. However, this will disallow the possibility to determine the arrangement of the plates along the member (see “Bond Check” stage below), as the solution obtained will not provide the sufficient strengthening level for the critical sections.



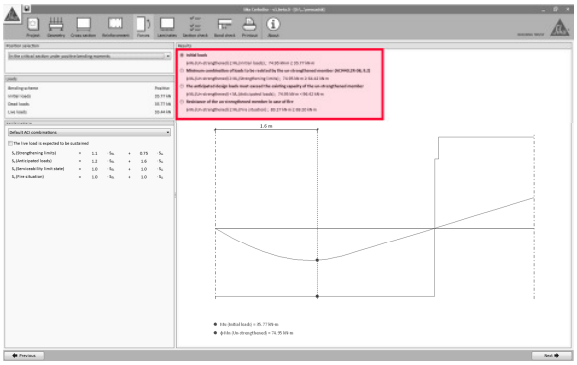
Once selected, the information concerning the anticipated loads in the section will be displayed.



Different combinations of loads are indicated on the left side of the screen, showing the default combination factors as indicated in ACI 318 and ACI 440.2R-08.

- **Strengthening limits** concerns the minimum load to be carried by the RC member in case that the CFRP system is damaged. This value is altered if the live load is expected to be sustained. Please checkon page 4 for additional information.
- **Anticipated loads** indicate the design load to be expected after the FRP strengthening.
- **Serviceability Limit State** shows the combination of service loads.
- **Fire situation** indicates the load level in case of a fire scenario.

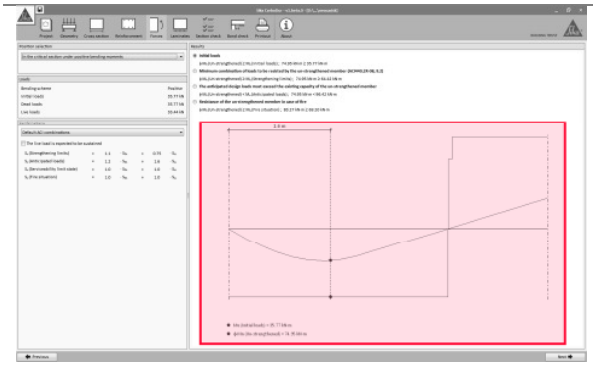
The combination factors for each case can be adjusted manually by the user if necessary.



The main screen displays the preliminary checks concerning the performance of the unstrengthened member when compared to the anticipated loads entered by the user. The user can toggle the diagram shown in the main screen by clicking the corresponding option.

- The first verification comprises the initial loads during strengthening. The software verifies that those forces do not exceed the initial strength of the un-strengthened element. This condition must be fulfilled in order to continue with the calculation.
- The second condition verifies if the existing member is able to support a reduced combination of the loads entered by the user (Refer to page 4 for additional information). This condition must be fulfilled to continue with the calculation.
- The 3rd verification checks that the requested loads exceed the strength of the existing, unreinforced member. This condition must be obviously verified to continue with the calculation.
- The last check shows if the acting load in case of fire can be initially assumed by the unreinforced element (considering that the unprotected FRP is damaged due to the high temperatures). Otherwise the software will allow the calculation, but the printout document will remind the user of need for FRP protection. Refer to section 2.1.2 for additional

information.



The information concerning the bending diagram for each combination of forces is shown in the main screen as a green line.

The value concerning the strength of the member under the different situations is shown as a red line.

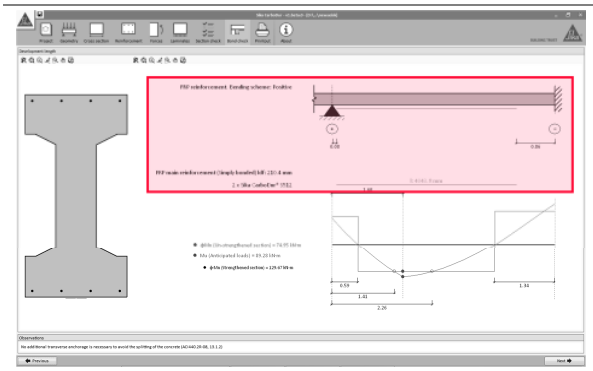
3.6.5 Laminates

Refer to section 3.5.4.

3.6.6 Section check

Refer to section 3.5.5.

