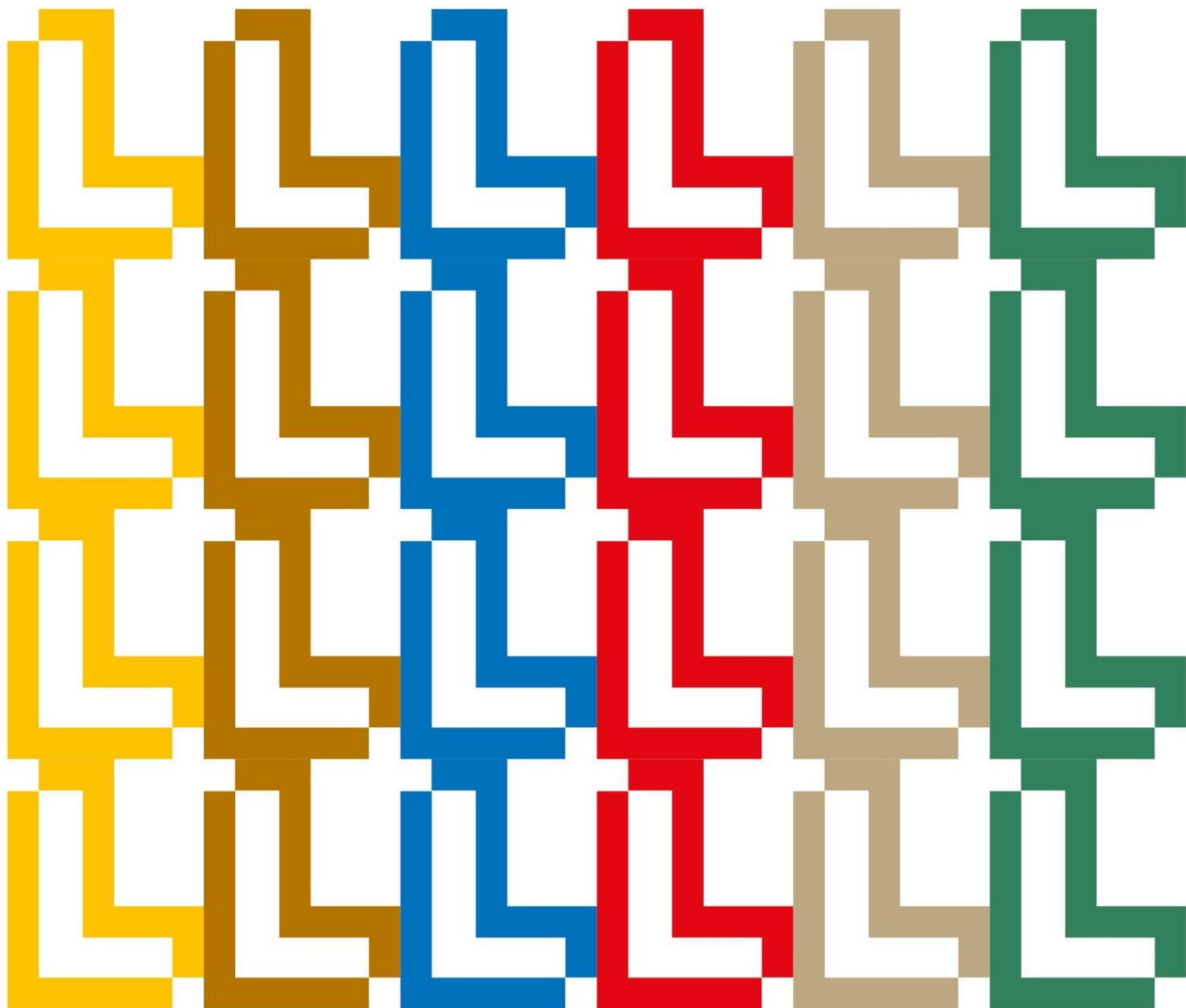




Guide and Validation

Guide for use, validation and regulatory references for the strengthening of concrete-concrete mixed floors

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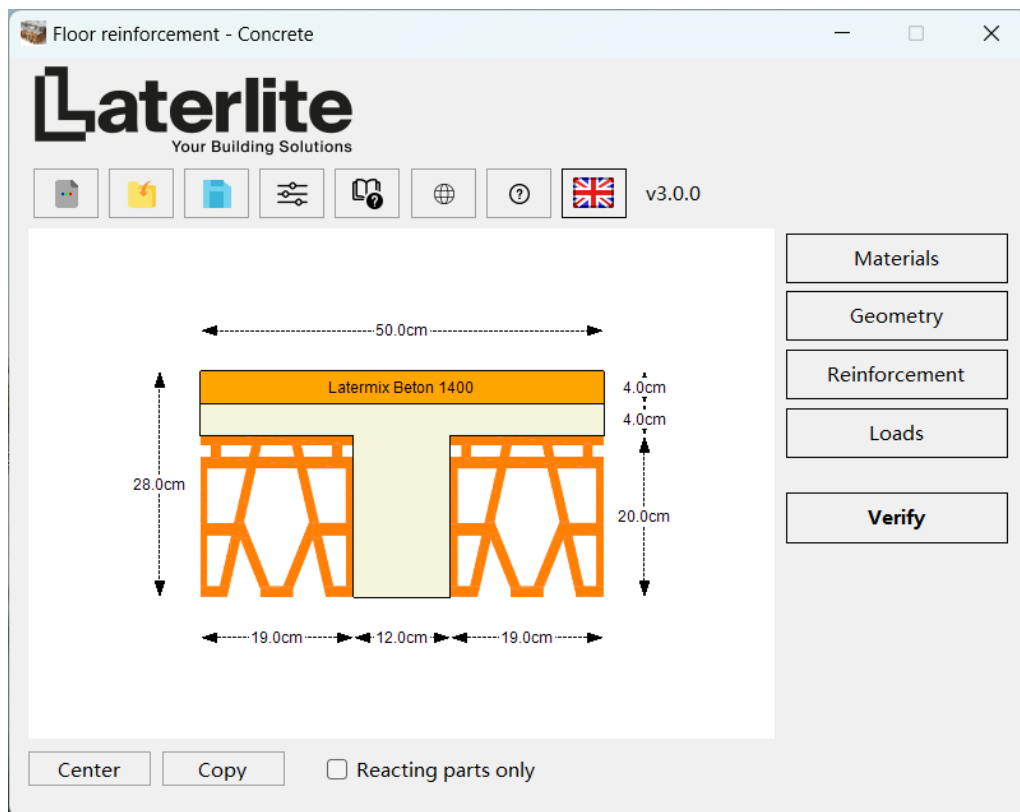
1. USER GUIDE

1.1. Introduction

The program **Project of CONCRETE floors with CentroStorico Connectors and lightweight structural Laterlite concretes** allows the calculation of concrete floors using lightweight structural concrete from Laterlite S.p.A. (called **Latermix Beton 1400**, **Latermix Beton 1600**, **Latermix Beton1800** and **Concrete CS**) and connectors by Laterlite S.p.A. (called **Chemical Connector CS**, **Concrete Connector Plus D12**, **Mini Concrete Connector**).

The software runs the following verifications:

- Positive and negative bending checks at the Ultimate Limit State (ULS) of the existing floor and the reinforced floor;
- Ultimate Limit State (ULS) shear verification for elements without specific shear reinforcement in the existing floor and reinforced floor;
- Verify the sliding action on the contact surface with the new slab, whenever it is intended to use **Chemical Connector CS** as the connection system between the existing floor and the new slab;
- Calculation of design strength of **Mini Concrete Connector** or **Concrete Connector Plus D12** and calculation of the spacing (variable or constant per span) of the connectors, if it is planned to use **Mini Concrete Connector** or **Concrete Connector Plus D12** as a connection system between the existing floor and the new slab.



If the reinforced floor is not verified using only the lightweight structural concrete slab and **Chemical Connector CS**, the software allows the user to design and verify the existing floor slab with new joists (inside the floor or on top of the floor) using lightweight structural concrete from Laterlite S.p.A.; while in the case

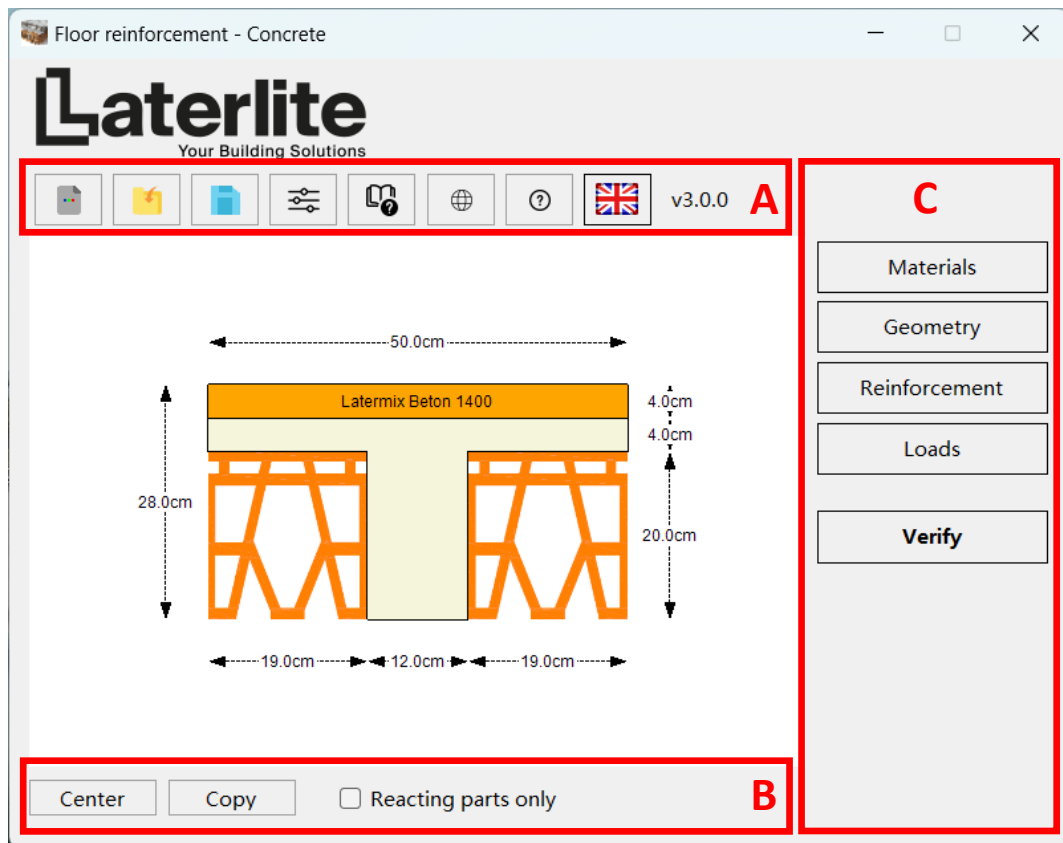


of failure to verify the reinforced floor using only lightweight structural concrete slabs and mechanical connectors, the program suggests designing the new joists, using **Chemical Connector CS**.

1.2. Use of the software

The software interface and controls are described below.

1.2.1. Main window



The main screen of the software is divided into three button panels (top “A”, bottom “B” and right “C”) and the drawing of the beam section, with dimensions in *centimetres*.

For group “A” buttons (in order from left to right):

- **New** allows the creation of a new file;
- **Open** allows the opening of an existing file with the extension *.l/1*;
- **Save** saves the current file with the extension *.l/1*;
- **Customized options** allow you to change some default calculation options;
- **Guide** opens this guide and validation document;
- **Web** opens the website www.laterlite.com;
- **Info** opens the window with information about the software and licences;
- **Language** allows users to select the software language between Italian, English, French and Spanish. It is necessary to restart the application to change the language.



For buttons in group “B” (in order from left to right)):

- **Center** centres the drawing of the floor section within the dedicated screen.;
- **Copy** copies the current drawing to the clipboard as an image;
- **Reacting parts only** if enabled, only shows the effective parts of the section.

The buttons in group C allow users to enter the information required for the calculation, according to the suggested order of operation with the programme. Please refer to the following paragraphs for a detailed description.

1.2.2. Customized options

Customized options	
Use ductile parameters?	No ▾
Height of the concrete web [cm]	3
Width of the concrete web [cm]	8
Θ angle for shear check (0=seek for balanced failure) [°]	0
Points per beam	30

OK

The window allows the user to set the following calculation options:

- **Using ductile parameters?** allows the user to select whether to use ductile or fragile parameters for existing concrete and steel. By default, fragile parameters are used. For further details, see the *Materials* chapter;
- **Depth of the concrete web** allows the user to set the thickness of the concrete web created with the addition of insulation panels to lower the weight, in *centimetres*;
- **Width of the concrete web** allows the user to set the separation width between two adjacent insulating panels or, in other words, the width of the lightweight structural concrete web to be created if the panel is present, in *centimetres*;
- **Θ angle for shear check** allows the user to specify an angle, in degrees, between 21.8° and 45° for the shear verification of new joists. If the angle is 0 (default), the program automatically searches for the balanced break;
- **Points per beam** allows the user to choose how many points to discretize each floor span analysed (you can enter a number between 10 and 100).



1.2.3. Materials

The Materials window allows the user to enter the mechanical characteristics of existing concrete and steel, as well as defining the Knowledge Levels and corresponding Confidence Factors, and selecting the connection system and lightweight structural concrete to be used for the new composite floor.

The screenshot shows a software window titled "Materials" with three main sections:

- Concrete:**
 - Strength: Report value (dropdown)
 - fck [MPa]: 20.0 (input field)
 - Class: C20/25 (dropdown)
 - Knowledge Level: LC3 (dropdown)
 - CF: 1.00 (input field)
- Reinforcement steel:**
 - Strength: Report value (dropdown)
 - f_{yk} [MPa]: 450.0 (input field)
 - Class: B450C (dropdown)
 - Knowledge Level: LC3 (dropdown)
 - CF: 1.00 (input field)
- Reinforcement solutions:**
 - Structural lightweight concrete: Latermix Beton 1400 (dropdown)
 - Connection: Chemical Connector CS (dropdown)

At the bottom, there is a link "Change default parameters" and an "Apply" button.

In the Concrete box the user can enter the mechanical properties of existing concrete by choosing from the following options:

- **Report value** allows the choice of the concrete class from those proposed in the drop-down menu;
- **Test value** allows the user to enter the average strength value f_{cm} obtained from tests performed on site;
- **Customized value** the user can enter directly the design strength f_{cd} .

In the Reinforcement steel box, the user can enter the mechanical properties of existing steel, choosing from the following options:

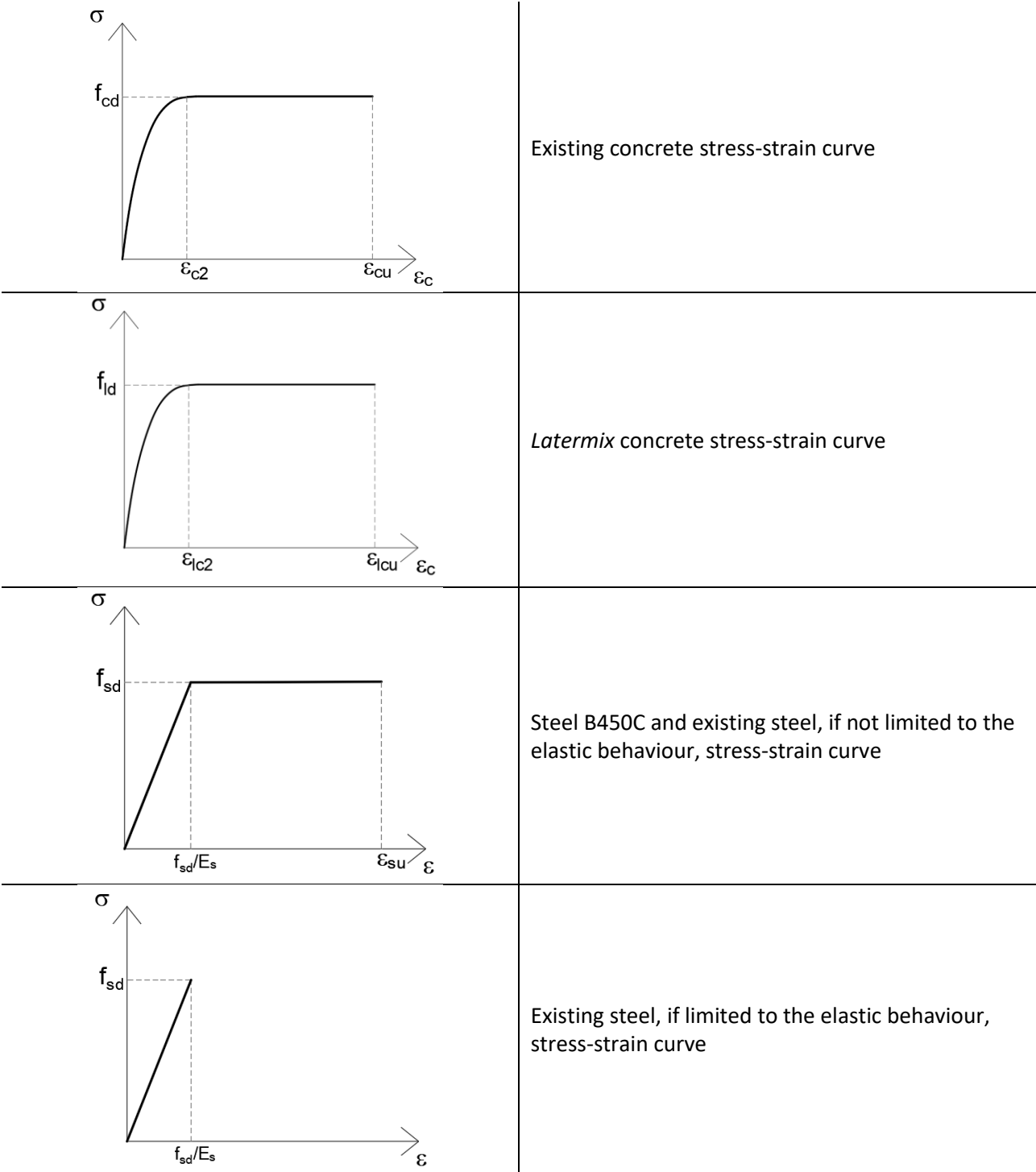
- **Report value** allows the choice of the concrete class from those proposed in the drop-down menu;
- **Test value** allows the user to enter the average strength value f_{ym} obtained from tests performed on site;
- **Customized value** the user can enter directly the design strength f_{yd} .

For each existing material, the Knowledge Level box allows the selection, via a drop-down menu, of the Knowledge Level achieved and defines the corresponding Confidence Factor. It is possible to choose a customized Knowledge Level and then define the value of the Confidence Factor assigned.



Finally, the Reinforcement Solutions box allows the selection of a lightweight structural concrete by Laterlite S.p.A. for the new collaborating slab between **Latermix Beton 1400**, **Latermix Beton 1600**, **Latermix Beton1800** e **Concrete CS** and the choice of the connection existing floor – new slab between **Chemical Connector CS**, **Concrete Connector Plus D12**e **Mini Concrete Connector**.

The stress-strain curve that the software uses are the following:



The design strengths of materials are determined according to the following table:



	<i>fragile behaviour</i>	<i>ductile behaviour</i>
REPORT VALUE	$f_{cd} = \frac{0.85f_{ck}}{\gamma_c CF}$	$f_{cd} = \frac{0.85f_{ck}}{CF}$
TEST VALUE	$f_{cd} = \frac{f_{cm}}{\gamma_c CF}$	$f_{cd} = \frac{f_{cm}}{CF}$
CUSTOMIZED VALUE	\	\

The **Change Default Parameters** option allows the modification of partial coefficients for existing materials and the option of limiting existing steel to the elastic branch.

Material options

Concrete partial safety factor

1.5

Steel partial safety factor

1.15

Limit the existing steel to the elastic branch?

No

▼

OK

Press **Apply** to save the choices made. The **Apply** button is red colored to indicate the change made to the parameters and returns to black after being pressed.



1.2.4. Geometry

The **Geometry** window allows the user to set the dimensions of the existing floor and the new slab.

Geometry		
New slab thickness	4	cm
Existing slab thickness	4	cm
Joist width	12	cm
Joist depth	20	cm
Joist spacing	50	cm

☐ Provide a lightening panel

Static diagram of the floor

Number of spans:

n.	Length [cm]
1	500

Degree of stiffness at the ends $ql^2/$

Left	Zero stiffness	0.0
Right	Zero stiffness	0.0

Apply

Specifically, the parameters are:

- the thickness of the new lightweight structural concrete slab (the minimum slab thickness is 4 cm for **Chemical Connector CS** and **Mini Concrete Connector** and 5 cm for **Concrete Connector Plus D12**);
- the thickness of the existing top slab (if any);
- the width of the existing joist;
- the depth of the existing joist;
- the spacing between existing joists.

The option **Provide a lightening panel**, if activated, inserts a panel (polystyrene, EPS, ...) between the existing slab and the new slab, creating a new T-section. The definition of the thickness of the lightening panel and the base of the connection is done through the **Customized Options** menu (see section 1.2.2.), which opens automatically when the option is first ticked. The option is not present when using the **Mini Concrete Connector**.

The Static diagram of the floor box contains settings for the number and span L of the slab spans and the degree of stiffness to be adopted at the left and right ends.

Is it possible to calculate floors with a maximum of four spans; the number of spans is defined using the appropriate menu, while the length of each span in *cm* has to be entered in the corresponding table.



