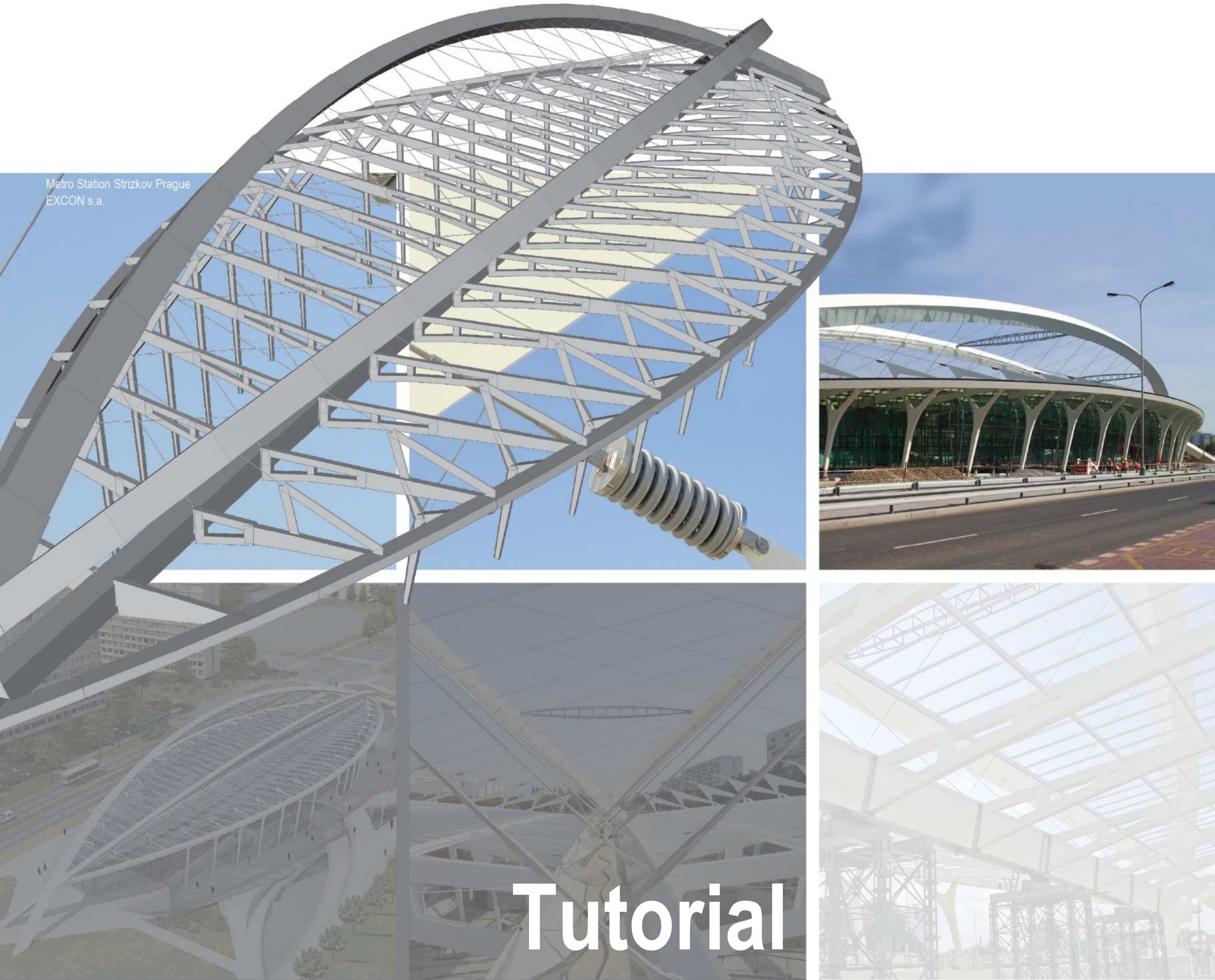
NEMETSCHEK Scia



Tutorial

Post-tensioned concrete slab
EN1992-1-1

Scia Engineer

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1 Description of the tutorial

Idea of this tutorial is to provide to user information how two defined prestressing in such type of the structure and perform design of necessary reinforcement and also verify the structure according to EN1992-1-1 [1]. Two main type of the modelling such structure are described in this tutorial. The models are the following:

- **Model with real defined prestressing tendon**
- **Model using equivalent load method**

Explanation of the each model is explained later in the text (from chapter 4). Some of the detailed outputs are demonstrated mainly for the typical slab S138.

This example doesn't deal about user definition of the structure. The input and definition of the typical entities as beams, slabs, loadcases, combinations etc are explained in the other manuals or tutorial. This manual is especially designed for experience user and focused on definition, calculation, design and check of the prestressed 2D structures. The prestressed 1D structure is described in the manual. The calculation of the column is also explained in the different manual.

The design example proposed in this tutorial is related to small five floor parking house. The building is designed in category F. The floor structure is directly loaded by the transport. The columns are rectangular with dimensions BxH =0,55x0,55m. The slab thickness is 290mm. The dimensions of the statical system are the following.

- $n_x = 3$ - number of the spans in x direction
- $n_y = 4$ - number of the spans in y direction
- $l_x = 9{,}0m$ - length of the span in x direction
- $l_y = 9{,}0m$ - length of the span in x direction
- $l_c = 0{,}2*lx(ly)$ - length of the cantilever

Material used in the structure is the following:

- Concrete C35/45
- Prestressing Y1770S7-15,7
- Reinforcement B500B

The structure is loaded by the following loads:

- Roof weight g1 = 3kN/m2
- Variable q = 8kN/m2

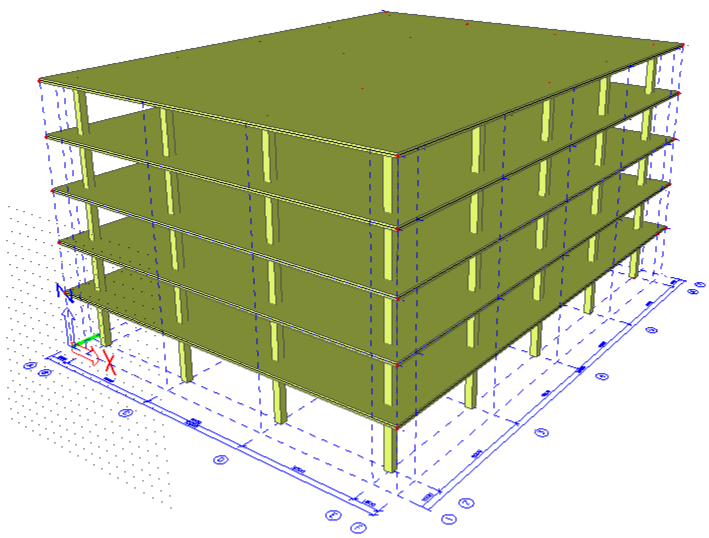


Fig. 1 Plan view of the structure and supports' scheme

Only the 4th floor has been used for this tutorial.

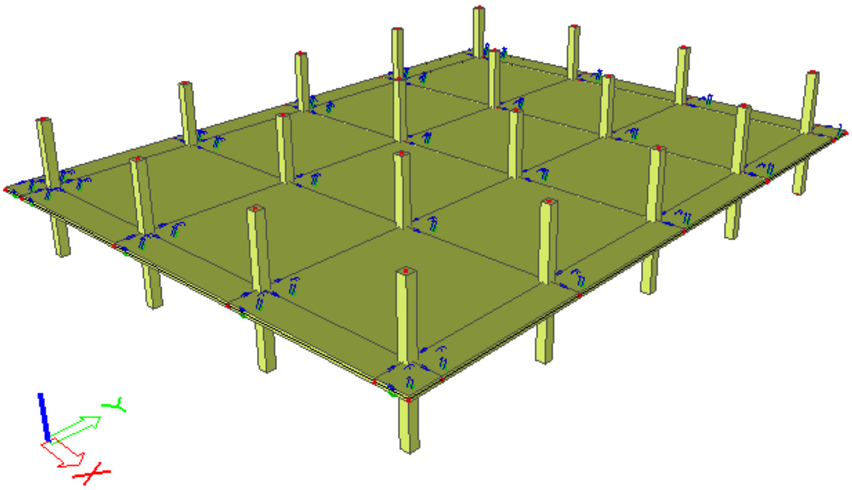


Fig. 2 Model of the 4th floor

Snow, wind and other type of loads are neglected in this tutorial

The input of the model is basic knowledge of the user. For more information see [8].

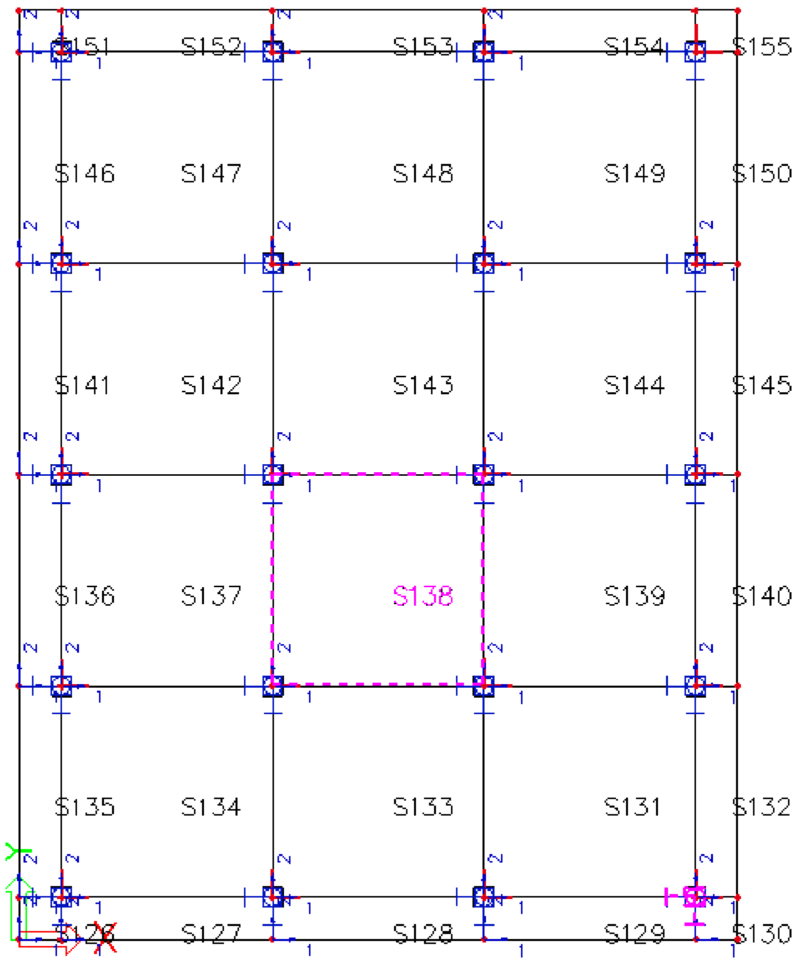


Fig. 3 Numbering of the slabs

2 Input

2.1 Material characteristics

The following materials properties have been considered:

− **Concrete grade C35/45**

Characteristic compressive strength	f_{ck} = 35.0 MPa;
Design compressive strength:	f_{cd} = 23,3 MPa;
Mean value of tensile strength:	f_{ctm} = 3,20 MPa;
Modulus of elasticity:	E_c = 34,1 GPa;
Shear modulus:	G = 14,2 GPa
Poisson ratio:	v = 0.2

− **Prestressing steel Y1860S7-15,7**

Characteristics tensile strength	f_{pk} = 1860 MPa;
0.1% proof stress	$f_{p0.1k}$ = 1670 MPa
Total elongation at maximum load:	ε_{uk} > 35‰
Modulus of elasticity:	E_p = 195 GPa;
Friction coefficient	μ = 0,06
Unintentional angular displacement	K = 0,0005/m
Relaxation class	3 (ρ_{1000} = 4%)
Nominal area	A_{p1} = 150mm^2

− **Reinforcing steel, B 500 B:**

Characteristics yield strength	f_{yk} = 500.0 MPa;
Design strength:	f_{yd} = 434.8 MPa;
Modulus of elasticity:	E_s = 200 GPa.

Name	Type	Unit mass [kg/m³]	E mod [MPa]	Poisson - nu	G mod [MPa]	Thermal exp [m/mK]	Characteristic compressive cylinder strength fck(28) [MPa]
C30/37	Concrete	2500,00	3,2800e+04	0,2	1,3667e+04	0,01e-003	30,00

Name	Type	Unit mass [kg/m³]	E mod [MPa]	Poisson - nu	G mod [MPa]	Thermal exp [m/mK]	Characteristic yield strength fyk [MPa]
B 500B	Reinforcement steel	7850,00	2,0000e+05	0,2	8,3333e+04	0,01e-003	500,0

Name	Type of diagram	Characteristic tensile strength (fpk) [MPa]	Characteristic 0,1% proof stress (fp0,1k) [MPa]	Ductility factor (k = fpk / fp01k) [-]	Design strain limit (eps ud) [1e-4]	E mod [MPa]
Y1770S7-15,7	Bi-linear with an inclined top branch	1770,0	1560,0	1,13	315,0	1,9500e+05

2.2 Supports

The whole structure is supported by the rigid point support in all displacements and all rotations in the bottom part of the building.

The model of the 4th floor is supported on both sides of the columns. Lower side is fully rigid and upper side is rigid but free in Z direction.

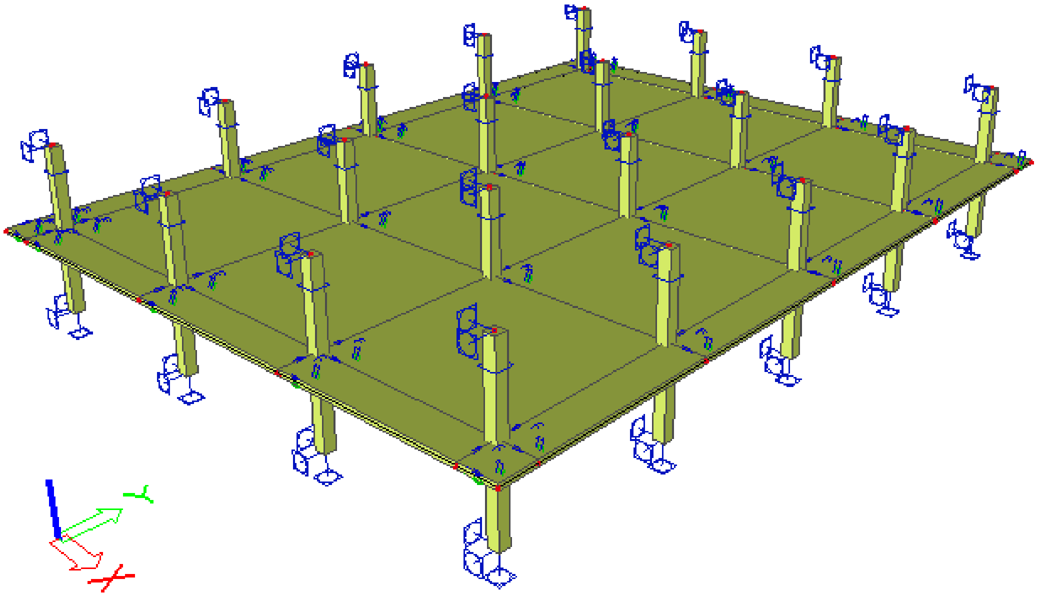


Fig. 4 Model of the 4th floor

Properties	Lower support		Upper support	
	Properties		Properties	
	Support in node (1)		Support in node (1)	
	Name	Sn4	Name	Sn40
	Type	Standard	Type	Standard
	Angle [deg]		Angle [deg]	
	X	Rigid	X	Rigid
	Y	Rigid	Y	Rigid
	Z	Rigid	Z	Free
	Rx	Rigid	Rx	Rigid
	Ry	Rigid	Ry	Rigid
	Rz	Rigid	Rz	Rigid
	Default size [m]	0,200	Default size [m]	0,200
	Node	N64	Node	N120

2.3 Loadcases

The following loadcases have been defined in the example. The permanent load LC1; LC2 and LC8 can be assigned in the same load group (LG1). Variable loadcases are stored in LG2 which has exclusive relation and it is in category F. Two permanent loadcases Prestress X and prestress Y are needed for the model using equivalent load (explained in detail in 4.1.1)

Load cases

Name	Description	Action type	LoadGroup	Load type	Spec	Direction	Duration	Master load case
LC1	Selfweight	Permanent	LG1	Self weight		-Z		
LC2	Roof_Permanent	Permanent	LG1	Standard				
LC4	Variable_1	Variable	LG2	Static	Standard		Short	None
LC3	Variable_Full	Variable	LG2	Static	Standard		Short	None
LC5	Variable_2	Variable	LG2	Static	Standard		Short	None
LC6	Prestress	Permanent	LG1	Prestress				

Load cases

Name	Description	Action type	LoadGroup	Load type	Spec	Direction	Duration	Master load case
LC1	Selfweight	Permanent	LG1	Self weight		-Z		
LC2	Roof_Permanent	Permanent	LG1	Standard				
LC4	Variable_1	Variable	LG2	Static	Standard		Short	None
LC3	Variable_Full	Variable	LG2	Static	Standard		Short	None
LC5	Variable_2	Variable	LG2	Static	Standard		Short	None
LC6	Prestress X	Permanent	LG1	Standard				
LC7	Prestress Y	Permanent	LG1	Standard				

2.4 Loads

The load is defined in standard way. The variable load is used as Variable full. It means all 2D members are loaded by the variable load. Load from LC4 – Variable_1 means that only certain parts of the building floor are loaded. Opposite loading scheme as in LC4 is used for the loadcase LC5.

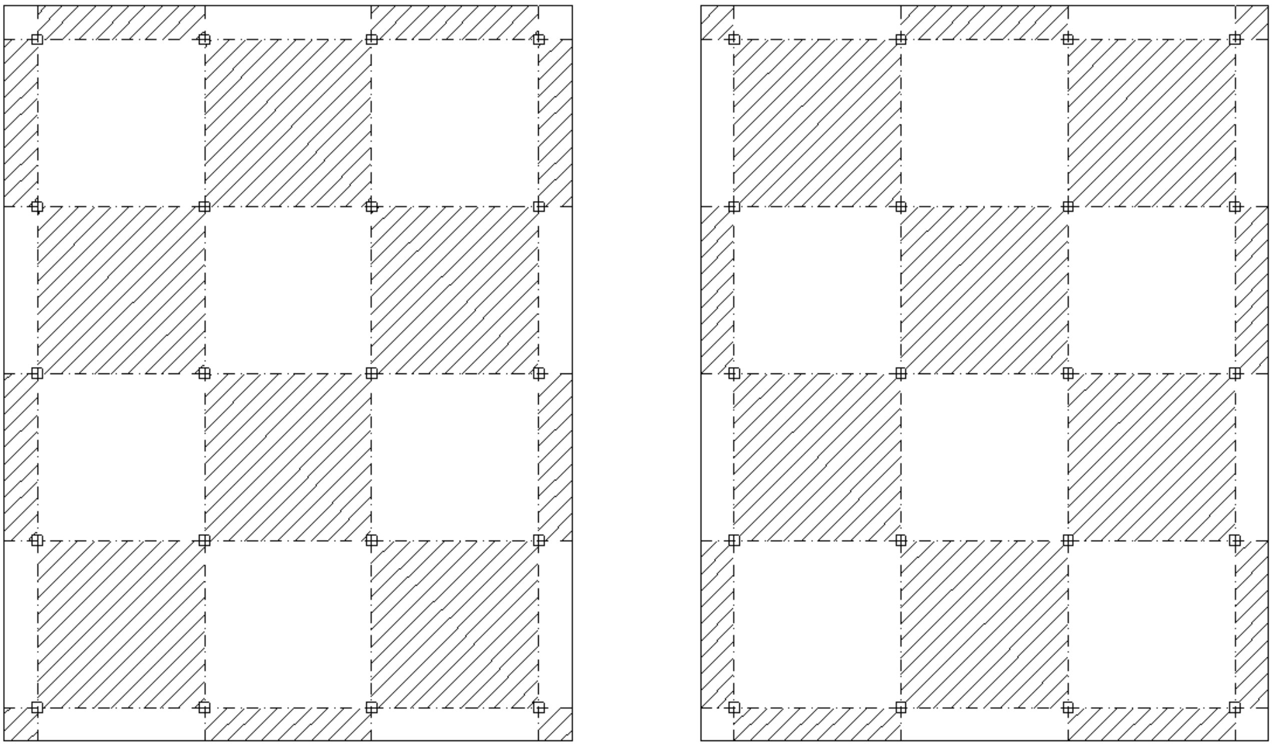


Fig. 5 Extreme position of the variable load

2.5 Combinations

Several combinations are defined in this example. One group is for ultimate limit state (***ULS_short***, ***ULS_long***) and the second group is for serviceability limit state (***characteristic, frequent, quasi-permanent***). On the following figure you can see only content of the combination. The load factors are automatically taken into account for each combination in the background. Combinations are defined with respect of type of the modelling of the prestressing (real tendon, equivalent load). For more information about both types see chapter 4.

2.5.1 Combination in case of real tendon

When the prestressing is modelled as real tendon then shorterm losses are calculated automatically. It means only reduction for longterm losses (estimation 15%) is applied for this case.

Name	Type	Load cases	Coeff. [-]
ULS_short	EN-ULS (STR/GEO) Set B	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	1,00
ULS_long	EN-ULS (STR/GEO) Set B	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	0,85

Name	Type	Load cases	Coeff. [-]
SLS_Char_short	EN-SLS Char.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	1,00
SLS_Fre_short	EN-SLS Freq.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	1,00
SLS_QP_short	EN-SLS Quasi.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	1,00
SLS_Char_long	EN-SLS Char.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	0,85
SLS_Fre_long	EN-SLS Freq.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	0,85
SLS_QP_long	EN-SLS Quasi.	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress	0,85

2.5.2 Combination in case of equivalent load

When the prestressing is modelled using equivalent load then shorterm and also longterm losses should be estimated. It means reductions for shorterm (10%) and longterm losses (estimation 15%) are applied for this case. Loadcases where prestressing is defined using equivalent load are separated into each direction (Prestress X, Prestress Y).

Name	Type	Load cases	Coeff. [-]
ULS_short	EN-ULS (STR/GEO) Set B	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,90
		LC7 - Prestress Y	0,90
ULS_long	EN-ULS (STR/GEO) Set B	LC1 - Selfweight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,77
		LC7 - Prestress Y	0,77

Name	Type	Load cases	Coeff. [-]
SLS_Char_short	EN-SLS Char.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,90
		LC7 - Prestress Y	0,95
SLS_Fre_short	EN-SLS Freq.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,90
		LC7 - Prestress Y	0,90
SLS_QP_short	EN-SLS Quasi.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,90
		LC7 - Prestress Y	0,90
SLS_Char_long	EN-SLS Char.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,77
		LC7 - Prestress Y	0,77
SLS_Fre_long	EN-SLS Freq.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,77
		LC7 - Prestress Y	0,77
SLS_QP_long	EN-SLS Quasi.	LC1 - Self weight	1,00
		LC2 - Roof_Permanent	1,00
		LC3 - Variable_Full	1,00
		LC4 - Variable_1	1,00
		LC5 - Variable_2	1,00
		LC6 - Prestress X	0,77
		LC7 - Prestress Y	0,77

2.6 Classes

The classes are needed for the calculation of required areas during Design ULS+SLS. Class ULS+SLS was prepared with the following content. Design for both limit states is done for longterm losses of prestressing. Combination ***ULS_long*** and ***SLS_QP_long*** are selected to class only.

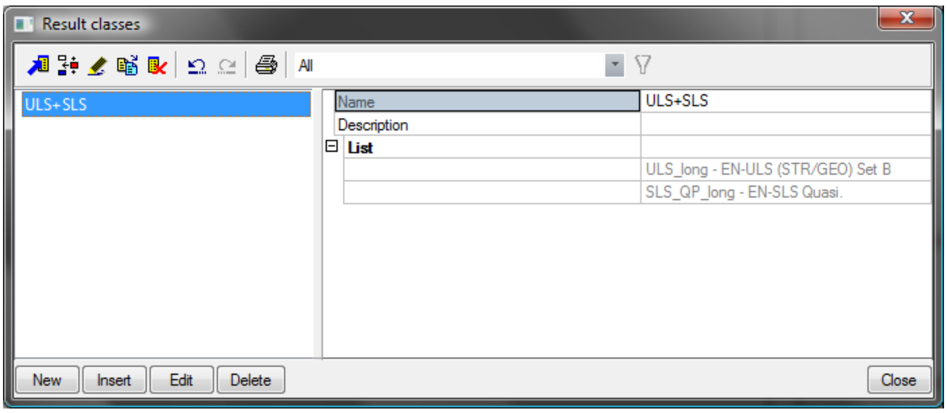


Fig. 6 ULS+SLS class

3 Design of the prestressing

For design of prestressing force is supposed that prestressing tendons are designed in scheme d) from the figure. The half of the tendons in each direction uniformly distributed in the span and half concentrated over the columns. This seems to be optimum solution in respect of both design and economy.

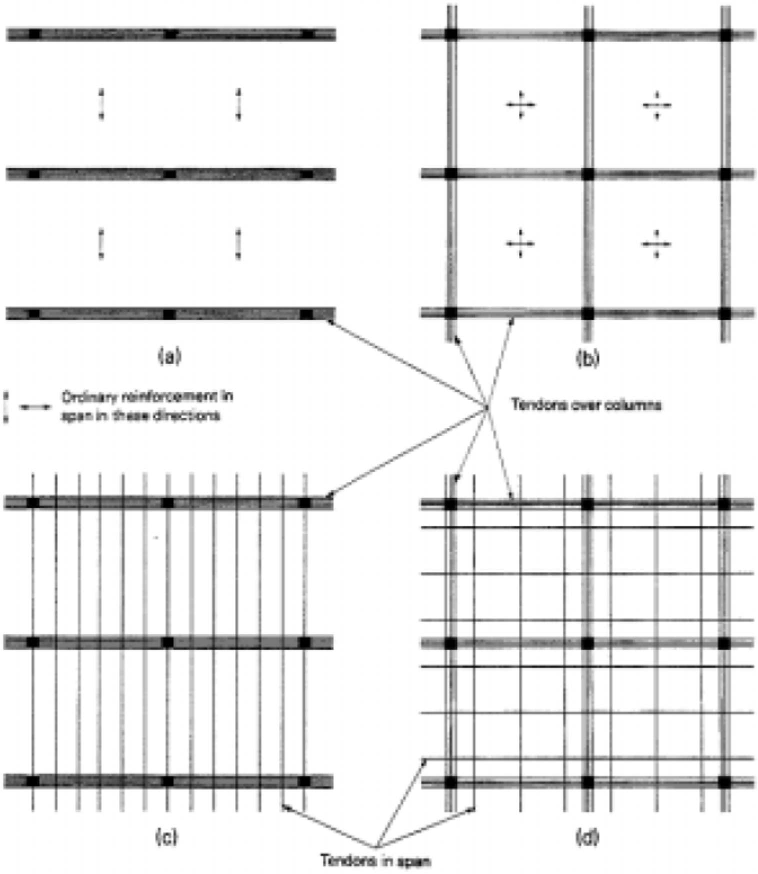


Fig. 7 Tendon layout (picture overtaken from [2])

The actions of the tendons from the option d) on the slab are visible on the Fig. 8

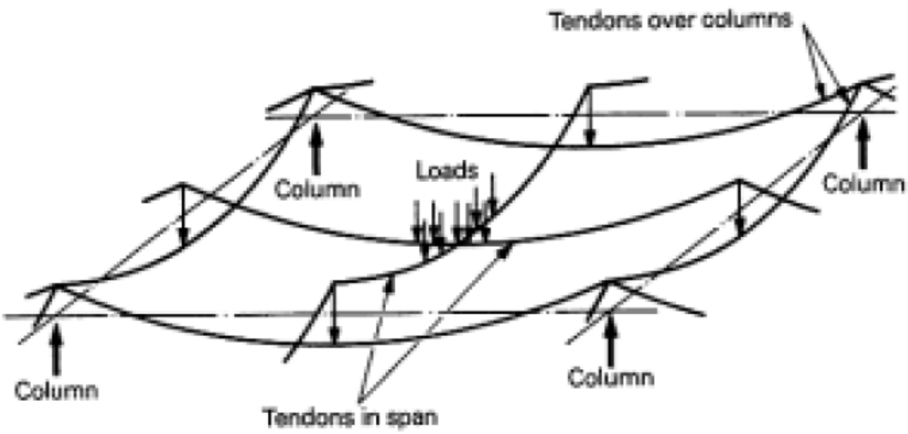


Fig. 8 Actions of the tendon on the slab (picture overtaken from [2])

The recommendations for design are taken from the [2].

- Maximal tendon spacing in the span 6,0*h
- Inflection point of the tendons ds/2 from the column edge
- Minimal radius of curvature r = 2,50 m

3.1 Design of prestress force

Very simple load-balancing method is used for the design of prestressing. At the beginning it is necessary to estimate losses of prestressing. As the simplification the following losses are taken into account:

- Short term losses 10% (only for model type Equivalent load)
- Longterm losses 15%

3.1.1 Concrete cover

The following settings are required for this structure:

- Exposure class XD1
- Design working life 50years

3.1.1.1 Concrete cover for prestressing

Nominal concrete cover (c_{nom}) has to be calculated

$$\mathrm{c_{nom}} = \mathrm{c_{min}} + \Delta \mathrm{c_{dev}} = 43 + 10 = 53\mathrm{mm}$$

Structural class (Table 4.3N [1])

Default 4
Slab structure -1
Final structural class 4 – 1 = S3

Minimal cover form the point of durability for S3+XD1 (Table 4.5N)

$$c_{min,dur} = 40mm$$

Minimal cover from the point of bond (4.4.1.2(3) [1]). We suppose the rectangular ducts similar as in the following figure

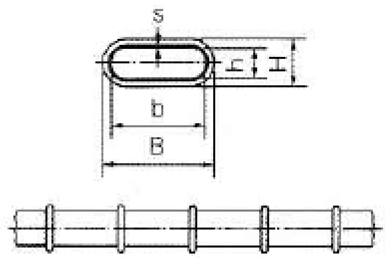


Fig. 9 Rectangular duct for postensioned slab

$$B = 86mm; H = 35mm$$

$$c_{min,b} = \max\left(\min(A;B);\frac{\max(A;B)}{2}\right) = \max\left(\min(86;35);\frac{\max(86;35)}{2}\right) = \max(35;43) = 43\mathrm{mm}$$

Calculation of minimal cover (formula 4.2 [1])

$$c_{min} = max\ (c_{min,b}; c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add}; 10mm) = \max(40;43;10) = 43mm$$

$$\Delta c_{dur,\gamma} = \Delta c_{dur,st} = \Delta c_{dur,add} = 0mm$$

Deviation of the concrete cover (4.4.1.3(1) [1])

$$\Delta c_{dev} = 10mm$$

Automatic calculation of the concrete cover for prestressing reinforcement is not implemented in the version 2010.1

3.1.2 Maximal stress in strand

For the preliminary design the estimation of the shorterm and longterm losses will be done. The shorterm losses are estimated as 10% and longterm as 15%. It is necessary to calculate maximal stress in strand after longterm losses.