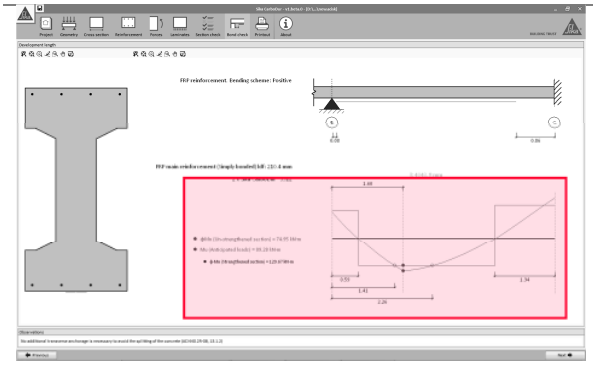
3.6.7 Bond check



The software determines the necessary arrangement of the FRP laminates according to ACI 440.2R-08, 13.1.

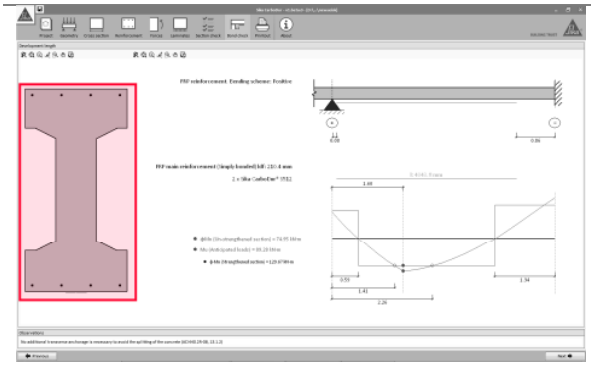
The different FRP laminates are shown schematically in the screen, showing its position and the necessary development length (l_{df} for bonded FRP, l_{db} for NSM).

Please note that the calculation comprises a single span; hence, in case of negative bending strengthening, the arrangement will only show the necessary length for the calculated span (the FRP laminate must be subsequently extended to the adjacent span or properly anchored).

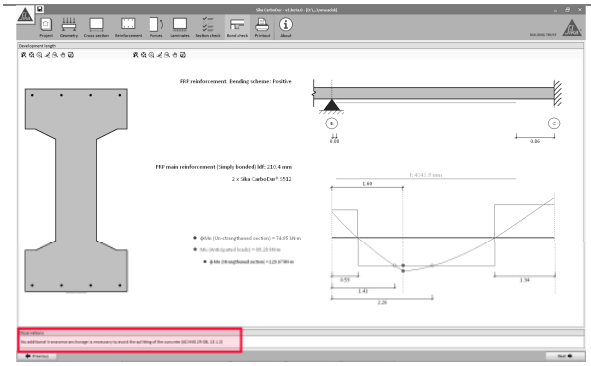


The bending diagram on the main screen displays the distribution of the bending moments corresponding to the anticipated design loads, as well as the original strength of the un-strengthened member.

The strength corresponding to the strengthened section is displayed on the text on the left, alongside additional information.



A general overview of the strengthened section is displayed on the left.



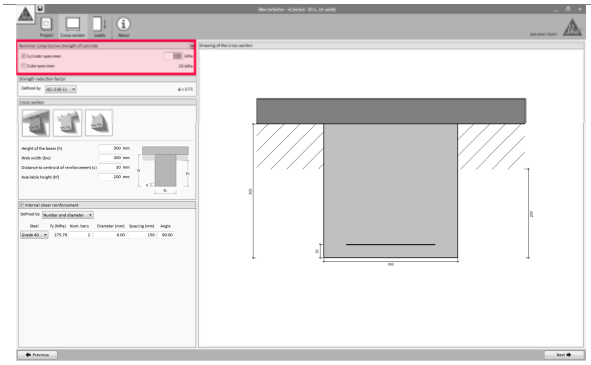
Verification concerning the end peeling of the FRP (ACI 440.2R-08, is displayed at the bottom. In case that the factored shear force at the termination point is greater than 2/3 the concrete shear strength, the FRP must be anchored to prevent the concrete cover layer from splitting.

3.6.8 Printout

Refer to section 3.4.6.

3.7 SHEAR STRENGTHENING (SINGLE SECTION)

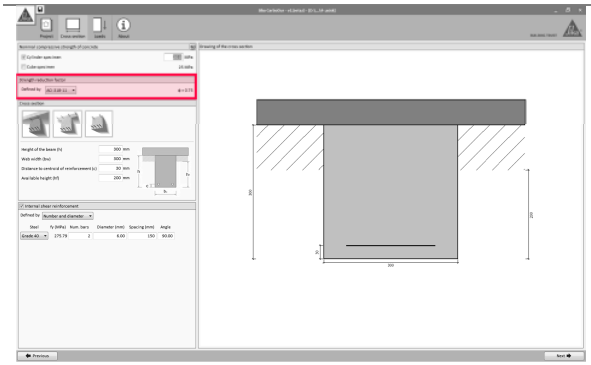
3.7.1 Cross section



The compressive strength of the concrete (f'_c) must be defined by the user.