The options for stiffness at the ends are:

- Zero stiffness (moment applied at the end equal to 0);
- Very low stiffness (moment applied at the end equal to $-qL^2/48$, with q load per linear metre in combination with the Ultimate Limit State and L length of the span to which the constraint is applied);
- Low stiffness (moment applied at the end equal to $-qL^2/36$, with q load per linear metre in combination with the Ultimate Limit State and L length of the span to which the constraint is applied);
- Semi-fixed support (moment applied at the end equal to $-qL^2/24$, with q load per linear metre in combination with the Ultimate Limit State and L length of the span to which the constraint is applied);
- Fixed support (moment applied at the end equal to $-qL^2/12$, with q load per linear metre in combination with the Ultimate Limit State and L length of the span to which the constraint is applied)*;
- Free end
- Customized thickness (allows the user to define the denominator X of the moment, equal to $-qL^2/X$, with q load per linear metre in combination with the Ultimate Limit State and L length of the span to which the constraint is applied);

*Only in the case of a single-span floor, with “Free end” selected at one end, “Fixed support” must be selected at the other end and a moment of $-qL^2/2$ is applied to ensure the stability of the structure.

Press **Apply** to save the choices made. The **Apply** button is red colored to indicate the change made to the parameters and returns to black after being pressed.



1.2.5. Reinforcement

The **reinforcement** window allows the entry of existing and new (if any) reinforcements for each span.

Reinforcement

Span n.

1

☐ Different rebars at the supports

Rebars

n.

0

ϕ

5

mm

n.

0

ϕ

5

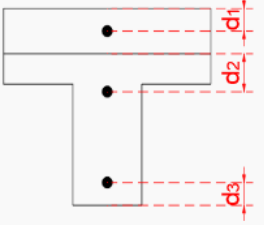
mm

Area

0.00

cm²

Enter



Reinforcement	Area [cm ²]			d
span 1	left	centre	right	[cm]
New		0		2
Existing top		0		2
Existing bottom		0		2
Length [cm]				
Full RC length [c...	0		0	

Plot

Homogeneous

Apply

First, the user needs to select the span number for which they need to enter data via the **Span n.** menu. This will allow the input table for the selected span to appear.

The option **Different rebars at the supports** allows to define different reinforcements between the zone in the span (**centre**) and the zone at the supports (**left** and **right**) and to specify the **Length** of the rebars from the ends, in **cm**, of the zones with different reinforcement:

Reinforcement	Area [cm ²]			d
span 1	left	centre	right	[cm]
New	0	0	0	2
Existing top	0	0	0	2
Existing bottom	0	0	0	2
Length [cm]	0		0	
Full RC length [c...	0		0	

For each editable box, it is possible to add the area of reinforcement in cm²:

- **New** for possible reinforcement in the new slab;
- **Existing top** for upper reinforcement of the existing joist (if any);
- **Existing bottom** for lower reinforcement of the existing joist.



Reinforcement can be inserted by using the commands in the Reinforcement box, choosing the number and diameter of the reinforcement and pressing **Enter**. The value in the **Area** box will be inserted in the selected cell. The command is only valid for active cells that may contain areas of reinforcement.

The **Full RC length** allows the user to specify the extent of the full concrete zone at the ends of the beam, if any (e.g. floor support beam). This option influences the shear strength of the section in which the solid zone is present, since it affects the value of b_w used in the shear strength formula for elements without specific shear reinforcement, and the flexural strength since it changes the resistant section of concrete. The weight increase caused by the solid zone is neglected.

The last column **d** indicates the concrete cover, defined as shown in the window, for each reinforcement level.

Finally, the **Plot** menu allows the user to see the reinforcement in the drawing by selecting the appropriate portion.

Press **Apply** to save the choices made, when you have finished entering the information for the individual span before moving on to the next one. The **Apply** button is red colored to indicate the change made and returns to black after being pressed.

The described procedure must be repeated for all the spans of the floor.



1.2.6. Loads

In the **Loads** window, all loads acting on the floor are defined:

Parameter	Value	Unit
Existing floor own weight	3.11	kN/m ²
New collaborating slab	0.62	kN/m ²
Screed	Latermix Facile	10 kN/m ³
thickness [cm]	4.0	0.40 kN/m ²
Base screed	Base screed CS	6.5 kN/m ³
thickness [cm]	5.0	0.33 kN/m ²
Other dead loads	1.00	kN/m ²
Variables	Customized	2.00 kN/m ²
ULS load combination on single beam	5.15	kN/m

Change or check default parameters before proceeding

[Change default parameters](#) **Apply**

Specifically, the user can enter the following information:

- **Existing floor weight**, automatically evaluated by the software;
- **New collaborating slab**, whose weight is automatically evaluated by the software.

It is possible to enter permanent non-structural and variable loads as follows:

- **Screed**, which allows the user to select one of the screeds produced by Laterlite S.p.A. and enter the required thickness; if not specified, select “Absent”;
- **Base screed**, which allows the user to select one of the base layer screeds produced by Laterlite S.p.A. and enter the required thickness; if not specified, select “Absent”;
- **Other dead loads**, which allows the user to enter the total load given by any other permanent loads (es. Internal partitions, floor);
- **Variables**, allows the input of a value chosen by the user.

The ULS load combination is assessed as follows:

$$q = i_{tr} \cdot [\gamma_{G1} \cdot (P_{floor} + P_{slab} + P_{screed} + P_{base\ screed}) + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}]$$



with i_{tr} the joist spacing, P_{floor} the weight of the existing floor, P_{slab} the weight of the new lightweight structural concrete slab, P_{screed} the weight of the screed (if any), $P_{base\ screed}$ the weight of the base layer screed (if any), P_{others} the weight of other dead loads and Q_{var} the weight of variable loads.

The options **Change default parameters** allow the definition of combination coefficients for dead loads, non-structural dead loads and variable loads, as well as the setting of the weight of the hollow bricks of the existing floor (if any).

Load combinations options

γG1 coeff. for dead loads	1.3
γG2 coeff. for non-str. dead loads	1.5
γQ coeff. for variable loads	1.5
Hollow bricks weight [kN/m³]	6

OK

It is necessary to check default parameters before proceeding with the calculation.

Press **Apply** to save the choices made. The **Apply** button is red colored to indicate the change made and returns to black after being pressed.

The load on the individual beam in the ULS combination is updated by pressing the **Apply** button.



1.2.7. Verification

The window **Verify**, for the point where the verification is most restrictive, shows:

- bending and shear stresses resulting from the static scheme;
- the corresponding flexural strengths (positive moment and negative moment);
- the shear strength;
- the tangential tension at the interface between the existing floor and the new slab, comparing it with the **Chemical Connector CS**, design strength value of 0.72 MPa, if this connector has been selected in the Materials window.

In order to obtain the results, you must press **Calculate**.

The screenshot shows a software window titled 'Results'. Inside, there is a section 'Calculation results' with the following data:

Msd+	13.40	kNm	Met
Mrd+	23.03	kNm	
Msd-	-2.68	kNm	Met
Mrd-	-15.90	kNm	
Vsd	12.87	kN	Met
Vrd	15.31	kN	
τ_{sd}	0.08	MPa	Met
τ_{rd}	0.72	MPa	

At the bottom of the window, there are two buttons: 'Calculate' and 'M, V diagrams'.

The **Tabella connettori Connector Table** button displays the table containing the number and variable spacing of **Mini Concrete Connector** or **Concrete Connector Plus D12**, if one of these connectors has been selected in the Materials window.



Results

Calculation results

Msd+

13.67

kNm

Met

Mrd+

24.59

kNm

Msd-

-2.73

kNm

Met

Mrd-

-15.92

kNm

Vsd

13.12

kN

Met

Vrd

15.31

kN

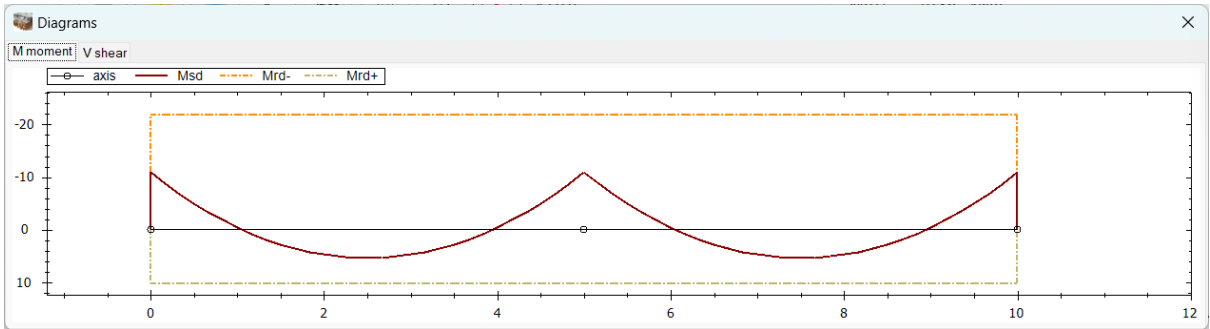
Calculate

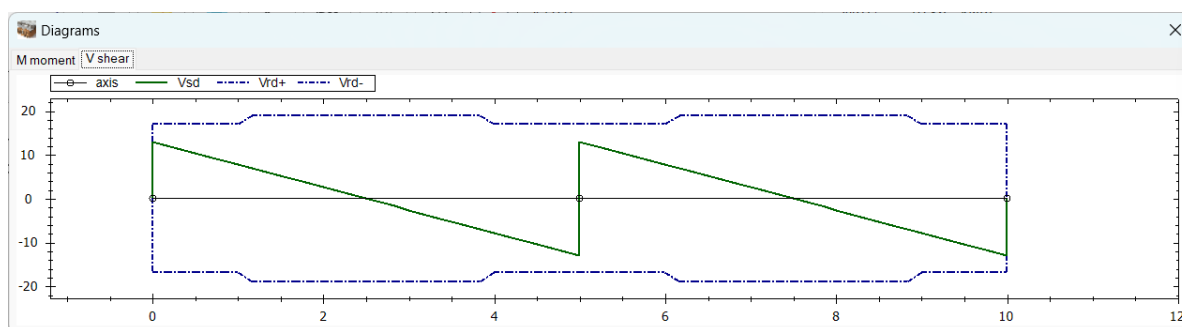
M, V diagrams

Connector table

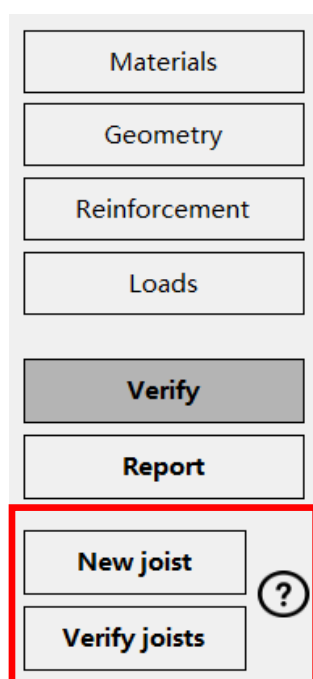
Connectors table - Concrete Connector Plus D12				✕
VARIABLE SPACING				
	Span 1			
	L/4	L/2	L/4	
Length [cm]	125.0	250.0	125.0	
N° conn. [-]	3	6	3	
Spacing [cm]	41.7	41.7	41.7	
N° conn. per m²	4.8			
N° conn. tot [-]	12			
-				

The **M, V Diagrams** button displays the stress and strain diagrams of the analysed floor.





Once the check has been performed, the **Report** button appears, through which the calculation report can be exported in DocX (Word®) format.



If at least one check is not satisfied for the floor reinforced only with lightweight structural concrete slab, if the **Chemical Connector CS** has been selected in the Materials window, the **New Joist** and **Verify joists** buttons appear, to allow the user to dimension and verify a new joist for the existing slab (inside or on top of the floor) with lightweight structural concrete of Laterlite S.p.A.

The ? button opens the guide that explains the intervention of creating new joists inside and on top of the floor and provides useful guidelines for design.

On the other hand, in the event that at least one verification is not fulfilled for floor reinforced using only the lightweight structural concrete slab, if the **Mini Concrete Connector** or the **Concrete Connector Plus D12**, has been selected in the Materials window, an alert appears under the Calculate / M, V Diagrams / Connector table buttons, suggesting that new joists should be carried out, using **Chemical Connector CS**. In order to proceed with the design, it is necessary to change the connection system in **Materials**, re-run **Calculate** and then use the **New joist** and **Verify Joists** buttons.

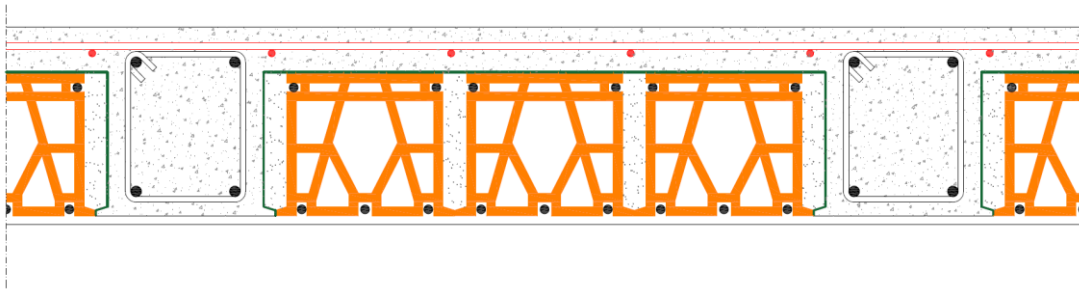


1.2.8. New Joist

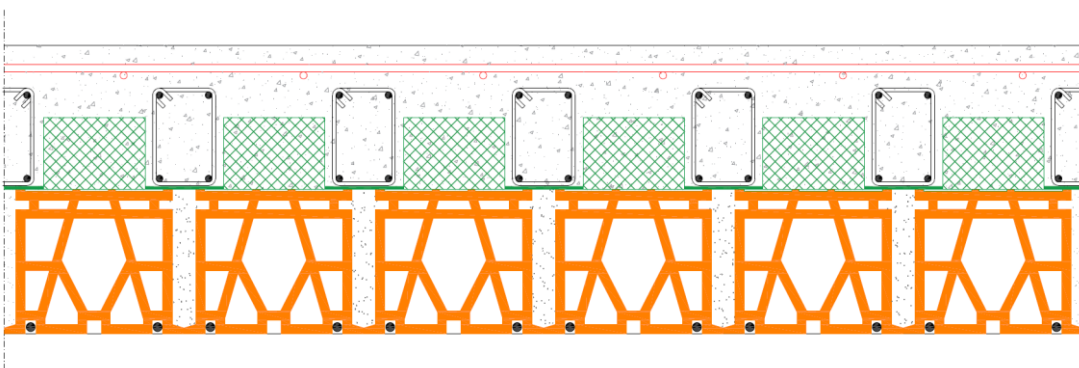
The **New joist** window allows the user to enter the geometry of the new joist after activating the tick on **Add new joist**.

The drop-down menu on the right allows a choice between:

- **New joist inside the floor**, which consists of the construction of new T-joists in structural lightweight concrete and suitably reinforced to be built in the thickness of the existing floor, in order to limit the overall thickness of the intervention, within the voids specifically created by removing hollow bricks of the existing floor at a defined spacing



- **New joist on top of the floor**, which consists of the construction of new T-shaped joists in lightweight structural concrete, suitably reinforced above the existing floor slab, by laying appropriate lightweight panels.



In both cases, the geometry of the new T-beam must be entered; the section shown is the one of the new joist.



New joist

☒ Add new joist

Inside the floor

New slab thickness	4	cm
New joist width	20	cm
New joist depth	24	cm
New joist spacing	150	cm

Rebars

Stirrups

n.

0

ϕ

5

mm

n.

0

ϕ

5

mm

Area

0.00

cm²

ci [cm]

3

Enter

Reinforcement	Area [cm ²]	c [cm]
New joist intrados	3.08	5
New joist extrados	4.62	5

Span n.

1

Apply

Specifically, for **New joist inside the floor**:

- the width of the new joist may not be greater than the spacing of the existing joists;
- the depth of the joist may not exceed the overall thickness of the existing floor;
- the spacing must be a multiple of the existing floor spacing.

While, for **New joist on top the floor**:

- the minimum depth of the joist is set at 6 cm;
- the minimum slab height is set at 5 cm;
- the spacing can be 1 or 2 times the spacing of the existing joists.

For further information refer to the guide for the design of new joists.

To insert reinforcements, the user can use the commands in the box **Rebars**, choosing the number and diameter of the rebars and pressing **Enter**. The value in the **Area** box and the concrete cover **c** will be inserted in the selected row.



Rebars

Stirrups

n.

0

5

mm

0

5

mm

Area

0.00

cm²

ci [cm]

3

Enter

Reinforcement	Area [cm ²]	c [cm]
New joist intrados	0	3
New joist extrados	0	3

In the **Stirrups** box it is possible to add stirrups in the new joist, in terms of number of legs, diameter and spacing. Press **Edit** to save the values entered.

Rebars

Stirrups

Legs

2

ϕ

8

mm

Spacing

20.0

cm

2 legs d8/20

Edit

Reinforcement values must be entered for each span by selecting it in the **Span n.** box and then pressing **Apply**.



1.2.9. Verify joists

The window **Verify joists** shows the verifications carried out for the new joists, in a similar manner to that seen in section 1.2.7.

Results new joists

Calculation results - slab with new joists

ULS load combination on single beam		11.27	kN/m
Msd+	27.40	kNm	Met
Mrd+	39.29	kNm	
Msd-	-7.82	kNm	Met
Mrd-	-35.55	kNm	
Vsd	28.18	kN	Met
Vrd	84.75	kN	
τ_{sd}	0.16	MPa	Met
τ_{rd}	0.72	MPa	

Calculate new joist

M, V diagrams

Calculation length for sliding [cm]

82.0

It is also shown the combined ULS load applied to the individual new joist, given by the own weight of the new joist, the weight of the existing floor, and the previously imposed dead and variable loads.

Press **Calculate new joist** to proceed with the calculation.

The **M, V diagrams** button displays the stress and strength diagrams of the stiffened floor.

In the case of new joist inside the floor, the highlighted option for the **Calculation length for sliding** appears. By default, the value is equal to the difference between the spacing of the new joist and its base. If the user changes it, it is necessary to press **Calculate new joist** again to proceed with the calculation. In the case of stiffening on top of the floor, the software automatically determines this length.



2. CALCULATION REFERENCES

2.1. Reference legislation

- EN 1992-1-1:2004 “Eurocode 2 – Design of concrete structures - Part 1-1: General rules and rules for buildings”
- EN 1992-4:2018 “Eurocode 2 – Design of concrete structures - Part 4: Design of fastenings for use in concrete”
- EN 1998-3:2005 – “Eurocode 8 – Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings”
- D.M. 17/01/2018 “Norme Tecniche per le costruzioni”
- CIRCOLARE 21/01/2019, n.7 C.S.LL.PP. Instructions for the application of “Norme tecniche per le costruzioni” referred to D.M. 17/01/2018

2.2. ULS flexural strength calculation

The sections are calculated using a numerical procedure to find the plastic neutral axis, which follows the following steps:

- Each section is divided internally with a series of points. from each area the software calculates static moments and moments of inertia;
- Each figure in the cross section is associated with its own material. Every material is associated with the correspondent FC (Confidence Factor) and γ_m values, as well as the deformations and strengths. Please refer to *Chapter 1.2.3.* for constitutive bonds assumed during calculation;
- From the geometric properties of each section part is calculated the centre of gravity;
- The section is then analysed by moving the plastic neutral axis along the depth and verifying the balance between tension and compression. For the ULS calculation, the ultimate deformation compatible with material, geometry and reinforcement is set and the plane representing the compatible deformation at all points of the section is calculated;
- The search is carried out using the bisection method and, at the convergence of the method, the resistant moments, the maximum concrete deformation and the steel deformations are provided.

Please refer to the sliding verification chapter for the specification of the calculation of the section in the elastic branch and the evaluation of the geometric properties.



2.3. Calculation of shear strength

The shear strength is calculated using the relationships illustrated below for elements without specific shear reinforcement and for elements with specific shear reinforcement.

For elements without specific shear reinforcement (in accordance with §4.1.2.3.5.1 and §C4.1.12.1.3.2.1 of the *Norme tecniche delle costruzioni*) according to the following report:

$$V_{Rd} = \max \left\{ \left[\frac{0.18}{\gamma_m} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}} + 0.15 \cdot \sigma_{cp} \right] \cdot b_w \cdot ds, (v_{\min} + 0.15 \cdot \sigma_{cp}) \cdot b_w \cdot ds \right\}$$

with:

$$k = 1 + \sqrt{\frac{200}{ds}} \leq 2$$

$$v_{\min} = 0.035 \cdot k^{1.5} \cdot f_{ck}^{0.5}$$

$$\rho_l = \frac{A_{sl}}{b_w \cdot ds} \leq 0.02$$

$$\sigma_{cp} = 0$$

And ds effective depth of the section, A_{sl} area of the longitudinal reinforcement under tension, b_w minimum base of the effective section.

Specifically, depending on the choice of the mechanical characteristics of the existing concrete between '**Report value**', '**Test value**' and '**Customized value**', the software replaces the term f_{ck} indicated above with the following formulations:

- Report value: f_{ck}/CF
- Test value: f_{cm}/CF
- Customized value: f_{cd}

With CF Confidance Factor.

If $f_{ck,LATRMIX} < f_{ck}/CF$ o $f_{ck,LATERMIX} < f_{cm}/CF$ o $f_{ck,LATERMIX} < f_{cd}$ according to the choice made for the existing concrete, the strength $f_{ck,LATERMIX}$ is assumed in the shear resistance calculation (being the minimum between the strengths of the two concretes involved):

$$V_{rd} = \max \left\{ \left[\frac{0.15}{\gamma_m} \cdot \eta_1 \cdot k \cdot (100 \cdot \rho_l \cdot f_{lck,LATER.})^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w \cdot ds, (v_{l,\min} + 0.15 \sigma_{cp}) b_w \cdot ds \right\}$$

with:

$$\eta_1 = 0.4 + 0.6 \cdot \frac{\rho}{2200}$$

$$v_{l,\min} = 0.030 \cdot k^{1.5} \cdot f_{lck}^{0.5}$$



$$\rho_l = \frac{A_{sl}}{b_w \cdot ds} \leq 0.02$$

$$\sigma_{cp} = 0$$

And ρ upper limit value of the mass class per unit volume of lightweight structural concrete, and with the other symbols used previously.