Maximal stress during tensioning (5.10.2.1(1) [1])

$$\sigma_{p,max} = min(0{,}8 \cdot f_{pk}; 0{,}9 \cdot f_{p0,1k}) = min(0{,}8 \cdot 1860; 0.9 \cdot 1670) = min(1488; 1503) = 1488MPa$$

Maximal stress after anchoring (5.10.3(2) [1])

$$\sigma_{p,m0} = min(0{,}75 \cdot f_{pk}; 0{,}85 \cdot f_{p0,1k}) = min(0{,}75 \cdot 1860; 0.85 \cdot 1670) = min(1395; 1420) = 1395MPa$$

From the value above we can say the initial stress has to be lower than 1488MPa. The initial stress was set to 1450MPa.
The preliminary designed prestressing forces per one strand are after

- Shorterm losses (10%)

  $$P_{aa} = \sigma_{p,aa} \cdot A_{p1} = 0{,}9 \cdot 1450 \cdot 150 = 195{,}75kN$$

- Longterm losses (15%)

  $$P_{ltl} = \sigma_{p,ltl} \cdot A_{p1} = 0{,}85 \cdot 0{,}9 \cdot 1450 \cdot 150 = 166{,}39kN$$

For the determination of the amount of strands the force after longterm losses (P_{ltl}) will be used.

3.1.3 Determination of prestress force – load balancing method

Required prestressing force is determined using load-balancing method. This method was first published by the T.Y. Lin in 1963 [4]. It is supposed the 80% of permanent and variable load is balanced by the prestressing force in this case. The surface load (f=g+q) from the span area is spread to the column line according to following figure. The triangular spreading is used for calculation of the load $f_{x(y)1(2)}$*. This triangular load is substituted by the rectangular line load $f_{x(y)1(2)}$. The recalculated load is used for the load balancing method. As was written above 50% of tendons will be designed in the column line and 50% in the span area.

$$g_{slab} = h \cdot \gamma_c = 0{,}29 \cdot 26 = 7{,}54\ kN/m^2$$
$$q_{slab} = 8{,}0kN/m^2$$

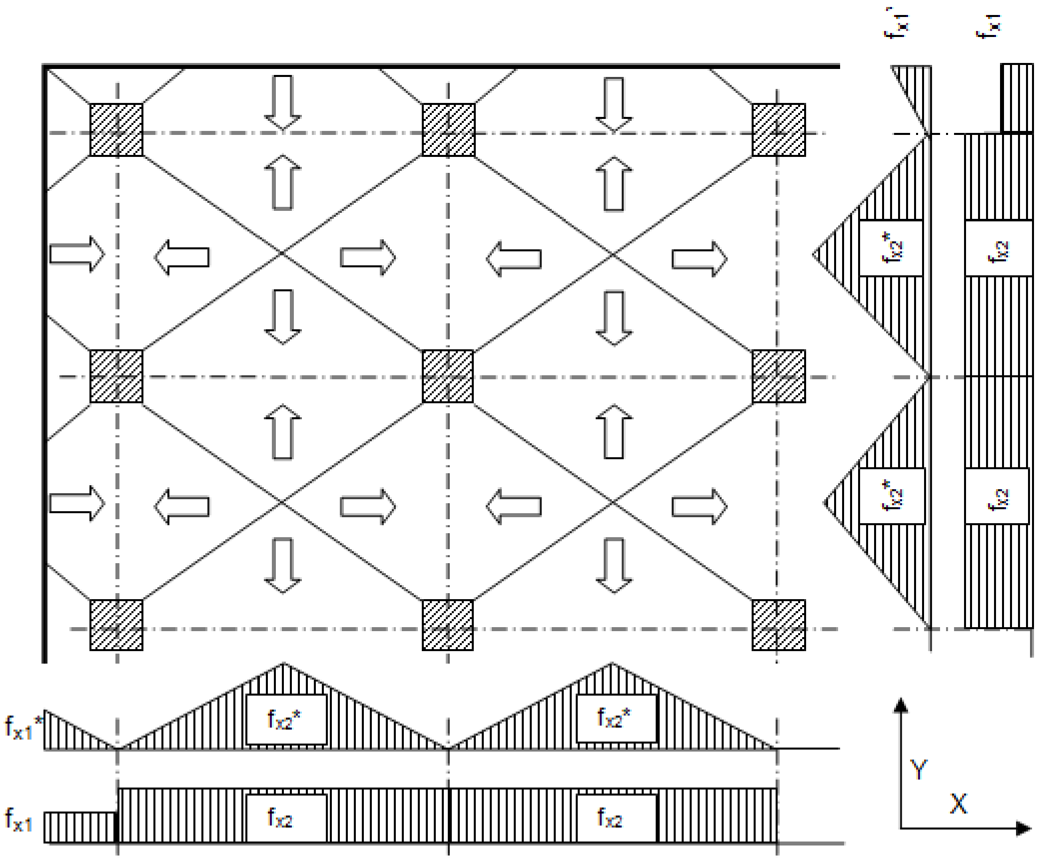


Fig. 10 Load distribution

Triangular line load

a) permanent load

$f_{x1,g}{}^{*} = f_{y1,g}{}^{*} = 2 \cdot 1{,}8 \cdot 7{,}54 = 27{,}14kN/m$

$f_{x2,g}{}^{*} = f_{y2,g}{}^{*} = 2 \cdot 4{,}5 \cdot 7{,}54 = 67{,}86kN/m$

b) variable load

$f_{x1,q}{}^{*} = f_{y1,q}{}^{*} = 2 \cdot 1{,}8 \cdot 8{,}0 = 28{,}80kN/m$

$f_{x2,q}{}^{*} = f_{y2,q}{}^{*} = 2 \cdot 4{,}5 \cdot 8{,}0 = 72{,}00kN/m$

Rectangular recalculated line load

a) permanent load

$f_{x1,g} = f_{y1,g} = 5/8 \cdot 27{,}14 = 16{,}96kN/m$

$f_{x2,g} = f_{y2,g} = 5/8 \cdot 67{,}86 = 42{,}41kN/m$

b) variable load

$f_{x1,q} = f_{y1,q} = 5/8 \cdot 28{,}80 = 18{,}00kN/m$

$f_{x2,g} = f_{y2,g} = 5/8 \cdot 72{,}00 = 45{,}00kN/m$

Using load-balancing method the rectangular recalculated line loads (80%(g+q)) are balanced by the uniform load representing the prestressing force.

$p_{x1} = p_{y1} = 0{,}8 \cdot \left(f_{x1,g} + f_{x1,q}\right) = 0{,}8 \cdot \left(f_{y1,g} + f_{y1,q}\right) = 0{,}8 \cdot (16{,}96 + 18{,}00) = 27{,}97kN/m$

$p_{x2} = p_{y2} = 0{,}8 \cdot \left(f_{x2,g} + f_{x2,q}\right) = 0{,}8 \cdot \left(f_{y2,g} + f_{y2,q}\right) = 0{,}8 \cdot (42{,}41 + 45{,}00) = 69{,}93kN/m$

The particular design for each direction (x,y) has to be done with respect of the different camber (h_p) of the parabolic tendon in each direction. These cambers are determined from the minimal radius of the tendon above the support and maximal possible tendon eccentricity witch respect of the concrete cover of the tendon in the span. The camber is measured from the inflexion point to the maximal eccentricity in the span. The eccentricity in the x direction is less than in the y direction because the tendons are crossing each others.

As the simplification the geometry of the tendon in the edge part of the slab is considered as straight line in this case. It means the equivalent load px1 is not taken into account and effect of the prestressing is covered by the vertical point force Vx1 (see chapter).

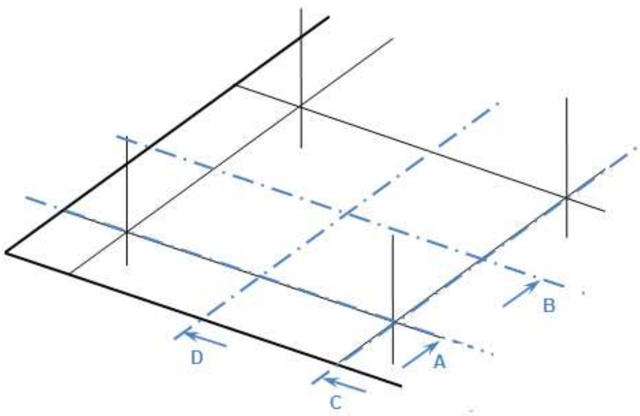


Fig. 11 Section on the slab for design of prestressing

<u>Direction x</u>

- Section A – 50% of the tendons will be in column line

$$h_{pA} = 0{,}115 \cdot \frac{(0{,}5 \cdot l_x)^2}{\left(0{,}45 \cdot l_y\right)^2} = 0{,}115 \cdot \frac{(0{,}5 \cdot 9{,}0)^2}{(0{,}45 \cdot 9{,}0)^2} = 0{,}142m$$

$$P_A = \frac{1}{2} \cdot \frac{p_{x2} \cdot l_x{}^2}{8 \cdot h_{pA}} = \frac{1}{2} \cdot \frac{69{,}93 \cdot 9{,}0^2}{8 \cdot 0{,}142} = 2493{,}10kN$$

$$n_{pA} = \frac{P_A}{P_{ltl}} = \frac{2493{,}10}{166{,}39} = 14{,}98 \rightarrow 15\ strands$$

The 5 pieces of the 3strand tendons are used

$$P_{xA} = n_{pA} \cdot P_{aa} = 15 \cdot 195{,}75 = 2936{,}25kN$$

- Section B – 50% of the tendons will be in span

$$h_{pB} = 0{,}115 \cdot \frac{(0{,}5 \cdot l_x)^2}{\left(0{,}45 \cdot l_y\right)^2} = 0{,}115 \cdot \frac{(0{,}5 \cdot 9{,}0)^2}{(0{,}45 \cdot 9{,}0)^2} = 0{,}142m$$

$$P_B = \frac{1}{2} \cdot \frac{p_{x2} \cdot {l_x}^2}{8 \cdot h_{pB}} = \frac{1}{2} \cdot \frac{69{,}93 \cdot 9{,}0^2}{8 \cdot 0{,}142} = 2493{,}10kN$$

$$n_{pB} = \frac{P_B}{P_{ltl}} = \frac{2493{,}10}{166{,}39} = 14{,}98 \rightarrow 15\ strands$$

The 5 pieces of the 3strand tendons are used

$$P_{xB} = n_{pB} \cdot P_{aa} = 15 \cdot 195{,}75 = 2936{,}25kN$$

Direction Y

- Section C – 50% of the tendons will be in column line

$$h_{pC} = 0{,}150 \cdot \frac{\left(0{,}5 \cdot l_y\right)^2}{\left(0{,}45 \cdot l_y\right)^2} = 0{,}150 \cdot \frac{(0{,}5 \cdot 9{,}0)^2}{(0{,}45 \cdot 9{,}0)^2} = 0{,}185m$$

$$P_C = \frac{1}{2} \cdot \frac{p_{y2} \cdot {l_y}^2}{8 \cdot h_{pC}} = \frac{1}{2} \cdot \frac{69{,}93 \cdot 9{,}0^2}{8 \cdot 0{,}185} = 1913{,}63kN$$

$$n_{pC} = \frac{P_C}{P_{ltl}} = \frac{1913{,}63}{166{,}39} = 11{,}5 \rightarrow 12\ strands$$

The 4 pieces of the 3strand tendons are used

$$P_{yC} = n_{pc} \cdot P_{aa} = 12 \cdot 195{,}75 = 2349{,}00kN$$

- Section D – 50% of the tendons will be in span

$$h_{pD} = 0{,}150 \cdot \frac{\left(0{,}5 \cdot l_y\right)^2}{\left(0{,}45 \cdot l_y\right)^2} = 0{,}150 \cdot \frac{(0{,}5 \cdot 9{,}0)^2}{(0{,}45 \cdot 9{,}0)^2} = 0{,}185m$$

$$P_D = \frac{1}{2} \cdot \frac{p_{y2} \cdot {l_y}^2}{8 \cdot h_{pD}} = \frac{1}{2} \cdot \frac{69{,}93 \cdot 9{,}0^2}{8 \cdot 0{,}185} = 1913{,}63kN$$

$$n_{pD} = \frac{P_D}{P_{ltl}} = \frac{1913{,}63}{166{,}39} = 11{,}5 \rightarrow 12\ strands$$

The 4 pieces of the 3strand tendons are used

$$P_{yD} = n_{pD} \cdot P_{aa} = 12 \cdot 195{,}75 = 2349{,}00kN$$

4 Prestressing of 2D members in Scia Engineer

Definition of the prestressing on 2D members can be done in Scia Engineer in three ways:

- **Definition of the equivalent load** – equivalent load is calculated from the geometry and stress in the tendon
- **Real tendon on the 1D rib** – tendon is defined on the fictive 1D rib which is part of the 2D slab
- **Real tendon on the 2D member directly** – tendon is defined directly on the 2D member using "hanging node"

Before the description of each option is explained the short summary of the each method is provided.

Item	Equivalent load	Real tendon on 1D rib	Real tendon on 2D
Preparation and definition of the prestressing	Difficult	Standard	Simple
Shorterm losses	NO	YES	YES
Longterm losses	NO	NO	NO
Internal forces from prestressing in design	YES	YES	YES
Area of prestressing in design	NO (freebars are used)	NO (freebars duplicate geometry of the tendons)	NO (freebars duplicate geometry of the tendons)
Design ULS(ULS+SLS)	YES	YES	YES
Check of allowable concrete stresses	NO	NO	NO
Check prestressed capacity or response	NO	NO	NO
Check of prestressing reinforcement	NO	YES	YES (partly)
Check punching with respect of prestressing	YES	YES	YES
Code dependent deflection (CDD)	YES	NO	NO

4.1 Three possibilities of prestressing input

4.1.1 Definition of the equivalent load

Prestressing can be defined using equivalent load which represent the prestressing tendon. The calculation of the load is dependent on the geometry of the tendon and the initial stress in the tendon.
This solution requires time for calculation of all value from tendon geometry. Parabolic arcs are replaced by the permanent line load (p). Arcs above the supports are replaced by the vertical force representing the arc. Normal force and bending moment are added at the beginning of the tendon.

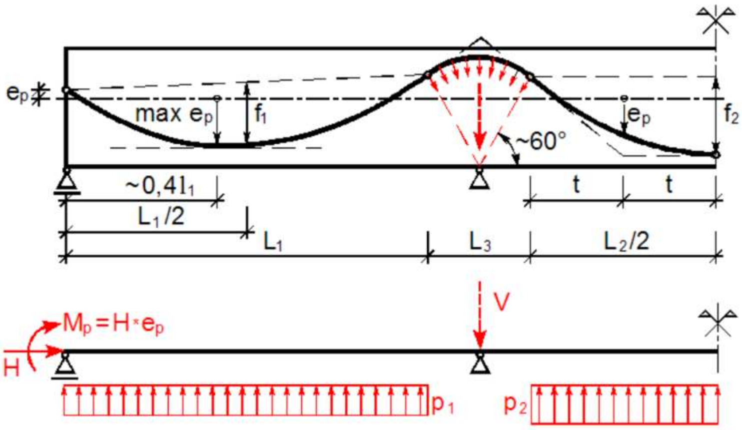


Fig. 12 Load balancing method – equivalent load (picture overtaken from [3])

4.1.1.1 Surface equivalent load

The spreading of the load from the prestressing is supposed in the angle 45degre to the centreline of the slab and to the width equal to 1,5*depth of the slab.

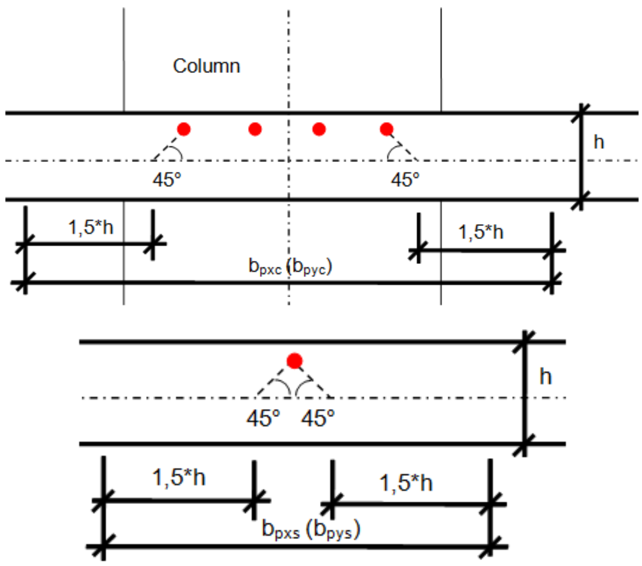


Fig. 13 Determination of the spreading width of the prestressing

Spreading width of the prestressing is calculated for the span and for the column line separately.

	Direction X	Direction Y
Column line	$\boldsymbol{b_{pxc}} = 4 \cdot \mathrm{s_p} + 2 \cdot \mathrm{e_{pxc}} + 2 \cdot 1{,}5 \cdot \mathrm{h} =$ $= 4 \cdot 0{,}1 + 2 \cdot 0{,}04 + 2 \cdot 1{,}5 \cdot 0{,}29$ $= \mathbf{1{,}35}\boldsymbol{m}$	$\boldsymbol{b_{pyc}} = 3 \cdot \mathrm{s_p} + 2 \cdot \mathrm{e_{pyc}} + 2 \cdot 1{,}5 \cdot \mathrm{h} =$ $= 3 \cdot 0{,}1 + 2 \cdot 0{,}075 + 2 \cdot 1{,}5 \cdot 0{,}29 = \mathbf{1{,}32}\boldsymbol{m}$
Span line	$\boldsymbol{b_{pxs}} = 2 \cdot \mathrm{e_{pxc}} + 2 \cdot 1{,}5 \cdot \mathrm{h} =$ $= 2 \cdot 0{,}04 + 2 \cdot 1{,}5 \cdot 0{,}29 = \mathbf{0{,}95}\boldsymbol{m}$	$\boldsymbol{b_{pys}} = 2 \cdot \mathrm{e_{pyc}} + 2 \cdot 1{,}5 \cdot \mathrm{h} =$ $= 2 \cdot 0{,}075 + 2 \cdot 1{,}5 \cdot 0{,}29 = \mathbf{1{,}02}\boldsymbol{m}$

Based on the new spread width the equivalent line load will be recalculated to the equivalent surface load.

		Direction X	Direction Y
Column	**1**	$\boldsymbol{p_{x1c}} = \frac{\mathrm{p_{x1}}}{2 \cdot \mathrm{b_{pxc}}} = \frac{27{,}97}{2 \cdot 1{,}35} = \mathbf{10{,}36}\boldsymbol{kN/m^2}$	$\boldsymbol{p_{y1c}} = \frac{\mathrm{p_{y1}}}{2 \cdot \mathrm{b_{pyc}}} = \frac{27{,}97}{2 \cdot 1{,}32} = \mathbf{10{,}59}\boldsymbol{kN/m^2}$

line			
	2	$\boldsymbol{p_{x2c}} = \frac{\mathrm{p_{x2}}}{2 \cdot \mathrm{b_{pxc}}} = \frac{69{,}93}{2 \cdot 1{,}35} = \mathbf{25{,}9 kN/m^2}$	$\boldsymbol{p_{y2c}} = \frac{\mathrm{p_{y2}}}{2 \cdot \mathrm{b_{pyc}}} = \frac{69{,}93}{2 \cdot 1{,}32} = \mathbf{26{,}49 kN/m^2}$
Span line	1	$\boldsymbol{p_{x1s}} = \frac{\mathrm{p_{x1}}}{2 \cdot \mathrm{n_{pB}} \cdot \mathrm{b_{pxs}}} = \frac{27{,}97}{2 \cdot 5 \cdot 0{,}95} = = \mathbf{2{,}94 kN/m^2}$	$\boldsymbol{p_{y1s}} = \frac{\mathrm{p_{y1}}}{2 \cdot \mathrm{n_{pD}} \cdot \mathrm{b_{pys}}} = \frac{27{,}97}{2 \cdot 4 \cdot 1{,}02} = = \mathbf{3{,}43 kN/m^2}$
	2	$\boldsymbol{p_{x2s}} = \frac{\mathrm{p_{x2}}}{2 \cdot \mathrm{n_{pB}} \cdot \mathrm{b_{pxs}}} = \frac{69{,}93}{2 \cdot 5 \cdot 0{,}95} = = \mathbf{7{,}36 kN/m^2}$	$\boldsymbol{p_{y2s}} = \frac{\mathrm{p_{y2}}}{2 \cdot \mathrm{n_{pD}} \cdot \mathrm{b_{pys}}} = \frac{69{,}93}{2 \cdot 5 \cdot 1{,}02} = = \mathbf{8{,}57 kN/m^2}$

4.1.1.2 Vertical and horizontal forces in the edges

The horizontal and vertical forces should be presented in the free edges where the tendons are stressed and anchored.

	Direction X	Direction Y
α [°]	$arctg\left(\frac{e_{pxc}}{l_c}\right) = arctg\left(\frac{0{,}04}{1{,}8}\right) = 1{,}27$	$arctg\left(\frac{e_{pyc}}{l_c}\right) = arctg\left(\frac{0{,}075}{1{,}8}\right) = 2{,}386$
P [kN]	2936,25	2349,00
H [kN]	$P_x \cdot \cos(\alpha) = 2936{,}25 \cdot cos(1{,}27) = \mathbf{2935{,}53}$	$P_x \cdot \cos(\alpha) = 2349{,}00 \cdot cos(1{,}27) = \mathbf{2348{,}42}$
V [kN]	$P_x \cdot \sin(\alpha) = 2936{,}25 \cdot sin(1{,}27) = \mathbf{65{,}08}$	$P_x \cdot \sin(\alpha) = 2349{,}00 \cdot sin(1{,}27) = \mathbf{52{,}06}$

Furthermore those forces are recalculated to the spreading width of prestressing

	Direction X		Direction Y	
	Column line	Span line	Column line	Span line
H [kN/m]	$H_{xc} = \frac{H_x}{b_{pxc}} = \frac{2935{,}53}{1{,}35} = \mathbf{2174{,}47}$	$H_{xs} = \frac{H_x}{n_{pB} \cdot b_{pxs}} = \frac{2935{,}53}{5 \cdot 0{,}95} = \mathbf{618{,}01}$	$H_{yc} = \frac{H_y}{b_{pyc}} = \frac{2348{,}42}{1{,}32} = \mathbf{1779{,}11}$	$H_{ys} = \frac{H_y}{n_{pD} \cdot b_{pys}} = \frac{2348{,}42}{4 \cdot 1{,}02} = \mathbf{575{,}59}$
V [kN/m]	$V_{xc} = \frac{V_x}{b_{pxc}} = \frac{65{,}08}{1{,}35} = \mathbf{48{,}21}$	$V_{xs} = \frac{V_x}{n_{pB} \cdot b_{pxs}} = \frac{65{,}08}{5 \cdot 0{,}95} = \mathbf{13{,}70}$	$V_{yc} = \frac{V_y}{b_{pyc}} = \frac{52{,}06}{1{,}32} = \mathbf{39{,}44}$	$V_{ys} = \frac{V_y}{n_{pD} \cdot b_{pys}} = \frac{52{,}06}{4 \cdot 1{,}02} = \mathbf{12{,}76}$

4.1.1.3 Point forces from tendons in column line

When we look on the Fig. 8 we can see the acting of the tendon by the point force in the column line. These point force are calculated for each direction and for column and span line separately. We substitute equivalent load above the support by the point force load. The length of the arc of the tendon above the support is calculated from the inflexion points. We can suppose inflexion points in the edges of the column dimensions. It means for substituted support forces.

$$l_{x,sub} = l_{y,sub} = 0{,}55m$$

Then support point forces are the following

Direction X

- ***Column line***

$$F_{x1c} = V_x + \frac{p_{x2}}{2} \cdot \left(\frac{l_x}{2} - \frac{l_{x,sub}}{2}\right) = 65{,}08 + \frac{69{,}93}{2} \cdot \left(\frac{9{,}0}{2} - \frac{0{,}55}{2}\right) = 212{,}81kN$$

$$F_{x2c} = \frac{p_{x2}}{2} \cdot (l_x - l_{x,sub}) = \frac{69{,}93}{2} \cdot (9{,}0 - 0{,}55) = 295{,}45kN$$

- ***Span line*** – point force for each tendon ($n_{pB} = 5$)

$$F_{x1S} = \frac{V_x}{n_{pB}} + \frac{p_{x2}}{2 \cdot n_{pB}} \cdot \left(\frac{l_x}{2} - \frac{l_{x,sub}}{2}\right) = \frac{65{,}08}{5} + \frac{69{,}93}{2 \cdot 5} \cdot \left(\frac{9{,}0}{2} - \frac{0{,}55}{2}\right) = 42{,}56kN$$

$$F_{x2S} = \frac{p_{x2}}{2 \cdot n_{pB}} \cdot (l_x - l_{x,sub}) = \frac{69{,}93}{2 \cdot 5} \cdot (9{,}0 - 0{,}55) = 59{,}09kN$$

Direction Y

- ***Column line***

$$F_{y1c} = V_y + \frac{p_{y2}}{2} \cdot \left(\frac{l_y}{2} - \frac{l_{y,sub}}{2}\right) = 52{,}06 + \frac{69{,}93}{2} \cdot \left(\frac{9{,}0}{2} - \frac{0{,}55}{2}\right) = 199{,}79kN$$

$$F_{y2c} = \frac{p_{y2}}{2} \cdot (l_y - l_{y,sub}) = \frac{69{,}93}{2} \cdot (9{,}0 - 0{,}55) = 295{,}45kN$$

- ***Span line*** – point force for each tendon ($n_{pD} = 4$)

$$F_{y1S} = \frac{V_y}{n_{pD}} + \frac{p_{y2}}{2 \cdot n_{pD}} \cdot \left(\frac{l_y}{2} - \frac{l_{y,sub}}{2}\right) = \frac{52{,}06}{5} + \frac{69{,}93}{2 \cdot 4} \cdot \left(\frac{9{,}0}{2} - \frac{0{,}55}{2}\right) = 47{,}34kN$$

$$F_{y2S} = \frac{p_{y2}}{2 \cdot n_{pD}} \cdot (l_y - l_{y,sub}) = \frac{69{,}93}{2 \cdot 4} \cdot (9{,}0 - 0{,}55) = 73{,}86kN$$

Furthermore the possibilities are available for user how to input the prestressing using equivalent load on the structure.

- ***Input in 1 loadcase*** - summarize force above the column in both directions (see Fig. 14).

$$F_{x1y1} = F_{x1c} + F_{y1c} = 212{,}81 + 199{,}79 = 412{,}60kN$$
$$F_{x1y2} = F_{x1c} + F_{y2c} = 212{,}81 + 295{,}45 = 507{,}26kN$$
$$F_{x2y1} = F_{x2c} + F_{y1c} = 295{,}45 + 199{,}79 = 495{,}24kN$$
$$F_{x2y2} = F_{x2c} + F_{y2c} = 295{,}45 + 295{,}45 = 590{,}90kN$$

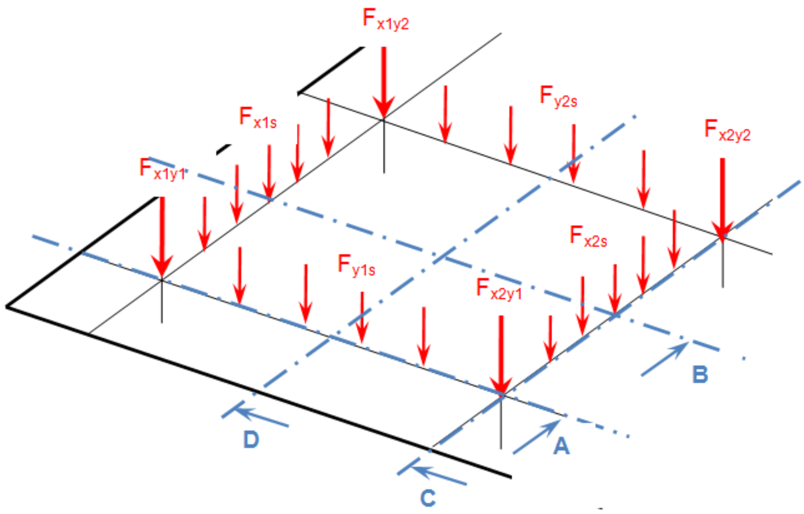
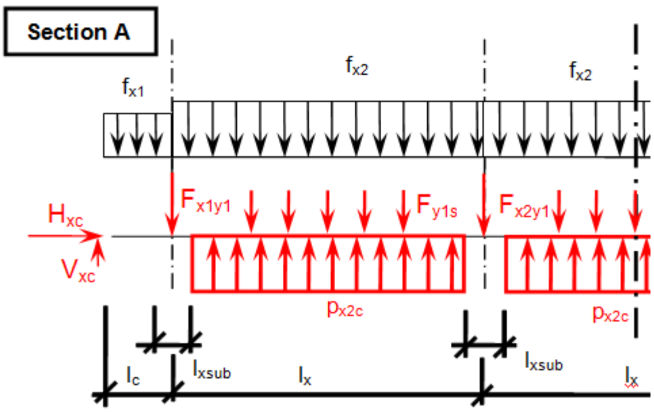


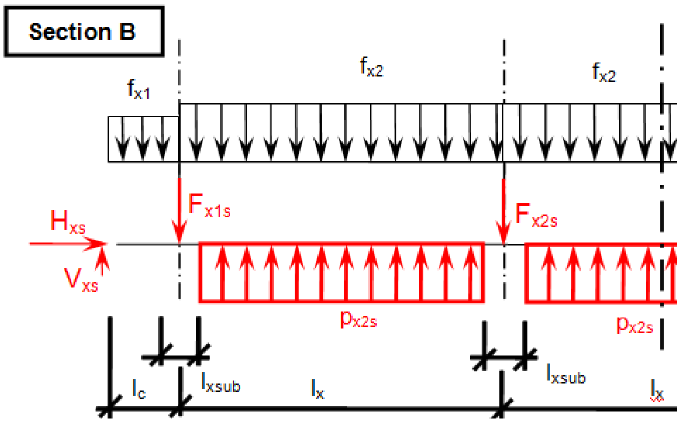
Fig. 14 Point force above column lines

- ***Input in 2 loadcases*** – prestressing defined by the equivalent load is inputted in 2 loadcases (prestressing X and prestressing Y). User has better overview about prestressing in each direction. In this case the summarization of the point forces above the column cross-link is not applied

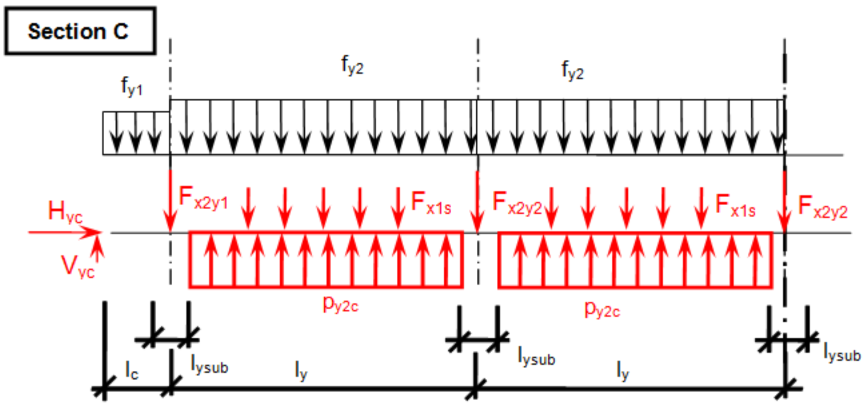
Finally the equivalent load in our case is the following.