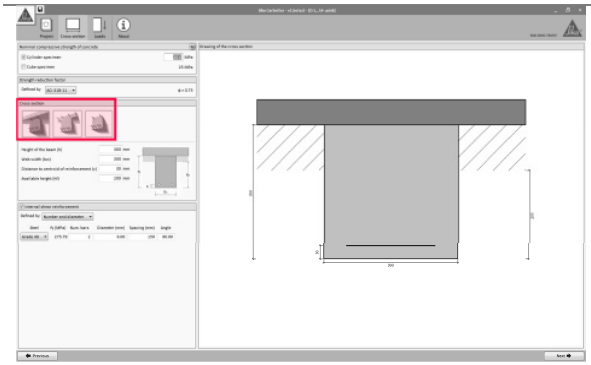
The strength is commonly based on cylinders, as indicated by ACI 318. However, the software allows entering strengths obtained from cube specimens, and proceeds to convert them into the equivalent cylinder strength (EN-1992-1-1).

Please note that the results provided in the printout documents will correspond to cylinder strength (ACI 318).



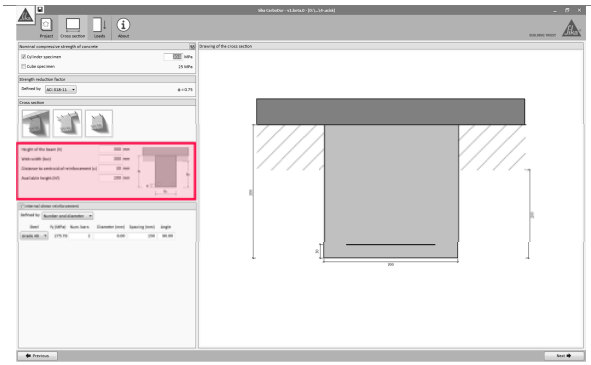
The design strength provided by a member shall be taken as the nominal strength of the member in accordance to ACI 318 and ACI 440.2R-08, multiplied by the strength reduction factor Φ.

The reduction factors follow ACI 318 as default. However, the user can modify the magnitudes corresponding to the reduction factors if necessary.

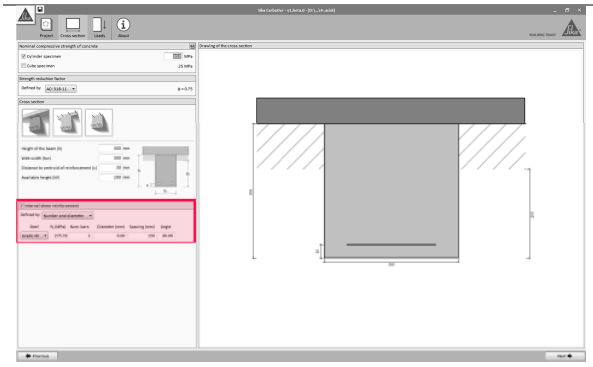


The drawings on the left area are used to select the cross-section of the member.

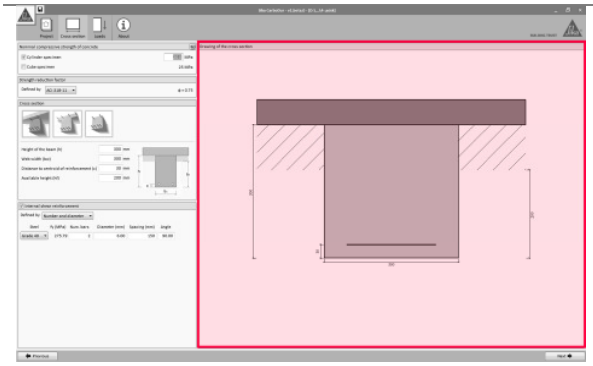
- Rectangular beams beneath slabs or any other element that blocks the access to the surface on top.
- T-beams or rectangular beams casted in conjunction with the slab.
- Rectangular beams.



The main geometry of the beam is defined by means of the text boxes on the left. Note that the available height for the FRP may be restricted as a consequence of the existence of mortars or panels beneath the slab or the flanges.

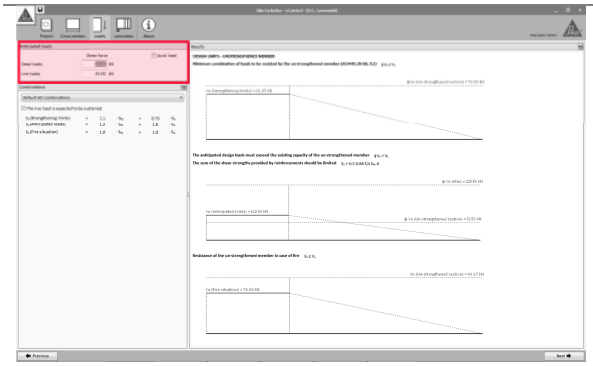


The internal shear reinforcement can be defined as a cross section or according to the distribution and geometry of the bars.