For elements with specific shear-resistant reinforcement (the new joists designed with the software), the following formulae are used in accordance with §4.1.2.3.5.2 and §C4.1.12.1.3.2.2 of the *Norme tecniche delle costruzioni*:

$$V_{Rsd} = 0.9 \cdot d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot (\cot\alpha + \cot\theta) \cdot \sin\alpha$$

$$V_{Rcd} = 0.9 \cdot d \cdot b_w \cdot 0.4f_{lcd} \cdot \frac{(\cot\alpha + \cot\theta)}{(1 + \cot^2\theta)}$$

$$V_{Rd} = \min(V_{Rsd}, V_{Rcd})$$

With A_{sw} area of transverse reinforcement (stirrups), s stirrups spacing, $\alpha = 90^\circ$ and $21.8^\circ \leq \theta \leq 45^\circ$

By default, the angle θ is automatically searched for the balanced shear break unless customized settings are made.



2.4. Slip verifications on the contact surface with the new slab (Chemical Connector CS)

For the calculation of perfect adhesion between the new lightweight structural concrete slab and the existing floor, the shear stress present at the existing floor-new slab interface is compared with the design value of the Chemical Connector CS, which is necessary for the correct collaboration between the two parts.

Modular ratio for areas subjected to positive bending:

$$n^+ = \frac{E_s}{\frac{E_{cls,LATERMIX}}{2}}$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{ex,concrete}}{2}}$$

$$\tau_{interface} = \frac{V_{Sd,max} \cdot S_{int}}{J_n \cdot b} < 0.72 \text{ MPa}$$

where 0.72 MPa represent the confrontational value considered for Chemical Connector CS, obtained with experimental tests to the *Politecnico di Milano* in Milan, Italy.

The terms of the Jourawski formula indicate:

- $V_{Sd,max}$: maximum value of the shear force in ULS combination;
- S_{int} : static moment (effective area) of the portion over the chord used to calculate the shear stress. It is considered the contribution of the compressed concrete and/or of the rebar over the chord;
- J_n : inertia of the whole effective section referred to the neutral axis;
- b : considered chord width, equal to the minimum contact width between the existing floor and the new slab.

The programme returns the section of the floor where the use of strength is maximum, i.e. where the ratio between strength and stress is highest.

The search for the elastic neutral axis is conducted as follows:

- Each section is divided internally with a series of points. from each area the software calculates static moments and moments of inertia;
- Each figure in the cross section is associated with its own material. Every material is associated with the correspondent FC (Confidence Factor) and γ_m values, as well as the deformations and strengths;
- From the geometric properties of each section part is calculated the centre of gravity;



- The section is then analysed by evaluating the deformations resulting from the application of the bending moment. The effective parts are then identified by calculating the stresses of each material (concrete, bars);
- the position of the neutral axis is calculated.

Below is described the calculation of the area and static moment of a section defined by N points x_i, y_i .

$$A = \frac{1}{2} \sum_i (x_i y_{i+1} - x_{i+1} y_i)$$

$$S_x = \frac{1}{6} \sum_i (x_{i+1} - x_i)(y_i^2 + y_i y_{i+1} + y_{i+1}^2)$$

The same is made for the moment of inertia.

In particular, for the static moment of the partial section, we proceed as follows:

- the part of the effective section, i.e. the compressed concrete area and reinforcement, is defined;
- the horizontal axis is moved to the neutral axis of the section;
- the static moment of the partial section is calculated considering only the parts above the verification chord, positioned between the new lightweight structural concrete slab and the existing floor in the case of a reinforced slab. In the case of new joists inside the floor, the chord is at the interface between the new joist and the slab above, while in the case of new joist on top of the floor, the chord is at the base of the new joist.

The same is true for the moment of inertia.

Finally, please refer to the following validation chapter for an illustration of the analytical formulae in the various cases.



2.5. Evaluation of the strength of mechanical connectors

The strength of the connector is assessed according to EN 1992-4:2018:

$$P_{Rd} = \min(V_{Rd,s}; V_{Rd,cp}; V_{Rd,c})$$

with:

- $V_{Rd,s}$ is the strength of an anchor for the mechanical properties of the steel it is composed of;
- $V_{Rd,cp}$ is the strength of an anchor to pry-out failure of concrete;
- $V_{Rd,c}$ is the strength of an anchor against concrete edge failure.

In addition, the strength of the connection system strongly depends on the stress state of the concrete in which it is embedded, therefore, two different values of P_{Rd} are calculated:

- $P_{Rd,ck}$ Design strength for calculation purposes in those portions of the floor where the existing concrete is cracked;
- $P_{Rd,uck}$ Design strength for calculation purposes in those portions of the floor where the existing concrete is uncracked.

The assessment and specifications in the following paragraphs refer to EN 1992-4:2018 with adaptations for the case of floor joists.

2.5.1. Application limits

The application limits of the **Mini Concrete Connector** are given below:

- Width of the joist: $b_t \geq 7 \text{ cm}$, given in the European Technical Product Standard Specification (ETA20/0830). If the limit is not met, the calculation is not performed by the software, and it is suggested to switch to **Chemical Connector CS**;
- Floor thickness (equal to the sum of the depth of the joist h_t and the existing slab h_c , if present): $h_t + h_c \geq 10 \text{ cm}$. If the limit is not met, the calculation is not performed by the software, and it is suggested to switch to **Chemical Connector CS**;
- Suggested new slab thickness: $4 \text{ cm} \leq s_n \leq 5 \text{ cm}$. If the user wants to create a slab that is less than the minimum thickness, the software suggests contact Laterlite technical support, whereas if you wish to create a slab that is more than 5 cm thick, the software suggests switching to **Chemical Connector CS** or **Concrete Connector Plus D12**, but does not prevent the calculation from continuing;
- The use of lightening panels is not permitted.

The minimum floor dimensions for the possible installation of **Concrete Connector Plus D12** are:

- Width of the joist: $b_t \geq 12 \text{ cm}$, given in the European Technical Product Standard Specification (ETA20/0830). If the joist base is $10 \text{ cm} \leq b_t < 12 \text{ cm}$, the software suggests switching to **Chemical Connector CS** or **Mini Concrete Connector**, but does not prevent the calculation from continuing, whereas if the joist base is $b_t < 10 \text{ cm}$, the calculation is not performed;



- Floor thickness (equal to the sum of the depth of the joist h_t and the existing concrete slab h_c , if present): $h_t + h_c \geq 12 \text{ cm}$. If the limit is not met, the calculation is not performed by the software, and it is suggested to switch to **Chemical Connector CS** or **Mini Concrete Connector**;

New slab thickness: $s_n \geq 5 \text{ cm}$

2.5.2. Rupture of anchor steel $V_{Rd,s}$

The characteristic strength of an anchor by rupture of its constituent steel is assessed in accordance with §7.2.2.1 EN 1992-4:2018:

$$V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$

where:

- $V_{Rk,s}$ is the strength of an anchor for the mechanical properties of its constituent steel against shear loads and is stated in the European Technical Product Standard Specification (ETA20/0830) as 7.5 kN for **Mini Concrete Connector** and 25.6 kN for **Concrete Connector Plus D12**;
- γ_{Ms} is the partial safety factor given in the European Technical Product Standard Specification (ETA20/0830) of 1.25.

2.5.3. Pry-out failure of concrete $V_{Rd,cp}$

The reference for the calculation of $V_{Rd,cp}$ is §7.2.2.4 EN 1992-4:2018. In order to know the strength against pry-out failure of concrete, it is necessary to know the characteristic strength of an anchor for tensile stresses against conical failure of concrete. This failure mode strongly depends on the compression/tensile state of the concrete in which the connector is inserted and, for this reason, two values of $N_{Rk,c}$ are calculated (one for the cracked concrete condition and one for the uncracked concrete condition), according to §7.2.1.4 EN 1992-4:2018:

$$N_{Rk,c} = N_{Rk,c}^0 \cdot \frac{A_{c,N}}{A_{c,N}^0} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$$

$N_{Rk,c}^0$ is the characteristic strength of the individual anchor not influenced by adjacent anchors or edges of the concrete in which it is embedded, and is evaluated as:

$$N_{Rk,c}^0 = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5}$$

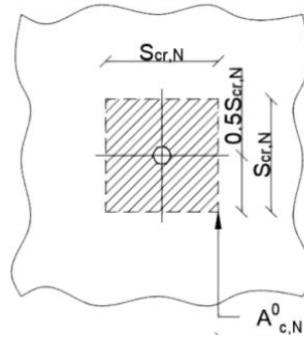
where:

- k_1 is 7.7 for cracked concrete ($k_{1,cr}$) and 11 for uncracked concrete ($k_{1,ucr}$);
- f_{ck} is the characteristic compressive strength of the concrete (referring to the one in which the connector is inserted, i.e. the existing one). Specifically, depending on the selection of the mechanical properties of the existing concrete in the Materials window, the software uses the value of f_{ck} if "Report value" is selected, the value of f_{cm} if "Test value" is selected, and the value of f_{cd} if "Customized value" is selected;



- h_{ef} is the effective anchorage length and is a value given in the European Technical Product Specification (ETA20/0830), which is 42 mm for **Mini Concrete Connector** and 52 mm for **Concrete Connector Plus D12**.

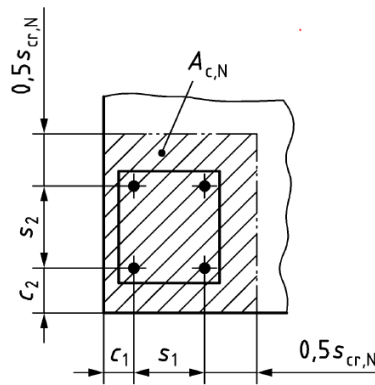
$A_{c,N}^0$ is the reference projection area that evaluates the influence of the position of the anchor installation against the edge of the concrete, and is evaluated as:



$$A_{c,N}^0 = s_{cr,N} \cdot s_{cr,N}$$

Where $s_{cr,N}$ is the critical spacing towards the concrete fracture cone and is a value given in the European Technical Product Specification (ETA20/0830), equal to 126 mm for **Mini Concrete Connector** and 156 mm for **Concrete Connector Plus D12**.

$A_{c,N}$ is the effective projection area limited by the overlapping of the rupture cones of adjacent anchors and is evaluated as:



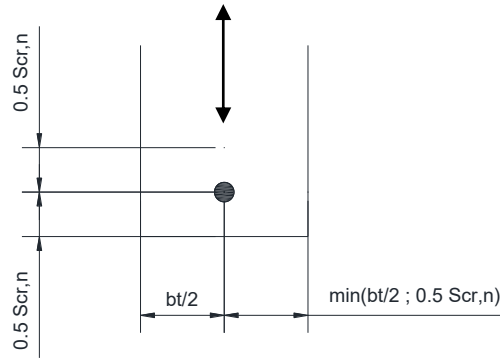
$$A_{c,N} = (c_1 + s_1 + 0.5s_{cr,N}) \cdot (c_2 + s_2 + 0.5s_{cr,N})$$

In the case of floors: if $h_{ef} \leq h_c$ (with h_c existing slab thickness) or if $s_{cr,N} \leq b_t$ (with b_t joist base), $A_{c,N} = A_{c,N}^0$, otherwise the formulation shown below is followed.

In the specific case of floors, neither group anchors nor double row anchors are engaged: this means that s_1 and s_2 are equal to 0; c_1 is the edge distance and is equal to $b_t/2$ and c_2 is the edge distance in the direction of the joist length, equivalent to $0.5s_{cr,N}$ (with $s_{cr,N} = 126 \text{ mm}$ for **Mini Concrete Connector** and $s_{cr,N} = 156 \text{ mm}$ for **Concrete Connector Plus D12**) given the extension of the joists within the masonry.



With reference to the previous image, it becomes:



Therefore, the previous formula becomes:

$$A_{c,N} = \left(\frac{b_t}{2} + \min\left(\frac{b_t}{2}; 0.5s_{cr,N}\right) \right) \cdot s_{cr,N}$$

$\psi_{s,N}$ is the reductive factor that considers the distortion of stress distribution in the concrete due to proximity to the edge of the element in which the connection system is installed and is evaluated as:

$$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} \leq 1$$

where:

- c is the effective distance of the anchor from the edge (equal to $b_t/2$ since **Mini Concrete Connector** and **Concrete Connector Plus D12** are installed in the mid-span of the joist);
- $c_{cr,N}$ is the critical edge distance in respect of concrete cone rupture and is a value given in the European Technical Product Specification (ETA20/0830), which is 63 mm for **Mini Concrete Connector** and 78 mm for **Concrete Connector Plus D12**.

$\psi_{re,N}$ is the spalling factor that evaluates the effect of the reinforcement between which the connector is installed when $h_{ef} < 100 \text{ mm}$ and is evaluated as:

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1$$

With h_{ef} effective anchor length and is a value given in the European Technical Product Specification (ETA20/0830) of 42 mm for **Mini Concrete Connector** and 52 mm for **Concrete Connector Plus D12**.

$\psi_{ec,N}$ and $\psi_{M,N}$ are respectively the coefficient that takes into account the group effect and the coefficient that takes into account the effect of a compressive force between anchor and concrete in the case of bending moments: they are not to be considered in the specific case as they are not provided for the applications of **Mini Concrete Connector** and **Concrete Connector Plus D12**.

It is therefore possible to determine the resistance of an anchor against pry-out shear stresses in concrete on the opposite side of the direction of loading. This strength is evaluated as:



$$V_{Rd,cp} = \frac{k_8 \cdot N_{Rk,c}}{\gamma_{Mc}}$$

where:

- k_8 is the specific factor of 1.0 and is given in the European Technical Product Standard Specification (ETA20/0830);
- $N_{Rk,c}$ is the strength of an anchor under tensile stress in the event of a previously calculated concrete cone failure;
- γ_{Mc} is the partial safety factor given in the European Technical Product Standard Specification (ETA20/0830) of 1.50.

2.5.4. Concrete edge failure $V_{Rd,c}$

The reference for the calculation of $V_{Rd,c}$ is §7.2.2.5 EN 1992-4:2018. This failure mode strongly depends on the compression/tension state of the concrete in which the connector is inserted and, for this reason, two values of $V_{Rk,c}$ are calculated (one for the cracked concrete condition and one for the uncracked concrete condition). The characteristic strength of an anchor loaded towards the edge can be evaluated as:

$$V_{Rk,c} = V_{Rk,c}^0 \cdot \frac{A_{c,V}}{A_{c,V}^0} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \psi_{\alpha,V} \cdot \psi_{re,V}$$

$V_{Rk,c}^0$ is the characteristic initial strength of the single anchor loaded perpendicularly to the edge and is evaluated as:

$$V_{Rk,c}^0 = k_9 \cdot d_{nom}^\alpha \cdot l_f^\beta \cdot \sqrt{f_{ck}} \cdot c_1^{1.5}$$

where:

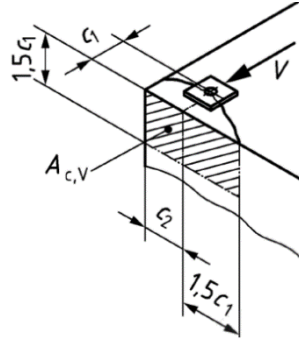
- k_9 is 1.7 for cracked concrete ($k_{9,cr}$) and 2.4 for uncracked concrete ($k_{9,ucr}$);
- d_{nom} is the outer diameter of the anchor and is given in the European Technical Product Specification (ETA20/0830) and is 7.5 mm for **Mini Concrete Connector** and 12.5 mm for **Concrete Connector Plus D12**;
- l_f (in the case of connectors with a uniform diameter) is equal to h_{ef} : the effective anchor length, a value given in the European Technical Product Specification (ETA20/0830) of 42 mm for **Mini Concrete Connector** and 52 mm for **Concrete Connector Plus D12**;
- f_{ck} is the characteristic compressive strength of the concrete (referring to the one in which the connector is inserted, i.e. the existing one). Specifically, depending on the choice of the mechanical properties of the existing concrete in the Materials window, the software uses the value of f_{ck} if "Report value" is selected, the value of f_{cm} if "Test value" is selected and the value of f_{cd} if "Customized value" is selected;
- c_1 is the minimum edge distance of ; $b_t/2$
- α and β are numerical parameters and are evaluated as:

$$\alpha = 0.1 \cdot \left(\frac{l_f}{c_1} \right)^{0.5}$$



$$\beta = 0.1 \cdot \left(\frac{d_{nom}}{c_1} \right)^{0.2}$$

$A_{c,v}$ is the area of the idealised concrete breaking body, limited by the overlapping concrete cones of adjacent anchors, the proximity from the edge and the thickness of the element in which it is installed:



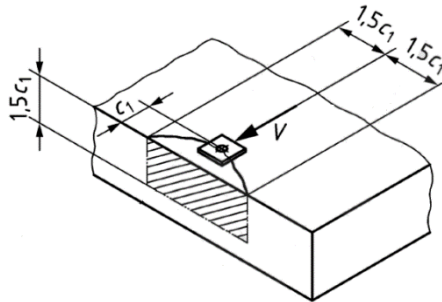
$$A_{c,v} = 1.5c_1 \cdot (c_2 + 1.5c_1)$$

In the specific case of slabs c_2 is equal to $b_t/2$ and c_1 is the distance of the first connector from the wall wire (30 mm for **Mini Concrete Connector** and 45 mm for **Concrete Connector Plus D12**), neglecting, for safety's sake, that the joist continues inside the masonry/wall. Since $A_{c,v}$ is an effective area, it must be verified that it can actually develop within the specific geometry of the slab under consideration. Therefore, the above formula becomes:

$$A_{c,v} = \min(h_t + h_c ; 1.5c_1) \cdot \min(3c_1 ; b_t)$$

With h_t depth of the joist, h_c thickness of the existing slab (if any), b_t width of the joist.

$A_{c,v}^0$ is the reference projection area for the idealised breaking range of a single anchor:



$$A_{c,v}^0 = 1.5c_1 \cdot (1.5c_1 + 1.5c_1) = 4.5c_1^2$$

In the specific case of floors c_1 is the distance of the first connector from the wall edge (30 mm for **Mini Concrete Connector** and 45 mm for **Concrete Connector Plus D12**).

$\psi_{s,v}$ is the reduction factor that takes into account the distortion of the stress distribution in the concrete due to other edges of the concrete element on the shear strength and is evaluated as:



$$\psi_{s,V} = 0.7 + 0.3 \cdot \frac{c_2}{1.5c_1} \leq 1$$

In the specific case of, $\psi_{s,V}c_1$ and c_2 are equivalent as the connectors are positioned in the centre of the joist and therefore both take on the value of $.b_t/2$

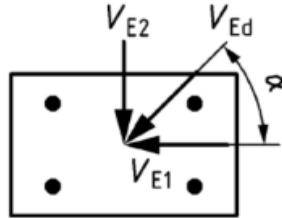
$\psi_{h,V}$ is the factor that takes into account that the strength of the concrete edge does not decrease in proportion to the thickness of the element assumed by the ratio $\frac{A_{c,V}}{A_{c,V}^0}$ and is evaluated as:

$$\psi_{h,V} = \left(\frac{1.5c_1}{h} \right)^{0.5} = \left(\frac{1.5 \cdot \frac{b_t}{2}}{h_t + h_c} \right)^{0.5} \geq 1$$

Where h represents the depth of the element in which the anchoring system is installed and coincides with the depth of the joist if the floor is shaved, otherwise with the sum of the depth of the joist and the thickness of the existing slab, c_1 is equal to $.b_t/2$

$\psi_{ec,V}$ is the coefficient that considers the group effect, it is not relevant for the application modes of **Mini Concrete Connector** and **Concrete Connector Plus D12**.

$\psi_{\alpha,V}$ is the factor that takes into account that the strength of the concrete edge does not decrease in proportion to the thickness of the element assumed by the ratio $\frac{A_{c,V}}{A_{c,V}^0}$ and is evaluated as:



$$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos \alpha_V)^2 + (0.5 \sin \alpha_V)^2}} \geq 1$$

Where α_V is the angle between a design stress shear load V_{Ed} and a line perpendicular to the verified edge, in the case of single anchors placed on floors: $\alpha_V = 90^\circ$

$\psi_{re,V}$ is the factor that takes into account the effect of the reinforcement along the edge and is equal to 1.0 in both cracked and uncracked concrete conditions.

It is therefore possible to determine the resistance of an anchor against shear stresses by breaking the concrete edge. This resistance is evaluated as:

$$V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$$



where:

- $V_{Rk,c}$ is the resistance of an anchor against fracture with respect to the previously calculated concrete edge;
- γ_{Mc} is the partial safety factor given in the European Technical Product Standard Specification (ETA20/0830), which is 1.50.

2.6. Calculation of creep and adhesion at the interface (mechanical connectors)

The number of connectors to be used is the number required to transmit the slip between the existing floor and the new structural lightweight concrete slab. Slip is calculated using the Jourawsky formula.