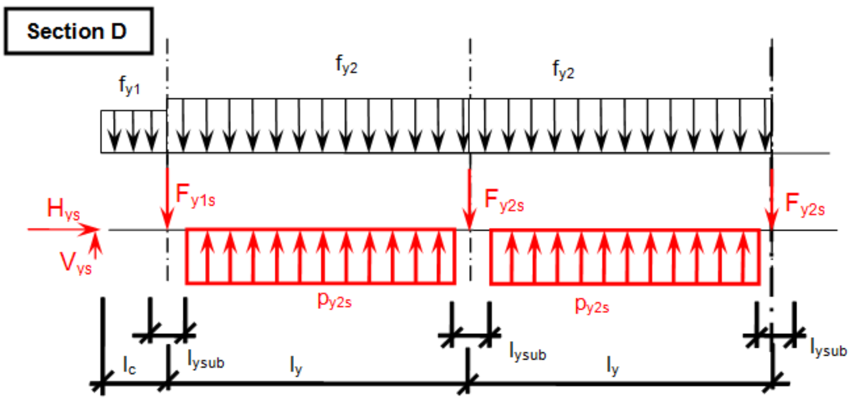
Direction X





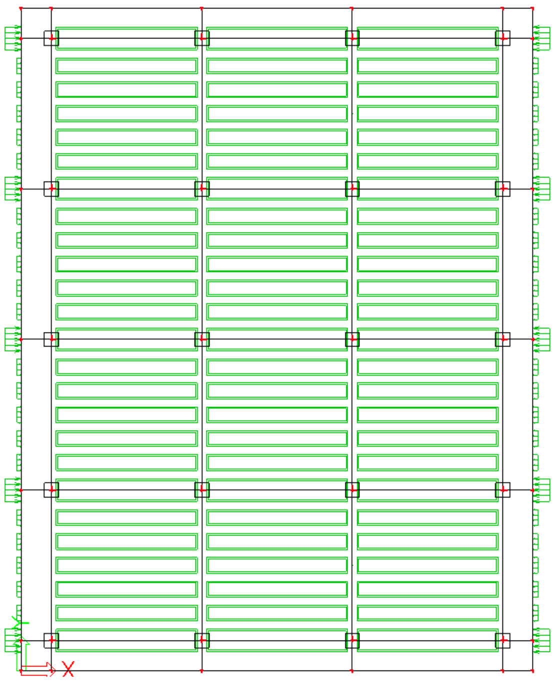
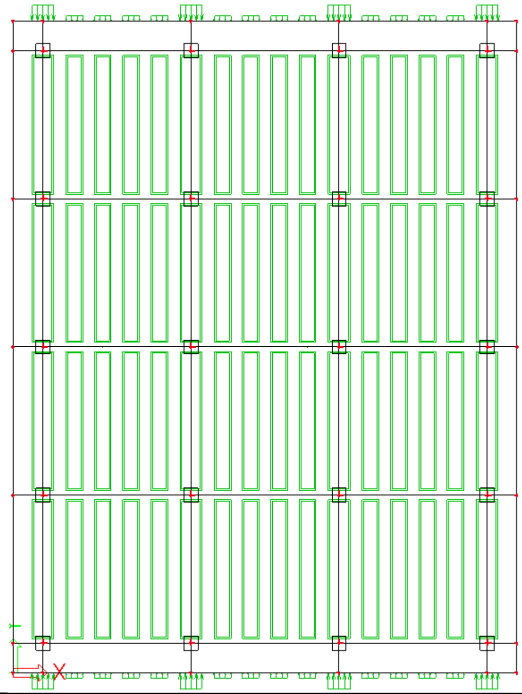
Direction Y





Disadvantage of this solution is the shorterm losses are not calculated automatically and has to be estimated by the user. Furthermore the load is modified with respect of the stress after shorterm and longterm losses.

Typical cases of the prestressing inputted using equivalent load in both directions separately are the following.

Prestress X	**Prestress Y**
	

4.1.2 Real tendon on the 1D rib

Definition of the prestressing in postensioned 2D member is done using standard tool Postensioned internal tendon. The fictive 1D member has to be defined in the position of the tendons. It means one rib in the column line and one rib for each tendon in the span. The definition is time consuming because you have to define slabs + ribs + tendons. The final screen of that structure is following

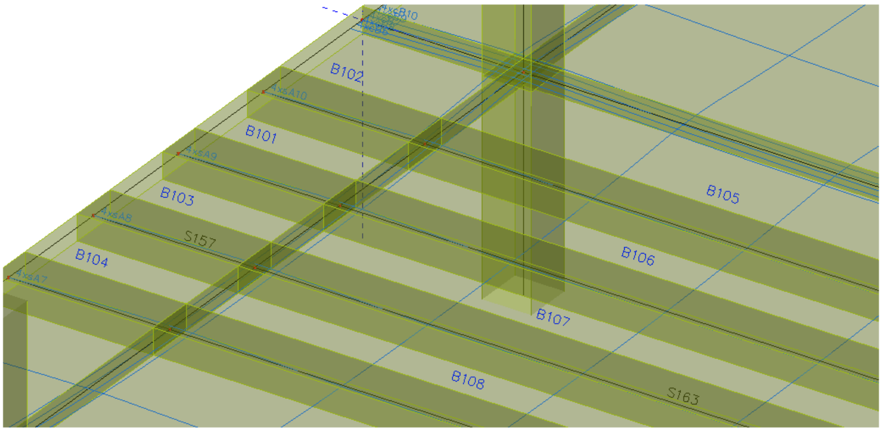


Fig. 15 Postensioned slab with internal ribs

The properties of the ribs are visible form figure Fig. 16. The material of the rib is fictive and unity mass is equal to 0,1kg/m3. Otherwise the selfweight of the rib is duplicated to the selfweight of the slab.

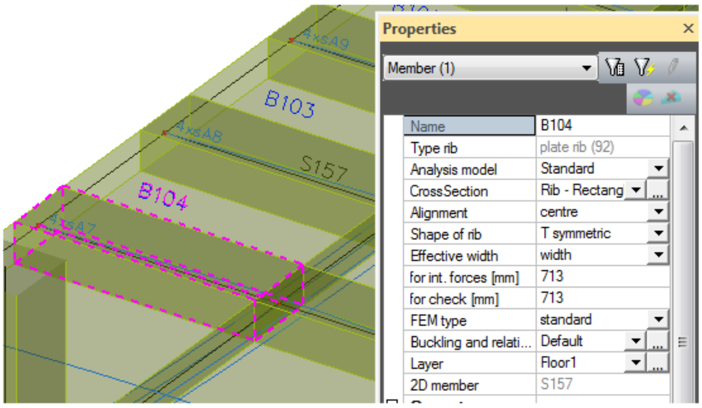


Fig. 16 Properties of the internal rib

Allocation of the tendons in this case is for 1D member only.

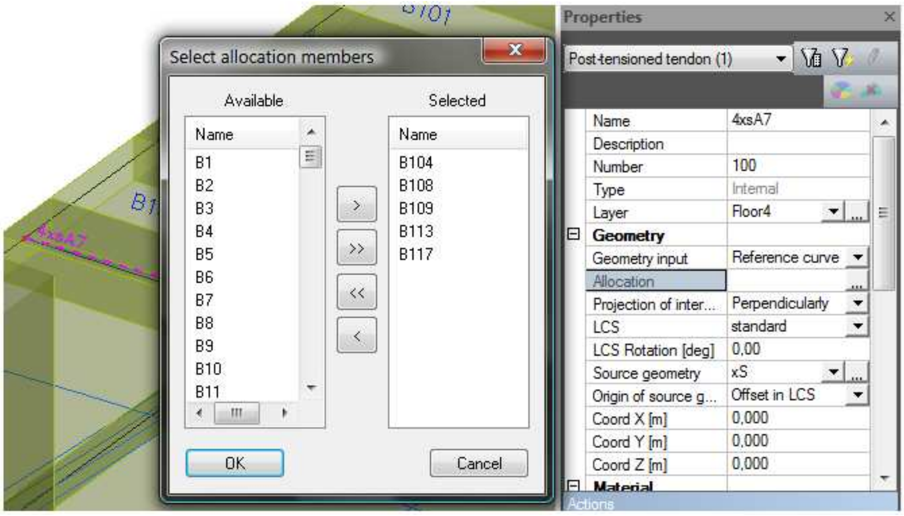


Fig. 17 Allocation of the tendon

The checkbox hanging nodes in Mesh setup can be switch OFF in this case.

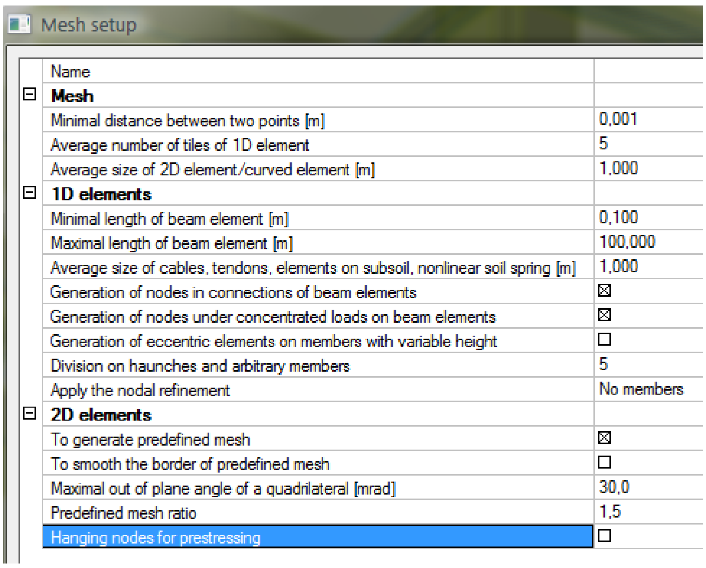


Fig. 18 Mesh setup

This option will not be commented and used in the following text.

4.1.3 Real tendon on the 2D member directly

Definition of the prestressing in postensioned 2D member is done again using standard tool Postensioned internal tendon. Till version Scia Esa PT 2007.1 postensioning on the 2D memebr had to be defined on the fictive rib which was defined on the slab. This solution was bit complicated and not so user friendly. That’s why concept of the “hanging nodes” has been implemented.
Hanging nodes is term used in finite element method describing interpretation of the element on the mesh. The mesh of the tendon and attached elements (1D beam or 2D) is independent. The tendons are modelled as 1D member on eccentricity in case without using hanging nodes. When the hanging nodes are used then stiffness of the tendon is added to the closest mesh element according to type of projection.

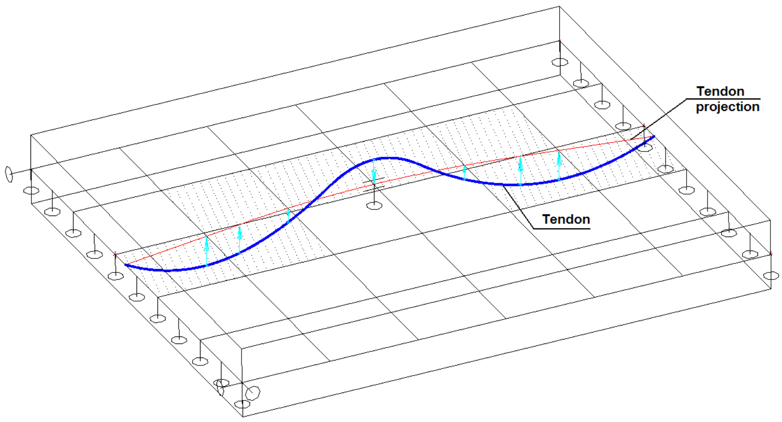


Fig. 19 Tendon defined on 2D members

This functionality enables to user attach internal post-tensioned tendons directly to 2D slab and shell elements. No dummy beam 1D (rib) is necessary. The mesh of internal post-tensioned tendon and attached 2D elements can be independent.
For tendons allocated on 1D members (beams) is possible to projection the tendon perpendicularly on beam or proportionally. For tendons allocated on 2D members (slabs) is perpendicularly projection only.

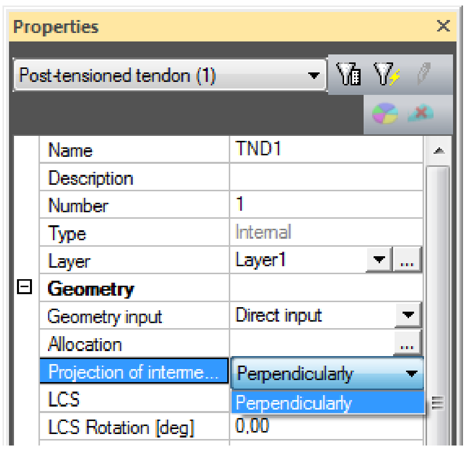


Fig. 20 Perpendicular projection for 2D members

4.2 Real tendon input

The definition of the tendon is in the standard way in menu tree, Structure>Tendons>Postensioned internal tendon.

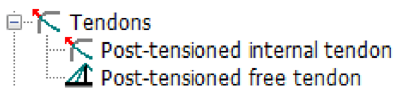


Fig. 21 Structure tree

For the definition of the real postensioned tendon in the slab is most suitable solution to use geometry input called reference line with source geometry. It means that user define some reference line (for instance line from CAD program) and source geometry. The final geometry is composition of the reference line and source geometry. Source geometry is winded on the reference line up tot final length of the source geometry.

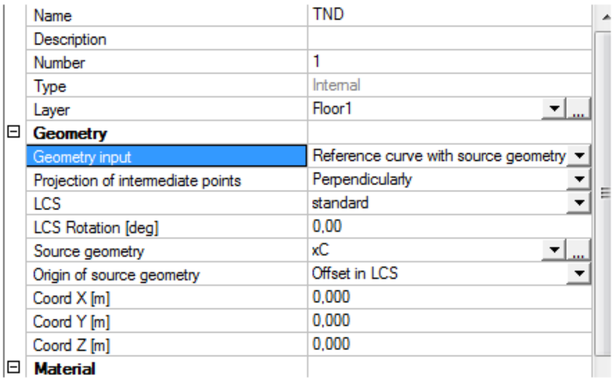


Fig. 22 Geometry type – Reference line + SG

The reference source geometry is prepared according to design from chapter 3. The four source geometries were prepared:

- **xC** – source geometry in column line in X direction
- **xS** – source geometry in span in X direction
- **yC** – source geometry in column line in Y direction
- **yS** – source geometry in span in Y direction

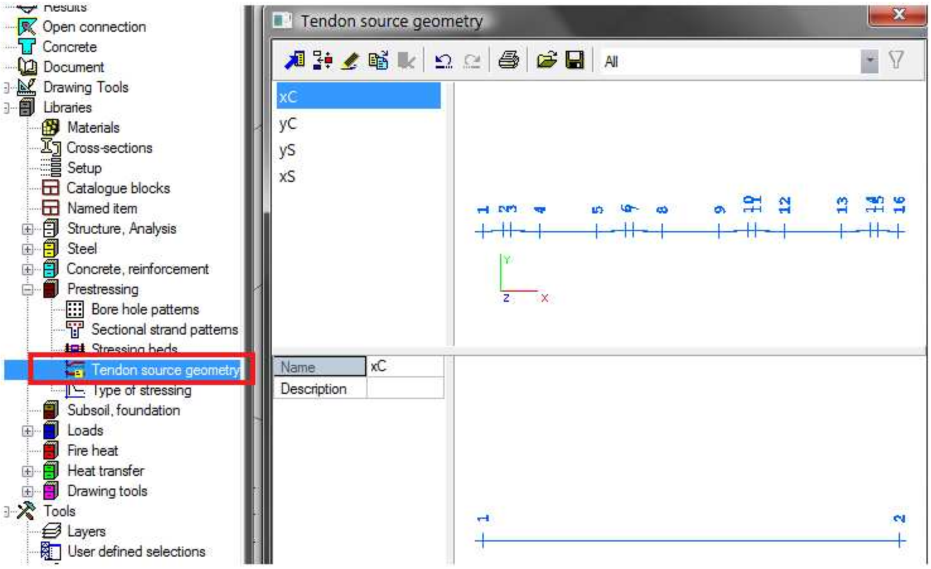


Fig. 23 Library of source geometry

The geometries of the span and column lines in each direction (X,Y) are the same. Only distances between each tendon are different. The tendons source geometries are the following.

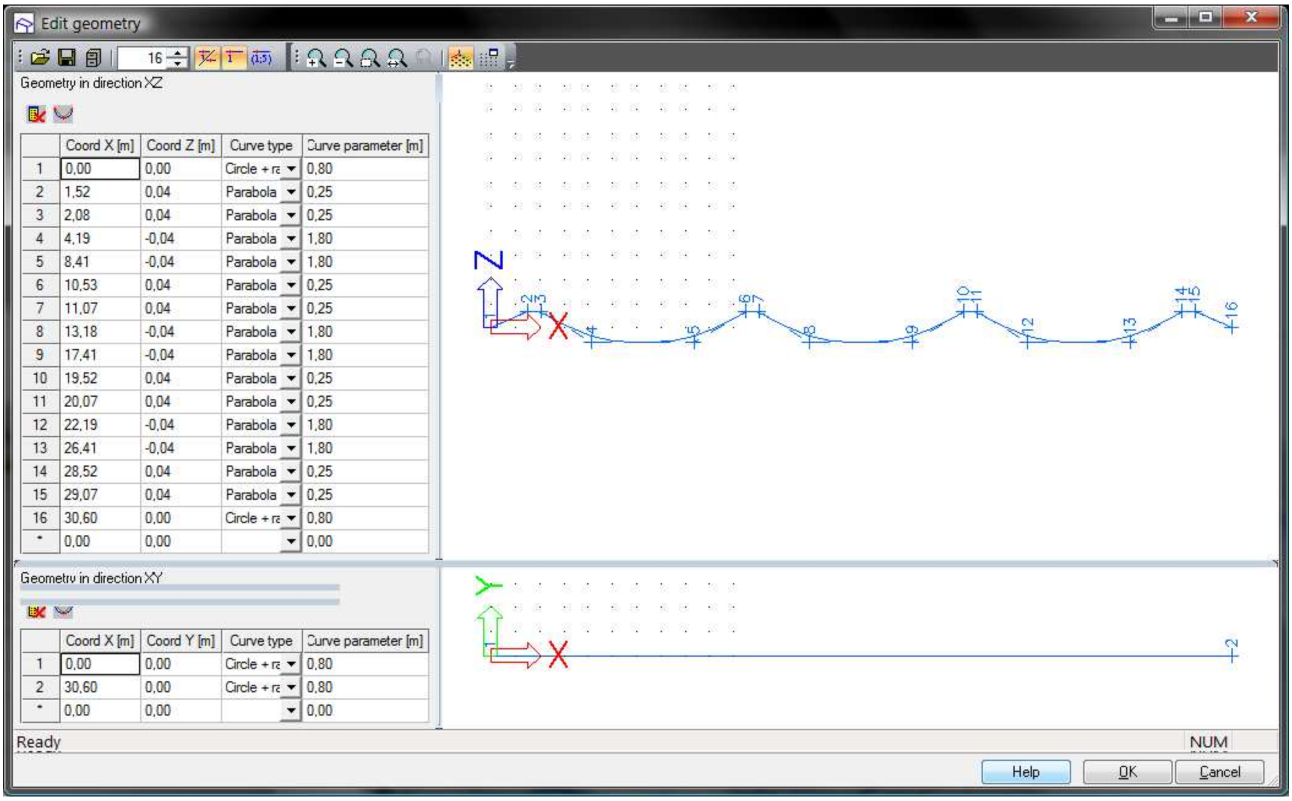


Fig. 24 Tendon source geometry xC; xS

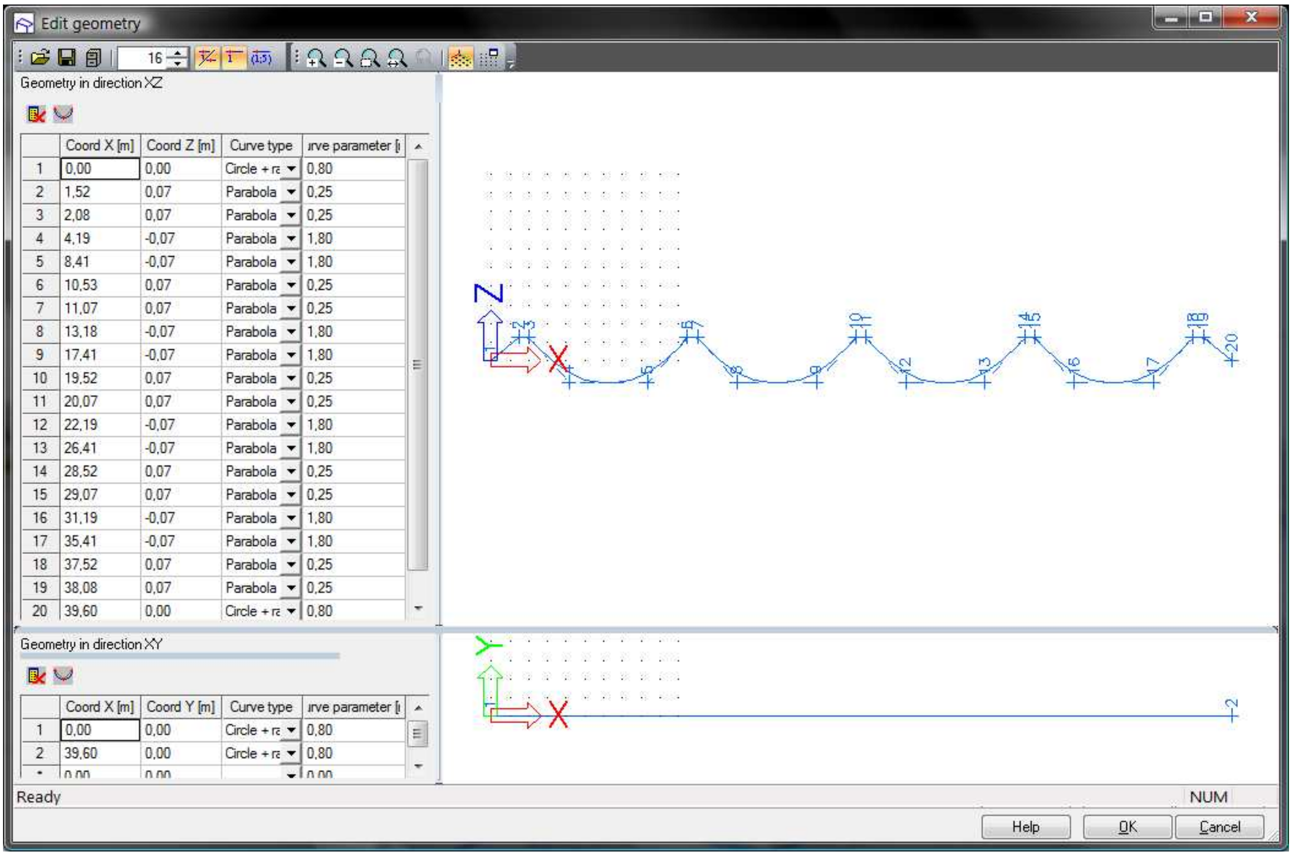


Fig. 25 Tendon source geometry yC; yS

When the source geometries are defined then we can set all properties of the tendon according to following dialogue.

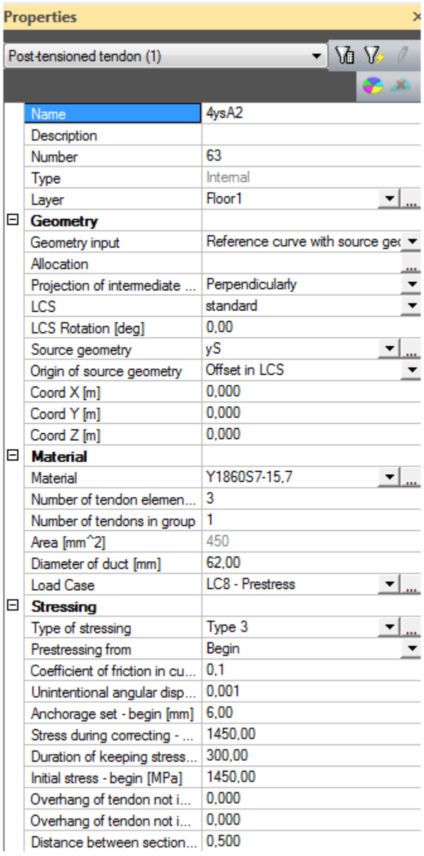


Fig. 26 Properties of the tendon

Then program asks for the definition of the reference line. So we insert new straight line in the axis X of the column line.

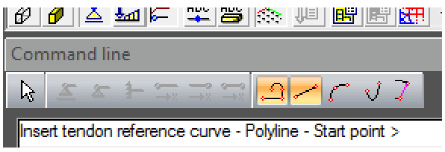


Fig. 27 Command line

After confirming of the action the program creates postensioned tendon automatically.

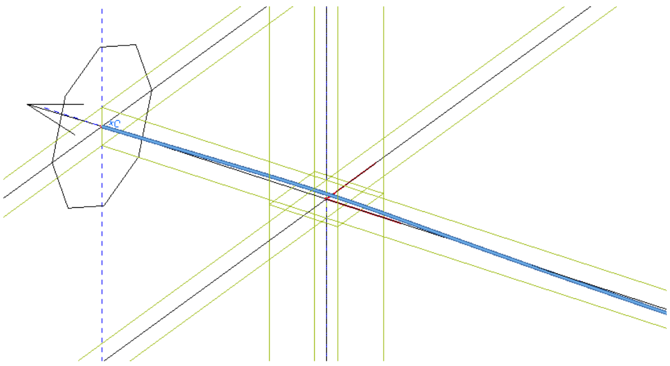


Fig. 28 One tendon in column line

To get all tendons in correct position we can use the ***multicopy*** action button to copy and offset this defined tendon to the new position.

Fig. 29 Multicopy

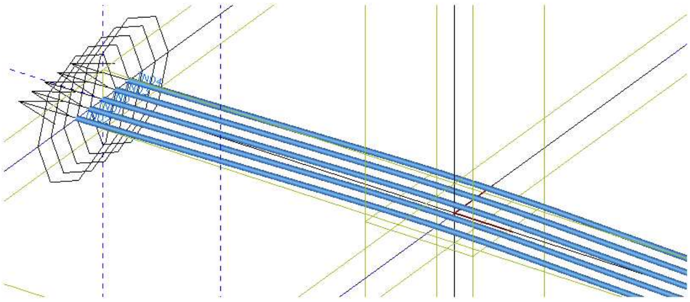


Fig. 30 Complete column line tendons' in x directions

Numbering of the tendon is the following:

4ysA2

- **4** – number of the floor, where tendon is defined
- **y** – direction of the tendon
- **s** – span (s) or column (c) tendon
- **A** – sign of the position of the column (A,B..) or the span (1,2...)
- **2** – number of the tendon with the same properties before

All tendons for the 4th floor are summarized on the following figure.

Name	Type	Material	Diameter of duct [mm]	Source geometry	Load Case	Type of stressing	Layer
4xc A4	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc A5	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc B1	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc B3	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc B2	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc B4	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc B5	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc C1	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc C3	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc C2	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc C4	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc C5	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc D1	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc D3	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc D2	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc D4	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc D5	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc E1	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc E3	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc E2	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc E4	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xc E5	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4yc A2	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc A3	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc A4	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc A1	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc B1	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc B2	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc B3	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc B4	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc C1	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc C2	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc C3	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4yc C4	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4

Name	Type	Material	Diameter of duct [mm]	Source geometry	Load Case	Type of stressing	Layer
4ycD1	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4ycD2	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4ycD3	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4ycD4	Internal	Y1860S7-15,7	62,00	yC	LC8 - Prestress	Type 3	Floor4
4xsA1	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsA2	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsA3	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsA4	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsA5	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsB1	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsB2	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsB3	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsB4	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsB5	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsC1	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsC2	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsC3	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsC4	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsC5	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsD1	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsD2	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsD3	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsD4	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4xsD5	Internal	Y1860S7-15,7	62,00	xS	LC8 - Prestress	Type 3	Floor4
4ysA1	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysA2	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysA3	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysA4	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysB1	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysB2	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysB3	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysB4	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysC1	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysC2	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysC3	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4ysC4	Internal	Y1860S7-15,7	62,00	yS	LC8 - Prestress	Type 3	Floor4
4xcA3	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xcA2	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4
4xcA1	Internal	Y1860S7-15,7	62,00	xC	LC8 - Prestress	Type 3	Floor4

So finally when we define all tendons on the floor we get the similar figure as the following one.