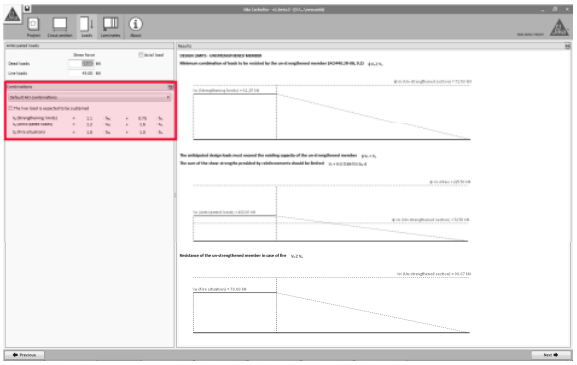
The main screen displays the resulting geometry of the section to be used for the calculation.

3.7.2 Loads



The anticipated combination of un-factored loads is introduced in the text boxes shown on the upper-left corner.

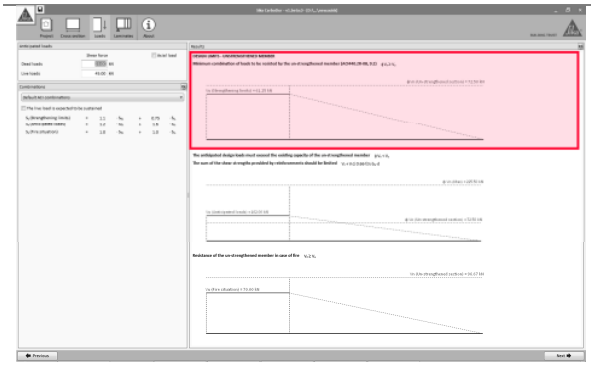
Additionally, axial forces can be similarly entered. The existence of axial forces allows the calculation of shear strengthening, in case of elements subjected to compressive forces (e.g. rectangular columns or prestressed beams).



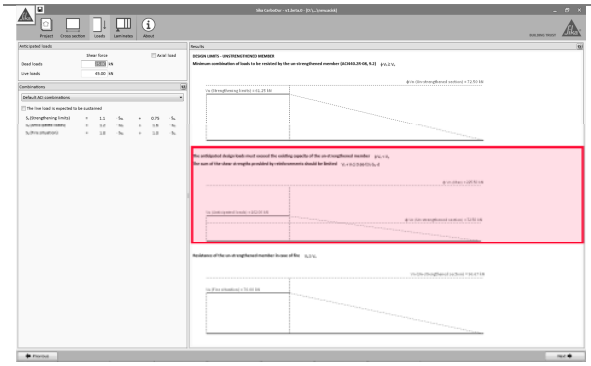
The different combinations of loads are indicated on the left side of the screen, showing the default combination factors as indicated in ACI 318 and ACI 440.2R-08.

- **Strengthening limits** concerns the minimum load to be carried by the RC member in case that the CFRP system is damaged. This value is altered if the live load is expected to be sustained. Please check on page 4 for additional information.
- **Anticipated loads** show the design load to be expected after the FRP strengthening.
- **Serviceability Limit State** shows the combination of service loads.
- **Fire situation** indicates the load level in case of a fire scenario.

The combination factors for each case can be adjusted manually by the user if necessary.

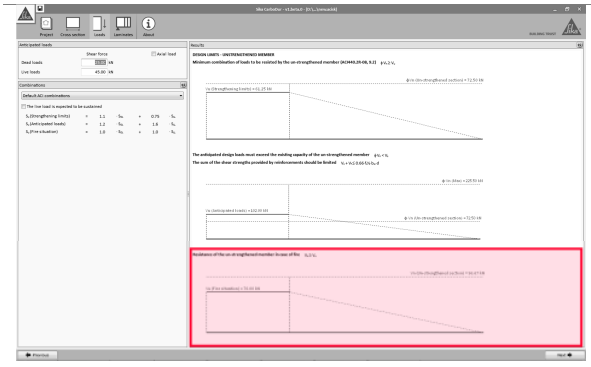


The first condition verifies if the existing member is able to support a reduced combination of the loads entered by the user (Refer to page 4 for additional information). This condition must be fulfilled in order to continue with the calculation



The 2nd verification comprises 2 different checks concerning the design loads with respect to the properties of the un-strengthened member:

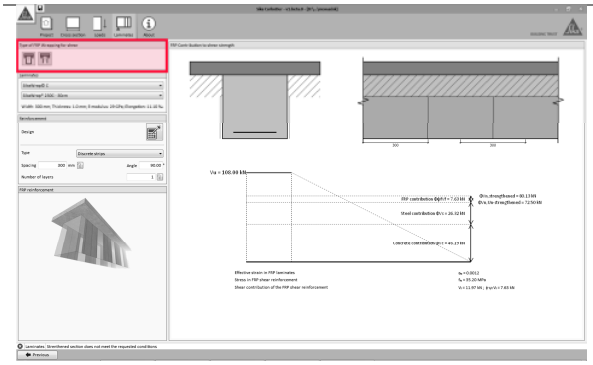
- The requested strength exceeds the strength of the existing, unreinforced member. This condition must be obviously verified to continue with the calculation.
- The sum of the shear strengths provided by the shear reinforcement (steel + FRP) is restricted. Refer to section 2.3.1 for additional information.



The last diagram shows whether the acting load in case of fire can be carried by the unreinforced element (considering that the unprotected FRP is damaged due to high temperatures). Otherwise, the software will allow the calculation, but the printout document will remind the use of the need of FRP protection.

Refer to section 2.1.2 for additional information.

3.7.3 Laminates

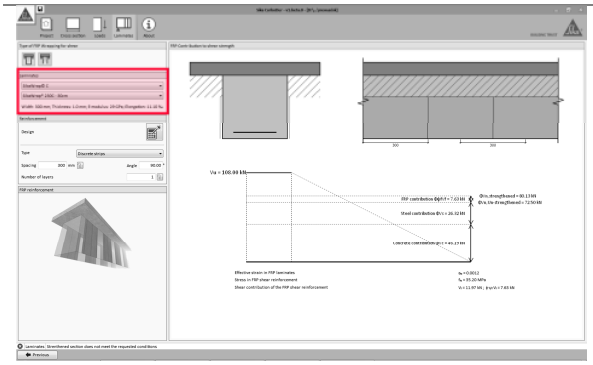


The possible FRP schemes are indicated in the upper-left corner of the screen

The user must define the FRP wrapping scheme to be used in the calculation (refer to section 2.3 for additional information).

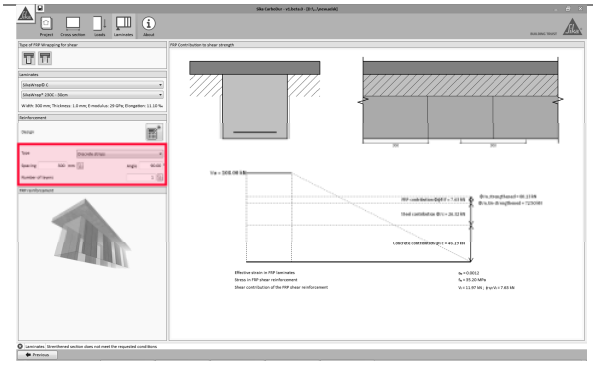
The available schemes are:

- Full Wrapping, in those cases where the 4 sides of the member are accessible.
- U-Wrapping.
- 2-sided configuration.



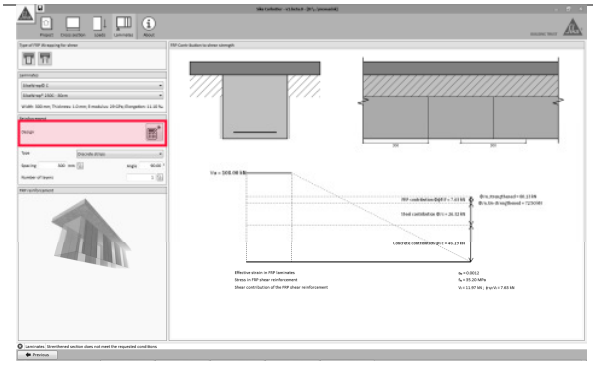
The Sika® range and the corresponding product to use are determined by the user in the corresponding dropdown boxes.

Note that the certain product ranges are available for a limited number of wrapping configurations.



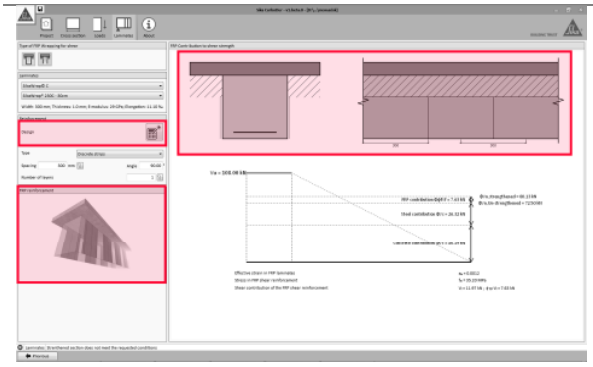
Additionally, the user can define the FRP arrangement for the selected laminate, defining the following values:

- Continuous wrapping or discrete strips. The maximum center-to-center spacing between consecutive strips is limited to *d*/4 plus the width of the strip.
- Number of layers
- Angle of the FRP strip (only for 2-sided configuration).