Modular ratio for areas subjected to positive bending:

$$n^+ = \frac{E_s}{\frac{E_{cls,LATERMIX}}{2}}$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{ex,concrete}}{2}}$$

$$\tau_{interface} \cdot b = \frac{V_{sd} \cdot S_{int}}{J_n}$$

The terms of the Jourawski formula indicate:

- $V_{sd,max}$: maximum value of the shear force in ULS combination;
- S_{int} : static moment (effective area) of the portion over the chord used to calculate the shear stress. It is considered the contribution of the compressed concrete and/or of the rebar over the chord;
- J_n : inertia of the whole effective section referred to the neutral axis;
- b : considered chord width, equal to the minimum contact width between the existing floor and the new slab.

This slip ($\tau_{interface} \cdot b$) is compared with the design resistance of the connector P_{Rd} (in the cracked or uncracked zone depending on the section considered), as illustrated in the following paragraph. The contribution offered by the slip adhesion v_{Rdi} , is also considered, evaluated in accordance with paragraph 6.2.5 of EN 1992-1-1:2015, using the parameters for smooth surfaces, with the following formula:

$$v_{Rdi} = \min(c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_{yd} \cdot (\mu \cdot \sin \alpha + \cos \alpha); 0.5 \cdot v \cdot f'_{cd})$$

where:

- c e μ for smooth surfaces are 0.2 and 0.6 respectively;
- f_{ctd} is the value of the design tensile strength (evaluated as follows);



- σ_n is the compressive stress produced by the minimum external force acting at the interface which may act simultaneously with the shear force (evaluated as follows);
- ρ is the ratio of the specific transverse reinforcement area across the interface to the area of the joint (equal to 0 in this case);
- ν is a resistance reduction coefficient (evaluated as follows).

The design tensile strength f_{ctd} is evaluated as the minimum between the tensile strength of existing concrete and that of lightweight structural concrete:

$$f_{ctd} = \min(f_{ctd,ex.concrete} ; f_{lctd})$$

with:

$$f_{ctd,ex.concrete} = \left\{ \begin{array}{ll} \frac{0.7 \cdot 0.3 f_{ck}^{2/3}}{FC \cdot \gamma_c} & \text{Report value} \\ \frac{0.7 \cdot 0.3 f_{cm}^{2/3}}{FC \cdot \gamma_c} & \text{Test value} \\ 0.7 \cdot 0.3 f_{cd}^{2/3} & \text{Customized value} \end{array} \right\}$$

$$f_{lctd} = \frac{0.85 \cdot f_{lctk}}{\gamma_c}$$

$$f_{lctk} = 0.7 \cdot f_{lctm}$$

$$f_{lctm} = 0.3 \cdot f_{lck}^{2/3} \cdot \eta_1$$

$$\eta_1 = 0.4 + 0.6 \cdot \frac{\rho}{2200}$$

Where ρ is the upper limit value of the mass per unit volume of the concrete for the relevant mass per unit volume class in kg/m³.

The compressive stress produced by the minimum external force acting at the interface that can act simultaneously with the shear force results:

$$\sigma_n = \min(q_{slu}^* ; 0.6f'_{cd})$$

with:

$$q_{slu}^* = \gamma_{G1} \cdot [P_{slab} + P_{screed} + P_{base\ screed}] + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}$$

$$f'_{cd} = \min(f_{cd,ex.concrete}, f_{agile\ par.}; f_{lcd})$$

The coefficient ν results:

$$\nu = \min \left[0.6 \cdot \left(1 - \frac{f_{ck,ex.concrete}}{250} \right); 0.5 \cdot \left(1 - \frac{f_{lck}}{250} \right) \right]$$



Where $f_{ck,ex.concrete}$, depending on the choice of mechanical properties of the existing concrete in the Materials window, the software uses the value of f_{ck} if 'Report value' is selected, the value of f_{cm} if 'Test value' is selected and the value of f_{cd} if 'Customized value' is selected; and f_{lck} represents the characteristic compressive strength of structural lightweight concrete.

The term v_{Rdi} is then multiplied by the term L in order to obtain a quantity comparable with $\tau_{interface} \cdot b$. The term L represents the corresponding width to which the adhesion slip is entrusted, which is equal to:

$$L = \begin{cases} b_t & \text{if } h_c < 20 \text{ mm and } h_p = 0 \text{ mm} \\ i_{tr} & \text{if } h_c \geq 20 \text{ mm and } h_p = 0 \text{ mm} \\ \min(b_t; b_r) & \text{if } h_c < 20 \text{ mm and } h_p > 0 \text{ mm} \\ b_r & \text{if } h_c \geq 20 \text{ mm and } h_p > 0 \text{ mm} \end{cases}$$

With b_t width of the joist, i_{tr} spacing of the floor slab, h_c thickness of the existing concrete slab, h_p thickness of the lightening board and b_r base of the concrete slab (if the lightening board is present).

The search for the elastic neutral axis is conducted as follows:

- Each section is divided internally with a series of points. from each area the software calculates static moments and moments of inertia;
- Each figure in the cross section is associated with its own material. Every material is associated with the correspondent FC (Confidence Factor) and γ_m values, as well as the deformations and strengths;
- From the geometric properties of each section part is calculated the centre of gravity;
- The section is then analysed by evaluating the deformations resulting from the application of the bending moment. The effective parts are then identified by calculating the stresses of each material (concrete, bars);
- the position of the neutral axis is calculated.

Below is described the calculation of the area and static moment of a section defined by N points x_i, y_i .

$$A = \frac{1}{2} \sum_i (x_i y_{i+1} - x_{i+1} y_i)$$

$$S_x = \frac{1}{6} \sum_i (x_{i+1} - x_i)(y_i^2 + y_i y_{i+1} + y_{i+1}^2)$$

The same is made for the moment of inertia.

In particular, for the static moment of the partial section, we proceed as follows:

- the part of the effective section, i.e. the compressed concrete area and reinforcement, is defined;
- the horizontal axis is moved to the neutral axis of the section;



- the static moment of the partial section is calculated considering only the parts above the verification chord, positioned between the new lightweight structural concrete slab and the existing floor.

The same is true for the moment of inertia.

2.7. Calculation of connector spacing and distribution

For the purpose of calculating the spacing and distribution of the connectors, it is necessary to know:

- slip at the interface $\tau_{interface} \cdot b$, with b chord width to be considered, equal to the minimum contact width between the existing slab and the new slab;
- the slip resistance offered by the adhesion; $v_{Rdi} \cdot L$
- the calculation strength of the chosen connector in the cracked zone $P_{Rd,ck}$ and in the uncracked zone; $P_{Rd,uck}$
- the direction of the moment in the condition before the intervention, hereafter referred to as; $M_{sd,pre-int}$
- the position of the positive-moment neutral axis in the condition before the intervention, hereafter referred to as $A_{N,pre-int}^+$

For each point at which the analysed floor has been discretized, the spacing (referred to as PC = calculated spacing) of the connectors in the considered coordinate is calculated as follows:

$$PC [mm] = \left\{ \begin{array}{ll} \frac{P_{Rd,ck}}{(\tau_{interface} \cdot b) - (v_{Rdi} \cdot L)} & \text{if } M_{sd,pre-int} < 0 \\ \frac{P_{Rd,ck}}{(\tau_{interface} \cdot b) - (v_{Rdi} \cdot L)} & \text{if } M_{sd,pre-int} \geq 0 \text{ e } A_{N,pre-int}^+ < 0.9h_{ef} \\ \frac{P_{Rd,uck}}{(\tau_{interface} \cdot b) - (v_{Rdi} \cdot L)} & \text{if } M_{sd,pre-int} \geq 0 \text{ e } A_{N,pre-int}^+ \geq 0.9h_{ef} \end{array} \right\}$$

For each coordinate, if the calculated spacing PC is less or equal to zero or greater than the maximum spacing, the maximum spacing of 500 mm is imposed, resulting in the correct calculated spacing : PCC

$$PCC [mm] = \left\{ \begin{array}{ll} s_{max} = 500 \text{ mm} & \text{if } PC \leq 0 \text{ o } PC > s_{max} \\ PC & \text{if } 0 < PC \leq s_{max} \end{array} \right\}$$

The software always calculates both the laying with variable spacing and the laying with constant spacing per span, reporting both laying options within the report and only the laying option with variable spacing by clicking on the **Connector Table** button in the software interface.

2.7.1. Variable spacing

For each span, the software identifies the points where the floor has been discretized belonging to $L/4$ left, to $L/4$ right and to $L/2$ centre and determines the theoretical spacing in the section considered as follows:



$$theoretical\ spacing = \begin{cases} \min(PCC) \text{ in } \frac{L}{4} \text{ left} \\ \min(PCC) \text{ in } \frac{L}{2} \text{ central} \\ \min(PCC) \text{ in } \frac{L}{4} \text{ right} \end{cases}$$

Once the theoretical spacing is known, it is possible to calculate the theoretical number of connectors for the section under consideration:

$$N.theoretical\ conn = \frac{L_i}{theoretical\ spacing}$$

With L_i equal to the length of the part considered.

If $N.theoretical\ conn$ isn't a non-integer number, the software proceed to round off the theoretical number of connectors, finding $N.connectors$ and thus the actual spacing at which the connectors will be laid in the section under consideration:

$$spacing = \frac{L_i}{N.connectors}$$

Specifically, rounding is performed as follows:

- to the next integer for **Mini Concrete Connector** at both $L/4$ and $L/2$
- to the next integer for **Concrete Connector Plus D12** in $L/4$
- to the next even integer for **Concrete Connector Plus D12** at $L/2$

If in any of the sections $spacing$ is smaller than the critical spacing $s_{cr,N}$ (equal to 126 mm for **Mini Concrete Connector** and $s_{cr,N} = 156\text{ mm}$ for **Concrete Connector Plus D12**), the software indicates with a special alert that the calculated spacing is smaller than the critical spacing according to ETA.

The number of connectors at m^2 is obtained by doing the sum of $N.connectors$ on the different sections and dividing the total by the sum of the spans and the spacing between joists.

If a free end is present in a span, the software returns the laying with constant spacing in that span (calculated as indicated in the following paragraph), while maintaining the laying with variable spacing in the other spans of the floor (if present).

2.7.2. Constant spacing per span

For each span, the software determines the theoretical laying spacing as follows:

$$theoretical\ spacing = \min(PCC)$$

Once the theoretical spacing is known, it is possible to calculate the theoretical number of connectors for the considered span:



$$N.theoretical\ conn = \frac{L_i}{theoretical\ spacing}$$

With L_i equal to the length of the considered span.

$N.conn\ theoric$ turns out to be a non-integer number, the software proceeds to round off the theoretical number of connectors, finding $N.connectors$ and thus the actual spacing at which the connectors will be laid:

$$spacing = \frac{L_i}{N.connectors}$$

Specifically, rounding is performed as follows:

- to the next integer for **Mini Concrete Connector**;
- to the next even integer for **Concrete Connector Plus D12** in spans without the free end;
- to the next integer for **Concrete Connector Plus D12** in free end spans.

If in any of the spans $spacing$ is smaller than the critical spacing $s_{cr,N}$ (equal to 126 mm for **Mini Concrete Connector** and $s_{cr,N} = 156\ mm$ for **Concrete Connector Plus D12**), the software will signal with a special alert that the calculated spacing is smaller than the critical spacing according to ETA.

The number of connectors at m^2 is obtained by doing the sum of $N.connectors$ on the different spans and dividing the total by the sum of the spans of the spans and the spacing between joists.



3. VALIDATION OF THE CALCULATION

In this chapter, calculation examples are given as validation of the calculation procedures adopted in the software.

3.1. Case 1 - Floor with new slab and Chemical Connector CS

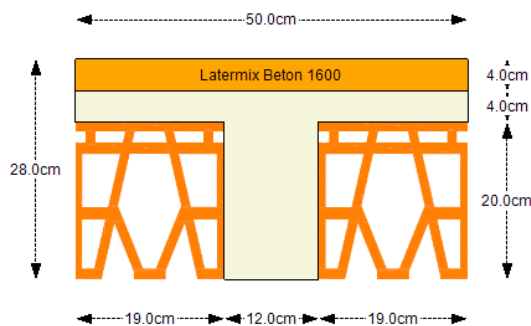
An existing slab with the characteristics described below is analysed, reinforced with a new slab in **Latermix Beton 1600** structural lightweight concrete, connected to the existing slab via **Chemical Connector CS**.

The following existing materials are adopted:

- for existing concrete, 'Report value' is chosen with a class C20/25 and a Knowledge Level LC2 corresponding to a Confidence Factor of 1.20;
- for existing steel, 'Report value' is chosen with a class FeB44k and a Knowledge Level LC1 corresponding to a Confidence Factor of 1.35.

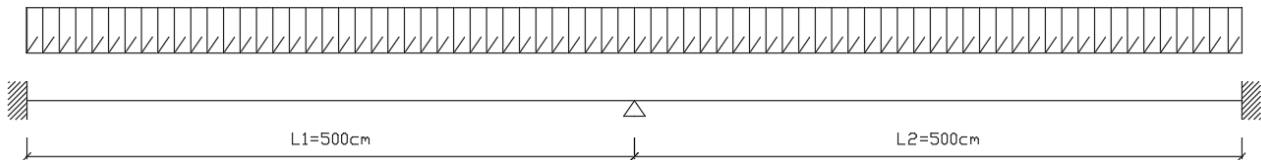
The calculation is carried out assuming brittle behaviour of existing materials.

The following geometry is adopted:



GEOMETRY		
New slab thickness	4.0	cm
Existing slab thickness	4.0	cm
Joist width	12.0	cm
Joist depth	20.0	cm
Joist spacing	50.0	cm
Span length 1	500.0	cm
Span length 2	500.0	cm

The static scheme of the floor consists of 2 spans of 500 cm with fixed supports at the ends:



The load at the Ultimate Limit State is determined as follows:

Partial safety factors	Permanent structural loads	γ_{G1}	1.3 -
	Other permanent non-structural loads	γ_{G2}	1.5 -
	Variable loads	γ_Q	1.5 -
Own weight	Existing floor	G_1	3.11 kN/m ²
	Collaborating slab (4 cm)		0.70 kN/m ²
Permanents	Latermix Facile (4.00 cm)	G_2	0.40 kN/m ²
	Base screed CS (5.00 cm)		0.33 kN/m ²
	Other permanents		1.00 kN/m ²
Variables		Q	2.00 kN/m ²

The ULS load combination considered is:

$$q = i_{tr} \cdot [\gamma_{G1} \cdot (P_{floor} + P_{slab} + P_{screed} + P_{base\ screed}) + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}]$$

The self-weight of the floor slab is assessed considering a concrete density of the existing joist of 25 kN/m³ and of the hollow brick of 6 kN/m³, the weight of the slab is assessed considering the density class to which the structural lightweight concrete belongs and the corresponding mass value per unit volume in accordance with Tab. C4.1.VI (unreinforced concrete).

The load per joist is therefore:

$$q = 0.5 \cdot [1.3 \cdot (3.11 + 0.7 + 0.4 + 0.325) + 1.5 \cdot 1 + 1.5 \cdot 2] = 5.2 \frac{kN}{m}$$

The stresses are here calculated:

$$V_{max} = \frac{qL}{2} = 13.00 \text{ kN}$$

$$M_{max} = \frac{qL^2}{24} = 5.42 \text{ kNm}$$

$$M_{min} = \frac{-qL^2}{12} = -10.83 \text{ kNm}$$



Sectional reinforcement is defined as follows:

	$A_{s1} = 2.26 \text{ cm}^2 \quad d_1 = 3 \text{ cm (B450C)}$ $A_{s2} = 0.50 \text{ cm}^2 \quad d_2 = 3 \text{ cm (FeB44k)}$ $A_{s3} = 1.13 \text{ cm}^2 \quad d_3 = 3 \text{ cm (FeB44k)}$ <p>For B450C:</p> $f_{yd} = \frac{f_{yk}}{\gamma_m} = \frac{450}{1.15} = 391.30 \text{ MPa}$ <p>For FeB44k:</p> $f_{sd} = \frac{f_{sk}}{\gamma_m FC} = \frac{430}{1.15 \cdot 1.35} = 276.97 \text{ MPa}$
--	--

Flexural verification

We then proceeded to calculate the positive and negative flexural strength at ULS of the reinforced slab using the **Latermix Beton 1600**, connected to the existing floor with **Chemical Connector CS**.

The distances from the extrados of the reinforcement in the section are:

$$c_1 = 3 \text{ cm}$$

$$c_2 = 7 \text{ cm}$$

$$c_3 = 25 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

In order to determine the position of the neutral axis, it is assumed that the reinforcement in the existing joist is tensioned and yielded while the reinforcement in the new collaborating slab is tensioned and in the elastic phase (deformation less than the yield strain evaluated as the ratio between the design stress and the elastic modulus E_s of the steel set at 210 000 MPa), that the neutral axis falls in the new slab in **Latermix Beton 1600** and that rupture is reached at the compressed extreme (ultimate deformation $\varepsilon_{lcu} = 3 \text{ ‰}$). These assumptions must then be verified.

The equilibrium equation at translation therefore results:

$$-0.8 \cdot f_{cd} \cdot i_{tr} \cdot x + A_{s1} \cdot E_s \cdot \frac{\varepsilon_{lcu}}{x} \cdot (c_1 - x) + A_{s2} \cdot f_{sd} + A_{s3} \cdot f_{sd} = 0$$

The deformation of the reinforcement in the slab is expressed through the similarity of triangles.

Solving the resulting second-degree equation and discarding the ineligible solution, the position of neutral axis is equal to:



$$x = 1.86 \text{ cm}$$

It is now verified that the deformations in the three reinforcement levels are consistent with the defined assumptions:

$$\varepsilon_{s1} = \frac{\varepsilon_{lcu}}{x} (c_1 - x) = 1.84 \text{ ‰} < 1.86 \text{ ‰}$$

$$\varepsilon_{s2} = \frac{\varepsilon_{lcu}}{x} (c_2 - x) = 8.30 \text{ ‰} > 1.32 \text{ ‰}$$

$$\varepsilon_{s3} = \frac{\varepsilon_{lcu}}{x} (c_3 - x) = 37.4 \text{ ‰} > 1.32 \text{ ‰}$$

The assumptions are verified, and the resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdp} = \varepsilon_{s1} E_s A_{s1} (c_1 - 0.4x) + f_{sd} A_{s2} (c_2 - 0.4x) + f_{sd} A_{s3} (c_3 - 0.4x) = 10.43 \text{ kNm}$$

The small differences in terms of neutral axis and resistant moment are due to the different constitutive models implemented in the software and used in the manual calculations.

The positive bending test is therefore satisfied:

$$M_{max} = \frac{qL^2}{24} = 5.42 \text{ kNm} < M_{rdp} = 10.43 \text{ kNm}$$

Now is it possible to calculate the negative bending strength.

The distances from the intrados of the reinforcement in the section are:

$$e_1 = 25 \text{ cm}$$

$$e_2 = 21 \text{ cm}$$

$$e_3 = 3 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for the existing concrete, but please note that a parabola-rectangle constitutive law was used in the software. The small differences in terms of neutral axis and resistant moment are due to the different constitutive laws implemented in the software and used in the manual calculations.

In order to determine the position of the neutral axis, it is assumed that all the reinforcements present are yielded, that the reinforcement A_{s3} is in compression while A_{s1} and A_{s2} are in tension, that the neutral axis falls within the existing joist and between the two levels of reinforcement present in the joist, and that rupture is reached at the extreme compressed end (ultimate deformation $\varepsilon_{cu} = 3.50 \text{ ‰}$). As before, these assumptions must then be verified.

The equilibrium equation at translation therefore results:



$$-f_{yd} \cdot A_{s1} - f_{sd} \cdot A_{s2} + f_{sd} \cdot A_{s3} + f_{cd} \cdot b \cdot 0.8 \cdot x1 = 0$$

Solving the equation the neutral axis equal to:

$$x1 = 7.83 \text{ cm}$$

It is now verified that the deformations in the three reinforcement levels are consistent with the defined assumptions:

$$\varepsilon_{s1} = \frac{\varepsilon_{cu}}{x1} (e_1 - x1) = 7.68 \text{ ‰} > 1.86 \text{ ‰}$$

$$\varepsilon_{s2} = \frac{\varepsilon_{cu}}{x1} (e_2 - x1) = 5.89 \text{ ‰} > 1.32 \text{ ‰}$$

$$\varepsilon_{s3} = \frac{\varepsilon_{cu}}{x1} (e_3 - x1) = -2.16 \text{ ‰} < -1.32 \text{ ‰}$$

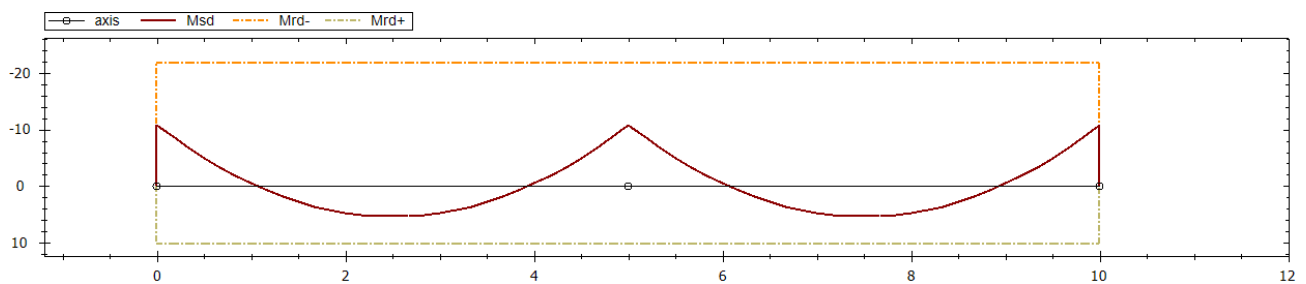
The assumptions are verified, and the resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdn} = f_{yd} A_{s1} (e_1 - 0.4x1) + f_{sd} A_{s2} (e_2 - 0.4x1) - f_{sd} A_{s3} (e_3 - 0.4x1) = 21.85 \text{ kNm}$$

The negative bending verification is therefore satisfied:

$$M_{min} = \frac{-qL^2}{12} = -10.83 \text{ kNm} < M_{rdn} = -21.85 \text{ kNm}$$

The graph produced by the software is shown:



Shear verification

The shear strength is assessed at the supports where the stress shear is maximum. In this area, the reinforcement under tension is A_{s1} and A_{s2}

Since $f_{ck,LATERMIX} > f_{ck}/CF$, we proceed with the **shear verification at ULS**, for elements without specific shear reinforcement, in accordance with §4.1.2.3.5.1 of the *Norme tecniche delle costruzioni*, according to the following report:



$$V_{Rd} = \max \left\{ \left[\frac{0.18}{\gamma_m} \cdot k \cdot \left(100 \cdot \rho_l \cdot \frac{f_{ck}}{FC} \right)^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w \cdot ds, (v_{\min} + 0.15 \sigma_{cp}) b_w \cdot ds \right\} = \max (V_{r1}; V_{r2})$$

with:

$$k = 1 + \sqrt{\frac{200}{ds}} = 1.89 \leq 2$$

$$v_{\min} = 0.035 k^{1.5} \left(\frac{f_{ck}}{FC} \right)^{0.5} = 0.373$$

$$\rho_l = \frac{A_{sl}}{b_w \cdot ds} = \frac{A_{s1} + A_{s2}}{b_w \cdot ds} = 0.0092 \leq 0.02$$

$$\sigma_{cp} = 0$$

And ds effective depth of the section equal to 25 cm, A_{sl} area of the longitudinal reinforcement under tension (sum of A_{s1} and A_{s2}), b_w minimum base of the reacting section equal to 12 cm and γ_m equal to 1.5.