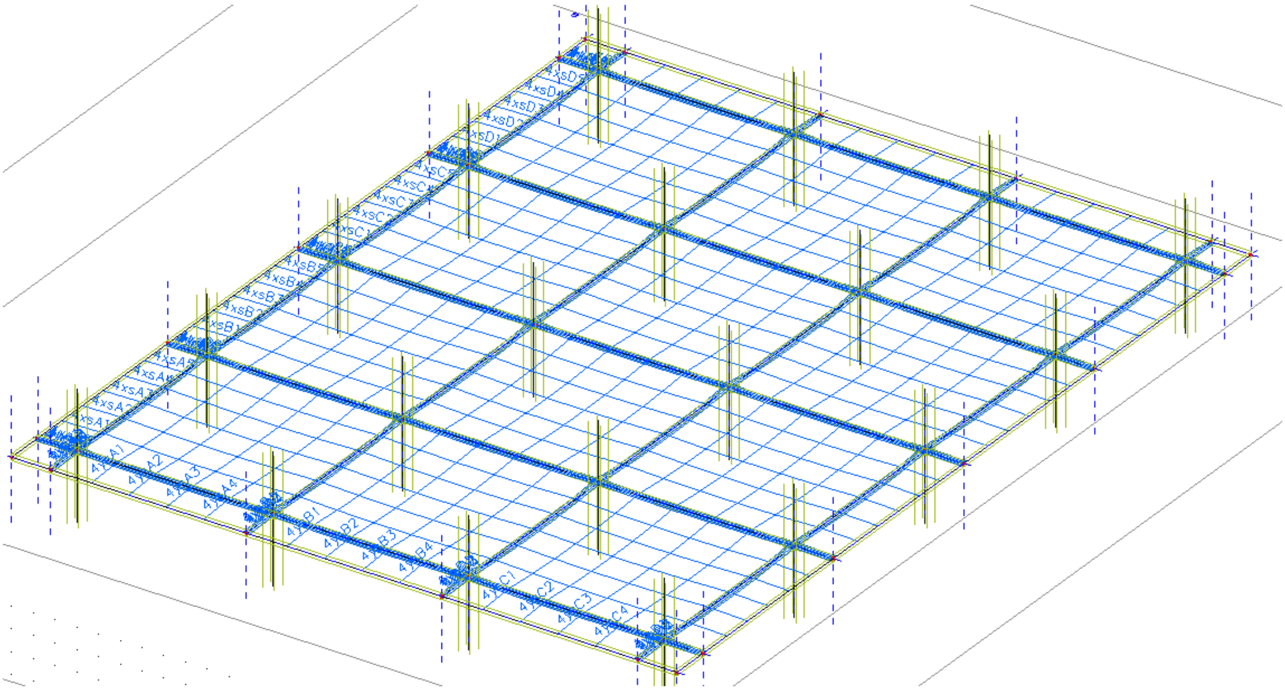


Fig. 31 The 4th floor after definition of all tendons

5 Results

5.1 Mesh settings, size and refinements

5.1.1 Recommended values of the Mesh size

The recommended value of the mesh size is 2*depth of the slab for 2D structures. For our case 2*0,290 = 0,58m ➔0,6m.

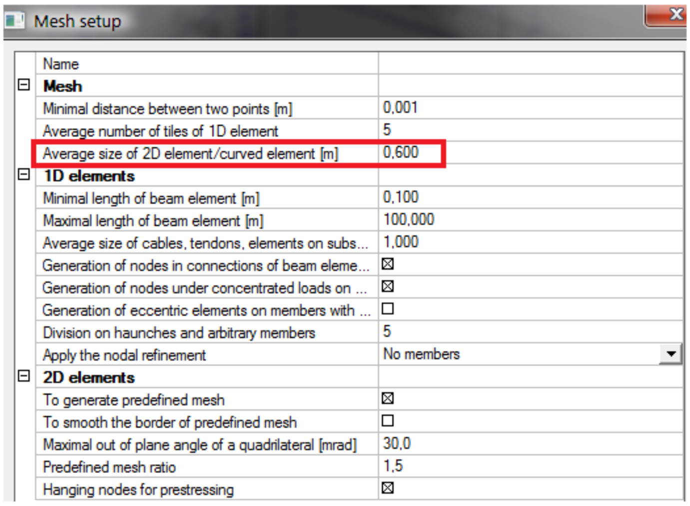


Fig. 32 Settings mesh size of 2D member

5.1.2 Setting for using Hanging nodes

The using hanging node for 2D member is possible to set in Mesh setup. The additional fictive 1D beam is not necessary in this case.

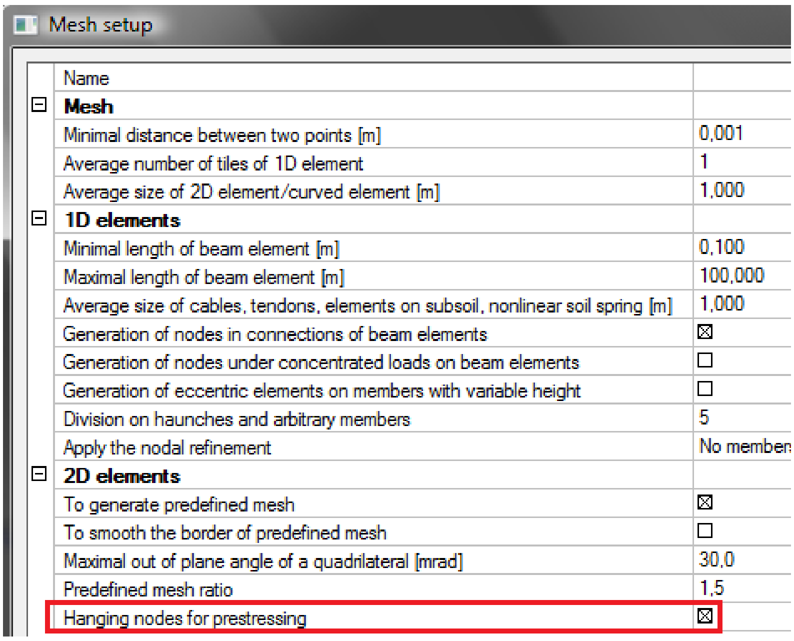
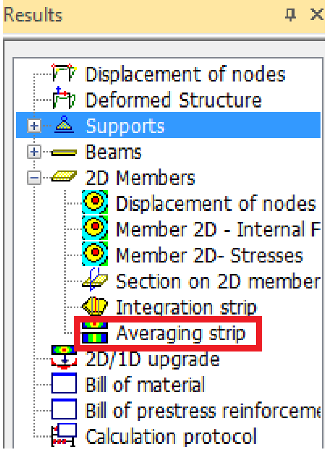
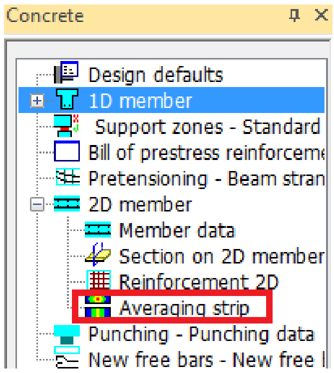


Fig. 33 Settings for hanging nodes

5.2 Averaging strips

For the reduction of peaks above the support it is recommended to define averaging strip above the support. We use the point averaging strips and we define averaging strip for each node represent the point support by column. Averaging strips can be defined from the two places:

Results > 2D members > Averaging strips	Concrete > 2D member >Averaging strips
	

We use **Point** averaging strip and the dimensions of the strips are recommended 1,5*dimension of the column. For this case we define value **Width = Length = 0,85m**. Direction of the averaging is also important and we select the type **Both**.

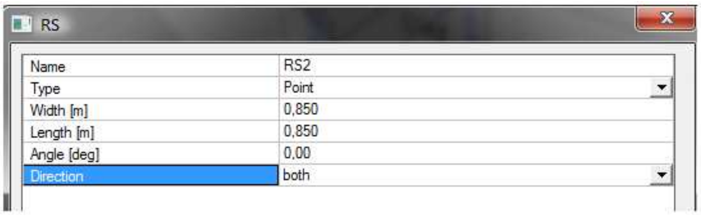


Fig. 34 Averaging strips settings

The definition of the averaging strips

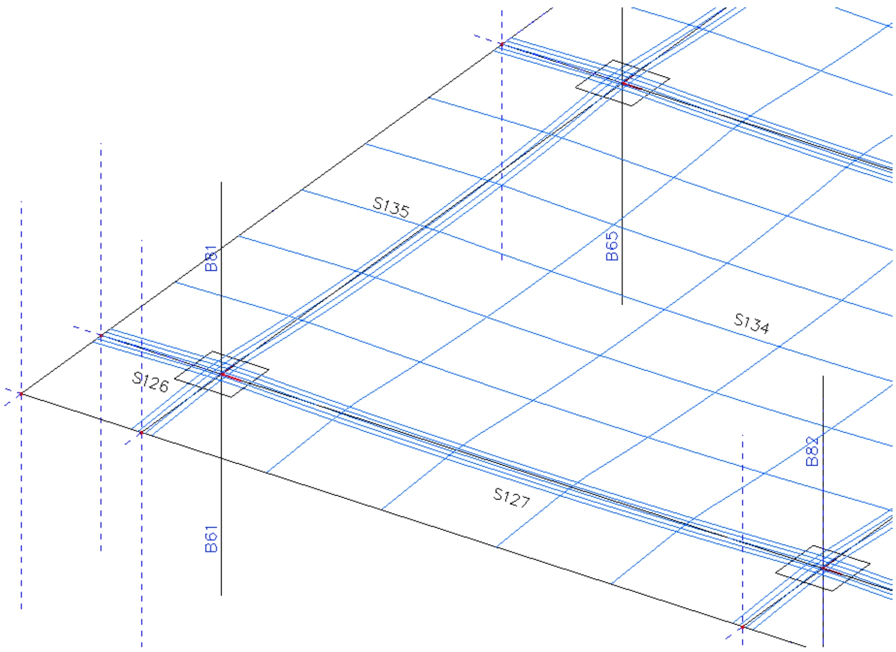


Fig. 35 Averaging strips settings defined on the structures

The difference between using with and without averaging strip is visible from the figure

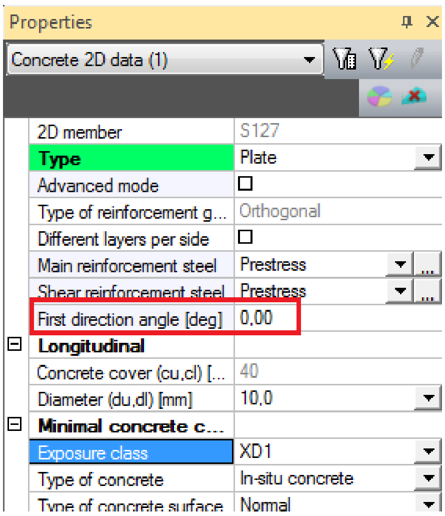
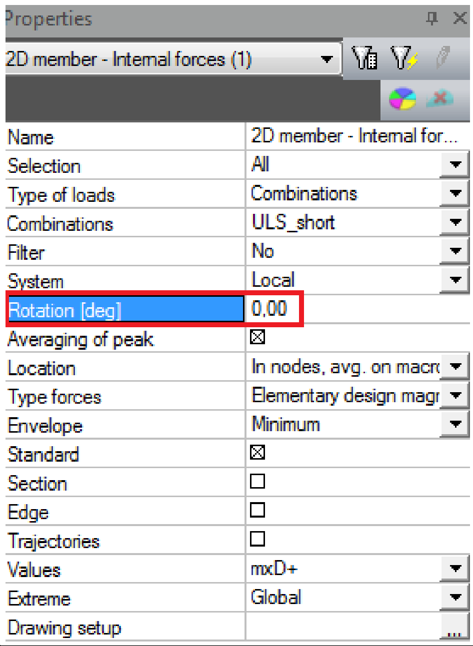
6 Evaluation of internal forces

Internal forces can be evaluated in the ***Results > 2D members > Member 2D - Internal forces*** and also in ***Concrete > 2D member > Member design > Internal forces ULS***. ***Basic magnitudes*** are the same for both cases, but the differences are in the ***Elementary design magnitudes***. There are several differences between those internal forces. Explanation about details is described in **Chyba! Nenalezen zdroj odkazů.**. The short overview of differences is summarized in the following table.

	Results	Concrete
Method for calculation of Design magnitudes	ENV method [6]	NEDIM (Baumann theory) [5]
Design magnitudes in direction of the local axis (X, Y) of the slab	YES	NO
Design magnitudes in direction of the direction of the reinforcement	NO	YES
Taking into account torsional moment *mxy*	YES	YES
Shear effect (6.2.3(7))	NO	YES

The design elementary magnitudes are the same in Results and Concrete part only if the following settings are fulfilled:

- Two directions of perpendicular reinforcement
- The first direction angle in ***Concrete 2D member data*** is the same with rotation in ***Results > 2D Internal forces*** service.

<table>
<tr><th>Concrete >2D member > Member data</th><th>Results > 2D Internal forces</th></tr>
<tr><td>
</td>
<td>
</td></tr>
</table>

- Shear effect is not taken into account in ***Concrete setup > ULS > Shear > 2D structures***

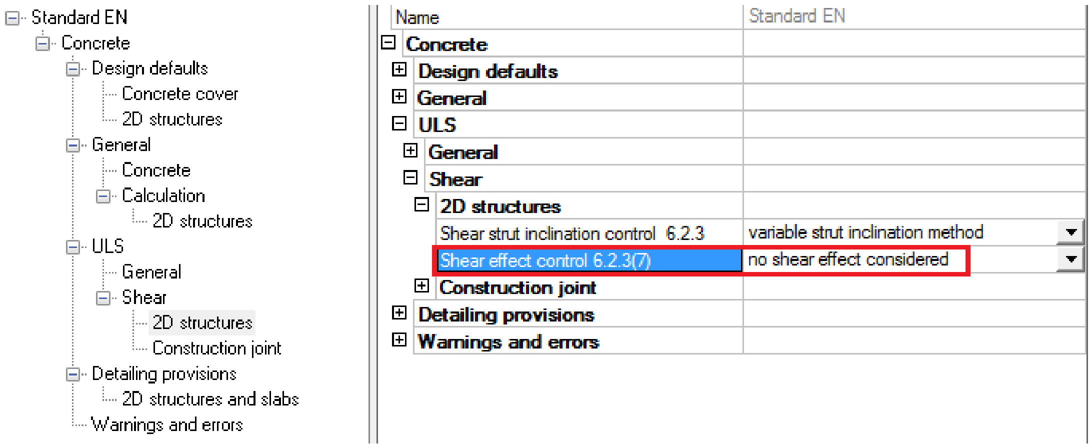


Fig. 36 Concrete setup for shear in 2D structures

6.1 Elementary design magnitudes - results

Elementary design magnitudes in ***Results*** are calculated according to different method (ENV method) and internal forces are recalculated to direction so f the local axis (x, y) of the 2D element instead of the direction of the reinforcement as it is for design internal forces in ***Concrete***. These internal forces cover also torsion *mxy* but they are not taking into account additional tensile forces from shear. These design internal forces are only for presentation and they are not used for design of reinforcement. The internal forces in ***Concrete***, which are recalculated into direction of the reinforcement, are used for design.

We can compare results from the model where prestressing is modelled using real tendon with model where the equivalent load is used. You can see results in the tables below. Because there are higher internal forces for model with real tendon probably the shorterm losses of 10% were overestimated with comparison of real calculation of shorterm losses on model with real tendon.

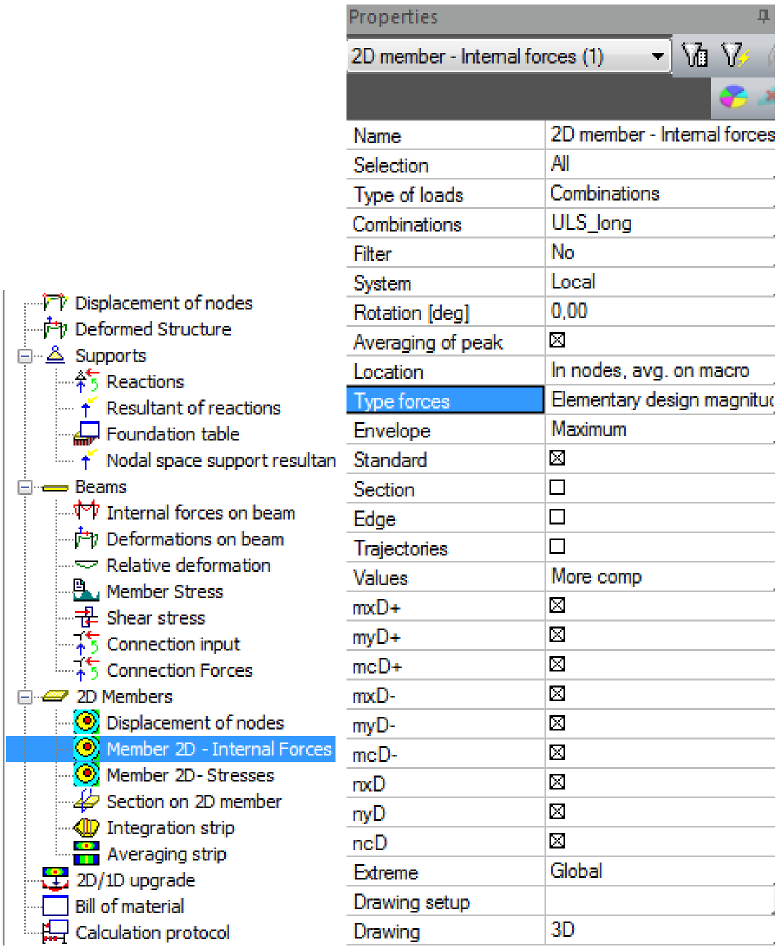


Fig. 37 Elementary design magnitudes - results

Description of the values above:

mxD+, mxD-	Design bending moment in direction x of LSS in lower surface (-) or upper surface (+)
myD+, myD+	Design bending moment in direction y of LSS in lower surface (-) or upper surface (+)
nxD+, nxD-	Design normal force in direction x of LSS in lower surface (-) or upper surface (+)
nyD+, nyD-	Design normal force in direction y of LSS in lower surface (-) or upper surface (+)
mcD+, mcD-	Design bending moment in compressive strut in lower surface (-) or upper surface (+) which have to be carried by concrete
ncD-, ncD+	Design normal force in compressive strut in lower surface (-) or upper surface (+) which have to be carried by concrete

Model	**Output table**
Equivalent load	see below
Real tendon	see below

Model: Equivalent load

2D member - Internal forces

Linear calculation, Extreme : Global
Selection : All
Combinations : ULS_long
Elementary design magnitudes. In nodes, avg. on macro.

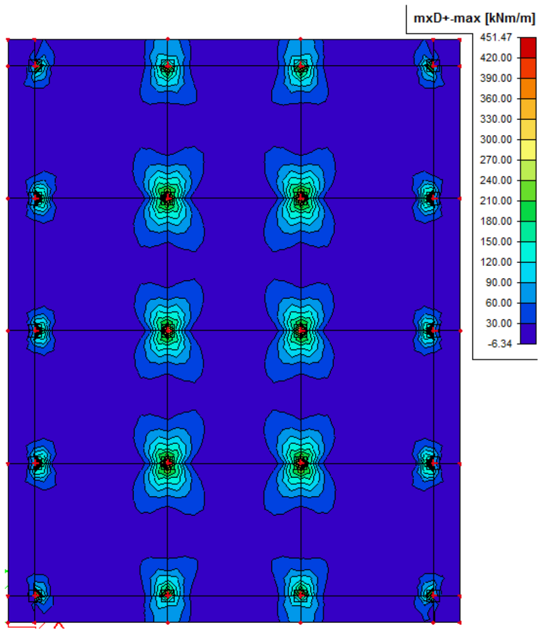
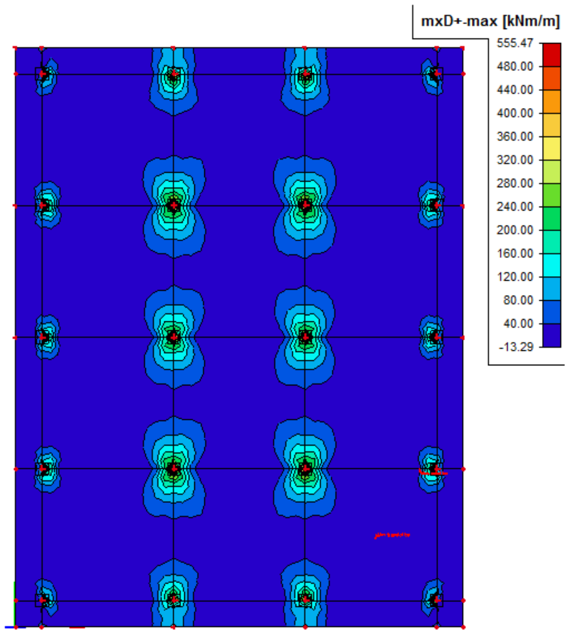
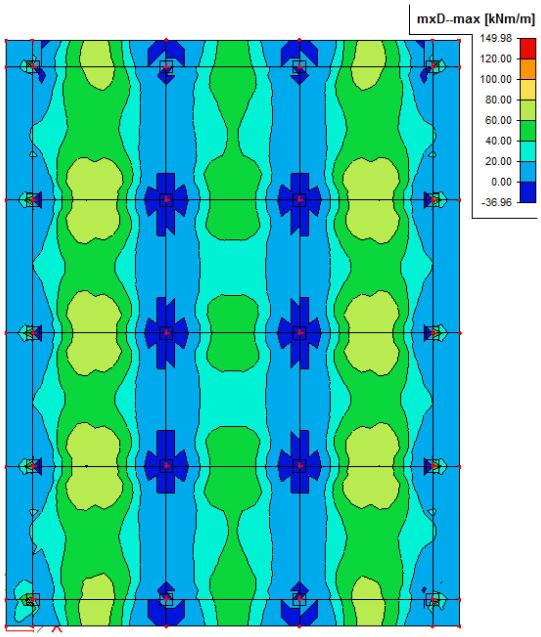
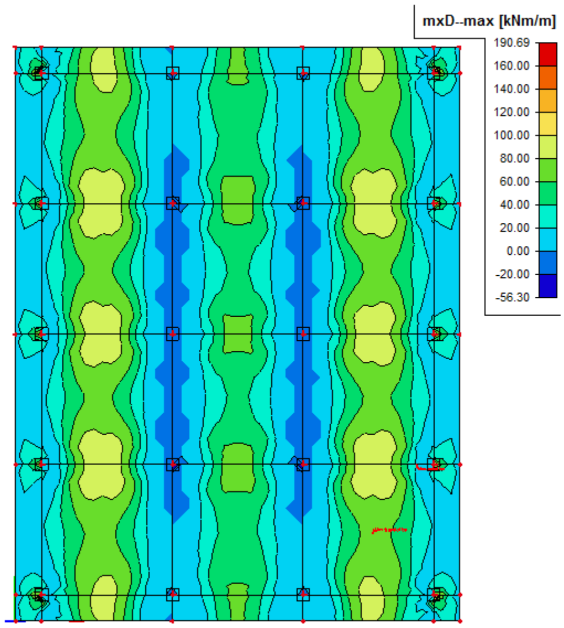
Case	Member	elem	mxD+ [kNm/m]	myD+ [kNm/m]	mcD+ [kNm/m]	mxD- [kNm/m]	myD- [kNm/m]	mcD- [kNm/m]	nxD [kN/m]	nyD [kN/m]	ncD [kN/m]
ULS_long	S134	744	**-49,78**	-49,15	-50,23	3,60	2,73	-2,24	0,00	-545,47	-641,87
ULS_long	S134	873	**451,47**	**448,43**	-34,84	0,00	-40,12	-54,03	0,00	-420,32	-515,27
ULS_long	S126	9	0,00	**-66,26**	-132,78	49,74	45,10	-130,43	0,00	-599,53	-881,71
ULS_long	S134	649	37,96	35,78	**-209,96**	0,00	-207,18	-297,98	0,00	-603,08	-887,23
ULS_long	S134	661	53,43	66,54	**-0,01**	0,52	2,49	-6,49	0,00	-458,22	-515,20
ULS_long	S148	2719	52,96	55,05	-89,27	**-338,03**	0,00	-373,85	0,00	-565,31	-659,32
ULS_long	S126	9	0,00	3,46	-47,16	**149,98**	**143,84**	-18,87	0,00	-444,10	-653,12
ULS_long	S134	873	65,08	63,91	-124,19	0,00	**-376,44**	**-399,28**	0,00	-567,44	-695,61
ULS_long	S142	1789	6,56	1,89	-6,47	17,82	44,11	**0,00**	-381,57	0,00	-435,99
ULS_long	S128	55	13,14	0,66	-17,03	0,00	-3,59	-82,07	**-2104,79**	0,00	-2661,30
ULS_long	S130	147	1,48	1,21	-0,84	5,13	15,98	-1,01	**385,50**	211,79	-275,53
ULS_long	S136	919	0,75	14,30	-17,12	-3,73	0,00	-84,74	0,00	**-2233,49**	-3219,04
ULS_long	S126	1	1,41	3,40	-1,89	18,26	6,74	-1,89	231,13	**320,80**	-288,47
ULS_long	S132	381	3,25	0,79	-13,71	-2,64	0,00	-15,98	0,00	-2079,65	**-3250,91**
ULS_long	S126	1	1,18	1,03	-1,96	5,08	5,28	-1,96	194,28	225,06	**-136,82**

Model: Real tendon

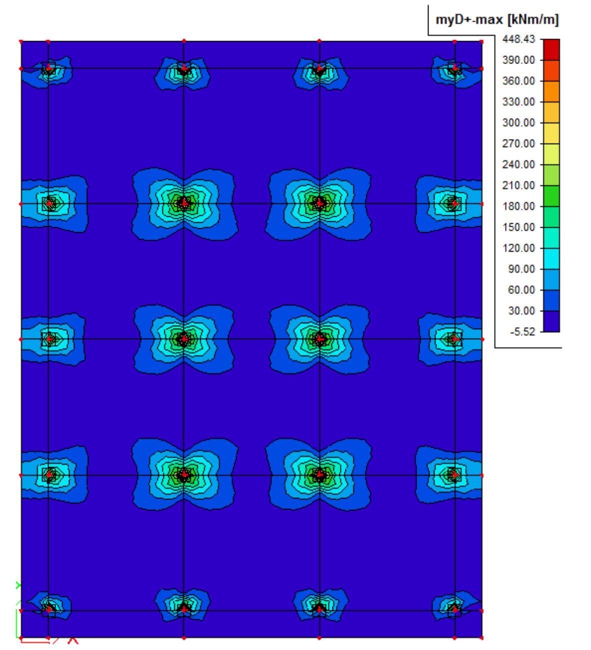
2D member - Internal forces

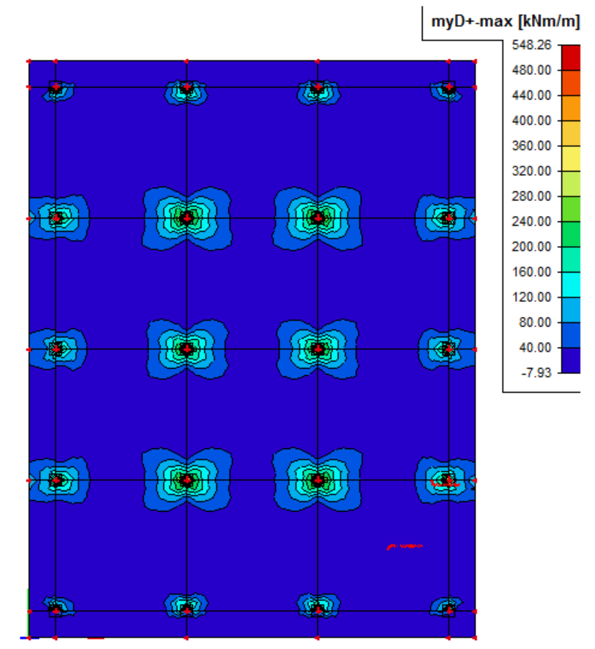
Linear calculation, Extreme : Global
Selection : All
Combinations : ULS_long
Elementary design magnitudes. In nodes, avg. on macro.