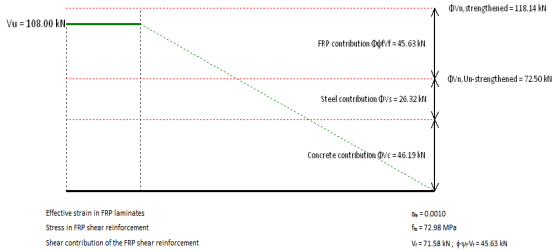
The automatic calculation of the FRP (calculator icon) will take into account the selected wrapping scheme, the type of FRP laminate and strips configuration (discrete strips or full wrapping).

Additionally, the automatic calculation will respect those additional parameters blocked by the user (locks) and the angle introduced by the user in 2-sided configurations.



The software displays auxiliary drawings in order to support the user´s selection:

- 3D model on the left.
- 2D scheme on top.



Finally, the FRP contribution to the strengthening will be displayed alongside the strengths corresponding to the existing steel reinforcement and concrete section.

The total strength of the un-strengthened and strengthened members, as well as the anticipated design forces for the section are shown.

Refer to section 2.3 for additional information.

3.7.4 Printout

Refer to section 3.4.6.

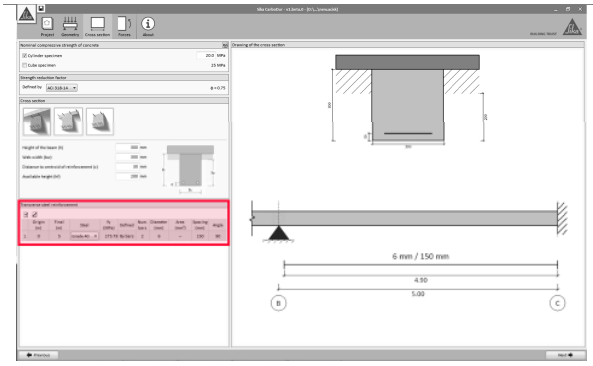
3.8 SHEAR STRENGTHENING (STRUCTURAL MEMBER)

3.8.1 Geometry

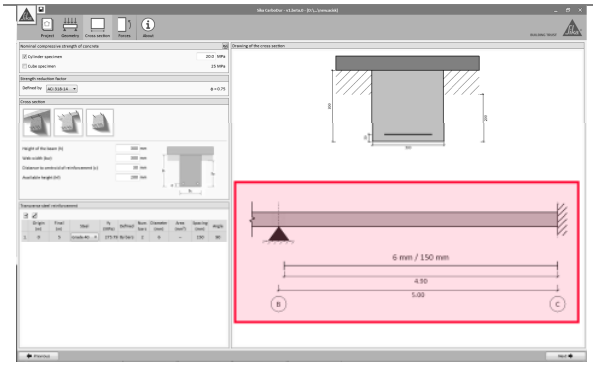
Refer to section 3.6.1.

3.8.2 Cross section

The definition of the cross section of the member follows the same principles as explained in section 3.7.1, with the following additional considerations:

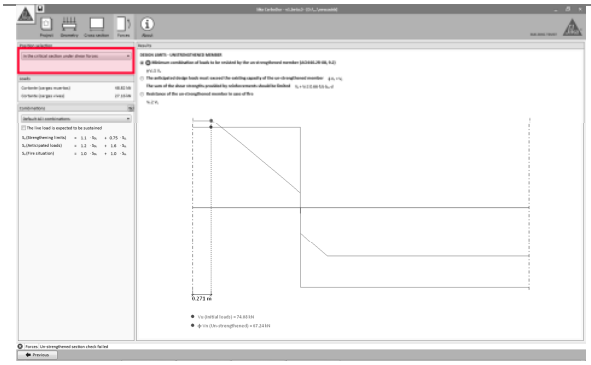


The transverse steel reinforcement must be defined for the whole span. Due to this, the user can enter different steel configurations (spacing, diameter, angle, steel grade…) for different segments of the span.