It therefore results:

$$V_{r1} = \left[\frac{0.18}{\gamma_m} \cdot k \cdot \left(100 \cdot \rho_l \cdot \frac{f_{ck}}{FC} \right)^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w \cdot ds = 16.94 \text{ kN}$$

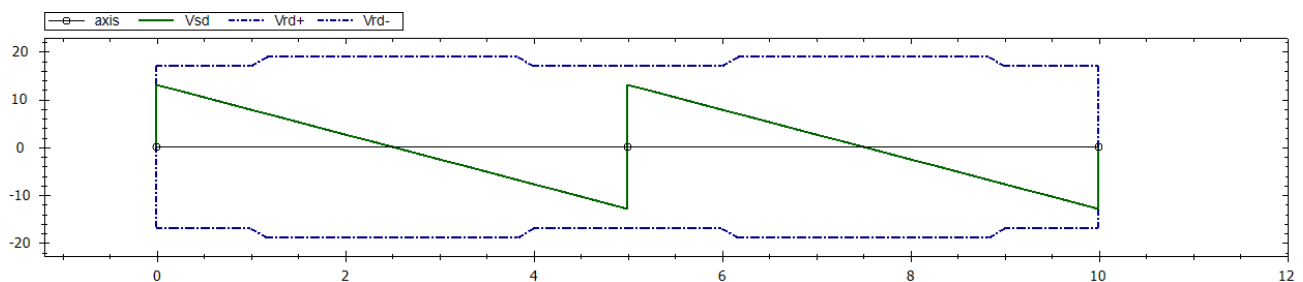
$$V_{r2} = (v_{\min} + 0.15 \sigma_{cp}) b_w \cdot ds = 11.18 \text{ kN}$$

$$V_{Rd} = \max(V_{r1}; V_{r2}) = 16.94 \text{ kN}$$

Shear verification is therefore satisfied:

$$V_{\max} = \frac{qL}{2} = 13.00 \text{ kN} < V_{Rd} = 16.94 \text{ kN}$$

The graph produced by the software is shown:



Slip verification on the contact surface with the new slab

For the calculation of perfect adhesion between the new **Latermix Beton 1600** concrete slab and the existing floor, the shear stress at the existing floor-new slab interface (evaluated using Jourawsky's formula) is compared with the **Chemical Connector CS** design value of 0.72 MPa, which is necessary for the two parts to work together correctly.

Modular ratio for areas subjected to positive bending:

$$n^+ = \frac{E_s}{\frac{E_{cls,LATERMIX}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{20000 \text{ MPa}}{2}\right)} = 21.0$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{ex,concrete}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{29962 \text{ MPa}}{2}\right)} = 14.02$$

In this case, the maximum stress shear of 13 kN occurs in an area subject to negative moment, therefore, subsequent evaluations are performed using n^-

We first evaluate the position of the neutral axis from the elastic calculation of the section, imposing that the static moment of the partially effective section with respect to the neutral axis is zero (assumption of neutral axis in the existing joist):

$$bx_n \frac{x_n}{2} + n^- [A_{s1}(x_n - e_1) + A_{s2}(x_n - e_2) + A_{s3}(x_n - e_3)] = 0$$

from which is derived $x_n = 9.06 \text{ cm}$. The hypothesis is verified.

The static moment of the part above chord b considered located at the interface between the existing floor and the new slab is then evaluated, which in this case involves only the reinforcement present in the slab:

$$S_{int} = A_{s1}n^-(e_1 - x_n) = 504.95 \text{ cm}^3$$

The moment of inertia of the partially effective section with respect to the neutral axis is evaluated as follows:

$$J_n = \frac{A_{c1} \cdot x_n^2}{12} + A_{c1} \cdot \left(\frac{x_n}{2}\right)^2 + n^- \cdot (A_{s1} \cdot (e_1 - x_n)^2 + A_{s2} \cdot (e_2 - x_n)^2 + A_{s3} \cdot (e_3 - x_n)^2)$$

$$J_n = 12605.03 \text{ cm}^4$$

With $A_{c1} = x_n b$ being the area of the compressed concrete part.

Finally, the tangential tension at the interface is calculated using Jourawsky's formula:

$$\tau_{interface} = \frac{V_{sd,max} \cdot S_{int}}{J_n \cdot b} = 0.10 \text{ MPa} < 0.72 \text{ MPa}$$



With $V_{sd,max} = V_{max} = 13 \text{ kN}$ and $b = 50 \text{ cm}$

The verification is fulfilled as the tension is lower than the design tension of the Chemical Connector CS.

The results obtained in the software are shown below:

Results

Calculation results

Msd+	5.42	kNm	Met
Mrd+	10.36	kNm	
Msd-	-10.83	kNm	Met
Mrd-	-21.79	kNm	
Vsd	13.00	kN	Met
Vrd	16.94	kN	
τ_{sd}	0.10	MPa	Met
τ_{rd}	0.72	MPa	

Calculate

M, V diagrams

Verification before intervention

The ULS load combination, considered is:

$$q = i_{tr} \cdot [\gamma_{G1} \cdot (P_{floor} + P_{screed} + P_{base\ screed}) + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}]$$

where the self-weight of the floor is evaluated considering a concrete density of the existing joist of 25 kN/m^3 and of the hollow brick of 6 kN/m^3 .

The load per joist is therefore:

$$q = 0.5 \cdot [1.3 \cdot (3.11 + 0.4 + 0.325) + 1.5 \cdot 1 + 1.5 \cdot 2] = 4.74 \frac{\text{kN}}{\text{m}}$$

The stresses of the joist are calculated as follows:

$$V_{max} = \frac{qL}{2} = 11.86 \text{ kN}$$



$$M_{max} = \frac{qL^2}{24} = 4.94 \text{ kNm}$$

$$M_{min} = \frac{-qL^2}{12} = -9.88 \text{ kNm}$$

Similarly to the above, the position of the neutral axis at positive moment is derived by writing the equilibrium equation at translation (assuming that the reinforcements are both unbonded and the neutral axis falls into the existing slab):

$$x = \frac{f_{sd}(A_{s2} + A_{s3})}{0.8f_{cd}i_{tr}} = 1.20 \text{ cm}$$

The positive resistant moment results:

$$M_{rdp} = f_{sd} \cdot A_{s2} \cdot (c_2 - 0.4 \cdot x) + f_{sd} \cdot A_{s3} \cdot (c_3 - 0.4 \cdot x) = 6.77 \text{ kNm}$$

where the values of c_2 and c_3 are assigned the effective depth of the reinforcement measured from the extrados of the existing slab.

We derive the position of the neutral axis at negative momentum by writing the equilibrium equation at translation (assuming that the reinforcement A_{s2} is yielded while the reinforcement A_{s3} is elastic):

$$-f_{sd} \cdot A_{s2} + \frac{E_s \cdot \varepsilon_{cu} \cdot (x1 - e_3)}{x1} \cdot A_{s3} + f_{cd} \cdot b \cdot 0.8 \cdot x1 = 0$$

$$x1 = 2.67 \text{ cm}$$

The negative resistant moment results:

$$M_{rdn} = f_{sd} \cdot A_{s2} \cdot (e_2 - 0.4 \cdot x1) - \varepsilon_{s3} \cdot E_s \cdot A_{s3} \cdot (e_3 - 0.4 \cdot x1) = 2.96 \text{ kNm}$$

where the values of e_2 and e_3 are assigned to the effective depth of the reinforcement measured from the intrados of the existing floor.

For the shear verification (at the supports), the formulation for non-reinforced shear elements is applied, similarly to what was done previously:

$$V_{Rd} = \max \left\{ \left[\frac{0.18}{\gamma_m} \cdot k \cdot \left(100 \cdot \rho_l \cdot \frac{f_{ck}}{FC} \right)^{\frac{1}{3}} + 0.15\sigma_{cp} \right] b_w \cdot ds, (v_{\min} + 0.15\sigma_{cp}) b_w \cdot ds \right\} = \max(V_{r1}; V_{r2})$$

with:

$$ds = h + s_e - c_2 = 21 \text{ cm}$$

$$\rho_l = \frac{A_{sl}}{b_w \cdot ds} = \frac{A_{s2} + A_{s3}}{b_w \cdot ds} = 0.00647 \leq 0.02$$



$$k = 1 + \sqrt{\frac{200}{ds}} = 1.98 \leq 2$$

$$v_{\min} = 0.035k^{1.5} \left(\frac{f_{ck}}{FC} \right)^{0.5} = 0.397$$

$$\sigma_{cp} = 0$$

And ds effective depth of the section equal to 21 cm, A_{sl} area of the longitudinal under tension reinforcement (sum of A_{s2} and A_{s3}), b_w minimum base of the effective section equal to 12 cm and γ_m equal to 1.5.

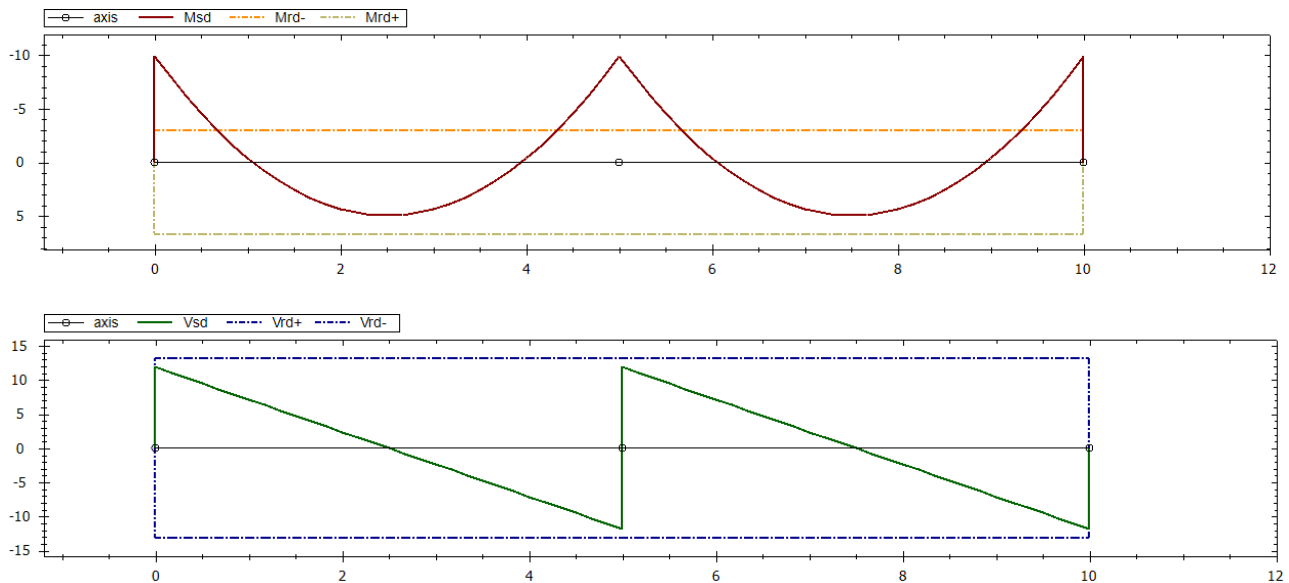
It results:

$$V_{r1} = \left[\frac{0.18}{\gamma_m} \cdot k \cdot \left(100 \cdot \rho_l \cdot \frac{f_{ck}}{FC} \right)^{\frac{1}{3}} + 0.15\sigma_{cp} \right] b_w \cdot ds = 13.20 \text{ kN}$$

$$V_{r2} = (v_{\min} + 0.15\sigma_{cp}) b_w \cdot ds = 10.00 \text{ kN}$$

$$V_{Rd} = \max(V_{r1}; V_{r2}) = 13.20 \text{ kN}$$

The graphs produced by the software are shown:



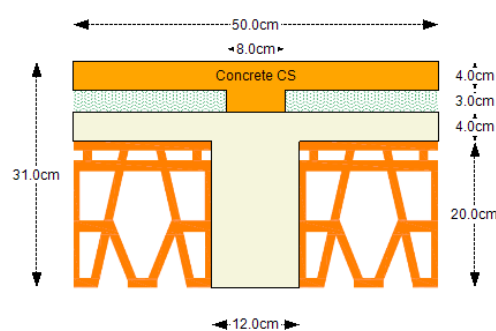
3.2. Case 2 - Floor with new slab and lightening panel and Chemical Connector CS

An existing slab, with the characteristics described below, is analysed, reinforced with a new light structural concrete slab in **Concrete CS**, connected to the existing slab with **Chemical Connector CS**. The installation of lightening panels is also planned, as detailed below.

The following existing materials are adopted:

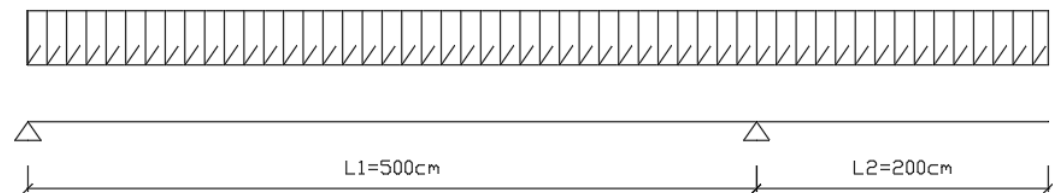
- for existing concrete, '**Customized value**' is chosen with a design compressive strength of 20 MPa;
- for existing steel, '**Customized value**' is chosen with a design yield stress value of 450 MPa.

The following geometry is adopted:



GEOMETRY		
New slab thickness	4.0	cm
Existing slab thickness	4.0	cm
Joist width	12.0	cm
Joist depth	20.0	cm
Joist spacing	50.0	cm
Width of concrete web	8.0	cm
Depth of concrete web	3.0	cm
Span length 1	500.0	cm
Span length 2	200.0	cm

The static scheme of the floor consists of 2 spans, the first of 500 cm and the second of 200 cm with a zero stiffness support at the left end while the other end is free:



There is also a Full reinforced concrete zone at the central support with an extension of 60 cm for the left span and 40 cm for the right one.



The load at the Ultimate Limit State is determined as follows:

Partial safety factors	Structural permanent loads	γ_{G1}	1.3 -
	Other non-structural permanent loads	γ_{G2}	1.5 -
	Variable loads	γ_Q	1.5 -
Own weight	Existing floor	G_1	3.11 kN/m ²
	Collaborating slab (4 cm)		0.74 kN/m ²
Permanents	-	G_2	0.00 kN/m ²
	-		0.00 kN/m ²
	Other permanents		1.50 kN/m ²
Variables		Q	2.00 kN/m ²

The ULS load combination considered is:

$$q = i_{tr} \cdot [\gamma_{G1} \cdot (P_{floor} + P_{slab}) + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}]$$

The self-weight of the floor slab is assessed considering a concrete density of the existing joist of 25 kN/m³ and of the hollow brick of 6 kN/m³, the weight of the slab is assessed considering the density class to which the structural lightweight concrete belongs and the corresponding mass value per unit volume in accordance with Tab. C4.1.VI (unreinforced concrete).

The load per joist is therefore:

$$q = 0.5 \cdot [1.3 \cdot (3.11 + 0.74) + 1.5 \cdot 1.5 + 1.5 \cdot 2] = 5.13 \frac{kN}{m}$$

The stresses are here calculated:

$$V_A = \frac{q \cdot (L1^2 - L2^2)}{2 \cdot L1} = 10.77 \text{ kN}$$

$$V_{B1} = -\left(\frac{q}{2 \cdot L1} \cdot (L1 + L2)^2 - q \cdot L2\right) = -14.87 \text{ kN}$$

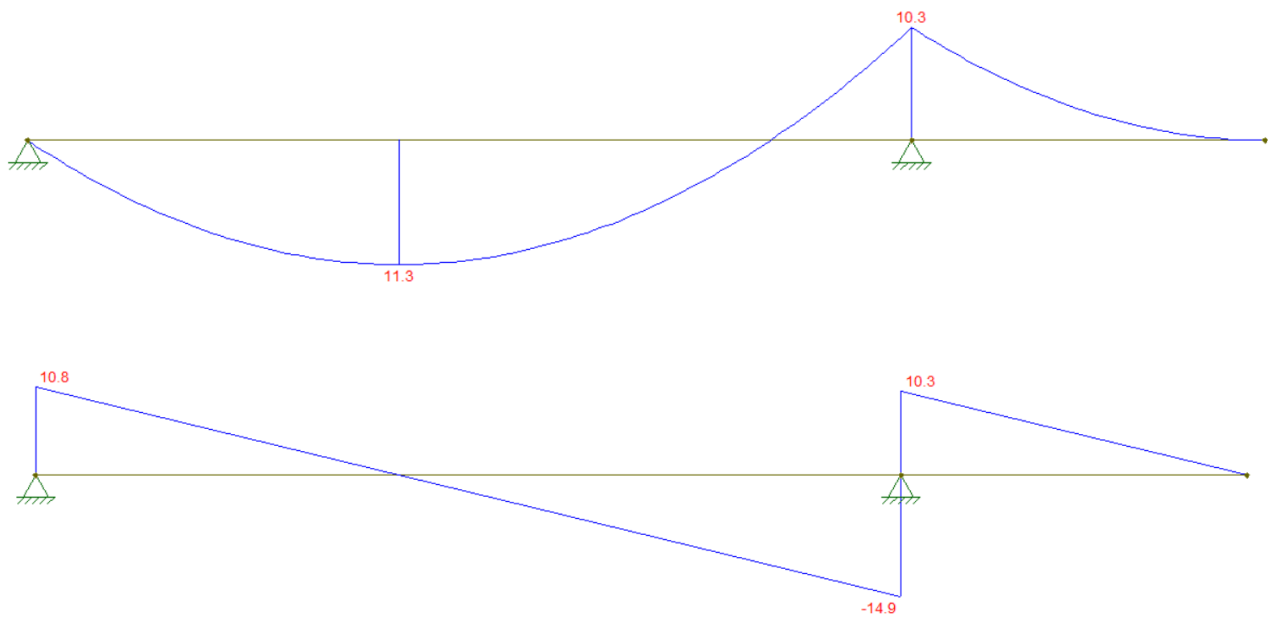
$$V_{B2} = q \cdot L2 = 10.26 \text{ kN}$$

$$x_0 = \frac{L1^2 - L2^2}{2 \cdot L1} = 2.1 \text{ m}$$

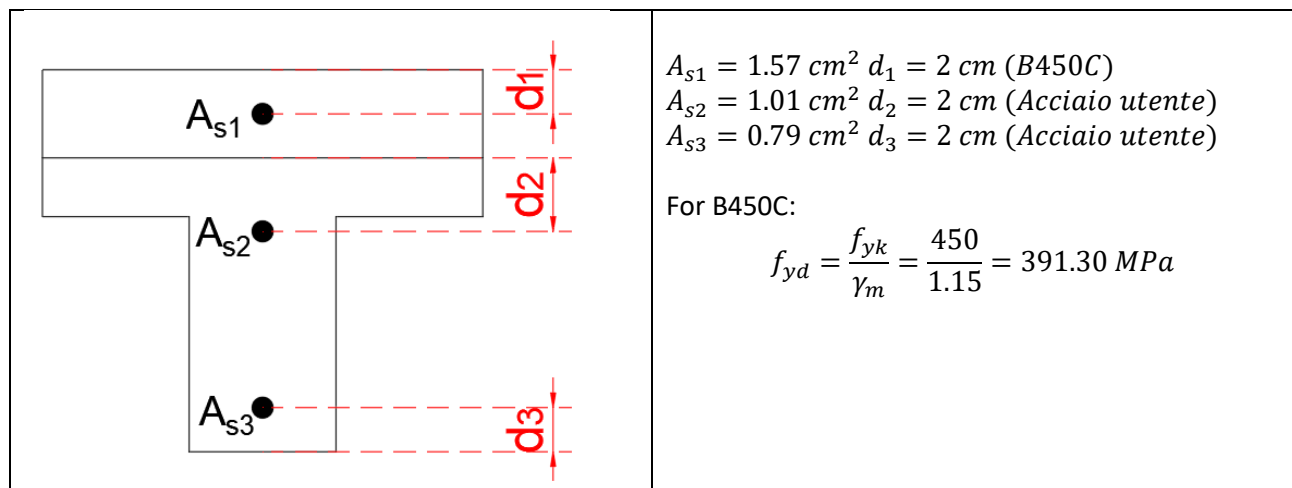
$$M_{max} = \frac{q}{2 \cdot L1} \cdot (L1^2 - L2^2) \cdot x_0 - \frac{q \cdot x_0^2}{2} = 11.3 \text{ kNm}$$

$$M_{min} = \frac{-q \cdot L2^2}{2} = -10.26 \text{ kNm}$$





Sectional reinforcement is defined as follows:



Flexural verification

We then proceeded to calculate the positive and negative flexural strength at ULS of the reinforced slab using **Concrete CS**, connected to the existing floor with **Chemical Connector CS**, and with the interposition of the lightening panel.