Case	Member	elem	mxD+ [kNm/m]	myD+ [kNm/m]	mcD+ [kNm/m]	mxD- [kNm/m]	myD- [kNm/m]	mcD- [kNm/m]	nxD [kN/m]	nyD [kN/m]	ncD [kN/m]
ULS_long	S155	3358	**-146,40**	0,00	-325,45	151,38	154,83	-313,44	0,00	-572,38	-959,48
ULS_long	S134	859	**860,36**	645,69	-109,34	0,00	-25,31	-146,78	0,00	-331,55	-938,13
ULS_long	S134	743	-58,69	**-59,38**	-59,96	7,36	0,00	-3,82	0,00	-572,79	-645,36
ULS_long	S134	663	662,31	**847,06**	-107,68	-37,88	0,00	-135,00	-498,34	0,00	-716,75
ULS_long	S134	649	150,13	128,55	**-506,61**	0,00	-377,42	-643,39	0,00	-555,30	-907,20
ULS_long	S152	3254	4,45	4,58	**-0,02**	20,29	5,75	-2,10	0,00	161,15	-396,05
ULS_long	S137	1188	112,85	116,79	-218,19	**-502,42**	0,00	-565,10	0,00	-583,23	-724,23
ULS_long	S155	3358	-42,76	0,00	-128,47	**361,05**	**363,25**	-83,95	0,00	-476,98	-799,56
ULS_long	S134	873	144,90	139,06	-298,17	0,00	**-558,87**	-636,74	0,00	-604,68	-742,03
ULS_long	S134	859	177,02	104,41	-394,45	0,00	-389,80	**-721,80**	0,00	-397,86	-1125,75
ULS_long	S131	359	0,00	33,45	-13,90	67,32	13,90	**0,00**	0,00	-424,38	-682,63
ULS_long	S153	3312	55,03	6,54	-20,23	0,00	-8,23	-132,94	**-1808,84**	0,00	-5667,82
ULS_long	S155	3366	0,87	1,15	-3,47	7,05	6,73	-3,47	**627,88**	**631,29**	-686,63
ULS_long	S145	2448	2,40	20,56	-19,17	-5,16	0,00	-102,39	0,00	**-1933,03**	-7030,79
ULS_long	S132	381	3,08	3,10	-7,92	-5,26	-2,19	-25,33	0,00	-1784,27	**-7036,04**
ULS_long	S140	1650	4,99	4,03	-3,35	6,69	11,75	-2,34	289,99	0,00	**-124,78**

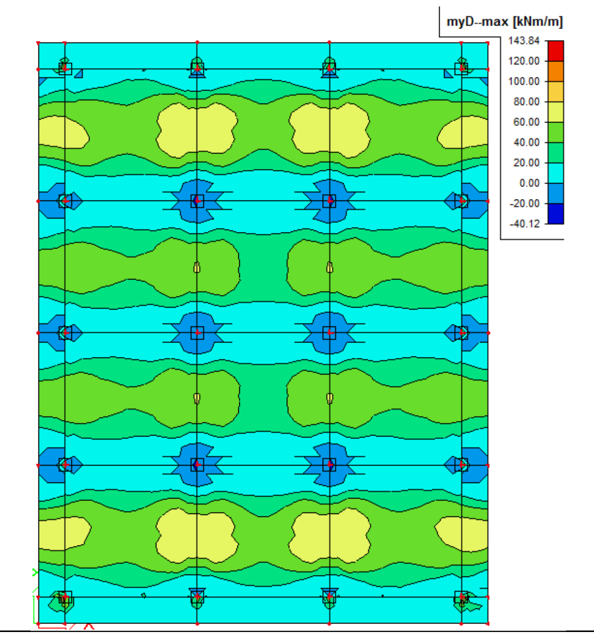
<table>
<tr><th></th><th>Equivalent load</th><th>Real tendon</th></tr>
<tr><td>mxD+</td><td>
</td><td>
</td></tr>
<tr><td>mxD-</td><td>
</td><td>
</td></tr>
</table>

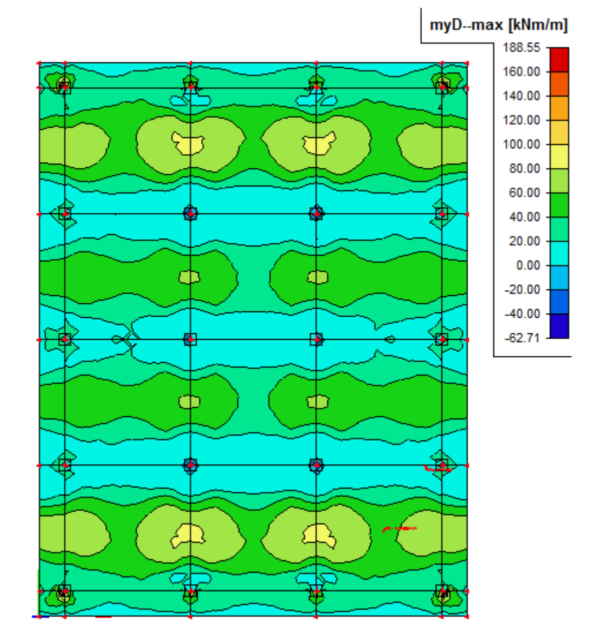
myD+

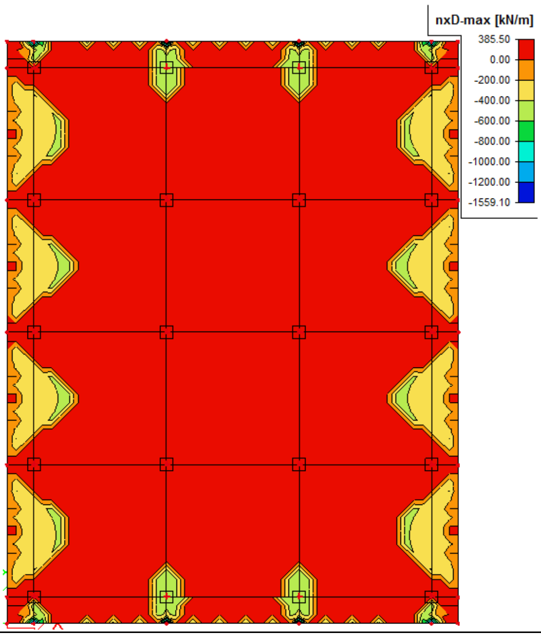
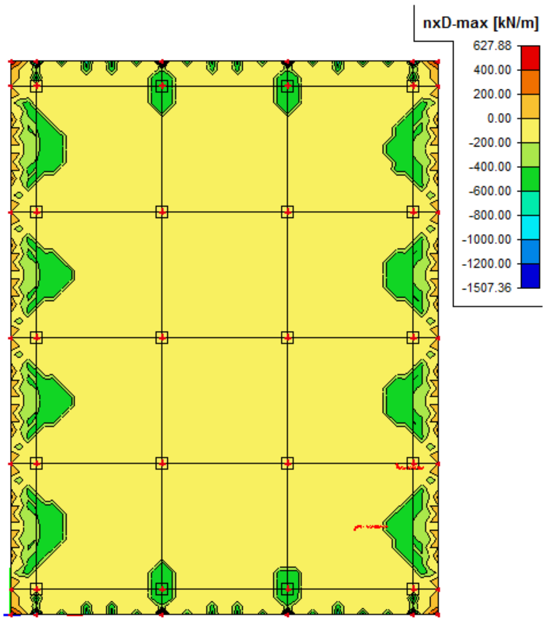
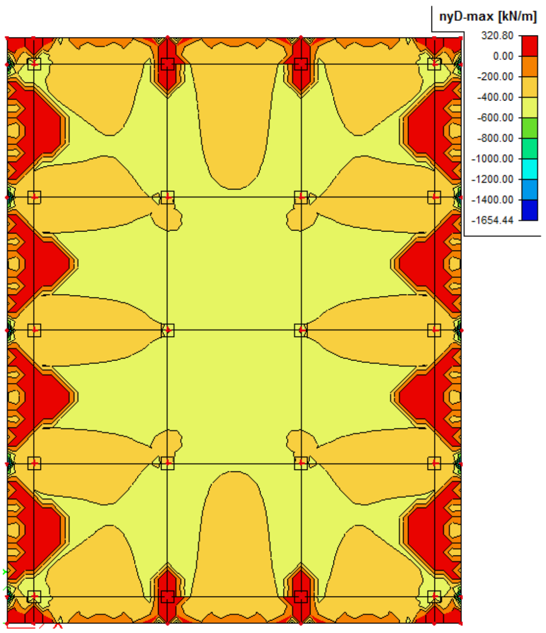
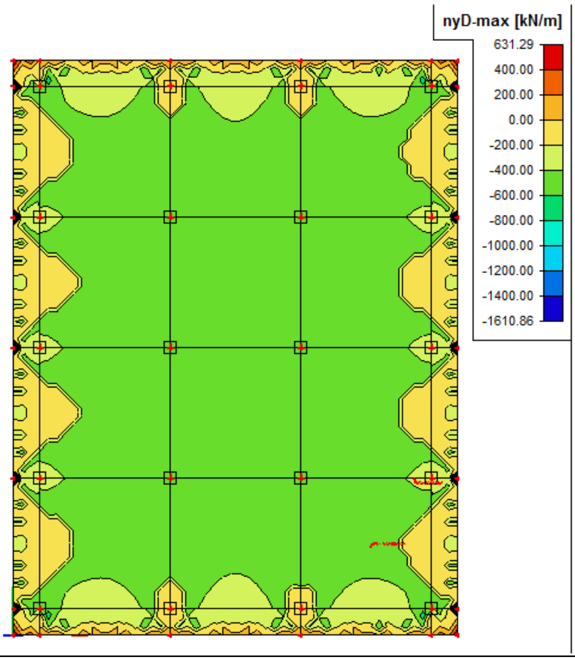

myD+-max [kNm/m]
448.43
390.00
360.00
330.00
300.00
270.00
240.00
210.00
180.00
150.00
120.00
90.00
60.00
30.00
-5.52


myD+-max [kNm/m]
548.26
480.00
440.00
400.00
360.00
320.00
280.00
240.00
200.00
160.00
120.00
80.00
40.00
-7.93

myD-


myD--max [kNm/m]
143.84
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.12


myD--max [kNm/m]
188.55
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-62.71

nxD		
nyD		

6.2 Elementary design magnitudes – concrete

These internal forces are recalculated into direction of reinforcement. Also torsional moment *mxy* and shear effect is taken into account with respect of the settings in the concrete setup (see 6.3)

Again we can compare results from the model where prestressing is modelled using real tendon with model where the equivalent load is used. The structure is type General XYZ (see project data). Only normal design forces (***n1-; n1+; n2-; n2+)*** are available for this type of structure.

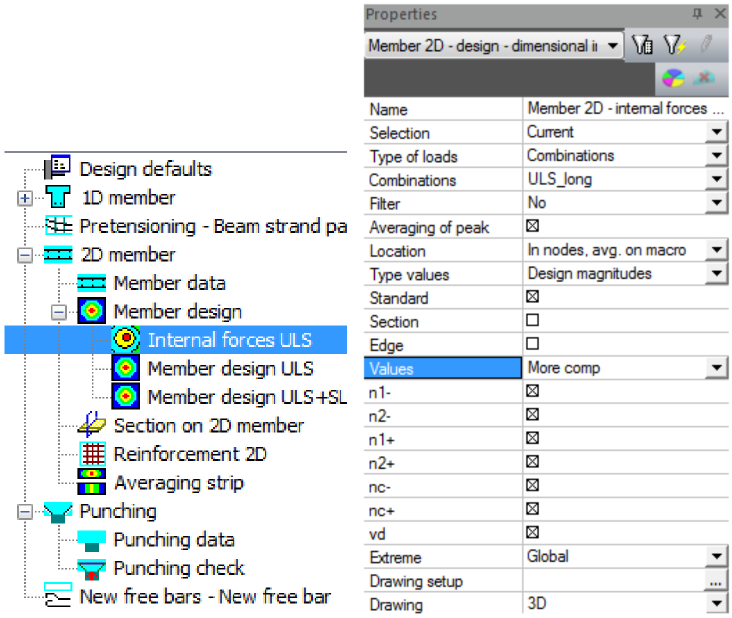


Fig. 38 Elementary design magnitudes – concrete

Description of the values above:

n1-,n2-,n3-,n1+,n2+,n3+ Design normal force in reinforcement direction 1,2 and 3 for lower surface (-) or upper surface (+). These values are used for reinforcement design

nc-, nc+ Design normal force in concrete compression strut for lower surface (-) or upper surface (+), which must be covered by concrete. If the concrete strut is not able to cover this force, design will end up with error message

vd Resultant shear force, which takes effect perpendicular to 2D member plane.

The results mentioned below are evaluated for combination ***ULS_long*** and the have covered the ***shear effect in SR2***.

Model	Output table
Equivalent load	**Member 2D - design - dimensional internal forces** Member 2D - internal forces - basic magnitudes Linear calculation, Extreme : Global Selection : All Combinations : ULS_long

Member	elem	Case	n1- [kN/m]	n2- [kN/m]	nc- [kN/m]	n1+ [kN/m]	n2+ [kN/m]	nc+ [kN/m]	vd [kN/m]
S146	2491	ULS_long	**-1442,07**	-918,16	-330,12	-1377,74	-829,05	-466,26	109,57
S126	9	ULS_long	**675,57**	**765,68**	-953,25	-647,85	-482,96	-312,18	433,17
S134	873	ULS_long	-1365,28	**-1300,88**	-524,19	**2960,83**	**2996,15**	-1714,17	**1030,34**
S132	423	ULS_long	-1421,22	-1215,81	-484,61	**-1419,90**	-847,68	-430,46	84,50
S151	3222	ULS_long	-817,43	-1157,04	-382,33	-785,03	**-1176,59**	-246,24	94,21
S134	844	ULS_long	119,83	522,89	**-1340,47**	646,81	862,66	-590,56	647,62
S133	573	ULS_long	-431,79	-213,55	**-0,67**	-385,14	-489,63	-5,95	68,93
S134	649	ULS_long	-830,99	-700,44	-324,01	2433,96	2525,80	**-2229,82**	945,86
S142	1948	ULS_long	-289,57	-384,89	-7,87	-550,46	-290,76	**-2,58**	65,31
S149	3056	ULS_long	-304,40	-246,70	-15,37	-573,41	-511,17	-15,60	**1,62**

Real tendon

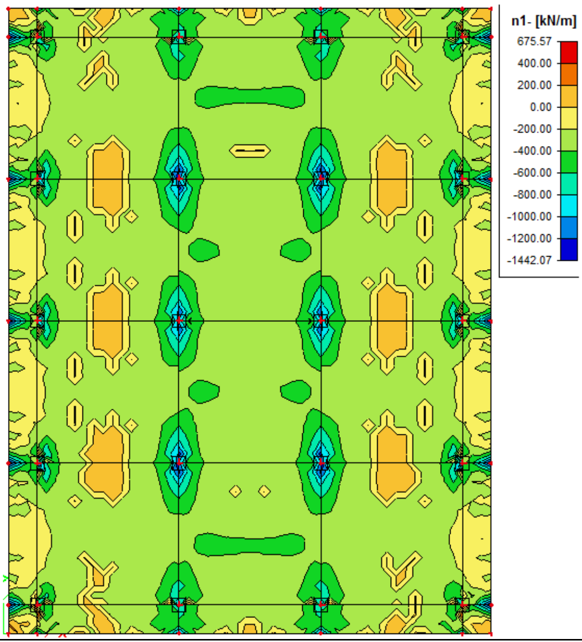
Member 2D - design - dimensional internal forces

Member 2D - internal forces - basic magnitudes
Linear calculation, Extreme : Global
Selection : All
Combinations : ULS_long

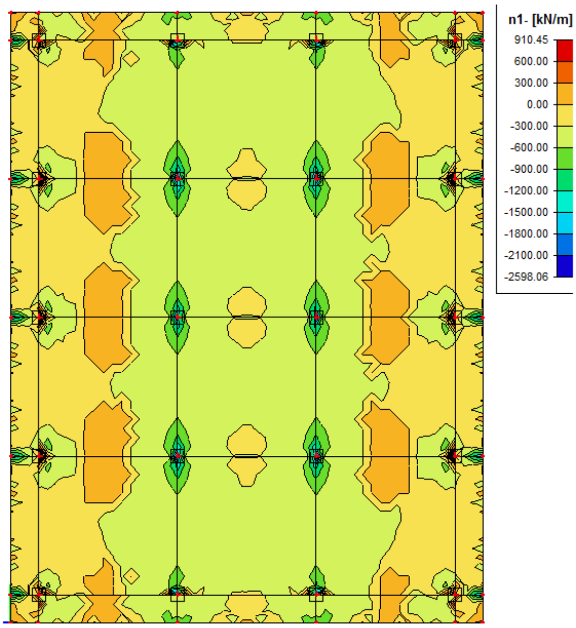
Member	elem	Case	n1- [kN/m]	n2- [kN/m]	nc- [kN/m]	n1+ [kN/m]	n2+ [kN/m]	nc+ [kN/m]	vd [kN/m]
S134	873	ULS_long	**-2598,06**	**-2502,02**	-757,46	2734,28	2751,29	-943,19	**1439,43**
S151	3216	ULS_long	**910,45**	1025,14	-1148,41	-608,17	-448,13	-419,78	424,63
S155	3358	ULS_long	900,70	**1035,22**	-1150,07	-627,29	-445,29	-421,41	425,55
S150	3212	ULS_long	-1270,81	157,54	-271,21	**-1448,54**	4,59	-357,52	62,87
S142	1953	ULS_long	-2036,91	-1833,52	-447,40	**3290,39**	3092,33	-1485,30	1296,99
S154	3342	ULS_long	-199,64	-956,48	-145,79	-228,17	**-1213,87**	-260,58	83,87
S133	648	ULS_long	-1795,78	-1804,02	-523,86	2993,32	**3286,56**	-1485,20	1270,30
S140	1641	ULS_long	-1432,46	-624,27	**-2855,01**	-1263,89	81,87	-2960,35	179,68
S131	368	ULS_long	-325,72	-400,58	**-0,36**	-595,92	-330,67	-7,76	68,59
S150	3171	ULS_long	-1445,62	-719,02	-2845,47	-1250,99	176,61	**-2976,13**	183,58
S142	1732	ULS_long	-332,43	-330,49	-2,94	-597,25	-343,12	**-0,40**	53,66
S137	1075	ULS_long	-290,89	-340,54	-6,23	-535,69	-422,86	-4,67	**2,84**

n1-

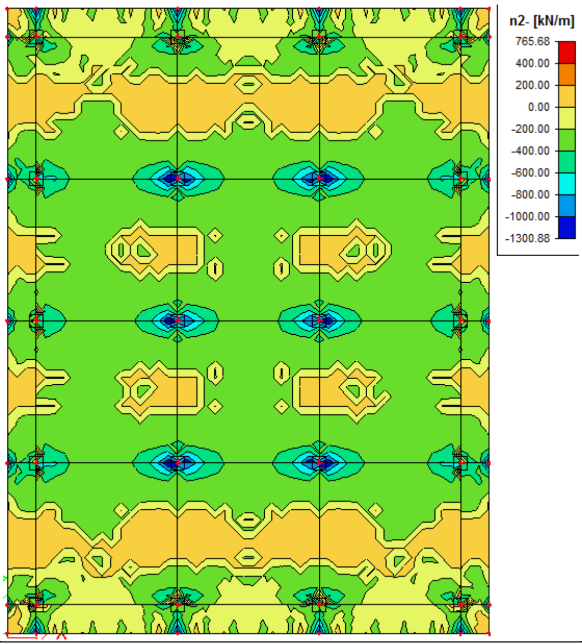
Equivalent load

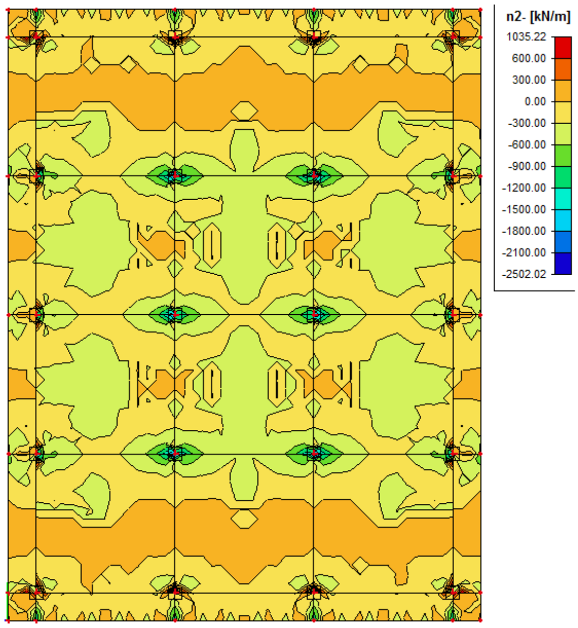


Real tendon

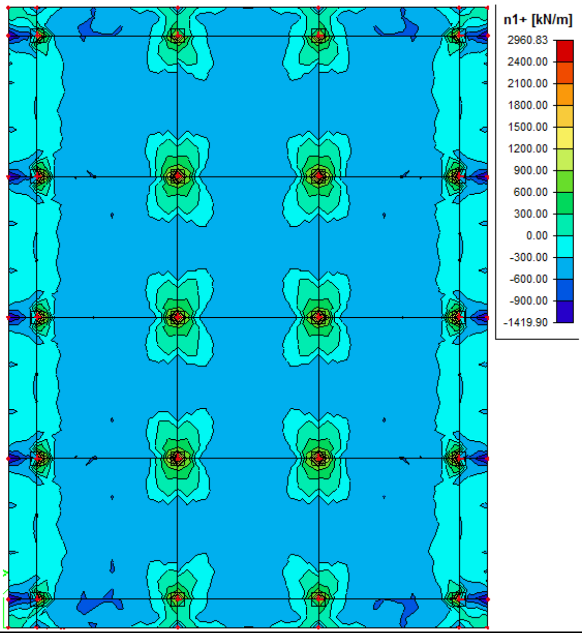


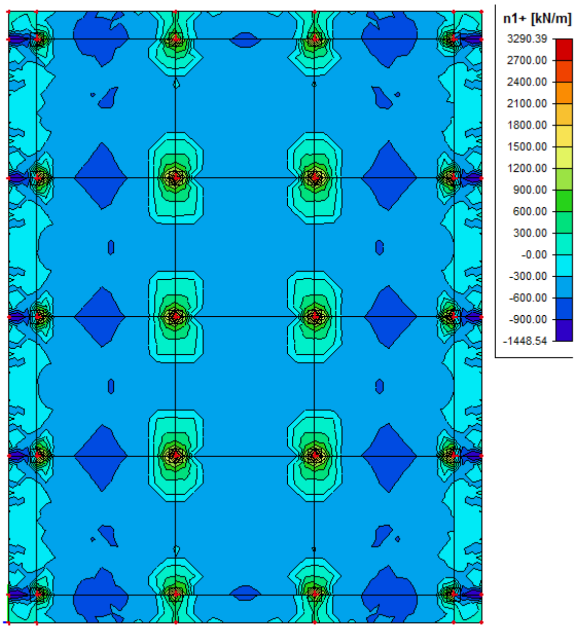
n2-


n2- [kN/m]
765.68
400.00
200.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1300.88

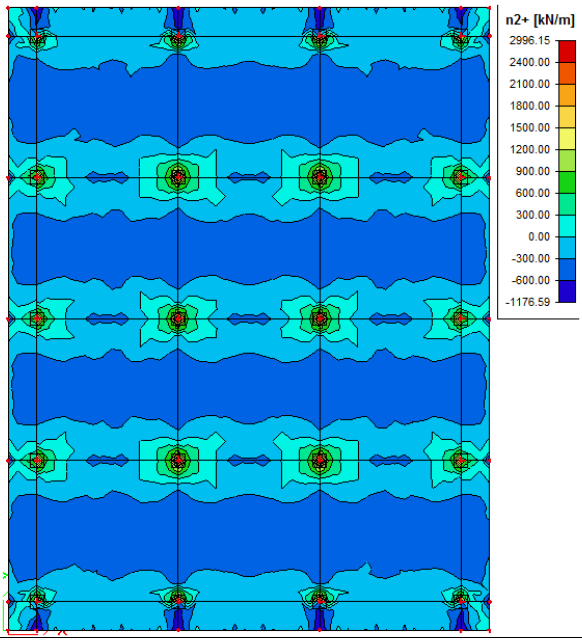

n2- [kN/m]
1035.22
600.00
300.00
0.00
-300.00
-600.00
-900.00
-1200.00
-1500.00
-1800.00
-2100.00
-2502.02

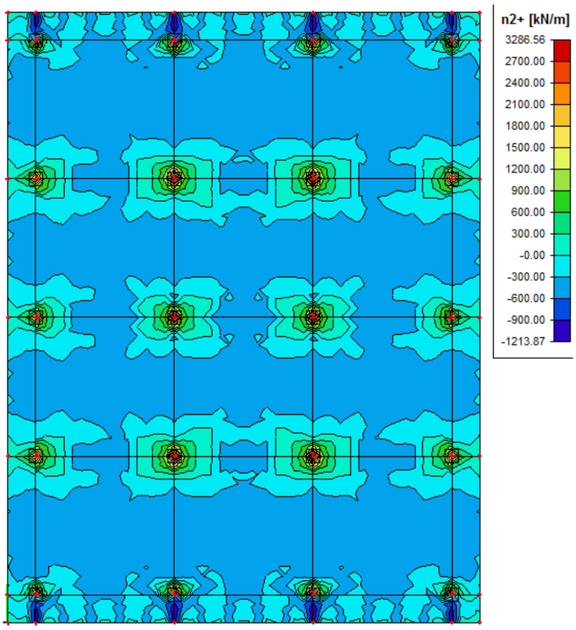
n1+


n1+ [kN/m]
2960.83
2400.00
2100.00
1800.00
1500.00
1200.00
900.00
600.00
300.00
0.00
-300.00
-600.00
-900.00
-1419.90

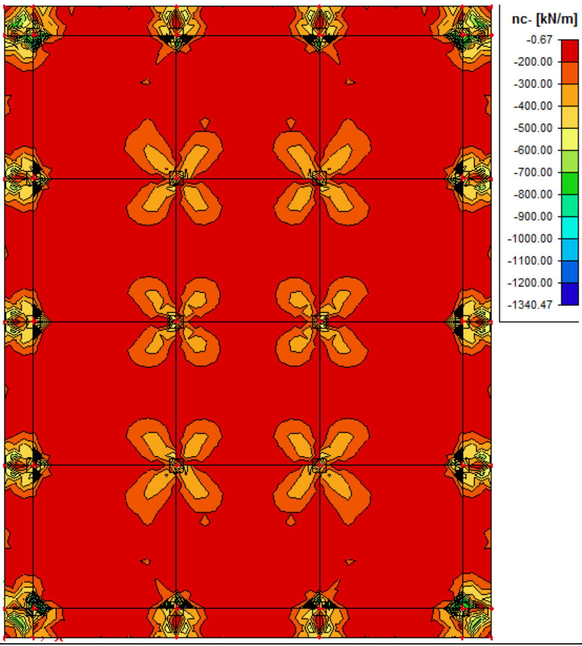

n1+ [kN/m]
3290.39
2700.00
2400.00
2100.00
1800.00
1500.00
1200.00
900.00
600.00
300.00
-0.00
-300.00
-600.00
-900.00
-1448.54

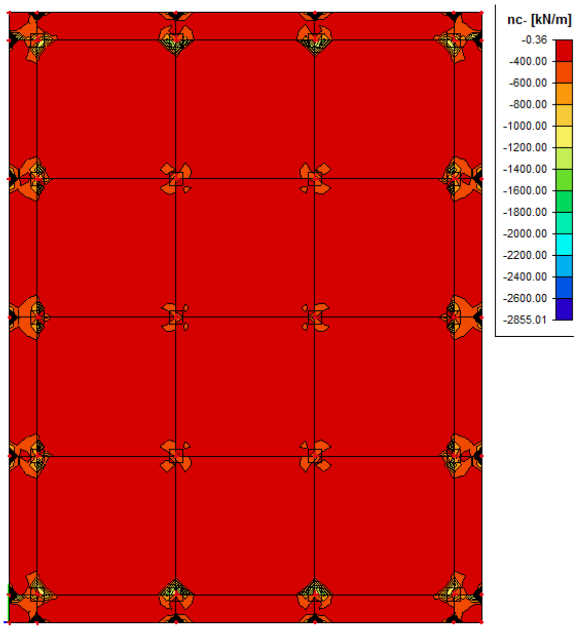
n2+


n2+ [kN/m]
2996.15
2400.00
2100.00
1800.00
1500.00
1200.00
900.00
600.00
300.00
0.00
-300.00
-600.00
-1176.59

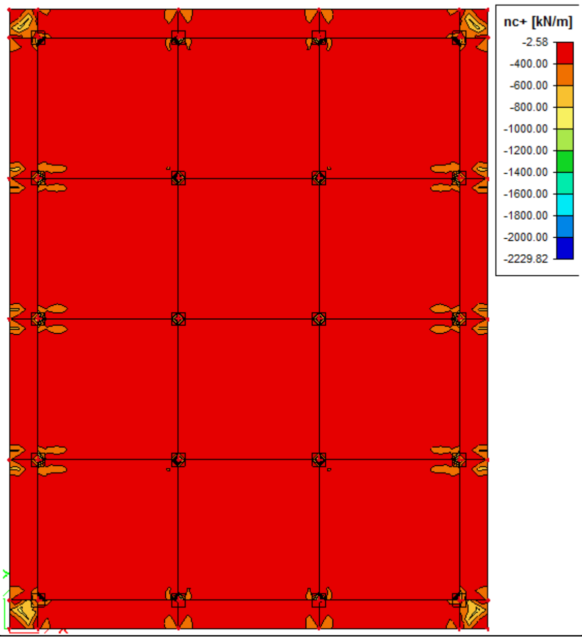

n2+ [kN/m]
3286.56
2700.00
2400.00
2100.00
1800.00
1500.00
1200.00
900.00
600.00
300.00
-0.00
-300.00
-600.00
-900.00
-1213.87

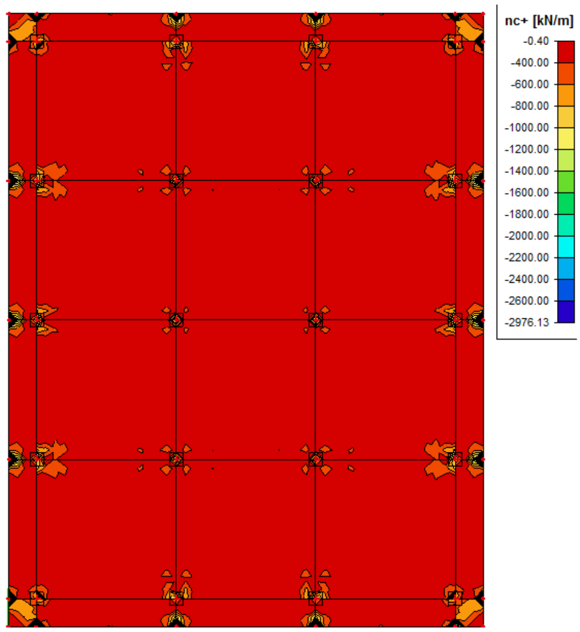
nc-


nc- [kN/m]
-0.67
-200.00
-300.00
-400.00
-500.00
-600.00
-700.00
-800.00
-900.00
-1000.00
-1100.00
-1200.00
-1340.47

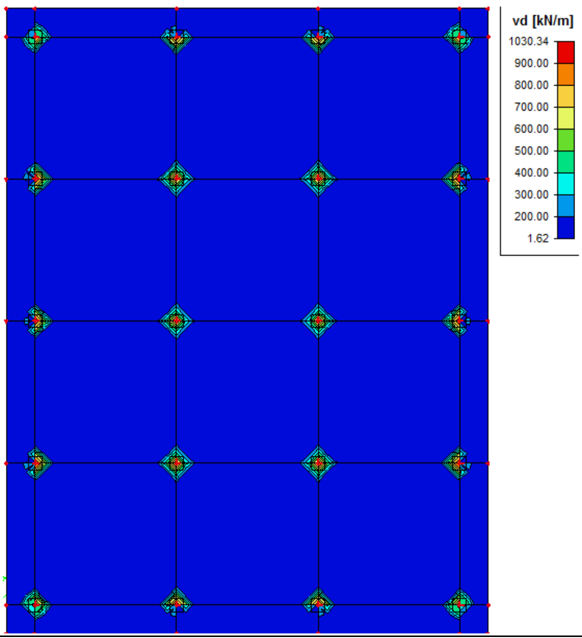

nc- [kN/m]
-0.36
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
-1600.00
-1800.00
-2000.00
-2200.00
-2400.00
-2600.00
-2855.01

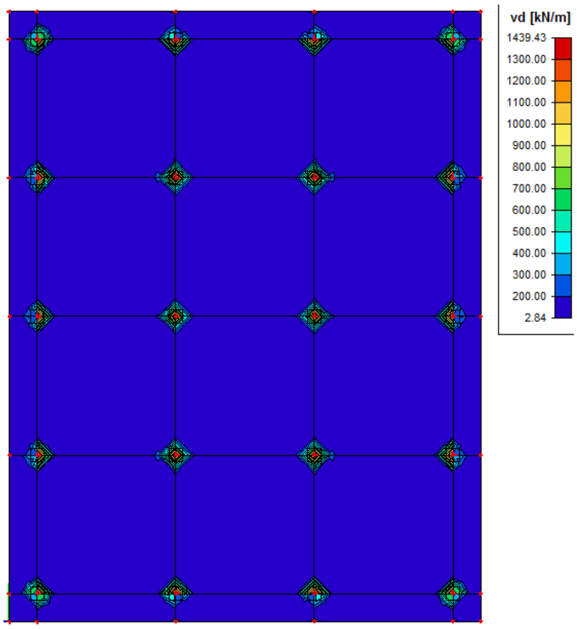
nc+


nc+ [kN/m]
-2.58
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
-1600.00
-1800.00
-2000.00
-2229.82


nc+ [kN/m]
-0.40
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
-1600.00
-1800.00
-2000.00
-2200.00
-2400.00
-2600.00
-2976.13

vd

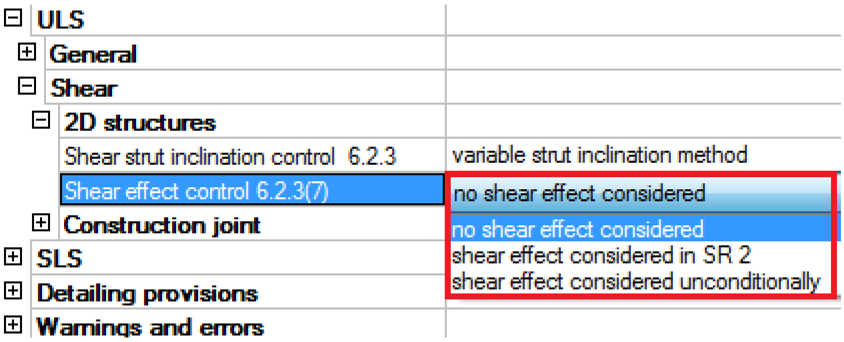

vd [kN/m]
1030.34
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
1.62


vd [kN/m]
1439.43
1300.00
1200.00
1100.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
2.84