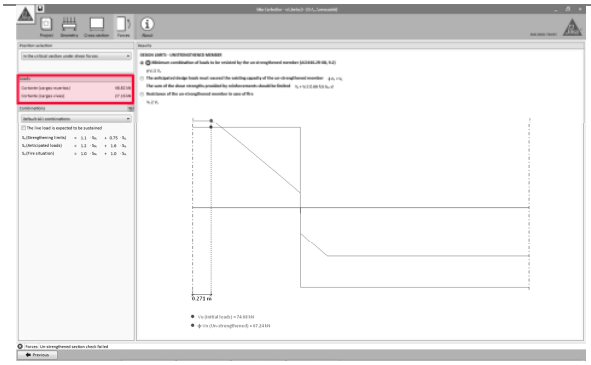
The resulting distribution will be displayed in the main screen on the right.

3.8.3 Forces

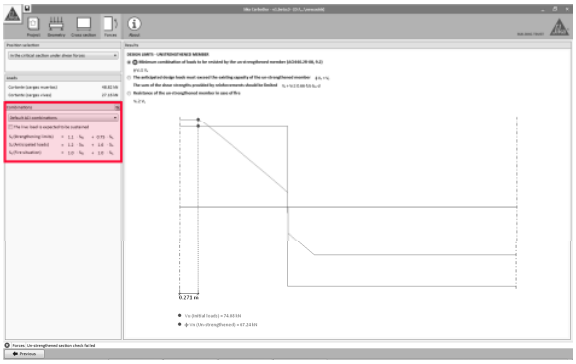


The calculation of the necessary FRP will be based on the critical section under shear forces, as automatically determined by the software.

The user can alternatively indicate a specific section for the calculation. However, this will disallow the possibility to automatically determine the arrangement of the FRP strips along the member, as the solution obtained may not provide the sufficient strengthening level for the critical sections.



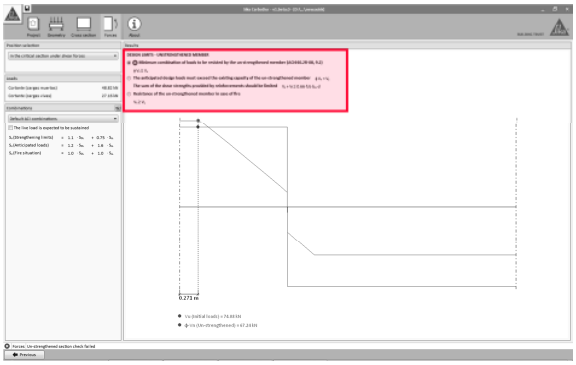
Once selected, the information concerning the anticipated loads in the section will be displayed.



The different combinations of loads are indicated on the left side of the screen, showing the default combination factors as indicated in ACI 318 and ACI 440.2R-08.

- **Strengthening limits** concerns the minimum load to be assumed by the RC member in case that the CFRP system is damaged. This value is altered if the live load is expected to be sustained. Please checkon page 4 for additional information.
- **Anticipated loads** indicate the design load to be expected after the FRP strengthening.
- **Fire situation** indicates the load level in case of a fire scenario.

The combination factors for each case can be adjusted manually by the user if necessary.



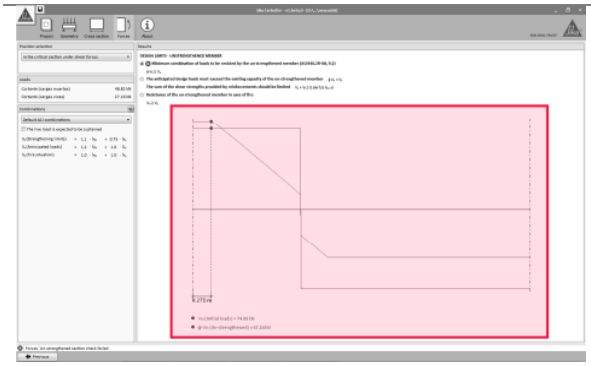
The main screen displays the preliminary checks concerning the performance of the unstrengthened member when compared to the anticipated loads entered by the user. The user can toggle the diagram shown in the main screen by clicking the corresponding option.

The first condition verifies whether the existing member is able to support a reduced combination of the loads entered by the user (Refer to page 4 for additional information). This condition must be fulfilled to continue with the calculation.

The 2nd verification comprises 2 different checks concerning the design loads with respect to the properties of the un-strengthened member:

- The requested strength exceeds the strength of the existing, unreinforced member. This condition must be obviously verified to continue with the calculation.
- The sum of the shear strengths provided by the shear reinforcement (steel + FRP) is restricted. Refer to section 2.3.1 for additional information.

The last check shows if the acting load in case of fire can be carried by the unreinforced element (considering that the unprotected FRP is damaged due to high temperatures). Otherwise the software will allow the calculation, but the printout document will remind the user of any need for FRP protection. Refer to section 2.1.2 for additional information.