The distances to the extrados of the reinforcement in the section are:

$$c_1 = 2 \text{ cm}$$

$$c_2 = 9 \text{ cm}$$

$$c_3 = 29 \text{ cm}$$



In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

The position of the neutral axis is calculated by imposing equilibrium at translation, making an assumption about the deformation state of the section to be verified later:

$$\frac{\varepsilon_{lcu} \cdot (c_1 - x)}{x} \cdot E_s \cdot A_{s1} + f_{sd} \cdot (A_{s2} + A_{s3}) - f_{Ld} \cdot i_{tr} \cdot 0.8 \cdot x = 0$$

Where ε_{lcu} is the ultimate deformation of structural lightweight concrete evaluated according to NTC18 and its Annex.

Solving the resulting second-degree equation and discarding the ineligible solution, the position of the neutral (positive bending) axis equal to:

$$x = 1.71 \text{ cm}$$

The initial assumptions are verified and the resistant moment is then evaluated by writing the equilibrium equation for rotation:

$$M_{rdp} = \varepsilon_{s1} \cdot E_s \cdot A_{s1} \cdot (c_1 - 0.4 \cdot x) + f_{sd} \cdot A_{s2} \cdot (c_2 - 0.4 \cdot x) + f_{sd} \cdot A_{s3} \cdot (c_3 - 0.4 \cdot x) = 14.06 \text{ kNm}$$

The small differences in terms of neutral axis and resistant moment are due to the different constitutive laws implemented in the software and used in the manual calculations.

The positive bending test is therefore satisfied.

The negative bending strength is calculated at the full RC zone.

The distances from the intrados of the reinforcement in the section are:

$$e_1 = 29 \text{ cm}$$

$$e_2 = 22 \text{ cm}$$

$$e_3 = 2 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for the existing concrete, but please note that a parabola-rectangle constitutive law was used in the software. The small differences in terms of neutral axis and resistant moment are due to the different constitutive laws implemented in the software and used in the manual calculations.

The position of the neutral axis is derived by imposing equilibrium at translation, making an assumption about the deformation state of the section to be verified later:

$$-f_{yd} \cdot A_{s1} - f_{sd} \cdot A_{s2} - \frac{\varepsilon_{cu} \cdot (e_3 - x_1)}{x_1} \cdot E_s \cdot A_{s3} + f_{cd} \cdot i_{tr} \cdot 0.8 \cdot x_1 = 0$$



The depth of the neutral axis at negative moment is equal to:

$$x_1 = 1.55 \text{ cm}$$

The initial assumptions are verified and the resistant moment is then evaluated by writing the equilibrium equation for rotation:

$$M_{rdn} = f_{yd} \cdot A_{s1} \cdot (e_1 - 0.4 \cdot x_1) + f_{sd} \cdot A_{s2} \cdot (e_2 - 0.4 \cdot x_1) + \sigma_{s3} \cdot A_{s3} \cdot (e_3 - 0.4 \cdot x_1) = 27.39 \text{ kNm}$$

with:

$$\sigma_{s3} = \frac{\varepsilon_{cu} \cdot (e_3 - x_1)}{x_1} \cdot E_s$$

The negative bending verification is therefore satisfied.

Shear verification

The shear resistance is evaluated at the $x=5$ m coordinate in the first span, where the stress shear is maximum. All reinforcement is under tension in this zone.

Since $f_{ck,LATERMIX} > f_{cd}$, we proceed with the **shear verification at ULS**, for elements without specific shear reinforcement, in accordance with §4.1.2.3.5.1 of the *Norme tecniche delle costruzioni*, according to the following report:

$$V_{Rd} = \max \left\{ \left[\frac{0.18}{\gamma_m} \cdot k \cdot (100 \cdot \rho_l \cdot f_{cd})^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w \cdot ds, (v_{\min} + 0.15 \sigma_{cp}) b_w \cdot ds \right\} = \max (V_{r1}; V_{r2})$$

with:

$$k = 1 + \sqrt{\frac{200}{ds}} = 1.83 \leq 2$$

$$v_{\min} = 0.035 k^{1.5} (f_{cd})^{0.5} = 0.388$$

$$\rho_l = \frac{A_{sl}}{b_w \cdot ds} = \frac{A_{s1} + A_{s2} + A_{s3}}{b_w \cdot ds} = 0.0145 \leq 0.02$$

$$\sigma_{cp} = 0$$

And ds effective depth of the section equal to 29 cm, A_{sl} area of the longitudinal reinforcement stretched, b_w minimum base of the effective section equal to 8 cm and γ_m equal to 1.5.



It therefore results:

$$V_{r1} = \left[\frac{0.18}{\gamma_m} \cdot k \cdot \left(100 \cdot \rho_l \cdot \frac{f_{ck}}{FC} \right)^{\frac{1}{3}} + 0.15 \sigma_{cp} \right] b_w \cdot ds = 15.67 \text{ kN}$$

$$V_{r2} = (v_{\min} + 0.15 \sigma_{cp}) b_w \cdot ds = 8.99 \text{ kN}$$

$$V_{Rd} = \max(V_{r1}; V_{r2}) = 15.67 \text{ kN}$$

Shear verification is therefore satisfied.

Slip test on the contact surface with the new slab

In order to calculate the perfect adhesion between the new **Concrete CS** slab and the existing floor, we compare the shear stress at the existing floor-new slab interface (evaluated using Jourawski's formula) with the design value of the **Chemical Connector CS** of 0.72 MPa, which is necessary for the two parts to work together correctly.

Modular ratio for areas subjected to positive bending:

$$n^+ = \frac{E_s}{\frac{E_{cls, LATERMIX}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{17000 \text{ MPa}}{2} \right)} = 24.71$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{ex, concrete}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{27085 \text{ MPa}}{2} \right)} = 15.51$$

As an example for areas subject to positive momentum, the position of the neutral axis from the elastic calculation of the section is evaluated, imposing that the static moment of the partially effective section with respect to the neutral axis is zero (assumption of neutral axis in the new concrete and in particular within the web of the concrete T):

$$h_s i_{tr} \left(x_p - \frac{h_s}{2} \right) + \frac{b_r (x_p - h_s)(x - h_s)}{2} + n^+ [A_{s1}(x_p - c_1) + A_{s2}(x_p - c_2) + A_{s3}(x_p - c_3)] = 0$$

from which is derived $x_p = 4.47 \text{ cm}$. The hypothesis is verified. In the above equation h_s is the thickness of the new slab (4 cm), b_r is the width of the concrete connection (8 cm).

The static moment of the part above chord b considered located at the interface between the existing floor and the new slab is then evaluated, which in this case involves the reinforcement in the slab and the compressed concrete portion:

$$S_{int} = h_s i_{tr} \left(x_p - \frac{h_s}{2} \right) + \frac{b_r (x_p - h_s)(x - h_s)}{2} + n^+ A_{s1}(x_p - c_1) = 591.63 \text{ cm}^3$$



The moment of inertia of the partially effective section with respect to the neutral axis is evaluated as follows:

$$J_n = \frac{i_{tr} \cdot h_s^3}{12} + h_s i_{tr} \cdot \left(x_p - \frac{h_s}{2}\right)^2 + b_r \frac{(x_p - h_s)^3}{12} + b_r (x_p - h_s) \left(\frac{x_p - h_s}{2}\right)^2 + n^+ \cdot \left(A_{s1} \cdot (x_p - c_1)^2 + A_{s2} \cdot (x_p - c_2)^2 + A_{s3} \cdot (x_p - c_3)^2\right)$$

$$J_n = 13979.99 \text{ cm}^4$$

Finally, the tangential tension at the interface is calculated using Jourawsky's formula in the left-hand support where the maximum shear for the areas subject to positive momentum is given:

$$\tau_{interface} = \frac{V_A \cdot S_{int}}{J_n \cdot b} = 0.57 \text{ MPa} < 0.72 \text{ MPa}$$

with $b = b_r = 8 \text{ cm}$

The verification is fulfilled as the tension is lower than the design tension of the Chemical Connector CS.

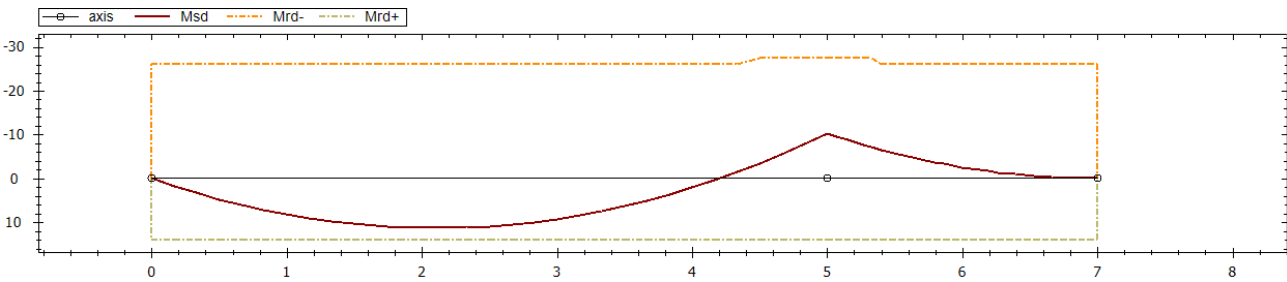
The results obtained in the software are shown below:

Results				
Calculation results				
Msd+	11.30	kNm		Met
Mrd+	14.01	kNm		
Msd-	-10.26	kNm		Met
Mrd-	-27.37	kNm		
Vsd	14.87	kN		Met
Vrd	15.67	kN		
τsd	0.57	MPa		Met
τrd	0.72	MPa		
			Calculate	M, V diagrams

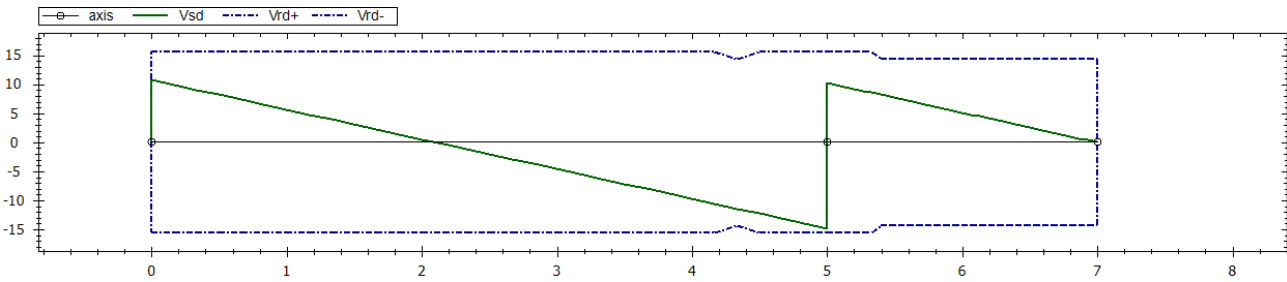
Bending moment and shear diagrams, including resistance values, are shown.



Moment diagram:



Shear diagram:



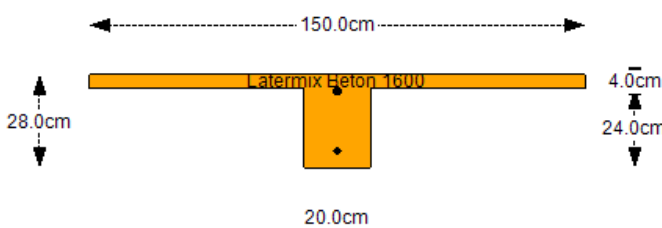
3.3. Case 3 – New Joist inside the floor

In the event that the strengthening of the existing slab through the construction of a new lightweight structural concrete slab, connected to the existing floor with Chemical Connector CS, does not allow all the Ultimate Limit State verifications to be satisfied, the software allows the design of new joist in the existing slab.

In this specific case, a new joist inside the floor is designed. Please refer to the following section for the design of the new joist on top of the floor.

The same static scheme, existing floor geometry and loads of Case 1 are maintained. A change in the existing reinforcement is assumed, set at 0.5 cm² for all the reinforcement levels.

With the change in the reinforcement, the slab is no longer verified with only the collaborating slab.



GEOMETRY	Type	Inside the floor
New slab thickness	4.0	cm
New joist width	20.0	cm
New joist depth	24.0	cm
New joist spacing	150.0	cm
Span length 1	500.0	cm
Span length 2	500.0	cm

Span	As [cm2].	c [cm2]	As' [cm2].	c' [cm2].	Stirrups and spacing
1	3.08	5.0	4.62	5.0	2φ6/25
2	3.08	5.0	4.62	5.0	2φ6/25

For the calculation of the load, in combination with the Ultimate Limit State, on the single new lightweight structural concrete joist, the mass per unit volume of reinforced concrete is used for the concrete class according to Table C4.1.VI of the Annex. Specifically, using **Latermix Beton 1600**, the value used is 18.5 kN/m³ (class D1.7).

The combined SLU load on the individual joist is 16.83 kN/m.

The mechanical properties of new steel and structural lightweight concrete **Latermix Beton 1600** are here recalled:

- **Latermix Beton 1600:**

$$f_{ick} = 31.5 \text{ MPa}$$

$$f_{lca} = \frac{0.85 f_{ick}}{1.5} = 18.85 \text{ MPa}$$

$$E = 20000 \text{ MPa}$$



- **B450C steel:**

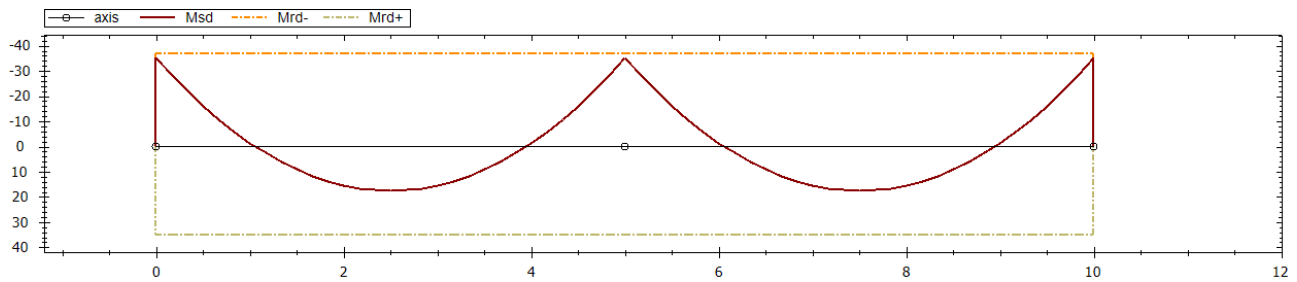
$$f_{yk} = 450 \text{ MPa}$$

$$f_{yd} = \frac{f_{yk}}{1.15} = 391.3 \text{ MPa}$$

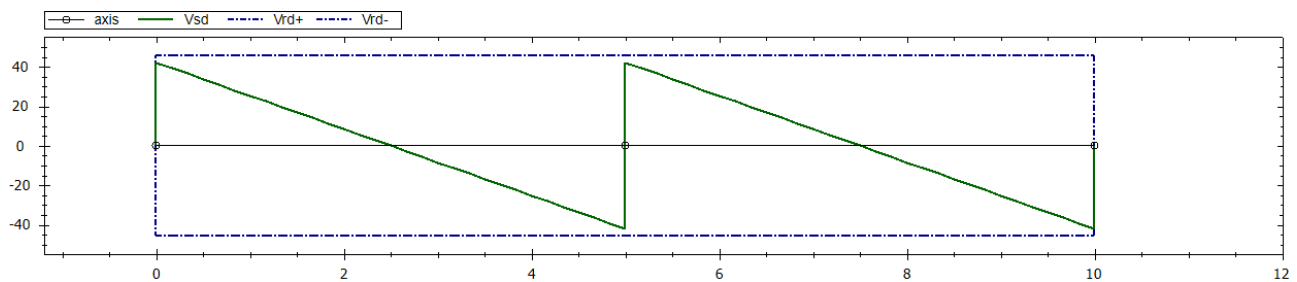
$$E_s = 210000 \text{ MPa}$$

Stress diagrams are shown.

Moment diagram



Shear diagram



Flexural verification

The positive resistant moment is first evaluated. The distances to the extrados of the reinforcements in the section result:

$$c_1 = 5 \text{ cm}$$

$$c_2 = 23 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

The position of the neutral axis, obtained by writing the equilibrium equation at translation assuming that it falls in the slab and that both reinforcement levels are yielded and under tension, results:



$$x_p = \frac{f_{yd} \cdot A_{s1} + f_{yd} \cdot A_{s2}}{f_{Ld} \cdot i_{tr} \cdot 0.8} = \frac{391.3 \text{ MPa} \cdot 4.62 \text{ cm}^2 + 391.3 \text{ MPa} \cdot 3.08 \text{ cm}^2}{17.85 \text{ MPa} \cdot 100 \text{ cm} \cdot 0.8} = 1.41 \text{ cm}$$

The assumptions are verified and the positive resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdp} = f_{yd} \cdot A_{s1} \cdot (c_1 - 0.4 \cdot x_p) + f_{yd} \cdot A_{s2} \cdot (c_2 - 0.4 \cdot x_p) = 35.06 \text{ kNm}$$

The small differences in terms of neutral axis and resistant moment are due to the different constitutive laws implemented in the software and used in the manual calculations.

The negative resistant moment is evaluated. The distances from the intrados of the reinforcement in the section are:

$$e_1 = 23 \text{ cm}$$

$$e_2 = 5 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

The equilibrium equation at translation, assuming that the intrados reinforcement is in compression and elastic phase and the extrados reinforcement is yielded and under tension, results:

$$f_{yd} \cdot A_{s1} - E_s \cdot \frac{\varepsilon_{lcu} \cdot (x_n - e_2)}{x_n} \cdot A_{s2} - f_{lcd} \cdot b_{tr} \cdot 0.8 \cdot x_n = 0$$

Solving the equation gives a neutral axis equal to:

$$x_n = 5.60 \text{ cm}$$

The assumptions are verified and the negative resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdn} = f_{yd} \cdot A_{s1} \cdot (e_1 - 0.4 \cdot x_n) + E_s \cdot \frac{\varepsilon_{lcu} \cdot (x_n - e_2)}{x_n} \cdot A_{s2} \cdot (e_2 - 0.4 \cdot x_n) = 38.10 \text{ kNm}$$

The differences in terms of neutral axis and resistant moment are due to the different constitutive models implemented in the software and used in the manual calculations.

Shear verification

The shear resistance is assessed for elements with transverse shear-resistant reinforcement in accordance with §4.1.2.3.5.2 and §C4.1.12.1.3.2.2 of the *Norme tecniche delle costruzioni*:

$$V_{Rsd} = 0.9d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot (\cot\alpha + \cot\theta) \cdot \sin\alpha$$



$$V_{Rcd} = 0.9d \cdot b_w \cdot 0.4f_{lcd} \cdot \frac{(\cot\alpha + \cot\theta)}{(1 + \cot^2\theta)}$$

$$V_{Rd} = \min(V_{Rsd}, V_{Rcd})$$

With A_{sw} area of transverse reinforcement (stirrups), s stirrups spacing, $\alpha = 90^\circ$ and $21.8^\circ \leq \theta \leq 45^\circ$

Specifically, A_{sw} results:

$$A_{sw} = \frac{n_b \cdot \pi \cdot \phi_{st}^2}{4} = \frac{2 \cdot \pi \cdot (6 \text{ mm})^2}{4} = 56.55 \text{ mm}^2$$

We research whether there is an angle θ for balanced shear failure by imposing equality between V_{Rcd} and V_{Rsd} . This equation yields an angle of 12.87° , which does not fall within the range required by the standard. Therefore, a value of 21.8° is assumed in subsequent calculations.

Steel-side and concrete-side strength are then assessed:

$$V_{Rsd} = 0.9d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot (\cot\alpha + \cot\theta) \cdot \sin\alpha = 45.80 \text{ kN}$$

$$V_{Rcd} = 0.9d \cdot b_w \cdot 0.4f_{lcd} \cdot \frac{(\cot\alpha + \cot\theta)}{(1 + \cot^2\theta)} = 101.93 \text{ kN}$$

With b_w equal to 20 cm and d equal to 23 cm.

The shear strength of the stiffener then results:

$$V_{Rd} = \min(V_{Rsd}; V_{Rcd}) = 45.80 \text{ kN}$$

Slip verification at the interface

Slip is assessed at the interface between the upper slab of the new joist, the existing slab and the web of the new joist at the area subject to positive moment. In the evaluation of the tangential stress, the existing floor slab is neglected.