6.3 Shear effect during design of reinforcement

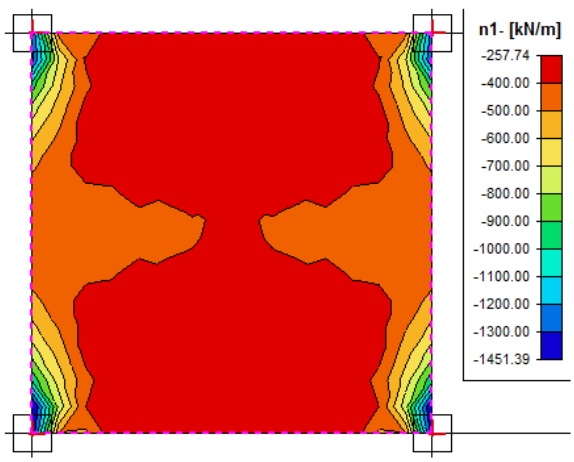
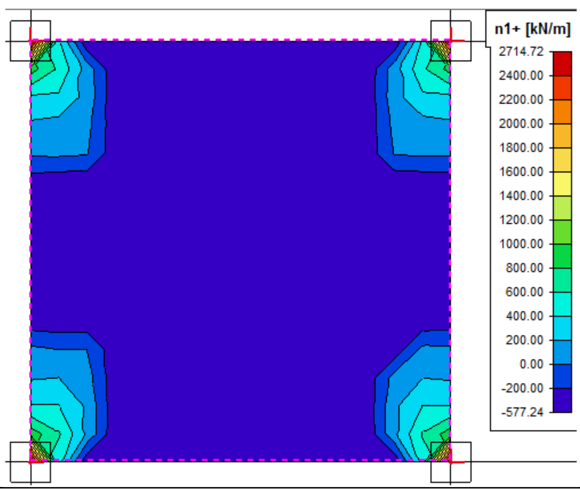
As mentioned above, dimensional magnitudes are recalculated into reinforcement directions, moreover in these values is torsion moment *mxy* also taken into account. It is also possible to calculate with influence of tension force caused by shear stress. This can be set in Concrete setup dialog with attribute Shear effect control ***6.2.3(7),*** under ***Concrete > ULS > Shear > 2D structures***. This attribute is possible to set three ways:

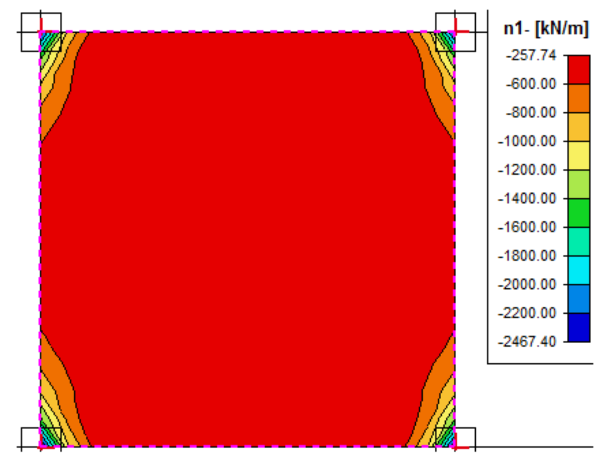
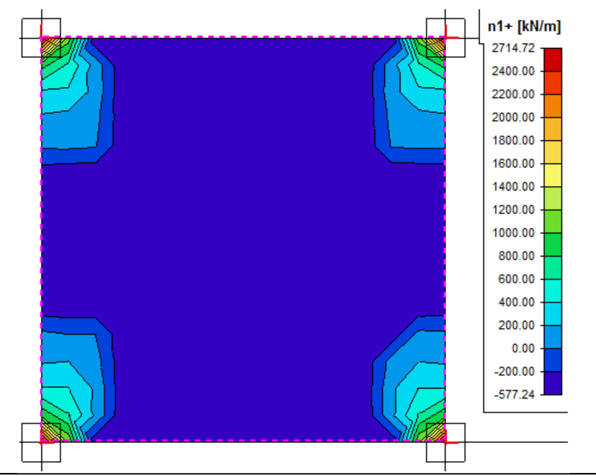
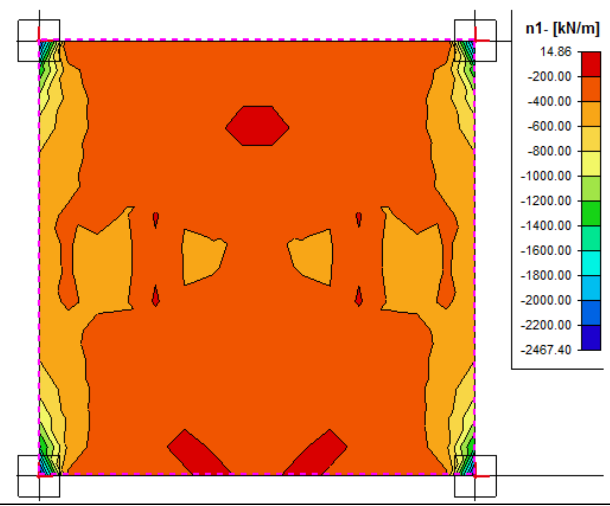
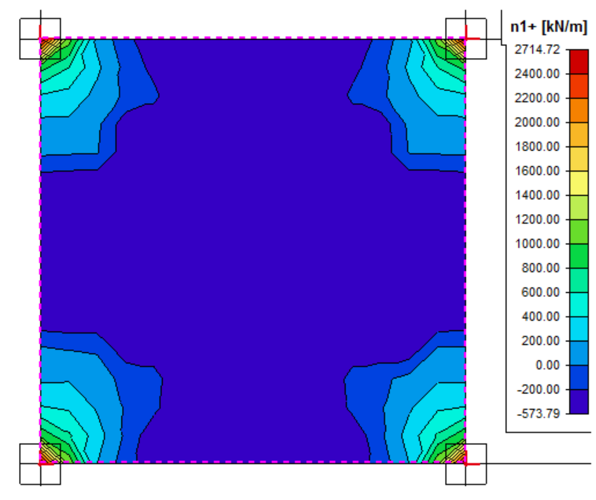
- **No shear effect considered** (tension force from shear stress will not be considered in design forces calculation)
- **Shear effect considered in SR2** (tension force from shear stress will be considered in design forces calculation only on elements, where shear force is not covered by concrete capacity, i.e. on elements, where shear reinforcement is needed)
- **Shear effect considered unconditionally** (tension force from shear stress will be considered in design forces calculation on all elements, nevertheless the shear reinforcement is, or is not needed)



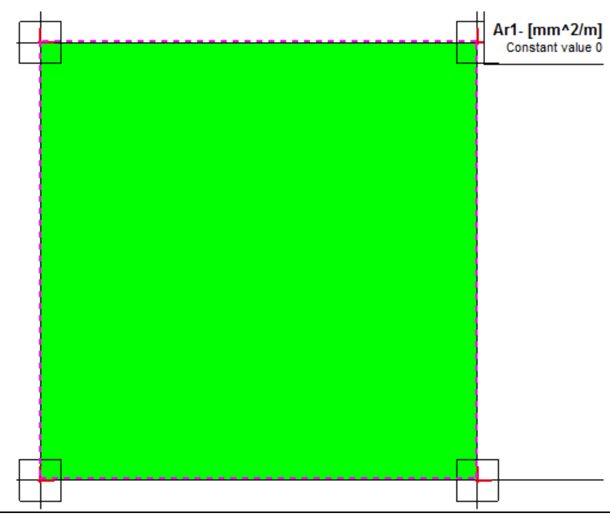
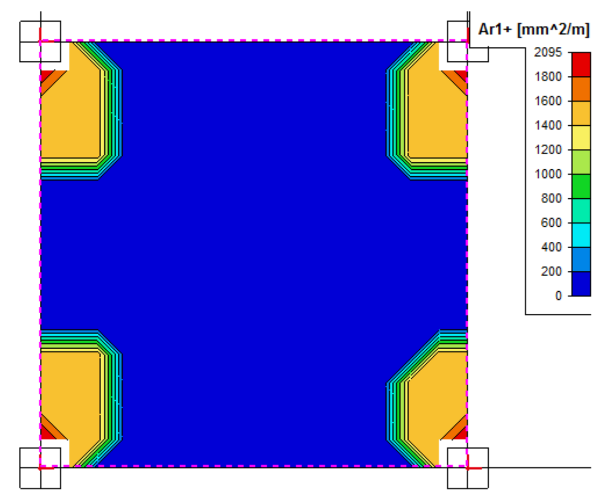
The recommended option is taking into account shear effect only in SR2.

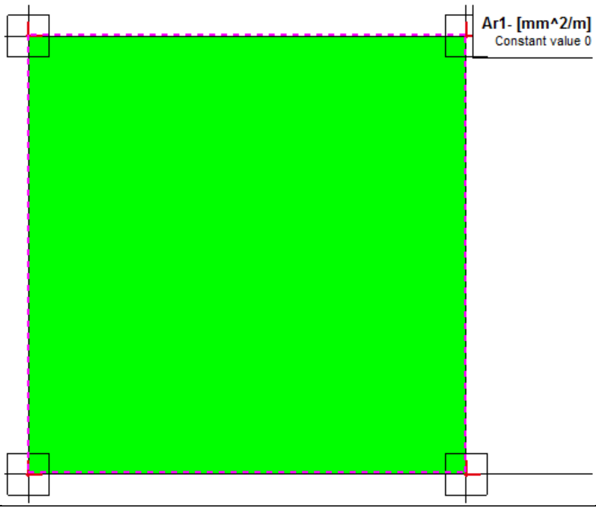
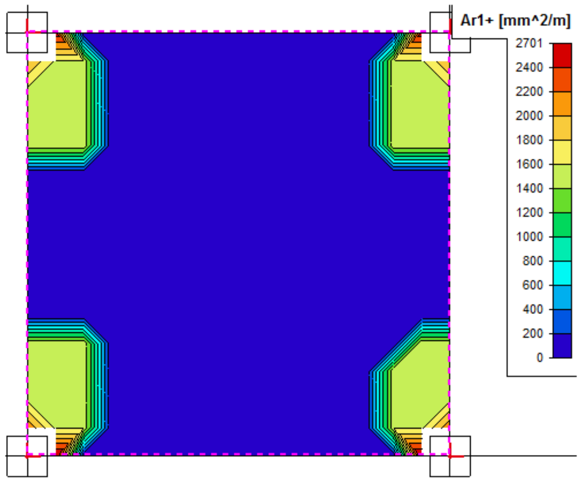
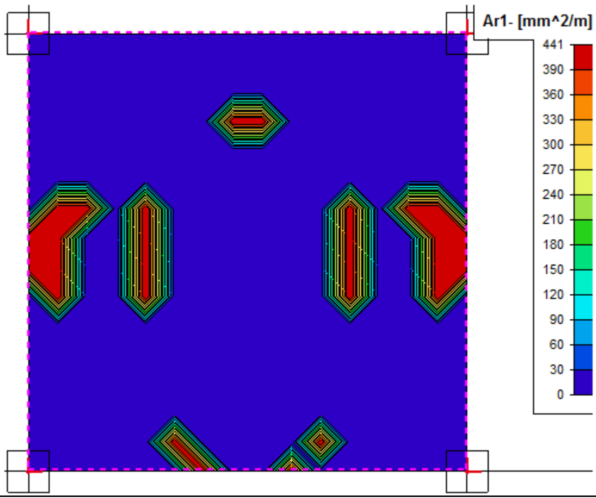
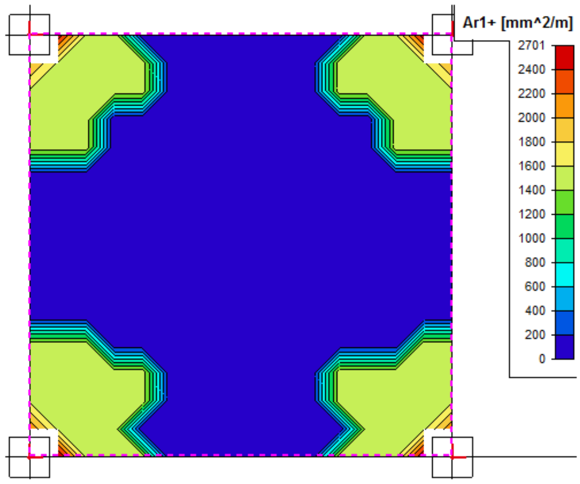
The comparison of the results for ***Elementary design forces*** and ***Design ULS+SLS*** on shear effect is performed for model with real tendon and only for slab S138 in the following two tables.

Type	n1-	n1+
No shear effect		

Shear effect in SR2		
Shear effect unconditionally		

From the table above is clear the shear effect has main influence only on design magnitudes for design of the lower reinforcement.

Type	Ar1-	Ar1+
No shear effect		

Shear effect in SR2		
Shear effect uncon dition ally		

7 Design of nonprestressed reinforcement

7.1 Concrete 2D data

The user overwrites default global settings with local settings defined for selected members by creating member data. Simply said, where user doesn't want use global concrete settings, user creates local concrete settings by defining member data. We recognize two types of these local settings for 2D concrete members

- **Member data**
- **Punching data** (more in chapter 8.1)

These member data may be created by selecting these two items in ***Concrete tree*** and choosing the proper 2D member, where this data want to be defined. These newly created settings will be loaded from default global settings and are possible to be changed to fit user needs.

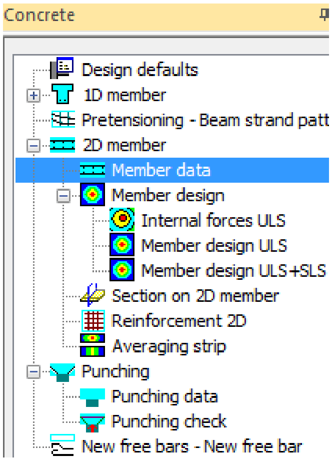


Fig. 39 Concrete tress with concrete member data

Concrete member data for slab S138 can look as following

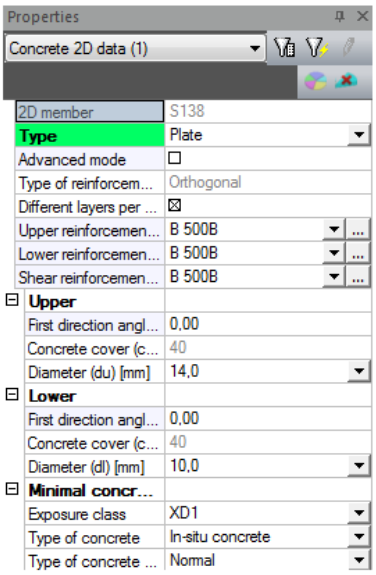


Fig. 40 Concrete member data for slab S138

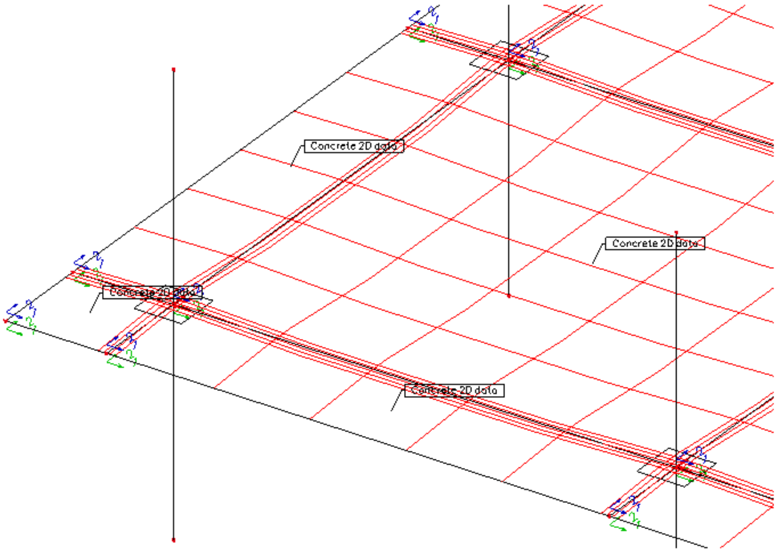


Fig. 41 Concrete member data in 3D window

7.2 User reinforcement

Effects of prestressing is taken into account automatically only partially for design of non-prestressed reinforcement in 2D members in version Scia Engineer 2011.
Internal forces are taken automatically into design but area of prestressing reinforcement is not taken automatically. This causes another workaround how to take amount of prestressing reinforcement into account for design or other checks.
Real postensioned tendon is possible to substitute by the nonprestressed reinforcement which is inputted as **Freebars**. The Freebars are possible to input from **Concrete > Freebars**. The geometry of the freebars will be the same as geometry of the postensioned tendon.

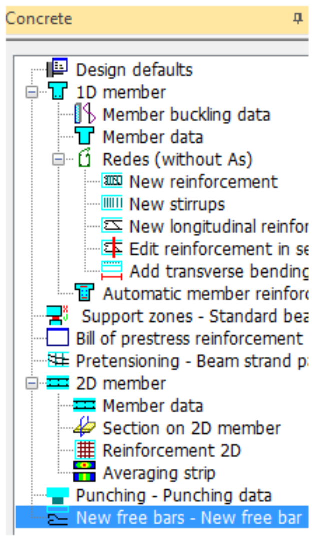


Fig. 42 Freebars in Concrete tree

Material of these freebars has to be also modified. We create completely new material based on the nonprestressed material and modified E modulus to 195GPa and tendon stresses.

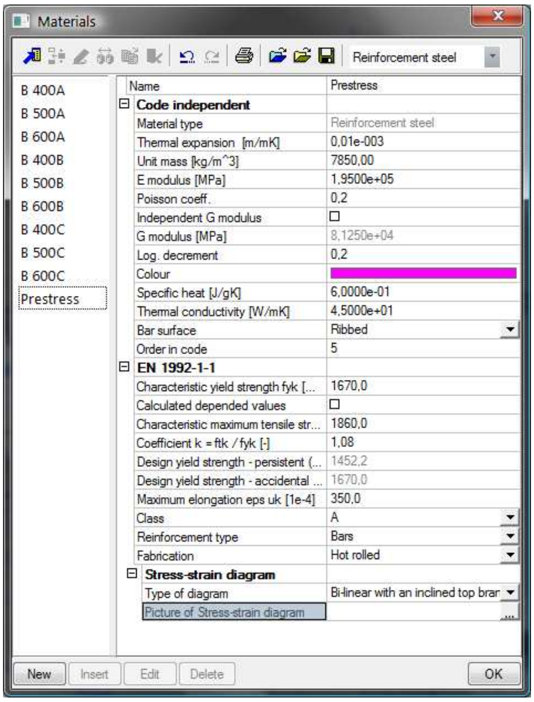


Fig. 43 Fictive prestressing material

The diameter of the fictive bar is calculated from the area of the strands. We suppose the 3strands in one tendon.

$$A_p = 3 \cdot A_{p1} = 3 \cdot 150 = 450mm^2$$

$$d = \sqrt{\frac{4 \cdot A_p}{\pi}} = \sqrt{\frac{4 \cdot 450}{\pi}} = 23{,}96mm$$

We can display the amount of user defined reinforcement (freebars representing the tendons) in services **Design ULS** or **Design ULS+SLS**. In the following table you can see the results for user reinforcement.

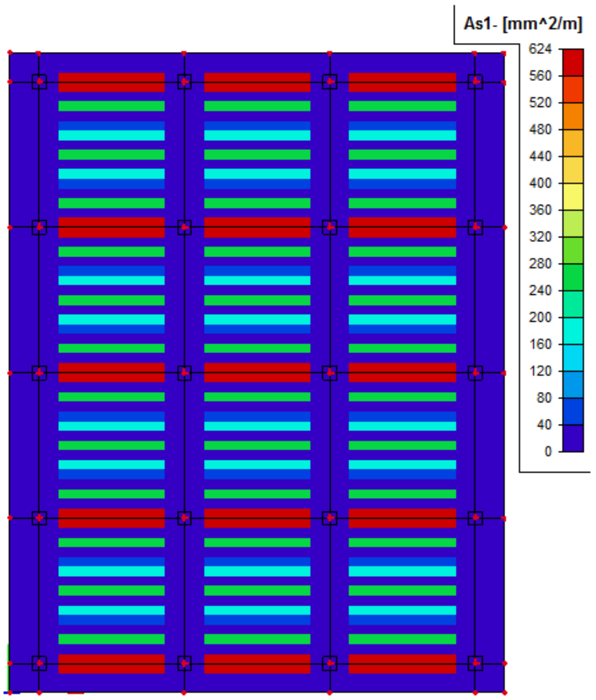
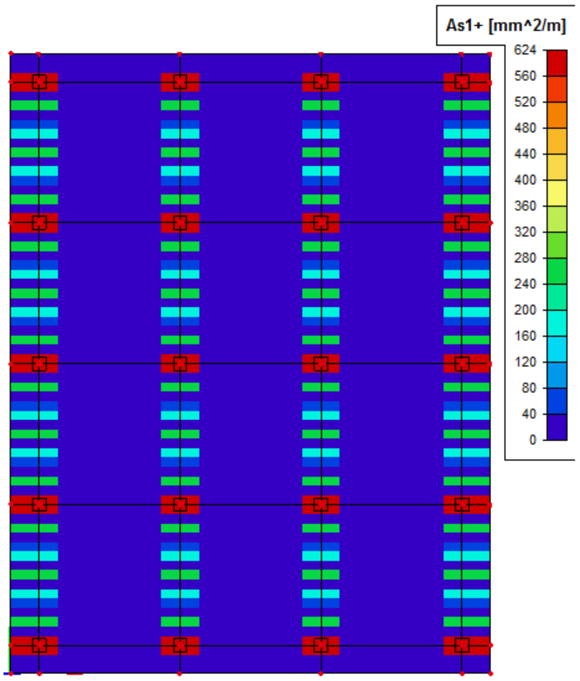
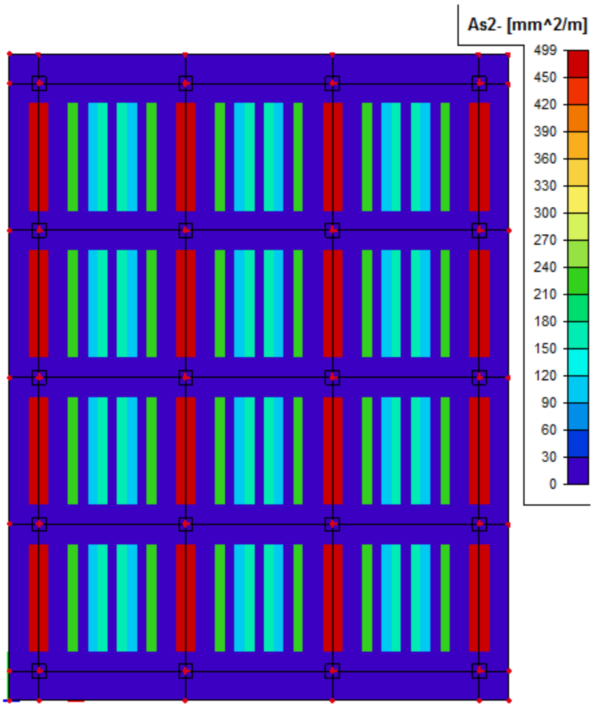
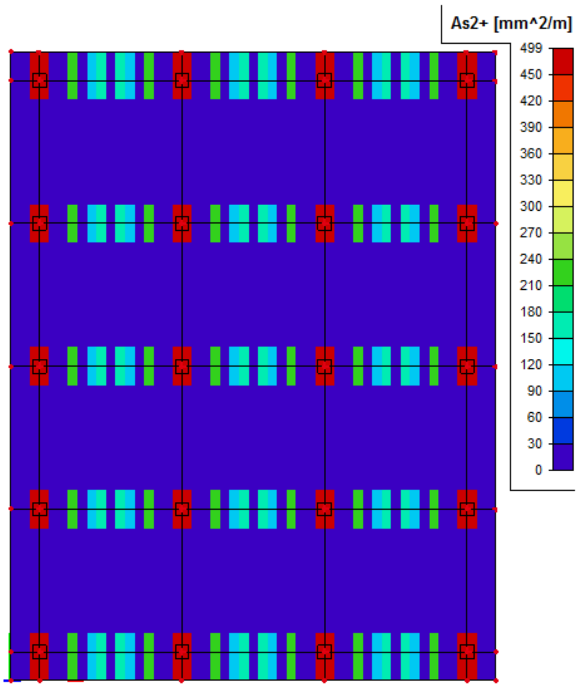
Note

- This amount can be displayed only if we have the same material of user defined reinforcement with material of designed reinforcement. That why it is necessary to switch material of freebars to B500B.
- The different colors of strips in the span line are caused
- Value **Asw** is of course equal to zero because no shear user reinforcement is defined in this moment

Member 2D - check cracks - required areas

Linear calculation, Extreme : Global
Selection : All
Class : ULS+SLS
User reinforcement
Necessary area for selected 2D member

Member	elem	Case	A_{r1-} [mm^2/m]	A_{r2-} [mm^2/m]	A_{r1+} [mm^2/m]	A_{r2+} [mm^2/m]	A_{sw} [mm^2/m^2]
S127	42	ULS+SLS	**624**	0	0	25	0
S131	184	ULS+SLS	0	**499**	250	0	0
S126	1	ULS+SLS	0	0	0	0	0
S126	7	ULS+SLS	0	0	**624**	0	0
S126	3	ULS+SLS	0	0	0	**499**	0
S131	154	ULS+SLS	0	0	624	499	**0**

Type of output	Lower (-)	Upper (+)
As1		
As2		

7.3 Design of necessary area of non-prestressed reinforcement

7.3.1 Design ULS

Design of necessary area of nonprestressed reinforcement is done in **Concrete > 2D member > Member design > Member design ULS**. The theory of the design is explained in details in [5] and **Chyba! Nenalezen zdroj odkazů.**.

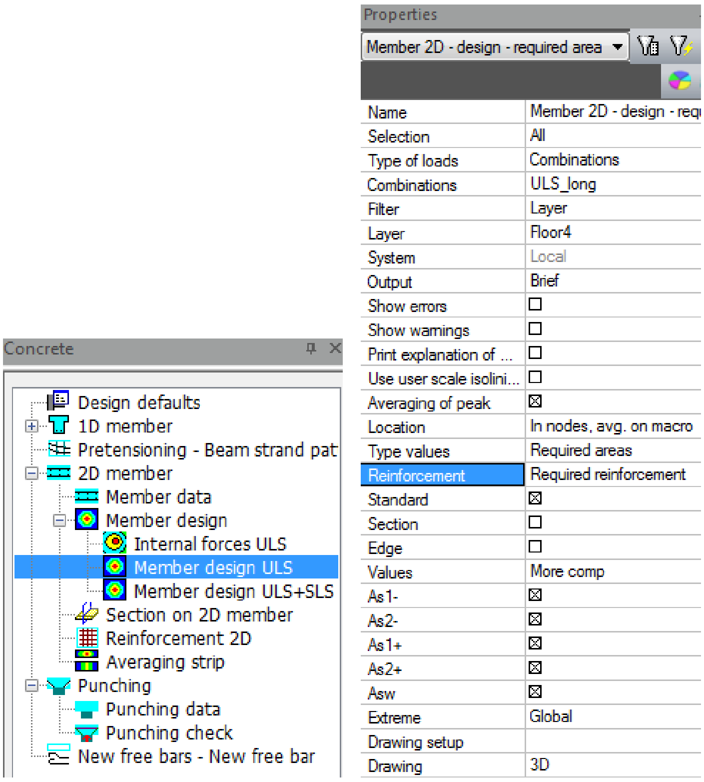


Fig. 44 Design ULS in the tree

Before design procedure starts we recommend checking the setting for detailing provisions of 2D structures in ***Concrete setup > detailing provisions >2D structures and slabs.***