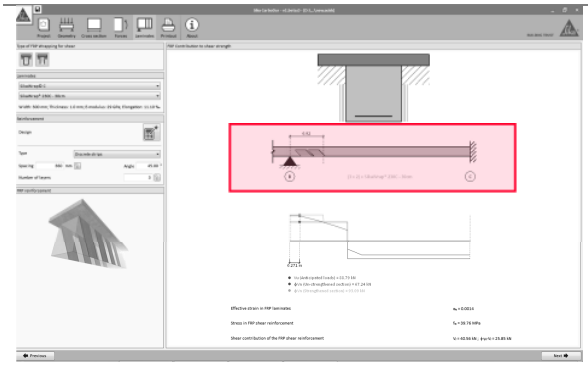


The information concerning the shear diagram for each combination of forces is shown in the main screen in a green line.

The value concerning the strength of the member under different situations is shown in a red line.

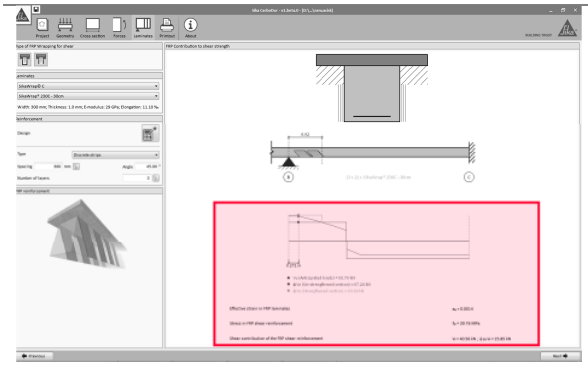
3.8.4 Laminates

The arrangement and calculation of the FRP strips follow the criteria shown in section 3.7.3. Note the following differences:



The software determines the necessary arrangement of the FRP laminates according to the expected loads and the strength of the original element.

The different FRP laminates are shown schematically in the screen, showing its position and configuration.



The shear diagram on the main screen displays the bending moment distribution corresponding to the anticipated design loads, as well as the original strength of the un-strengthened member.

The additional FRP contribution to shear strength is indicated in a blue line.

Auxiliary numerical information is also displayed.

3.8.5 Printout

Refer to section 3.4.6.

LEGAL NOTE

This software application is protected by copyright laws and international copyright treaties. The software application is licensed, not sold.

THIS SOFTWARE APPLICATION AND THE RESULTS DERIVED FROM ITS UTILIZATION ARE INTENDED ONLY FOR USE BY PROFESSIONAL USERS WITH EXPERT KNOWLEDGE IN THE AREA OF THE INTENDED APPLICATION. USERS MUST INDEPENDENTLY VERIFY THE RESULTS BEFORE ANY USE AND TAKE INTO ACCOUNT THE SITE AND APPLICATION CONDITIONS, PRODUCT DATA SHEET AND PRODUCT LITERATURE, TECHNICAL STATE OF THE ART AS WELL AS LOCAL APPLICABLE STANDARDS AND REGULATIONS.

With respect to the software application and results derived from its use, **SIKA MAKES NO WARRANTIES OF ACCURACY, RELIABILITY, COMPLETENESS, MERCHANTABILITY OR FITNESS FOR ANY PURPOSE. THE SOFTWARE APPLICATION IS PROVIDED ON AN "AS-IS" BASIS AND SIKA EXPRESSLY DISCLAIMS ANY WARRANTIES WITH RESPECT TO THE SOFTWARE APPLICATION AND RESULTS DERIVED FROM ITS USE.**

Sika shall not be liable for any consequential, punitive, incidental, exemplary, or special damages (including but not limited to loss of business opportunity or loss of profit) arising out of the evaluation or use of the software application and results derived from its use.

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

This License shall be governed by and construed and enforced in accordance with the material laws of Switzerland. The non-mandatory conflict of laws provisions shall be excluded. Exclusive forum shall be the courts of Zürich, Switzerland.

Privacy Policy:

Upon the first activation and on the occasion of any future software update or change of the relevant user information, this software application will collect, store and transmit to Sika the registration information submitted by you.

Processing of personal data shall be done for purposes of managing the licensing of the software application only. Additionally, in some instances, we may also use personal data to send users information regarding upgrades, enhancements or surveys concerning the software application.

Sika strictly protects the security of your personal data. You may change and modify your personal data at any time. Sika deletes personal data when all purposes of the personal-data processing have been fulfilled.

Sika (Thailand) Limited
TM Refurbishment

Version given by
Ranongthanee Rataporn
Phone: +6681 945 0100

Mail: rataporn.r@th.sika.com