Modular ratio:

$$n^+ = \frac{E_s}{E} = 21$$

The elastic neutral axis is evaluated by imposing that the static moment of the entire partial section is zero:

$$S = i_{tr} \cdot x \cdot \left(x - \frac{x}{2}\right) + n^+ \cdot A_{s1} \cdot (x - c_1) + n^+ \cdot A_{s2} \cdot (x - c_2) = 0$$

Solving the equation, we obtain:

$$x = 4.16 \text{ cm}$$



We then proceed with the evaluation of the terms needed to calculate the sliding at the interface:

$$\tau_{interface} = \frac{V_{sd} \cdot S_{int}}{J_n \cdot b}$$

The static moment (effective section) of the portion above the chord S_{int} applies:

$$S_{int} = x \cdot i_{tr} \cdot \frac{x}{2} = 1298.98 \text{ cm}^3$$

The inertia of the entire partial section with respect to the neutral axis J_n holds:

$$J_n = \frac{A_c \cdot x^2}{12} + A_c \cdot \left(\frac{x}{2}\right)^2 + n^+ \cdot (A_{s1} \cdot (c_1 - x)^2 + A_{s2} \cdot (c_2 - x)^2) = 26625.65 \text{ cm}^4$$

The width of the chord to be considered is cautiously set at 112 cm, which is the difference between the spacing of the new joist and the width of the hollow brick that is partly filled by the new joist.

The maximum shear stress in ULS combination in areas subject to positive moment is 22.44 kN.

The results of the software are shown below:

Results new joists

Calculation results - slab with new joists

ULS load combination on single beam	16.83	kN/m
Msd+	17.53 kNm	Met
Mrd+	34.99 kNm	
Msd-	-35.05 kNm	Met
Mrd-	-36.80 kNm	
Vsd	42.07 kN	Met
Vrd	45.80 kN	
τ_{sd}	0.10 MPa	Met
τ_{rd}	0.72 MPa	

Calculate new joist

M, V diagrams

Calculation length for sliding [cm]

112.0



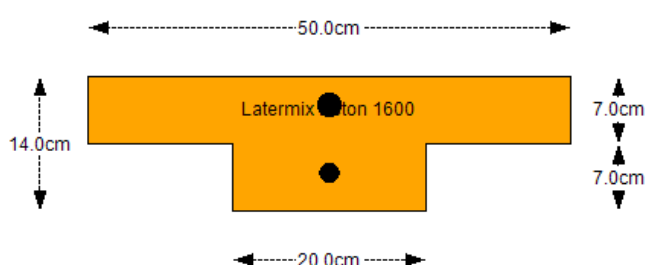
3.4. Case 4 - Out-of-thickness slab reinforcement

In the event that the strengthening of the existing slab through the construction of a new lightweight structural concrete slab, made to cooperate with CentroStorico Connectors, does not allow all the Ultimate Limit State verifications to be satisfied, the software allows the design of stiffeners for the existing slab.

In this specific case, an out-of-thickness floor stiffener is analysed.

The same static scheme, existing floor geometry and loads as in Case 1 are maintained. A change in the present reinforcement, fixed at 0.5 cm² for the lower reinforcement in the existing joist, and the absence of existing upper reinforcement are assumed.

With the change in the reinforcement, the slab is no longer verified with only the collaborating slab.



GEOMETRY	Type	out of thickness
New slab thickness	7.0	cm
New joist width	20.0	cm
New joist depth	7.0	cm
New joist spacing	50.0	cm
Span length 1	500.0	cm
Span length 2	500.0	cm

Span	As [cm2].	c [cm2]	As' [cm2].	c' [cm2].	Stirrups and spacing
1	3.08	3.0	4.62	4.0	2φ6/25
2	3.08	3.0	4.62	4.0	2φ6/25

For the calculation of the load, in combination with the Ultimate Limit State, on the single new lightweight structural concrete joist, the mass per unit volume of reinforced concrete is used for the concrete class according to Table C4.1.VI of the Annex. Specifically, using **Latermix Beton 1600**, the value used is 18.5 kN/m³ (class D1.7).

The combined SLU load on the individual joist is 5.92 kN/m.

The mechanical properties of new steel and structural lightweight concrete **Latermix Beton 1600** are here recalled:

- **Latermix Beton 1600:**

$$f_{lck} = 31.5 \text{ MPa}$$

$$f_{lcd} = \frac{0.85 f_{lck}}{1.5} = 18.85 \text{ MPa}$$

$$E = 20000 \text{ MPa}$$



- **B450C steel:**

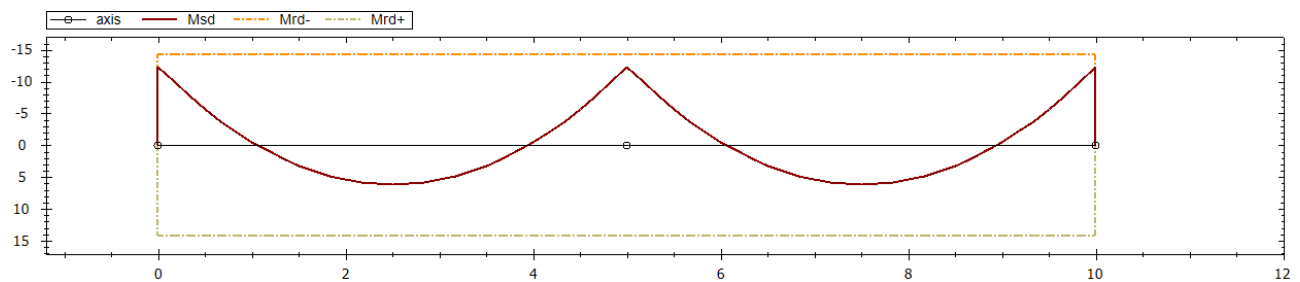
$$f_{yk} = 450 \text{ MPa}$$

$$f_{yd} = \frac{f_{yk}}{1.15} = 391.3 \text{ MPa}$$

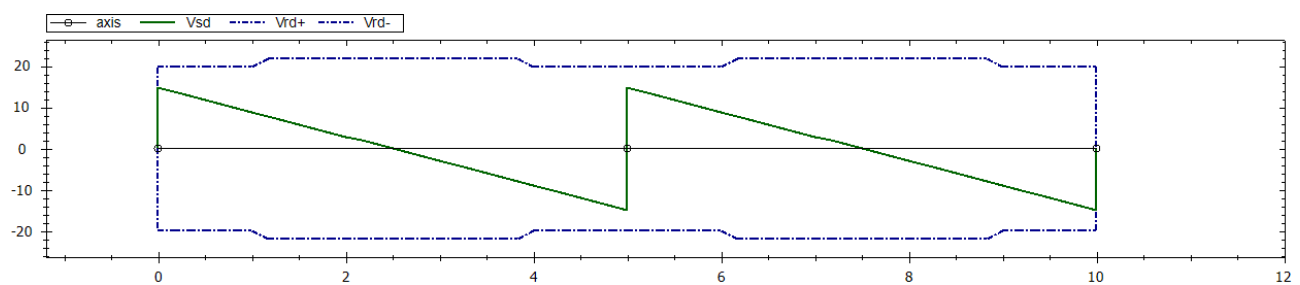
$$E_s = 210000 \text{ MPa}$$

Stress diagrams are shown.

Moment diagram



Shear diagram



Flexural verification

The positive resistant moment is first evaluated. The distances to the extrados of the reinforcements in the new joist section result:

$$c_1 = 4 \text{ cm}$$

$$c_2 = 11 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

The equation of equilibrium at translation, assuming that the intradosal reinforcement is under tension and yielded and the extrados reinforcement is under tension and in the elastic branch, results:



$$f_{yd} \cdot A_{s2} + E_s \cdot \frac{\varepsilon_{lcu} \cdot (c_1 - x_p)}{x_p} \cdot A_{s1} - f_{lcd} \cdot i_{tr} \cdot 0.8 \cdot x_p = 0$$

Solving the equation gives a neutral axis equal to:

$$x_p = 3.02 \text{ cm}$$

The assumptions are verified and the positive resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdp} = E_s \cdot \frac{\varepsilon_{lcu} \cdot (c_1 - x_p)}{x_p} \cdot A_{s1} \cdot (c_1 - 0.4 \cdot x_p) + f_{yd} \cdot A_{s2} \cdot (c_2 - 0.4 \cdot x_p) = 14.45 \text{ kNm}$$

The small differences in terms of neutral axis and resistant moment are due to the different constitutive models implemented in the software and used in the manual calculations.

The negative resistant moment is evaluated. The distances from the intrados of the reinforcement in the section are:

$$e_1 = 10 \text{ cm}$$

$$e_2 = 3 \text{ cm}$$

In the following, for the sole purpose of simplifying the manual execution of the validation calculations, a stress block constitutive law is used for structural lightweight concrete. It should be noted, however, that the parabola-rectangle constitutive law was used in the software, in accordance with the legislation.

The translation equilibrium equation, assuming that the reinforcement at the intrados is in compression and in the elastic branch and the reinforcement in the extrados is under tension and yielded, results:

$$f_{yd} \cdot A_{s1} - E_s \cdot \frac{\varepsilon_{lcu} \cdot (x_n - e_2)}{x_n} \cdot A_{s2} - f_{lcd} \cdot b_{tr} \cdot 0.8 \cdot x_n = 0$$

Solving the equation gives a neutral axis equal to:

$$x_n = 4.29 \text{ cm}$$

The assumptions are verified and the negative resistant moment is therefore evaluated by writing the equilibrium equation for rotation:

$$M_{rdn} = f_{yd} \cdot A_{s1} \cdot (e_1 - 0.4 \cdot x_n) + E_s \cdot \frac{\varepsilon_{lcu} \cdot (x_n - e_2)}{x_n} \cdot A_{s2} \cdot (e_2 - 0.4 \cdot x_n) = 14.23 \text{ kNm}$$

The small differences in terms of neutral axis and resistant moment are due to the different constitutive models implemented in the software and used in the manual calculations.



Shear verification

The shear resistance is assessed for elements with transverse shear-resistant reinforcement in accordance with §4.1.2.3.5.2 and §C4.1.12.1.3.2.2 of the *Norme tecniche delle costruzioni*:

$$V_{Rsd} = 0.9d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot (\cot\alpha + \cot\theta) \cdot \sin\alpha$$

$$V_{Rcd} = 0.9d \cdot b_w \cdot 0.4f_{lcd} \cdot \frac{(\cot\alpha + \cot\theta)}{(1 + \cot^2\theta)}$$

$$V_{Rd} = \min(V_{Rsd}, V_{Rcd})$$

With A_{sw} area of transverse reinforcement (stirrups), s stirrups spacing, $\alpha = 90^\circ$ and $21.8^\circ \leq \theta \leq 45^\circ$

Specifically, A_{sw} results:

$$A_{sw} = \frac{n_b \cdot \pi \cdot \phi_{st}^2}{4} = \frac{2 \cdot \pi \cdot (6 \text{ mm})^2}{4} = 56.55 \text{ mm}^2$$

It is searched whether there is an angle θ for balanced shear failure by imposing equality between V_{Rcd} and V_{Rsd} . This equation calculates an angle of 14.42° , which does not fall within the range provided by the standard. Therefore, a value of 21.8° is assumed in the following calculations.

The strength on the steel side and the concrete side are then evaluated:

$$V_{Rsd} = 0.9d \cdot \frac{A_{sw}}{s} \cdot f_{yd} \cdot (\cot\alpha + \cot\theta) \cdot \sin\alpha = 19.91 \text{ kN}$$

$$V_{Rcd} = 0.9d \cdot b_w \cdot 0.4f_{lcd} \cdot \frac{(\cot\alpha + \cot\theta)}{(1 + \cot^2\theta)} = 44.32 \text{ kN}$$

With b_w equal to 20 cm and d equal to 10 cm.

The shear strength of the new joist then results:

$$V_{Rd} = \min(V_{Rsd}; V_{Rcd}) = 19.91 \text{ kN}$$

The evaluation was carried out in areas subject to negative moment; similarly, using the correct depth, the evaluation is carried out in areas subject to positive moment.

Slip verification at the interface

Slips are assessed at the interface between the new joist and the existing floor at the area subject to positive moment.

Modular ratio for areas subjected to positive bending:



$$n^+ = \frac{E_s}{\frac{E}{2}} = 21$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{cls,es}}{2}} = 14.02$$

The evaluation of the elastic neutral axis, the static moment of the portion above the chord considered and the moment of inertia of the partially effective section with respect to the neutral axis for the zones subject to positive bending and for the zones subject to negative bending is carried out below. With regard to the stress shear to be considered for the evaluation of slip at the interface, it is necessary to consider the value of the shear in the exact section in which the verification is being performed. The width of the chord to be considered is equal to the base of the new joist.

Areas subject to positive bending:

The elastic neutral axis is evaluated by imposing that the static moment of the partially effective section is zero:

$$S = i_{tr} \cdot x_{p1} \cdot \left(x_{p1} - \frac{x_{p1}}{2}\right) + n^+ \cdot A_{s1} \cdot (x_{p1} - c_1) + n^+ \cdot A_{s2} \cdot (x_{p1} - c_2) + n^+ \cdot A_{se3} \cdot (x_{p1} - c_{e3}) = 0$$

With A_{se3} reinforcement in the existing joist equal to 0.50 cm^2 and placed 3 cm from the intrados of the existing floor and c_{e3} effective depth of this reinforcement measured from the extrados of the reinforced floor (35 cm).

Solving the equation, we obtain:

$$x_{p1} = 4.96 \text{ cm}$$

The static moment (effective section) of the portion above the chord S_{int} applies:

$$S_{int} = i_{tr} \cdot x_{p1} \cdot \left(x_{p1} - \frac{x_{p1}}{2}\right) + n^+ \cdot A_{s1} \cdot (x_{p1} - c_1) + n^+ \cdot A_{s2} \cdot (x_{p1} - c_2) = 315.47 \text{ cm}^3$$

The inertia of the entire effective section with respect to the neutral axis J_n holds:

$$J_n = \frac{i_{tr} \cdot x_{p1}^3}{12} + i_{tr} \cdot x_{p1} \cdot \left(x_{p1} - \frac{x_{p1}}{2}\right)^2 + n^+ \left(A_{s1} \cdot (c_1 - x_{p1})^2 + A_{s2} \cdot (c_2 - x_{p1})^2 + A_{se3} \cdot (c_{e3} - x_{p1})^2 \right)$$

$$J_n = 13958 \text{ cm}^4$$

Areas subject to negative bending:

The elastic neutral axis is evaluated by imposing that the static moment of the partially effective section is zero:



$$S = b \cdot x_{n1} \cdot \left(x_{n1} - \frac{x_{n1}}{2}\right) + n^- \cdot A_{s1} \cdot (x_{n1} - cn_1) + n^- \cdot A_{s2} \cdot (x_{n1} - cn_2) + n^- \cdot A_{se3} \cdot (x_{n1} - e_{e3}) = 0$$

With b base of the existing joist (12 cm), cn_1 effective depth of the reinforcement A_{s1} measured from the intrados of the reinforced floor (34 cm), cn_2 effective depth of the reinforcement A_{s2} measured from the intrados of the reinforced floor (27 cm) and e_{e3} effective depth of the reinforcement A_{se3} measured from the intrados of the reinforced floor (3 cm).

Solving the equation, we obtain:

$$x_{n1} = 16.04 \text{ cm}$$

The static moment (partial section) of the portion above the chord S_{int} applies:

$$S_{int} = n^- \cdot A_{s1} \cdot (x_{n1} - cn_1) + n^- \cdot A_{s2} \cdot (x_{n1} - cn_2) = 1635.89 \text{ cm}^3$$

The above value is given in absolute value.

The inertia of the partially effective section with respect to the neutral axis J_n holds:

$$J_n = \frac{b \cdot x_{n1}^3}{12} + b \cdot x_{n1} \cdot \left(x_{n1} - \frac{x_{n1}}{2}\right)^2 + n^- \cdot (A_{s1} \cdot (cn_1 - x_{n1})^2 + A_{s2} \cdot (cn_2 - x_{n1})^2 + A_{se3} \cdot (e_{e3} - x_{n1})^2)$$

$$J_n = 43774.9 \text{ cm}^4$$

The results of the software are shown below:

Results new joists				
Calculation results - slab with new joists				
ULS load combination on single beam		5.92	kN/m	
Msd+	6.17	kNm	Met	
Mrd+	14.29	kNm		
Msd-	-12.33	kNm	Met	
Mrd-	-14.15	kNm		
Vsd	14.80	kN	Met	
Vrd	19.91	kN		
τsd	0.28	MPa	Met	
τrd	0.72	MPa		
Calculate new joist			M, V diagrams	



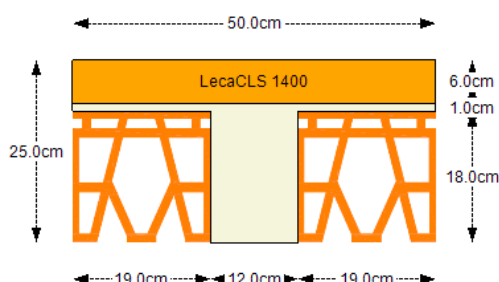
3.5. Case 5 - Floor with new slab and Concrete Connector Plus D12

An existing slab with the characteristics described below is analysed, reinforced with new slab in **Latermix Beton 1400** structural lightweight concrete, connected to the existing slab with **Concrete Connector Plus D12**.

The following existing materials with fragile parameters are adopted:

- for existing concrete, '**Report value**' is chosen with a class C20/25 and a Knowledge Level LC1 corresponding to a Confidence Factor of 1.35
- for existing steel, '**Report value**' is chosen with a class FeB44k and a Knowledge Level LC1 corresponding to a Confidence Factor of 1.35

The following geometry is adopted:



GEOMETRY		
New slab thickness	6.0	cm
Existing slab thickness	1.0	cm
Joist width	12.0	cm
Joist depth	18.0	cm
Joist spacing	50.0	cm
Span length 1	450.0	cm

The degree of stiffness is very low at both ends.

The load at the Ultimate Limit State is determined as follows:

Safety coefficients	Structural permanent loads	γ_{G1}	1.3 -
	Other non-structural permanent loads	γ_{G2}	1.5 -
	Variable loads	γ_Q	1.5 -
Own weight	Existing floor	G_1	2.15 kN/m ²
	Collaborating slab (6 cm)		0.93 kN/m ²
Permanents	Lecamix Facile (6.00 cm)	G_2	0.60 kN/m ²
	Other permanents		0.30 kN/m ²
Variables		Q	2.00 kN/m ²

The ULS load combination considered is:

$$q = i_{tr} \cdot [\gamma_{G1} \cdot (P_{floor} + P_{slab} + P_{screed}) + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var}]$$

The self-weight of the floor slab is assessed considering a concrete density of the existing joist of 25 kN/m³ and of the hollow brick of 6 kN/m³, the weight of the slab is assessed considering the density class to which the structural lightweight concrete belongs and the corresponding mass value per unit volume in accordance with Tab. C4.1.VI (unreinforced concrete).



The load per joist is therefore:

$$q = 50 \text{ cm} \cdot [1.3 \cdot (2.15 + 0.93 + 0.60) + 1.5 \cdot 0.30 + 1.5 \cdot 2.00] = 4.12 \frac{\text{kN}}{\text{m}}$$

In order to calculate the spacing of the connectors, it is necessary to know the trend of the bending moment before the intervention that is determined by the following expression:

$$M_{sd,pre-int}(x) = q_{pre-int} \cdot \frac{L}{2} \cdot x - q_{pre-int} \cdot \frac{x^2}{2} - q_{pre-int} \cdot \frac{L^2}{48}$$

The moment equals to zero at the following coordinates:

$$x = 4.30 \text{ m}$$

$$x = 0.20 \text{ m}$$

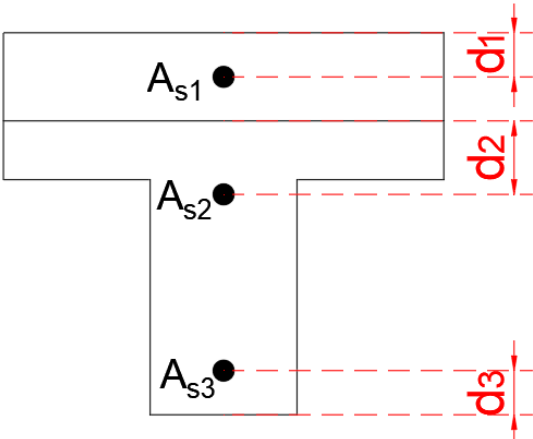
Therefore, in the case at hand for $x < 0.20 \text{ m}$ and $x > 4.30 \text{ m}$ the moment is negative while for $0.20 \text{ m} \leq x \leq 4.30 \text{ m}$ it is positive.

For the purpose of calculating the spacing of the connectors, it is also necessary to know the shear stress trend after the intervention:

$$V(x) = q \cdot \left(\frac{L}{2} - x \right)$$

The maximum value of shear occurs at the ends and is 9.26 kN.

Sectional reinforcement is defined as follows:

	$A_{s2} = 0.50 \text{ cm}^2 \quad d_2 = 3 \text{ cm (FeB44k)}$ $A_{s3} = 1.57 \text{ cm}^2 \quad d_3 = 2 \text{ cm (FeB44k)}$ <p>For FeB44k - fragile parameters:</p> $f_{sd} = \frac{f_{sk}}{FC \cdot \gamma_{ac,es}} = \frac{430}{1.35 \cdot 1.15} = 276.97 \text{ MPa}$ <p>For C20/25 - fragile parameters:</p> $f_{cd} = \frac{0.85 \cdot f_{ck}}{FC \cdot \gamma_{c,es}} = \frac{0.85 \cdot 20}{1.35 \cdot 1.50} = 8.40 \text{ MPa}$
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Before intervention: positive neutral axis calculation

The distances from the extrados of the existing reinforcement in section are as follows:

$$c_2 = 3 \text{ cm}$$

$$c_3 = 17 \text{ cm}$$

The position of the neutral axis is obtained by imposing equilibrium on the translation, assuming that failure is reached by reaching maximum deformation at the compressed edge of the concrete, that the neutral axis falls into the existing joist, that the upper reinforcement is under tension and in the elastic branch and that the lower reinforcement is in tension and yielded (these assumptions must then be verified). In a simplified manner, a stress-block constitutive law is used for the existing concrete (in the software, the law implemented is the parabola-rectangle):

$$i_{tr} \cdot f_{cd} \cdot h_{s,es} + b \cdot f_{cd} \cdot (0.8x - h_{s,es}) - A_{s3} \cdot f_{sd} - A_{s2} \cdot E_s \cdot \varepsilon_{s2} = 0$$

Where $h_{s,es}$ is the thickness of the existing slab, E_s equal to 210000 MPa and ε_{s2} is the deformation of the upper reinforcement that can be obtained by using the similarity between triangles in the linear diagram of deformations in section:

$$\varepsilon_{s2} = \frac{\varepsilon_{cu}(c_2 - x)}{x}$$

Solving the equation the neutral axis (positive bending) is equal to:

$$x = 2.46 \text{ cm}$$

The small differences in terms of the neutral axis are due to the different constitutive laws implemented in the software and used in manual calculations.