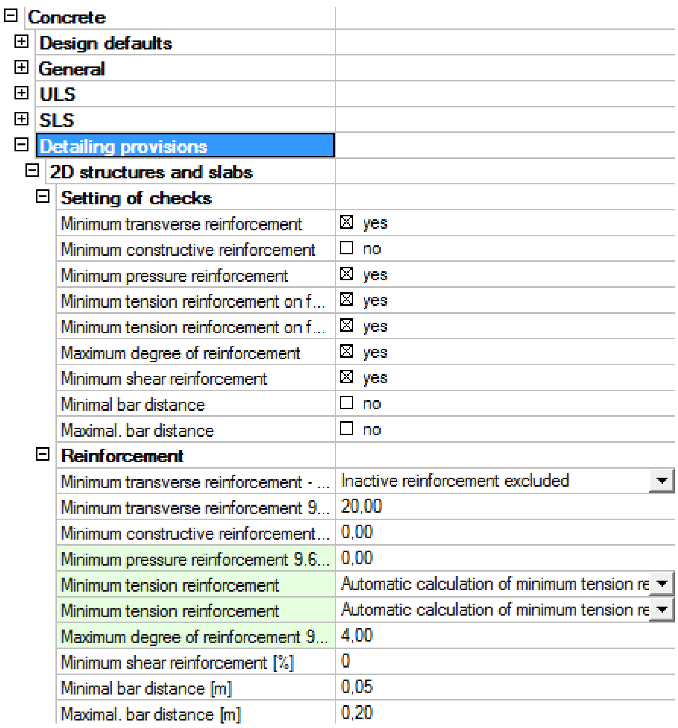
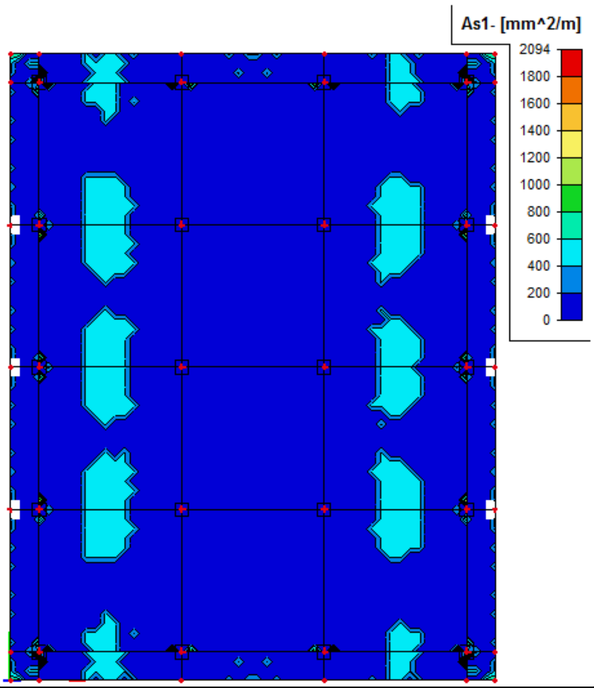
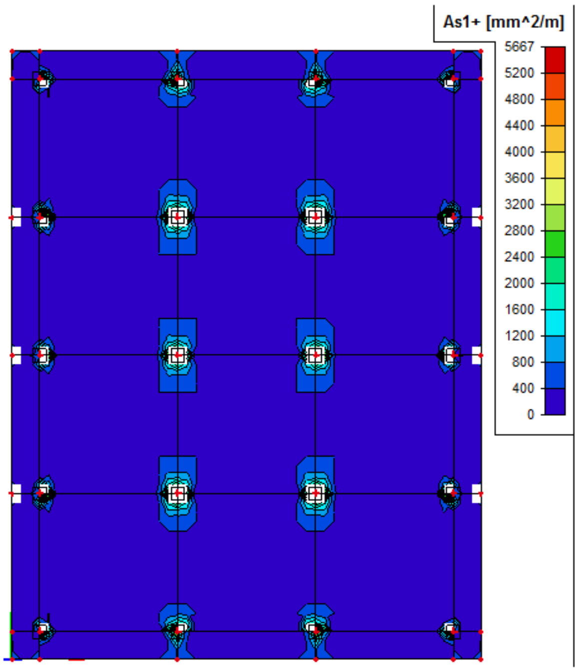
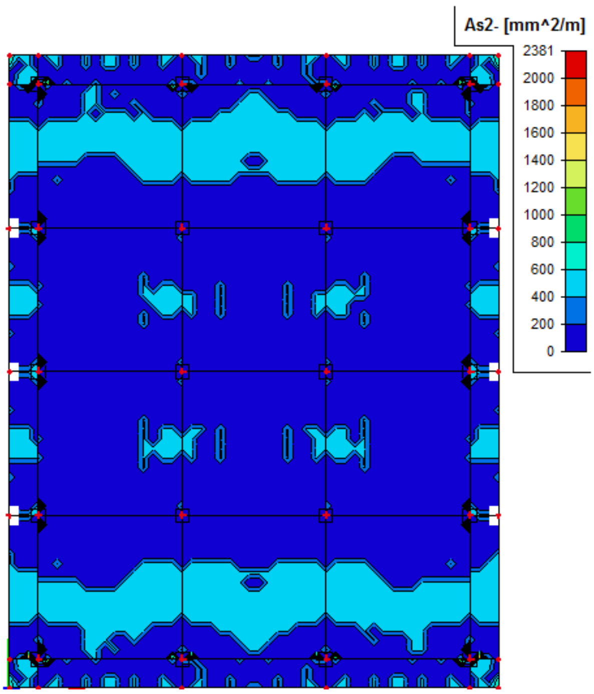
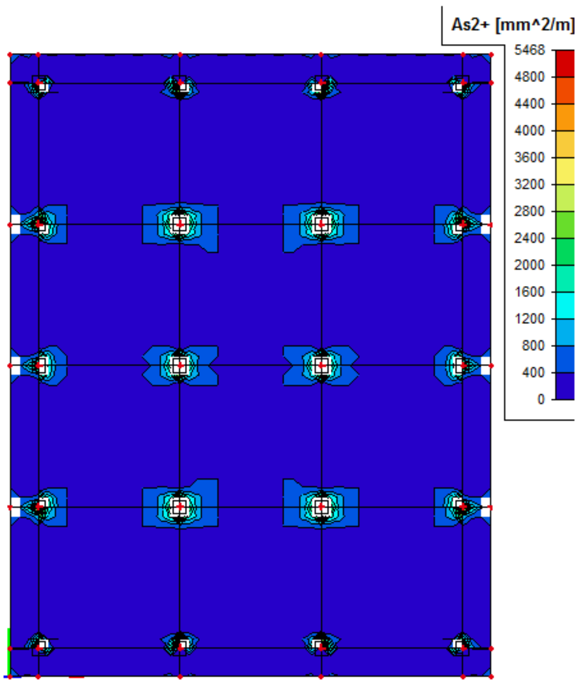


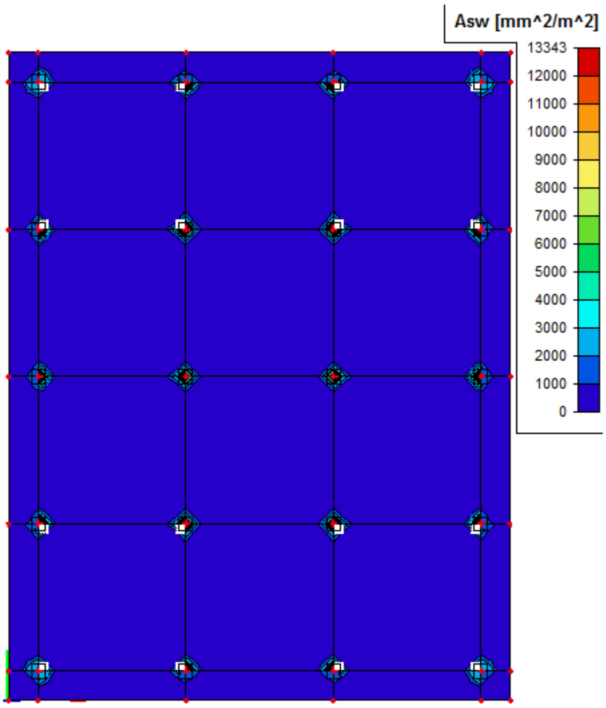
Fig. 45 Detailing provisions for 2D in concrete setup

We can split design reinforcement into five groups:

As1-	necessary area of lower reinforcement in the direction 1
As1+	necessary area of upper reinforcement in the direction 1
As2-	necessary area of lower reinforcement in the direction 2
As2+	necessary area of upper reinforcement in the direction 2
Asw	necessary area of shear reinforcement

In our case there is certain amount of postensioned tendons reinforcement. So we could design only **Additional reinforcement** which is needed to add to the current reinforcement, but due to problem mentioned in note of chapter 7.1 (different materials) we have to calculated **Required reinforcement** and these amount decrease by the user reinforcement. This is procedure how we can get the additional amount o reinforcement. The results mentioned below are evaluated for real tendon structure for combination ***ULS_long*** and they have covered the ***shear effect in SR2***.

Type of output	Lower (-)	Upper (+)
As1		
As2		

Asw	Asw [mm^2/m^2] 13343 12000 11000 10000 9000 8000 7000 6000 5000 4000 3000 2000 1000 0

7.3.2 Design ULS+SLS

Design of necessary area of nonprestressed reinforcement is done in **Concrete > 2D member > Member design > Member design ULS+SLS**. The theory of the design is explained in details in [5] and **Chyba! Nenalezen zdroj odkazů.**.

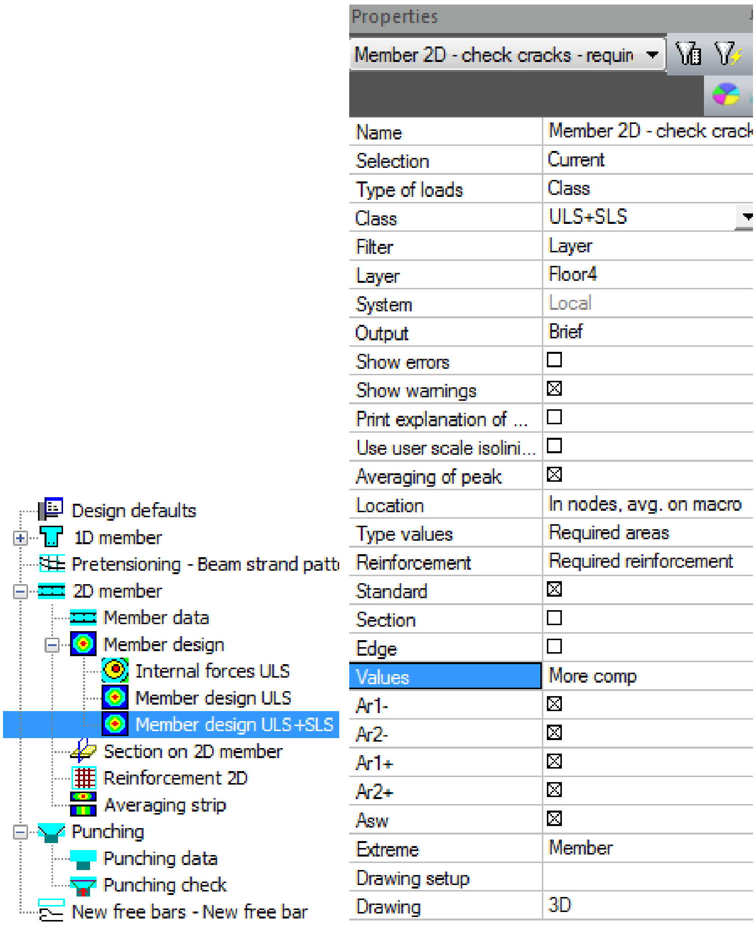


Fig. 46 Design ULS+SLS

The procedure of design of the nonprestressed reinforcement for both states (ULS+SLS) is done in the following steps.

1. Design of necessary reinforcement for ULS
2. Design of necessary reinforcement for SLS
    a. Design for SLS means the minimal area of reinforcement for reaching maximal allowable value of crack width (depending on exposure class).
    b. Check if reinforcement designed for ULS is satisfied for SLS too
        i. IF Yes THEN Design is finished
        ii. IF No THEN Design of additional reinforcement between SLS and ULS

Note

- o Design SLS doesn't calculate reinforcement with respect of Stress limitation or Deformation
- o Limited values of crack width are not implemented in Release 2010.1. It means user have to adapt manually maximal crack width for nonprestressed concrete in concrete setup. But in our case we use monostrands which are unbonded tendons and the limited values are the same as for nonprestressed concrete

The classes are required for Design ULS+SLS. The classes are described in chapter 2.6. Only one class which contains ULS_long and SLS_QP_long is needed.

The required additional areas for class ULS+SLS are the following for the each surface and direction. We can split design reinforcement into five groups:

- **Ar1-** necessary area of lower reinforcement in the direction 1
- **Ar1+** necessary area of upper reinforcement in the direction 1
- **Ar2-** necessary area of lower reinforcement in the direction 2
- **Ar2+** necessary area of upper reinforcement in the direction 2
- **Asw** necessary area of shear reinforcement

Member 2D - check cracks - required areas

Linear calculation, Extreme : Global
Selection : All
Class : ULS+SLS
Additional reinforcement
Necessary area for selected 2D member

Member	elem	Case	A_{r1-} [mm^2/m]	A_{r2-} [mm^2/m]	A_{r1+} [mm^2/m]	A_{r2+} [mm^2/m]	A_{sw} [mm^2/m^2]
S127	24	ULS+SLS	**0**	**0**	**0**	**0**	0
S126	1	ULS+SLS	992	1167	975	1138	0
S131	364	ULS+SLS	393	393	2970	4101	**0**

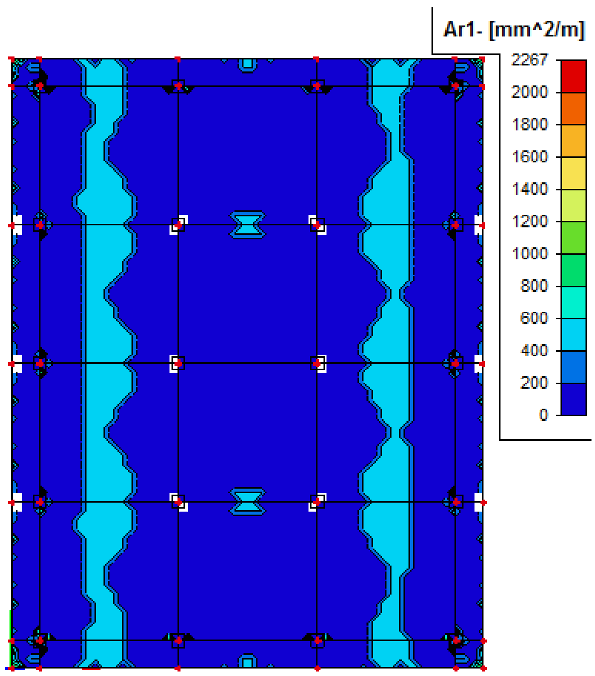
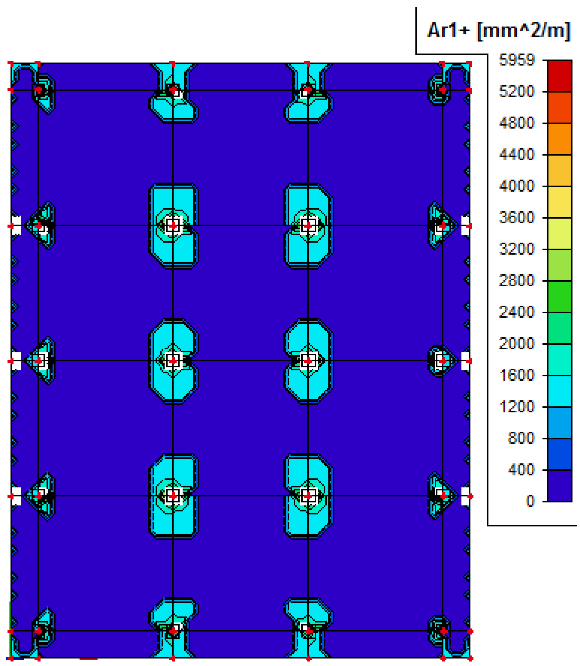
7.3.2.1 Design of longitudinal reinforcement with shear effect considered in SR2

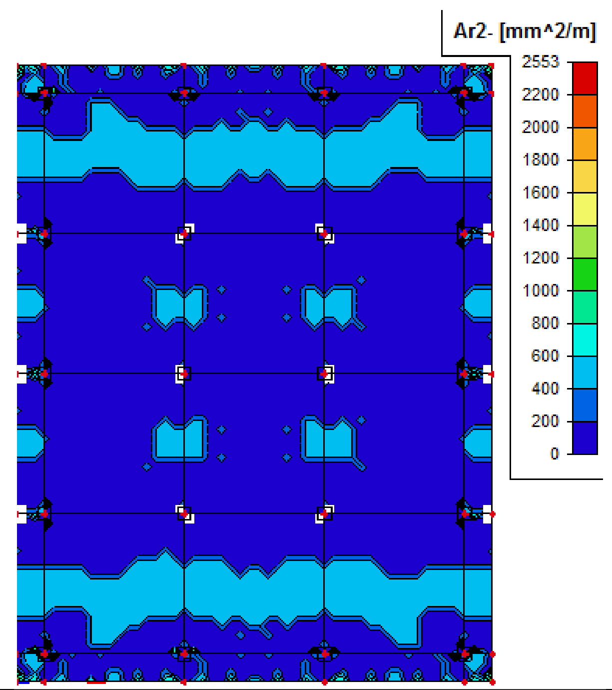
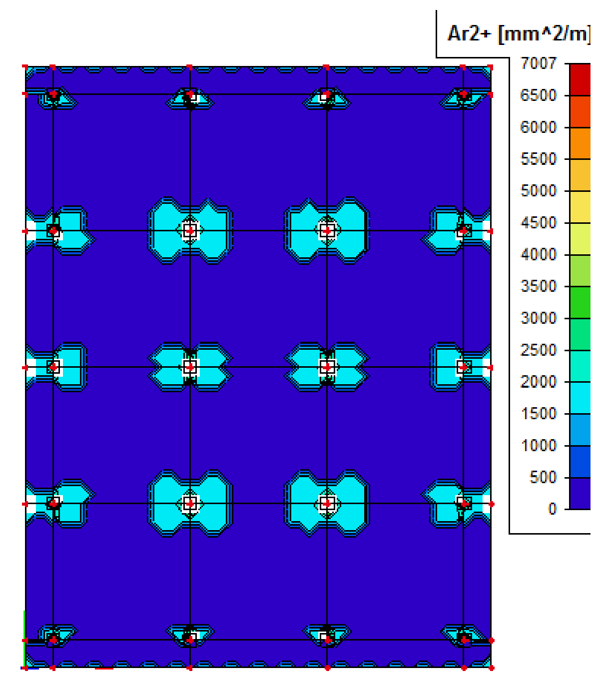
The results mentioned below are evaluated for real tendon structure for combination class ***ULS+SLS*** *(ULS_long+SLS_QP_long)* and they have covered the ***shear effect in SR2***.

Member 2D - check cracks - required areas

Linear calculation, Extreme : Global
Selection : All
Class : ULS+SLS
Required reinforcement
Necessary area for selected 2D member

Member	elem	Case	A_{r1-} [mm^2/m]	A_{r2-} [mm^2/m]	A_{r1+} [mm^2/m]	A_{r2+} [mm^2/m]	A_{sw} [mm^2/m^2]
S132	423	ULS+SLS	0	0	0	0	0
S126	1	ULS+SLS	1161	1328	1589	1780	0
S131	364	ULS+SLS	0	0	0	0	0
S131	154	ULS+SLS	0	0	5392	6991	**0**

Output	Lower (-)	Upper (+)
Ar1		

Ar2		

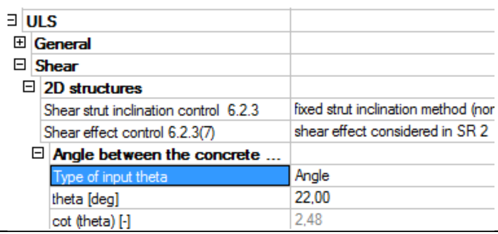
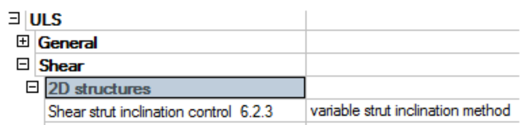
The 2D structure is prestressed. Warning W18 appears for this type of structure and other warning or errors are in the background. It is suitable to set OFF W18 in concrete solver and then you can see the exact warning and errors on the structure. But this is not possible in the current version

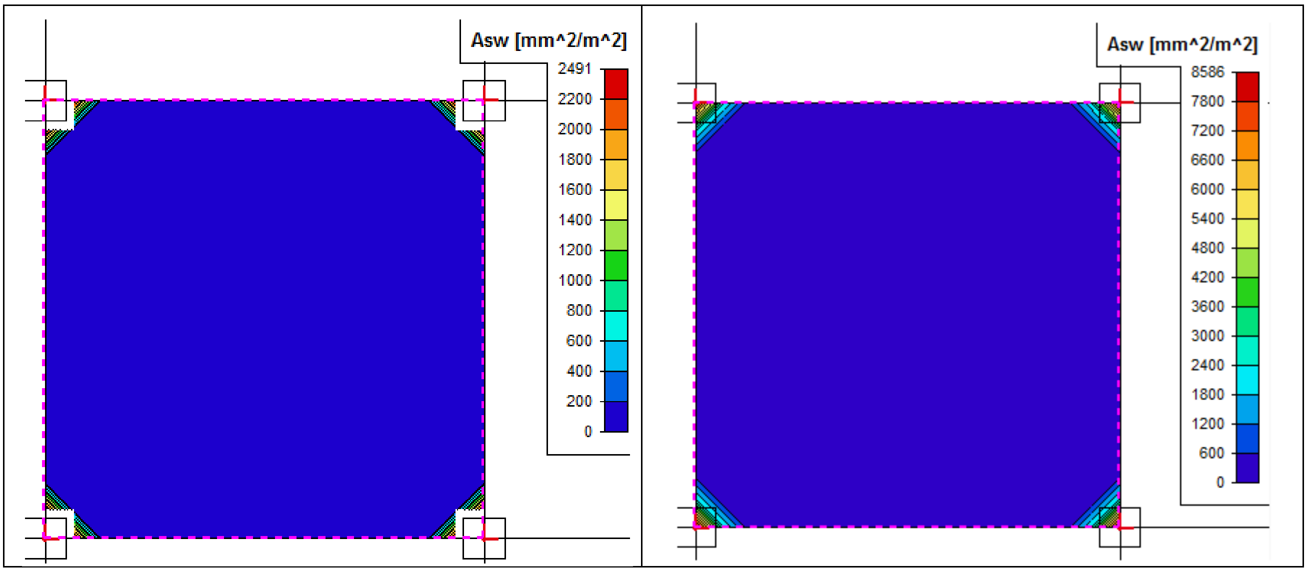
7.3.2.2 Design of shear reinforcement

The evaluation of the required areas of shear reinforcement can be done for

- **Variable strut inclination** – program optimizes the angle theta (recommended)
- **Fixed strut inclination** - value of cotangent is set to 2,48 (max =2,5)

The results of the necessary areas are displayed in the following table for real tendon and slab S138 again. You can see the required areas are less for case with fixed strut inclination.

Asw	
Fixed strut inclination	**Variable strut inclination**
	

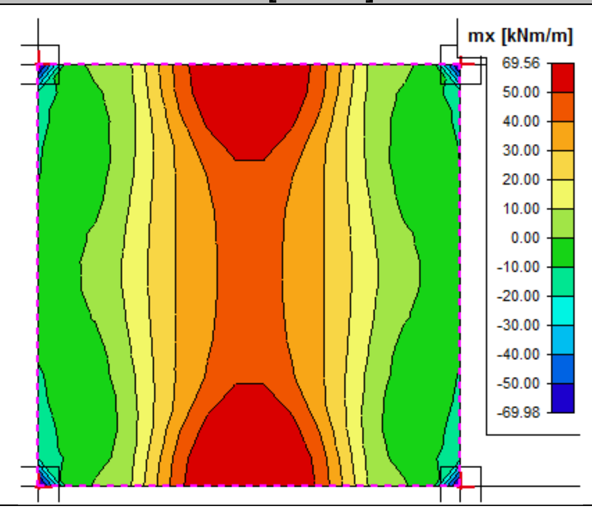
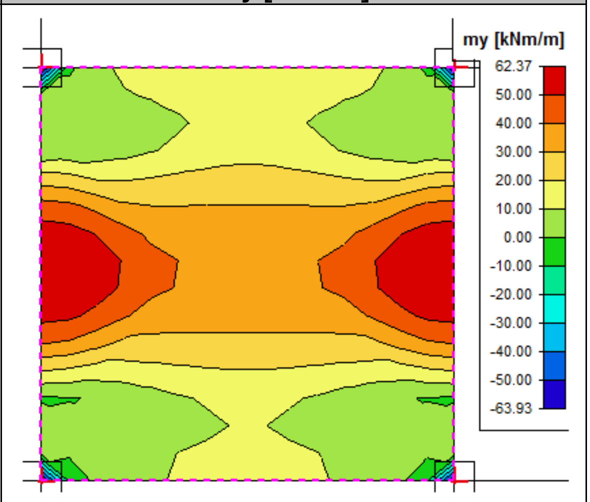


The recommended option is use variable strut inclination.

7.3.3 Summary from Design ULS+SLS of longitudinal reinforcement

The biggest required areas are for upper reinforcement above columns. These regions are problematic during our design from several reasons

- **Shear effect** - the regions above columns are very sensitive on taking into account or not shear effect on required areas of longitudinal reinforcement. If we can neglect shear effect we get much less values of the required areas. The explanation when we can neglect shear effect are the following:
    - **Punching check** - the shear effect can be verified by this design or can be checked also during punching check (Maximal concrete strut capacity). That's why we can neglect shear effect for design of longitudinal reinforcement if we also perform punching check.
    - **Limits for additional force caused by shear** – chapter 6.2.3(7) describe teh limit for the additional longitudinal force caused by the shear (***Med,max/z***) This limit is not verified by the NEDIM. That's why much higher longitudinal forces can be taken into account during design than they are allowed. Again we can compare the values for slab S138 with real tendon

Slab S138	mx [kNm/m]	my [kNm/m]
m		

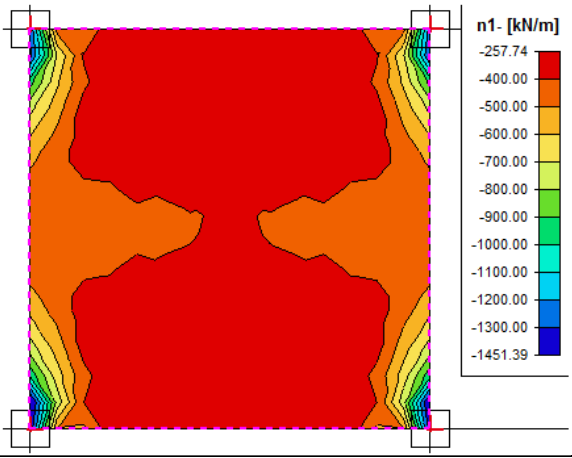
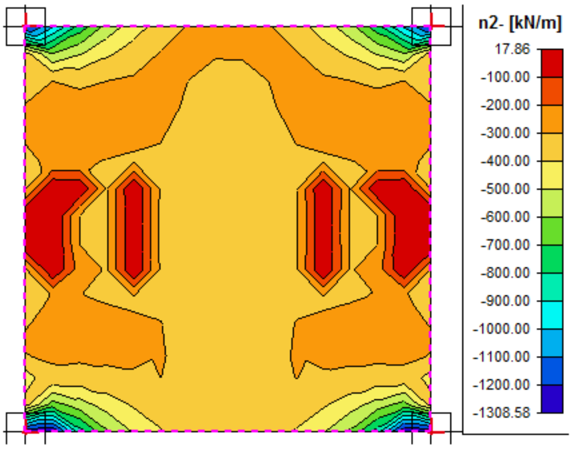
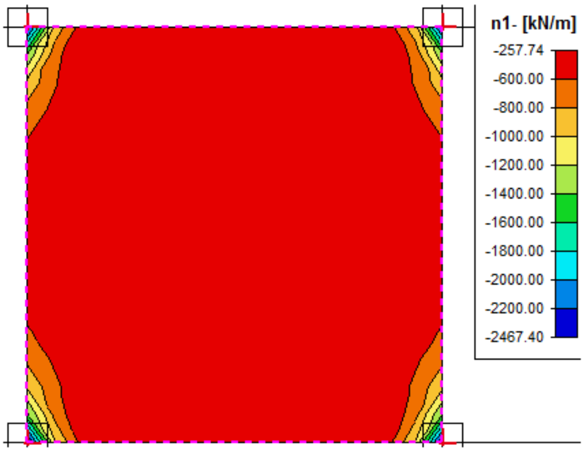
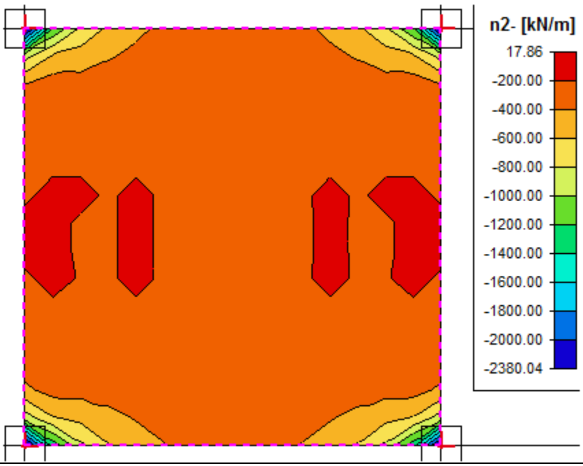
$$mx = 69{,}56kNm/m$$
$$my = 62{,}37kNm/m$$
$$z = 0{,}9 \cdot 0{,}9 \cdot h = 0{,}9 \cdot 0{,}9 \cdot 0{,}29 = 0{,}235m$$

$$\Delta F_{td,max} = \frac{\text{my}}{\text{z}} = \frac{69,56}{0,235} = \mathbf{296,13kN/m}$$

If you look on the table below you can see the values of additional longitudinal forces caused by shear. You get these values when you calculate difference between values with (SR2) and without shear effect. Values near the support are bigger almost twice in case when you consider shear effect. Then additional longitudinal force caused by shear is the following

$$\Delta F_{td} = 2467,40 - 1451,39 = \mathbf{1016,01}\boldsymbol{kN/m} \geq \mathbf{296,13kN/m} = \Delta F_{td,max}$$

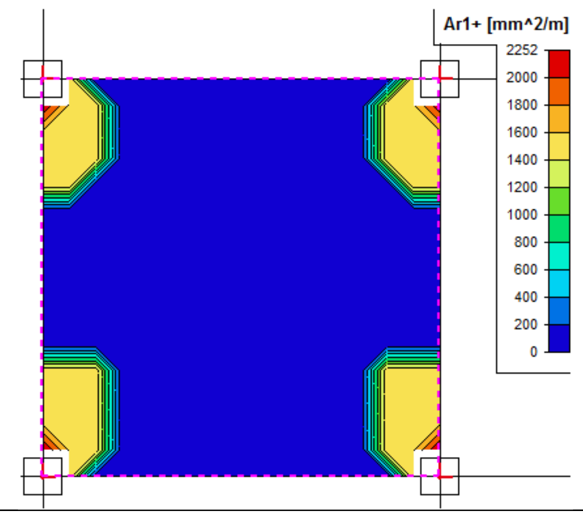
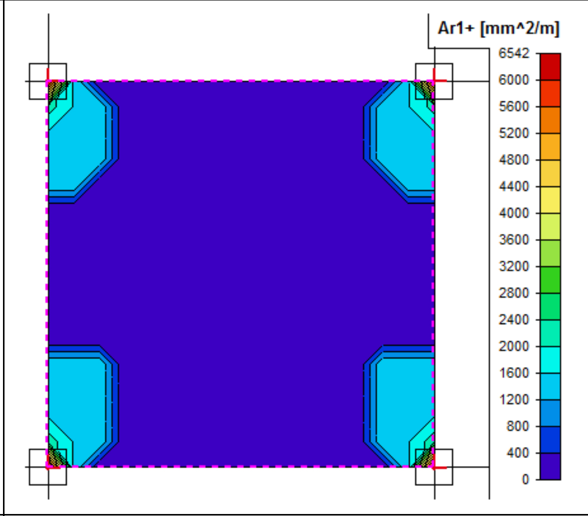
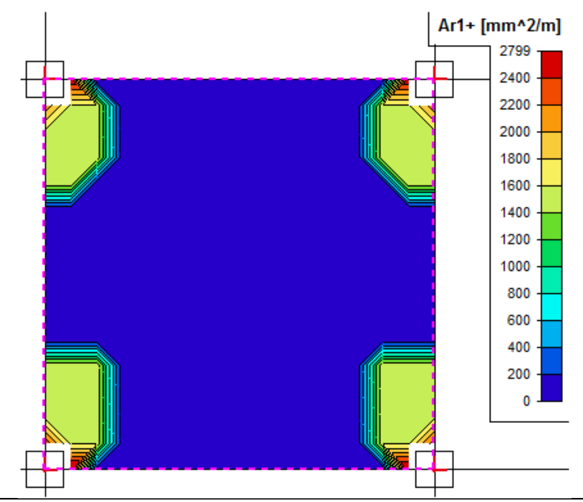
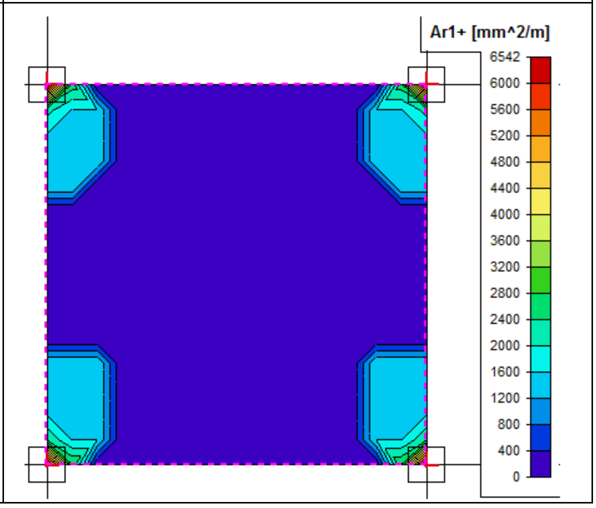
This value is much higher (3x) then allowed. From the investigation above we can assume to neglect shear effect because we get very high value of additional longitudinal force caused by shear.