The assumptions made are fulfilled.

Slip calculation at the interface

The number of connectors to be used is the number required to transmit the slip between the existing floor and the new structural lightweight concrete slab. Slip is calculated using the Jourawsky formula.

The evaluation is carried out for both positive and negative moment zones.

Modular ratio for areas subjected to positive bending:

$$n^+ = \frac{E_s}{\frac{E_{cls,LATERMIX}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{15000 \text{ MPa}}{2}\right)} = 28.0$$



We evaluate the position of the neutral axis from the elastic calculation of the section, imposing that the static moment of the partially effective section with respect to the neutral axis is zero (assumption of neutral axis in the slab in **Latermix Beton 1400**):

$$i_{tr} \cdot x_p \cdot \left(x_p - \frac{x_p}{2}\right) + n^+ \cdot \left(A_{s2} \cdot (x_p - c_2) + A_{s3} \cdot (x_p - c_3)\right) = 0$$

Where i_{tr} is the joists' spacing.

It is derived:

$$x_p = 5.68 \text{ cm}$$

The static moment of the part above the considered chord located at the interface between the existing slab and the new slab is then evaluated, which in this case involves the compressed portion of the structural lightweight concrete slab:

$$S_{int} = i_{tr} \cdot x_p \cdot \left(x_p - \frac{x_p}{2}\right) = 807.64 \text{ cm}^3$$

The moment of inertia of the partially effective section with respect to the neutral axis is evaluated as follows:

$$J_n = \frac{i_{tr} \cdot x_p^3}{12} + i_{tr} \cdot x_p \cdot \left(x_p - \frac{x_p}{2}\right)^2 + n^+ \cdot \left(A_{s2} \cdot (x_p - c_2)^2 + A_{s3} \cdot (x_p - c_3)^2\right) = 16395.68 \text{ cm}^4$$

Modular ratio for areas subjected to negative bending:

$$n^- = \frac{E_s}{\frac{E_{ex,concrete}}{2}} = \frac{210000 \text{ MPa}}{\left(\frac{29962 \text{ MPa}}{2}\right)} = 14.0$$

We evaluate the position of the neutral axis from the elastic calculation of the section, imposing that the static moment of the partially effective section with respect to the neutral axis is zero (assumption of neutral axis in the existing joist):

$$b_t \cdot x_n \cdot \left(x_n - \frac{x_n}{2}\right) + n^- \cdot \left(A_{s2} \cdot (x_n - e_2)^2 + A_{s3} \cdot (x_n - e_3)^2\right) = 0$$

Where b_t is the base of the joist and e_2 and e_3 are the distances of the reinforcement from the intrados i.e:

$$e_2 = 16 \text{ cm}$$

$$e_3 = 2 \text{ cm}$$

It is derived:

$$x_n = 3.23 \text{ cm}$$

The static moment of the portion above the considered chord located at the interface between the existing slab and the new slab is therefore zero:



$$S_{int} = 0 \text{ cm}^3$$

The moment of inertia of the partially effective section with respect to the neutral axis is evaluated as follows:

$$J_n = \frac{b_t \cdot x_n^3}{12} + b_t \cdot x_n \cdot \left(x_n - \frac{x_n}{2}\right)^2 + n^- \cdot (A_{s2} \cdot (x_n - e_2)^2 + A_{s3} \cdot (x_n - e_3)^2) = 1311.05 \text{ cm}^4$$

It is then possible to calculate the tangential tension at the interface for each point at which the floor has been discretized:

$$\tau_{interface} \cdot b = \frac{V_{sd} \cdot S_{int}}{J_n}$$

The following table shows the stress shear and the corresponding value of $\tau_{interfaccia} \cdot b$ at the discretization points of the floor:

Camp.	Progr. [m]	V _(sd) [kN].	S _(int) [cm ³].	J _(n) [cm ⁴].	τ _{sd} b [N/mm].
1	0.00	9.26	0.00	1311.05	0.00
1	0.15	8.65	0.00	1311.05	0.00
1	0.30	8.03	807.64	16395.68	39.55
1	0.45	7.41	807.64	16395.68	36.51
1	0.60	6.79	807.64	16395.68	33.47
1	0.75	6.18	807.64	16395.68	30.42
1	0.90	5.56	807.64	16395.68	27.38
1	1.05	4.94	807.64	16395.68	24.34
1	1.20	4.32	807.64	16395.68	21.30
1	1.35	3.71	807.64	16395.68	18.25
1	1.50	3.09	807.64	16395.68	15.21
1	1.65	2.47	807.64	16395.68	12.17
1	1.80	1.85	807.64	16395.68	9.13
1	1.95	1.24	807.64	16395.68	6.08
1	2.10	0.62	807.64	16395.68	3.04
1	2.25	0	807.64	16395.68	0.00
1	2.40	-0.62	807.64	16395.68	3.04
1	2.55	-1.24	807.64	16395.68	6.08
1	2.70	-1.85	807.64	16395.68	9.13
1	2.85	-2.47	807.64	16395.68	12.17
1	3.00	-3.09	807.64	16395.68	15.21
1	3.15	-3.71	807.64	16395.68	18.25
1	3.30	-4.32	807.64	16395.68	21.30
1	3.45	-4.94	807.64	16395.68	24.34
1	3.60	-5.56	807.64	16395.68	27.38
1	3.75	-6.18	807.64	16395.68	30.42
1	3.90	-6.79	807.64	16395.68	33.47
1	4.05	-7.41	807.64	16395.68	36.51
1	4.20	-8.03	807.64	16395.68	39.55
1	4.35	-8.65	0.00	1311.05	0.00
1	4.50	-9.26	0.00	1311.05	0.00



Interface adhesion calculation

The contribution of adhesion to slip v_{Rdi} is assessed in accordance with §6.2.5 UNI EN 1992-1-1:2015, using the parameters for smooth surfaces, using the following formula:

$$v_{Rdi} = \min(c \cdot f_{ctd} + \mu \cdot \sigma_n; 0.5 \cdot v \cdot f'_{cd})$$

where:

$$c = 0.2$$

$$\mu = 0.6$$

$$f_{ctd,ex.concrete} = \frac{0.7 \cdot 0.3 f_{ck}^{2/3}}{FC \cdot \gamma_c} = 0.76 \text{ MPa}$$

$$\eta_1 = 0.4 + 0.6 \cdot \frac{\rho}{2200} = 0.809$$

$$f_{lctm} = 0.3 \cdot f_{lck}^{\frac{2}{3}} \cdot \eta_1 = 1.93 \text{ MPa}$$

$$f_{lctk} = 0.7 \cdot f_{lctm} = 1.35 \text{ MPa}$$

$$f_{lctd} = \frac{0.85 \cdot f_{lctk}}{\gamma_c} = 0.77 \text{ MPa}$$

$$f_{ctd} = \min(f_{ctd,ex.concrete}; f_{lctd}) = 0.76 \text{ MPa}$$

$$f'_{cd} = \min(f_{cd,ex.concrete,fragile parameters}; f_{lcd}) = 8.40 \text{ MPa}$$

$$v = \min\left[0.6 \cdot \left(1 - \frac{f_{ck,ex.concrete}}{250}\right); 0.5 \cdot \left(1 - \frac{f_{lck}}{250}\right)\right] = 0.455$$

$$q_{slu}^* = \gamma_{G1} \cdot [P_{slab} + P_{screed}] + \gamma_{G2} \cdot P_{others} + \gamma_Q \cdot Q_{var} = 0.005 \text{ MPa}$$

$$\sigma_n = \min(q_{slu}^*; 0.6 f'_{cd}) = 0.005 \text{ MPa}$$

Where ρ is the upper limit value of the mass per unit volume of the concrete for the relevant mass per unit volume class in kg/m³, which is 1500 in this case.

It therefore results:

$$v_{Rdi} = \min(c \cdot f_{ctd} + \mu \cdot \sigma_n; 0.5 \cdot v \cdot f'_{cd}) = \min(0.16 \text{ MPa}; 1.91 \text{ MPa}) = 0.16 \text{ MPa}$$

The term v_{Rdi} is then multiplied by the term L in order to obtain a quantity comparable with $\tau_{interface} \cdot b$. The term L is equal to the base of the joist. $L = b_t = 120 \text{ mm}$



Therefore, it results:

$$v_{Rdi} \cdot L = 18.72 \frac{N}{mm}$$

Evaluation of the design resistance of Concrete Connector Plus D12

The terms that contribute to the determination of the design resistance of the connector to be used for calculation purposes are calculated in those portions of the floor where the existing concrete is cracked ($P_{Rd,ck}$) and where the existing concrete is uncracked ($P_{Rd,uck}$).

Rupture of the anchor steel:

The characteristic ultimate strength of the anchor steel, common to both the cracked and uncracked case, is:

$$V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}} = \frac{25.6 \text{ kN}}{1.25} = 20.48 \text{ kN}$$

Pry-out fracture of concrete:

This failure mode is highly dependent on the compression/tension state of the concrete in which the connector is inserted and, for this reason, two values of $N_{Rk,c}^0$ and thus $N_{Rk,c}$ are calculated (one for the cracked concrete condition and one for the non-cracked concrete condition).

$$N_{Rk,c}^0 = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5} = \begin{cases} 7.7 \cdot \sqrt{20} \cdot 52^{1.5} = 12912.51 \text{ N (ck)} \\ 11 \cdot \sqrt{20} \cdot 52^{1.5} = 18446.45 \text{ N (uck)} \end{cases}$$

$$A_{c,N}^0 = s_{cr,N} \cdot s_{cr,N} = 156 \cdot 156 = 24336 \text{ mm}^2$$

$$A_{c,N} = \left(\frac{b_t}{2} + \min \left(\frac{b_t}{2}; 0.5 s_{cr,N} \right) \right) \cdot s_{cr,N} = \left(\frac{120}{2} + \min \left(\frac{120}{2}; 0.5 \cdot 156 \right) \right) \cdot 156 = 18720 \text{ mm}^2$$

$$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} = 0.7 + 0.3 \cdot \frac{60}{78} = 0.931 \leq 1$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} = 0.5 + \frac{52}{200} = 0.76 \leq 1$$

$$N_{Rk,c} = N_{Rk,c}^0 \cdot \frac{A_{c,N}}{A_{c,N}^0} \cdot \psi_{s,N} \cdot \psi_{re,N} = \begin{cases} 12912.51 \cdot \frac{18720}{24336} \cdot 0.931 \cdot 0.76 = 7026.24 \text{ N (ck)} \\ 18446.45 \cdot \frac{18720}{24336} \cdot 0.931 \cdot 0.76 = 10037.49 \text{ N (uck)} \end{cases}$$

$$V_{Rd,cp} = \frac{k_8 \cdot N_{Rk,c}}{\gamma_{Mc}} = \begin{cases} \frac{1 \cdot 7026.24}{1.5} = 4684.16 \text{ N (ck)} \\ \frac{1 \cdot 10037.49}{1.5} = 6691.66 \text{ N (uck)} \end{cases}$$



Concrete edge failure:

This failure mode is highly dependent on the compression/tension state of the concrete in which the connector is inserted and, for this reason, two values of $V_{Rk,c}^0$ and thus $V_{Rk,c}$ are calculated (one for the cracked concrete condition and one for the non-cracked concrete condition).

$$\alpha = 0.1 \cdot \left(\frac{l_f}{c_1} \right)^{0.5} = 0.1 \cdot \left(\frac{52}{60} \right)^{0.5} = 0.093$$

$$\beta = 0.1 \cdot \left(\frac{d_{nom}}{c_1} \right)^{0.2} = 0.1 \cdot \left(\frac{12.5}{60} \right)^{0.2} = 0.073$$

$$V_{Rk,c}^0 = k_9 \cdot d_{nom}^\alpha \cdot l_f^\beta \cdot \sqrt{f_{ck}} \cdot c_1^{1.5} = \begin{cases} 1.7 \cdot 12.5^{0.093} \cdot 52^{0.073} \cdot \sqrt{20} \cdot 60^{1.5} = 5966.22 \text{ N (ck)} \\ 2.4 \cdot 12.5^{0.093} \cdot 52^{0.073} \cdot \sqrt{20} \cdot 60^{1.5} = 8422.90 \text{ N (uck)} \end{cases}$$

$$A_{c,v}^0 = 1.5c_1 \cdot (1.5c_1 + 1.5c_1) = 4.5c_1^2 = 4.5 \cdot 45^2 = 9112.5 \text{ mm}^2$$

$$A_{c,v} = \min(h_t + h_c; 1.5c_1) \cdot \min(3c_1; b_t) = \min(190; 67.5) \cdot \min(135; 120) = 8100 \text{ mm}^2$$

$$\psi_{s,v} = 0.7 + 0.3 \cdot \frac{c_2}{1.5c_1} = 0.7 + 0.3 \cdot \frac{60}{1.5 \cdot 60} = 0.90 \leq 1$$

$$\psi_{h,v} = \left(\frac{1.5c_1}{h} \right)^{0.5} = \left(\frac{1.5 \cdot \frac{b_t}{2}}{h_t + h_c} \right)^{0.5} = \left(\frac{1.5 \cdot 60}{190} \right)^{0.5} = 0.69 < 1 \rightarrow \psi_{h,v} = 1$$

$$\psi_{\alpha,v} = \sqrt{\frac{1}{(\cos \alpha_v)^2 + (0.5 \sin \alpha_v)^2}} = \sqrt{\frac{1}{(\cos 90^\circ)^2 + (0.5 \sin 90^\circ)^2}} = 2 \geq 1$$

$$V_{Rk,c} = V_{Rk,c}^0 \cdot \frac{A_{c,v}}{A_{c,v}^0} \cdot \psi_{s,v} \cdot \psi_{h,v} \cdot \psi_{\alpha,v} = \begin{cases} 5966.22 \cdot \frac{8100}{9112.5} \cdot 0.90 \cdot 1 \cdot 2 = 9545.96 \text{ N (ck)} \\ 8422.90 \cdot \frac{8100}{9112.5} \cdot 0.90 \cdot 1 \cdot 2 = 13476.65 \text{ N (uck)} \end{cases}$$

$$V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}} = \begin{cases} \frac{9545.96}{1.5} = 6363.97 \text{ N (ck)} \\ \frac{13476.65}{1.5} = 8984.43 \text{ N (uck)} \end{cases}$$

The design resistance of the connector can then be assessed:

$$P_{Rd,ck} = \min(V_{Rd,s}; V_{Rd,cp}; V_{Rd,c}) = \min(20480 \text{ N}; 4684.16 \text{ N}; 6363.97 \text{ N}) = 4.68 \text{ kN}$$

$$P_{Rd,uck} = \min(V_{Rd,s}; V_{Rd,cp}; V_{Rd,c}) = \min(20480 \text{ N}; 6691.66 \text{ N}; 8984.43 \text{ N}) = 6.69 \text{ kN}$$



Calculation of connector spacing and distribution

For each point at which the floor analysed has been discretized, the spacing (called PC) of the connectors in the considered coordinate is calculated. The design value of the **Concrete Connector Plus D12** is $P_{Rd,ck}$ in each coordinate, i.e. both in the negative moment zones and in the positive moment zones since the neutral axis, in the latter zones, respects the following condition:

$$A_{N,pre-int}^+ = 2.46 \text{ cm} < 0.9h_{ef} = 4.68 \text{ cm}$$

As an example, the calculation of PC at the point where slip is maximum is shown:

$$PC (x = 0.30 \text{ m}) = \frac{P_{Rd}}{(\tau_{interface} \cdot b) - (v_{Rdi} \cdot L)} = 225 \text{ mm}$$

For each coordinate, if the calculated spacing PC is less than or equal to zero or greater than the maximum spacing, the maximum spacing of 500 mm is imposed, resulting in the correct calculated spacing PCC . The following table shows the calculated steps and the corrected calculated steps for each discretization point of the floor:

Camp.	Progr. [m]	PC [cm]	PCC [cm]
1	0.00	-25.01	50.00
1	0.15	-25.01	50.00
1	0.30	22.50	22.50
1	0.45	26.35	26.35
1	0.60	31.79	31.79
1	0.75	40.06	40.06
1	0.90	54.14	50.00
1	1.05	83.51	50.00
1	1.20	182.49	50.00
1	1.35	-985.04	50.00
1	1.50	-133.15	50.00
1	1.65	-71.40	50.00
1	1.80	-48.78	50.00
1	1.95	-37.04	50.00
1	2.10	-29.86	50.00
1	2.25	-25.01	50.00
1	2.40	-29.86	50.00
1	2.55	-37.04	50.00
1	2.70	-48.78	50.00
1	2.85	-71.40	50.00
1	3.00	-133.15	50.00
1	3.15	-985.04	50.00
1	3.30	182.49	50.00
1	3.45	83.51	50.00
1	3.60	54.14	50.00
1	3.75	40.06	40.06
1	3.90	31.79	31.79
1	4.05	26.35	26.35
1	4.20	22.50	22.50
1	4.35	-25.01	50.00
1	4.50	-25.01	50.00



The arrangement of the connectors is then determined, both assuming constant spacing per span and variable spacing.

Constant spacing per span

The theoretical laying spacing is the minimum of the correct calculated spacing:

$$\text{theoretical spacing} = \min(PCC) = 22.50 \text{ cm}$$

Once the theoretical spacing is known, it is possible to calculate the theoretical number of connectors for the considered span:

$$N.\text{theoretical conn} = \frac{L_i}{\text{theoretical spacing}} = \frac{450}{22.50} = 20.02$$

The *N. theoric conn* is rounded to the next even integer, thus finding *N. connectors* (equal to 22) and thus the actual spacing with which the connectors will be laid:

$$\text{spacing} = \frac{L_i}{N.\text{connectors}} = \frac{450}{22} = 20.5 \text{ cm}$$

Finally, the number of connectors per square metre is determined by dividing the total number of connectors by the total span and spacing of the joists.

$$N.\text{conn. per m}^2 = \frac{N.\text{connectors}}{L_i \cdot i_{tr}} = \frac{22}{4.5 \cdot 0.50} = 9.8$$

This results in:

	Span 1
	L
Length [cm]	450.0
Conn. n. [-]	22
Spacing [cm]	20.5
N. of conn. per m ²	9.8
N. conn. tot [-]	22

Variable spacing

The variable spacing is calculated considering the extreme quarters of the beam and the mid-span. The points at which the floor has been discretized belonging to $L/4$ on the left, to $L/4$ on the right and to $L/2$ in the centre are identified, and for each of the sections the theoretical laying spacing is the minimum of the calculated corrected spacings of the points belonging to that section:



$$theoretical\ spacing = \begin{cases} \min(PCC) \text{ in } \frac{L}{4} \text{ left} = 22.50 \text{ cm} \\ \min(PCC) \text{ in } \frac{L}{2} \text{ central} = 50 \text{ cm} \\ \min(PCC) \text{ in } \frac{L}{4} \text{ right} = 22.50 \text{ cm} \end{cases}$$

Once the theoretical spacing is known, it is possible to calculate the theoretical number of connectors for the section under consideration:

$$N.theoretical\ conn = \frac{L_i}{theoretical\ spacing} = \begin{cases} \frac{112.5}{22.50} = 5.004 \text{ in } \frac{L}{4} \text{ left} \\ \frac{225}{50} = 4.5 \text{ in } \frac{L}{2} \text{ central} \\ \frac{112.5}{22.50} = 5.004 \text{ in } \frac{L}{4} \text{ right} \end{cases}$$

With L_i equal to the length of the considered part.

$N.theoretical\ conn$ turns out to be a non-integer number, we then proceed to round the theoretical number of connectors to the next integer in $L/4$ and the next even integer in $L/2$, thus finding $N.connectors$ and thus the actual spacing with which the connectors are to be laid:

$$spacing = \frac{L_i}{N.connectors} = \begin{cases} \frac{100}{6} = 18.8 \text{ cm in } \frac{L}{4} \text{ left} \\ \frac{200}{6} = 37.5 \text{ cm in } \frac{L}{2} \text{ central} \\ \frac{100}{6} = 18.8 \text{ cm in } \frac{L}{4} \text{ right} \end{cases}$$

Finally, the number of connectors per square metre is determined by dividing the total number of connectors by the total span and spacing of the joists.

$$N.conn.per\ m^2 = \frac{N.total\ connectors}{L_{tot} \cdot i_{tr}} = \frac{6 + 6 + 6}{4.5 \cdot 0.50} = 8.0$$

This results in:

	Span 1		
	L/4	L/2	L/4
Length [cm]	112.5	225.0	112.5
Conn. n. [-]	6	6	6
Spacing [cm]	18.8	37.5	18.8
N. of conn. per m²	8.0		
N. conn. tot [-]	18		



Best regards.

Technical Support

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