<table>
<tr><th>Slab S138</th><th>n1- [kN/m]</th><th>n2- [kN/m]</th></tr>
<tr><td>No shear effect</td><td>
</td><td>
</td></tr>
<tr><td>Shear effect in SR2</td><td>
</td><td>
</td></tr>
</table>

- **Maximal percentage of the reinforcement –** another limit during design seems to be maximal percentage of reinforcement. The default value is 4% (9.2.1.1(3) from [1]). This limit is exceeded for this case (see non-designability places above columns for case real tendon). If we increase this percentage for 5% the reinforcement is possible to design with respect to this condition.

> **German national annex is allowed to use reinforcement up to 8% of concrete areas. It means increasing of percentage from 4% to 5% probably will not affect the structural design and could be done. But we do not meet strictly general Eurocode.**

You can find the results for structure with real tendon and for the slab S138, class ULS+SLS for the upper reinforcement (Ar1+) in the following table.

<table>
<tr><th>Slab S138</th><th>4%</th><th>5%</th></tr>
<tr><td>No shear effect</td><td>
</td><td>
</td></tr>
<tr><td>SR2</td><td>
</td><td>
</td></tr>
</table>

However if we neglect shear effect we still get some non-designability places above columns (empty areas above column for no shear effect and 4% reinforcement limit). The solution how to solve this problem is introduced column with head (see chapter 7.4.)

7.4 Definition of column head

Due to reason described in the previous chapters it seems to be efficient to introduced column head in the structure. The column head as mentioned in the following figure have been modelled. Based on the span L=9,0m the outermost distance is 2,7m and the inner effective distance is 1,8m (see following figure). Depth of the head is 0,625+0,290=0,915m.

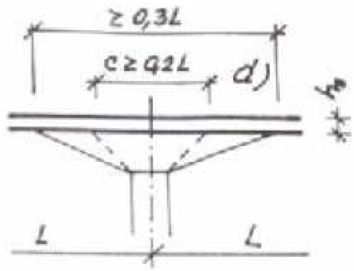


Fig. 47 Dimensions of column head

The column head are modelled as subregions in the existing slabs. The subregions are defined from the **Structure > 2D member > 2D members components**.

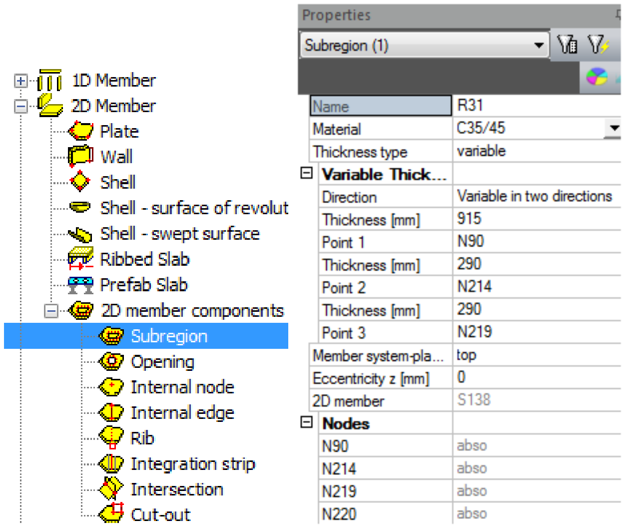


Fig. 48 Subregions

The 3D screen of the structure with column head is visible form the following figure.

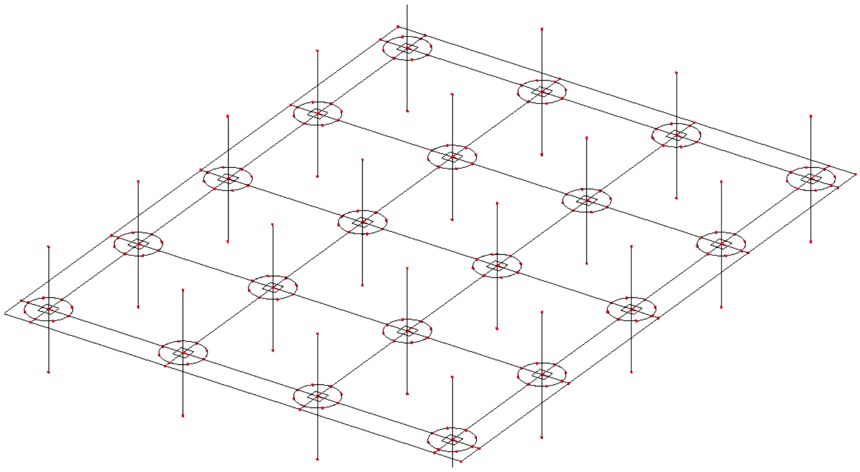


Fig. 49 General overview of the slab with column head

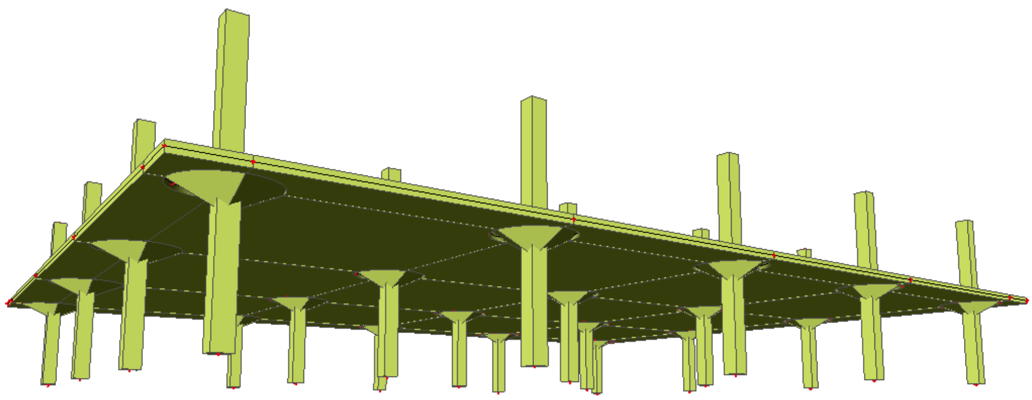


Fig. 50 Rendered 3D model of slab with column head

The local mesh refinement should be introduced above column head. Generally mesh size with length of finite element 0,6 m is used. ***Linear*** local mesh refinement with ratio **1,5** should be used above column head. Local mesh refinement is defined from the ***Calculation, mesh > Local mesh refinement > Node mesh refinement***. This option is dependent on the level of the project (***Advanced*** level is required).

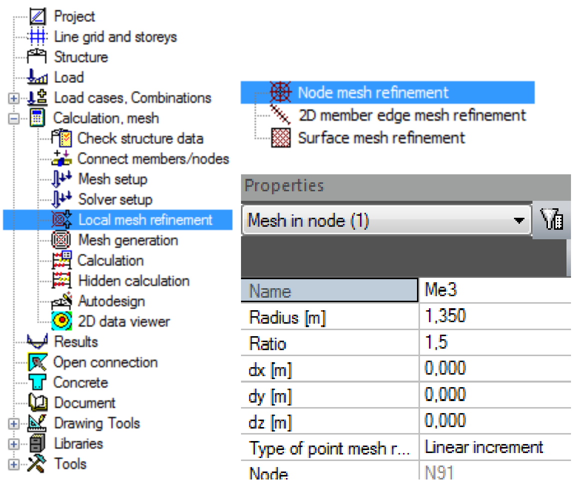


Fig. 51 Local mesh refinement

Local mesh refinement is graphically displayed using balls.

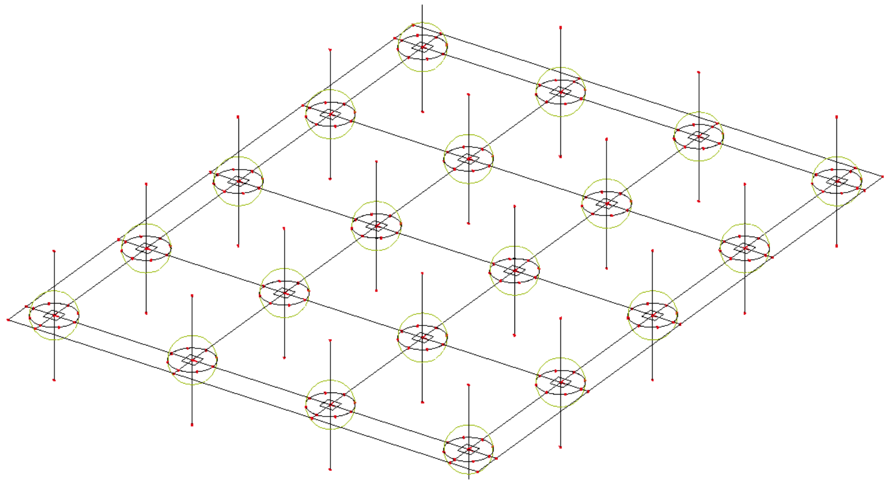
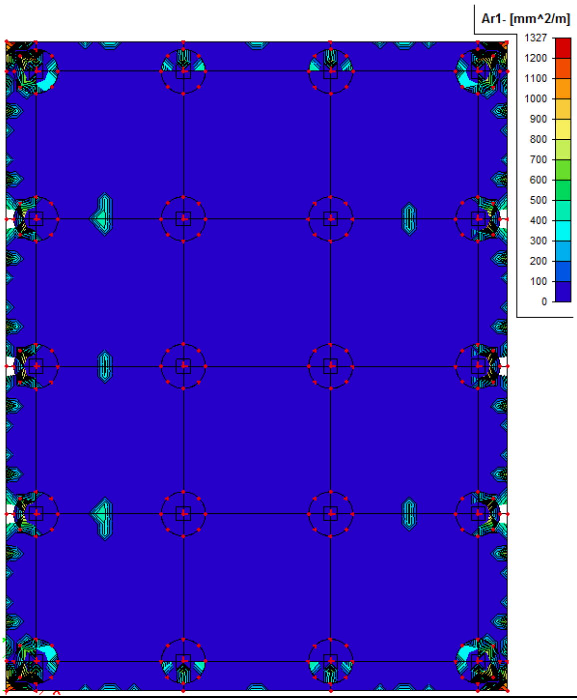
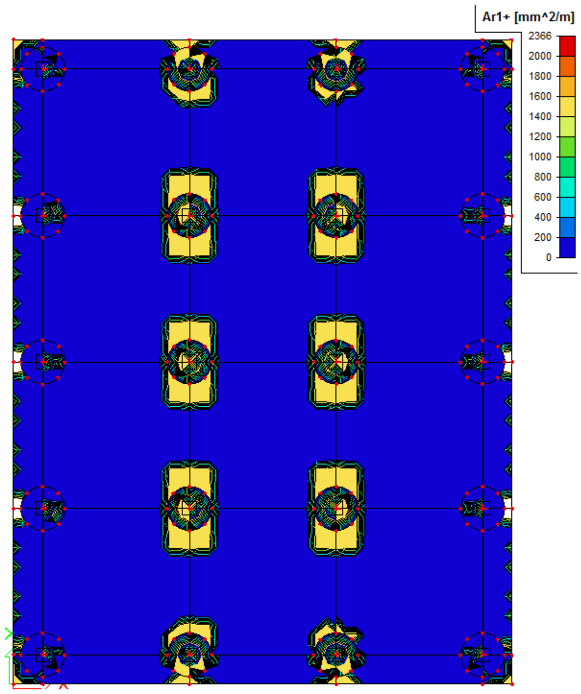
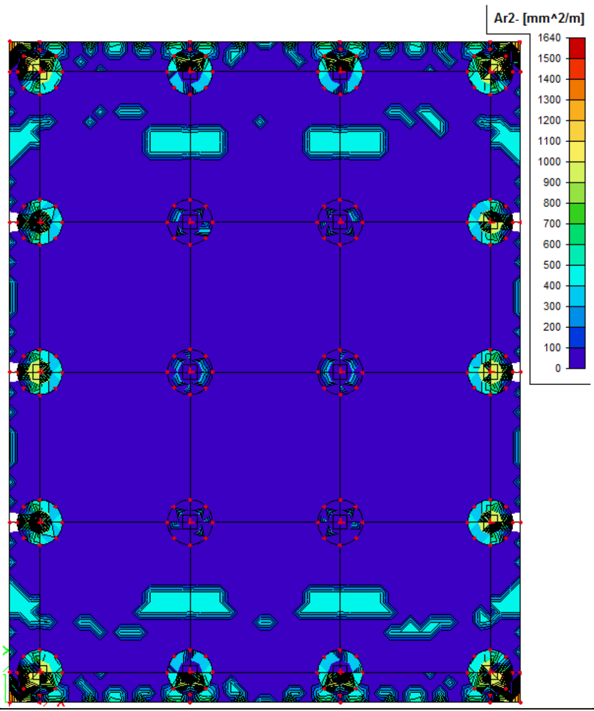
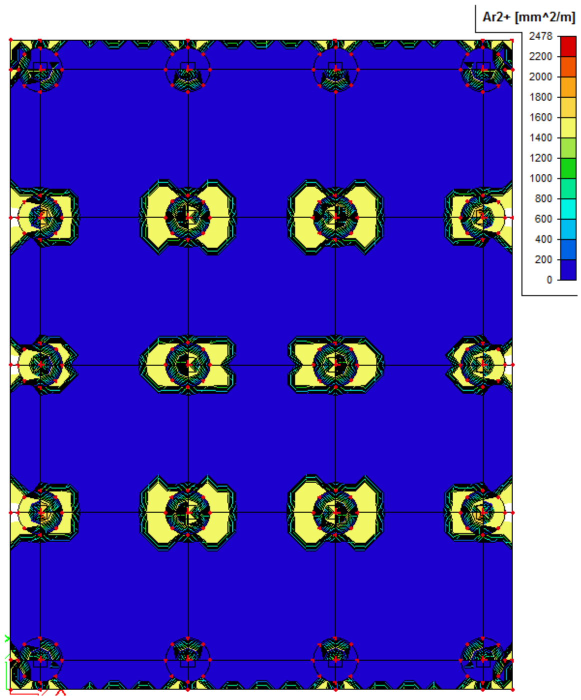


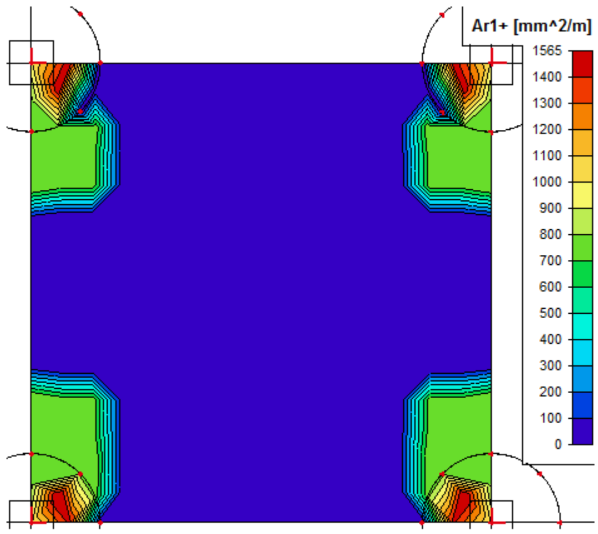
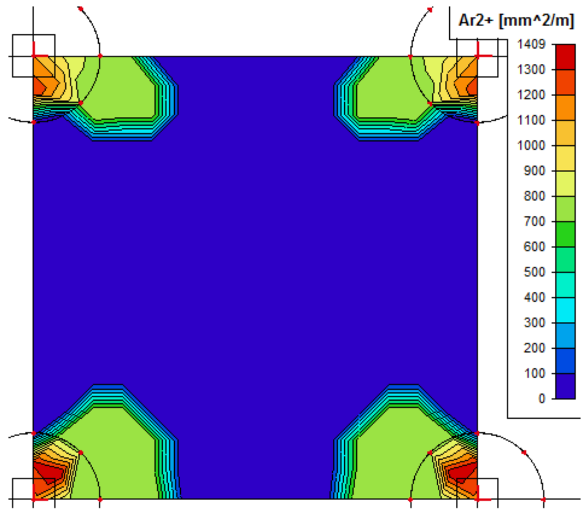
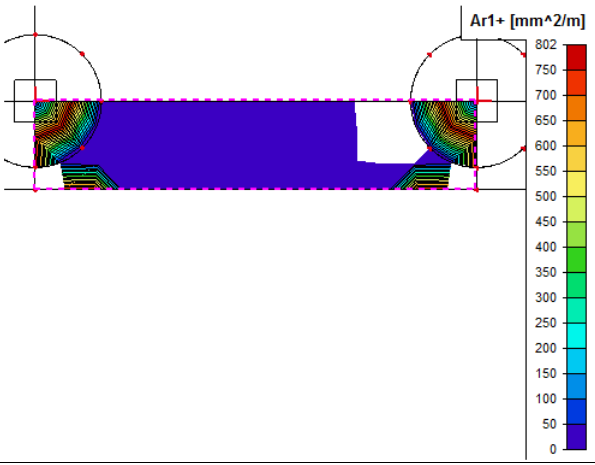
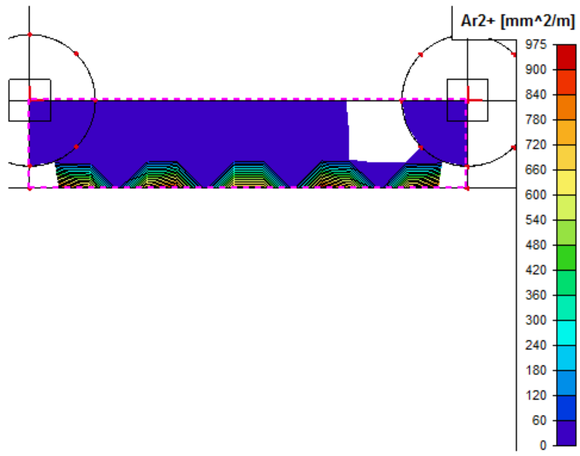
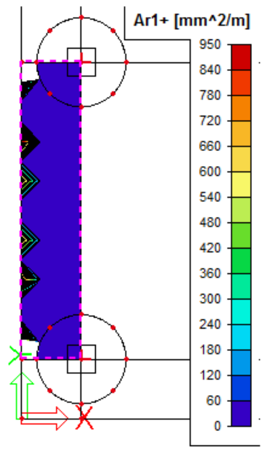
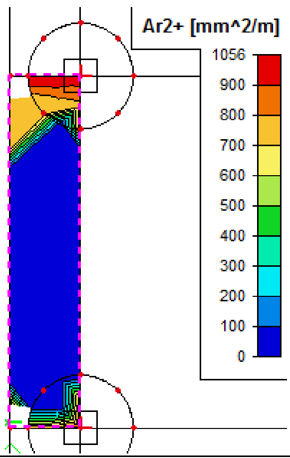
Fig. 52 Local mesh refinement on the whole structure

7.4.1.1 Design of longitudinal reinforcement for structure with column head

During preparation of this tutorial was found the best evaluation of the required areas for this type of structure is location ***In nodes avg***.
The results mentioned below are evaluated for real tendon structure with column heads for combination class ***ULS+SLS*** *(ULS_long+SLS_QP_long)* and these results are ***without shear effect*** (see chapter 7.3.3)

Output	Lower (-)	Upper (+)
Ar1		
Ar2		

When we focus again on the slab S138 then we can see exact values of the required areas. For the external column we can investigate also slab S128 and S135.

<table>
<tr><th>Output</th><th>Ar1+</th><th>Ar2+</th></tr>
<tr><td>S138</td><td>
</td><td>
</td></tr>
<tr><td>S128</td><td>
</td><td>
</td></tr>
<tr><td>S135</td><td>
</td><td>
</td></tr>
</table>

These areas are total required areas. There is also user reinforcement by the tendons. So finally the amount of additional reinforcement is difference between user and required areas. You can see detail of required areas for each region in the following table.

[mm2/m]	Span		Column internal		Column external	
	Lower 1	Lower2	Upper 1	Upper 2	Upper 1	Upper 2
Total required reinf	400	500	1565	1409	802	1056
User reinf	240	240	624	624	624	624
Additional reinf	160	260	941	785	178	432
Reinf	**8 a 150mm**	**8 a 150mm**	**14 a 150mm**	**14a 150mm**	**14 a 300mm**	**14 a 300mm**

There are also some special regions on the slab where prestressing tendons are anchored. The intensity of the stresses is too high in this regions and that's why it is not possible to design such regions. Special analysis for example strut and tie analysis should be done for proper investigation of the zone below anchors. This is not part of this manual.

7.5 Definition of additional required reinforcement

There was designed additional nonprestressed reinforcement for each surface on ULS+SLS in the chapter above. Now these necessary areas should be defined as user real reinforcement. The reinforcement above column should be designed in the rectangular areas at least **L/4** in each direction above columns. We increase value for **L/3,5** for internal columns. It means rectangular mesh reinforcement.

- **5,1m x 5,1m** above internal columns
- **3,6m x 3,6m** above external columns

7.5.1 Definition of additional longitudinal reinforcement

The additional longitudinal reinforcement is defined via service **2D member > Reinforcement 2D**.

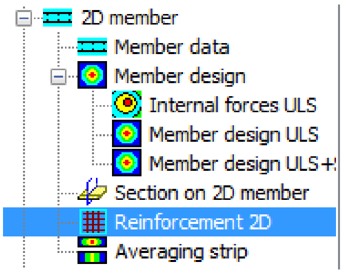
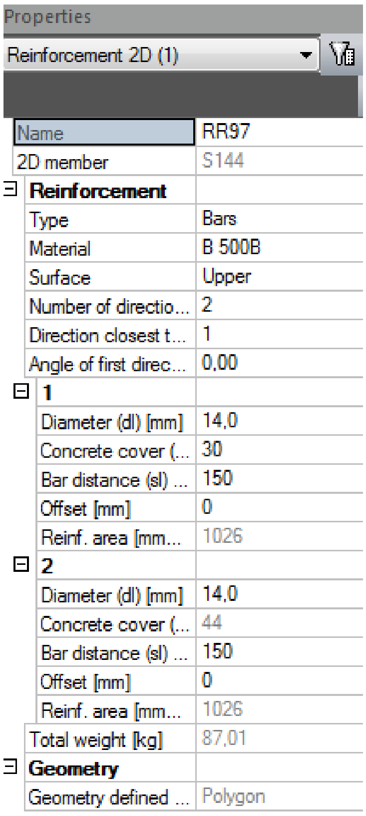


Fig. 53 Reinforcement 2D

Finally the additional reinforcement will be added as calculated in the previous chapter. We can add bars or mesh reinforcement. The setting of the reinforcement for both surfaces is the following:

Lower (-)

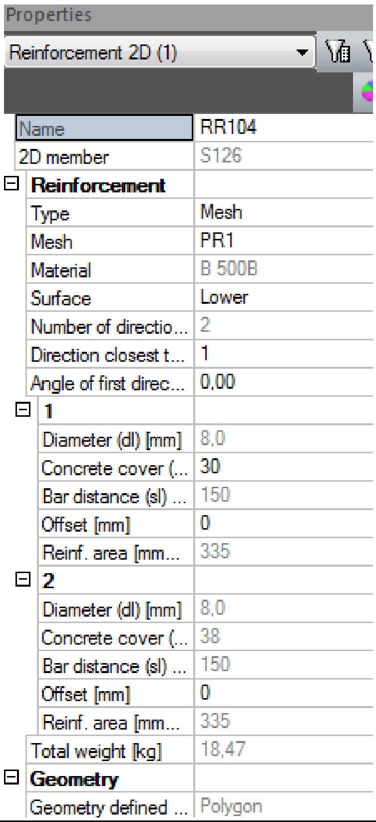


Properties

Reinforcement 2D (1)

Name	RR97
2D member	S144
Reinforcement	
Type	Bars
Material	B 500B
Surface	Upper
Number of directio...	2
Direction closest t...	1
Angle of first direc...	0,00
1	
Diameter (dl) [mm]	14,0
Concrete cover (...	30
Bar distance (sl) ...	150
Offset [mm]	0
Reinf. area [mm...	1026
2	
Diameter (dl) [mm]	14,0
Concrete cover (...	44
Bar distance (sl) ...	150
Offset [mm]	0
Reinf. area [mm...	1026
Total weight [kg]	87,01
Geometry	
Geometry defined ...	Polygon

Upper (+)



Properties

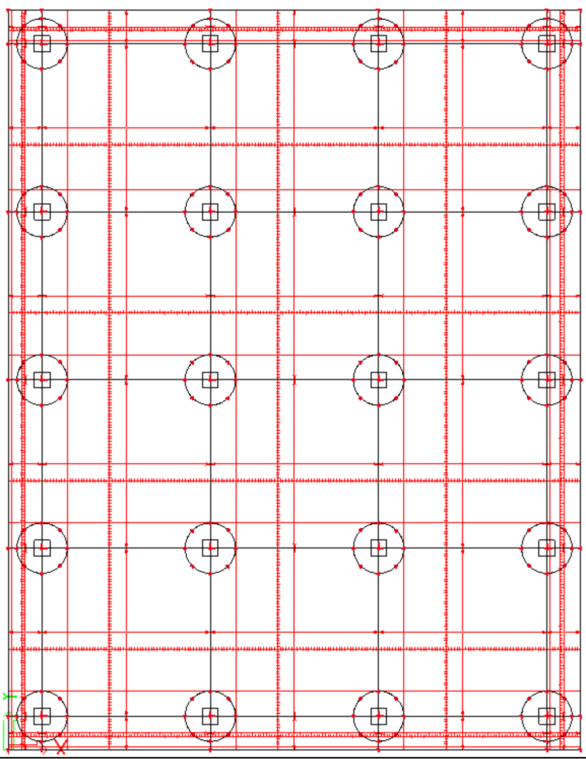
Reinforcement 2D (1)

Name	RR104
2D member	S126
Reinforcement	
Type	Mesh
Mesh	PR1
Material	B 500B
Surface	Lower
Number of directio...	2
Direction closest t...	1
Angle of first direc...	0,00
1	
Diameter (dl) [mm]	8,0
Concrete cover (...	30
Bar distance (sl) ...	150
Offset [mm]	0
Reinf. area [mm...	335
2	
Diameter (dl) [mm]	8,0
Concrete cover (...	38
Bar distance (sl) ...	150
Offset [mm]	0
Reinf. area [mm...	335
Total weight [kg]	18,47
Geometry	
Geometry defined ...	Polygon

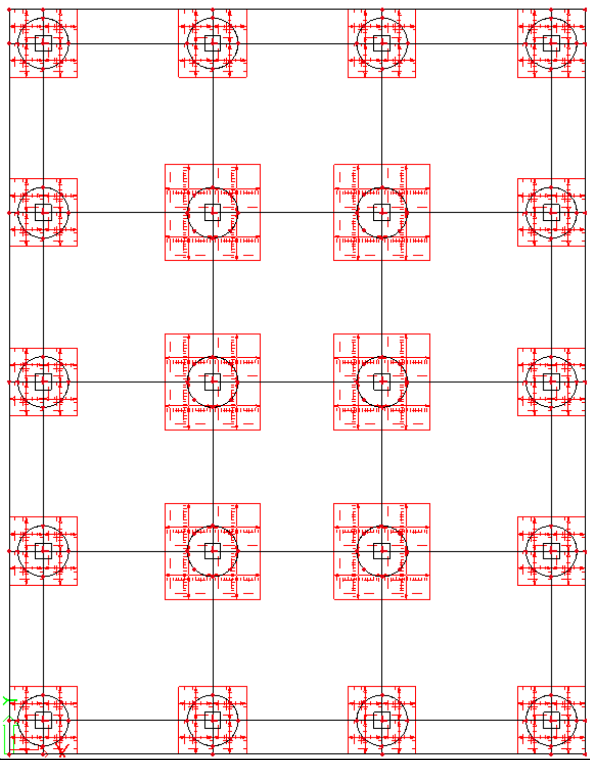
The current version of SEN is not able to calculate additional reinforcement with more material of nonprestressed reinforcement

The reinforcement can be displayed for each surface separately. Final shape of lower and upper 2D user reinforcement is the following.

Lower (-)



Upper (+)



Final reinforcement together with tendon is the following

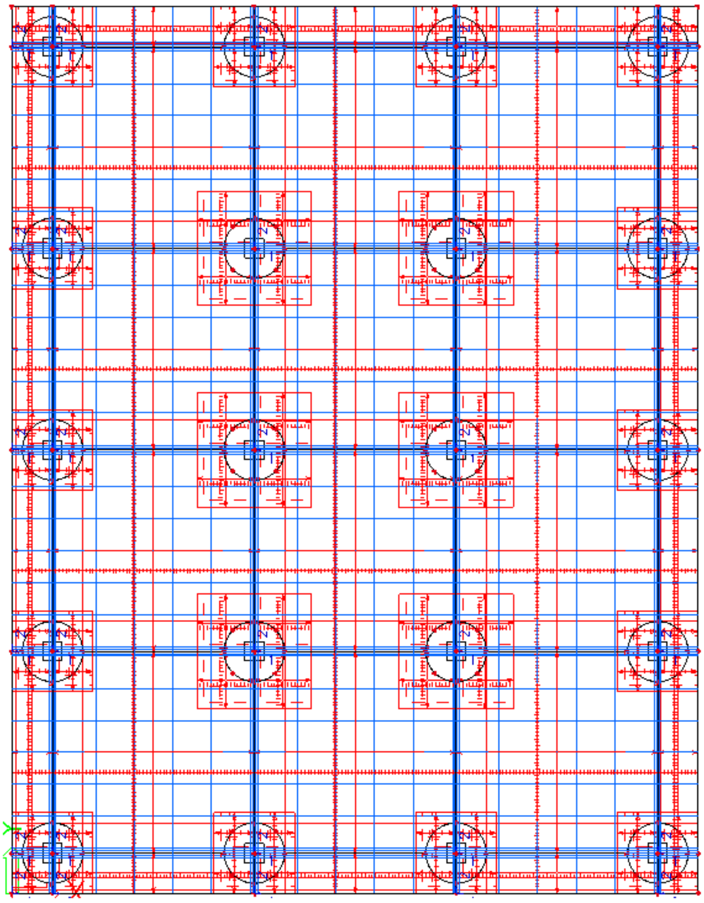


Fig. 54 Final reinforcement in the slab

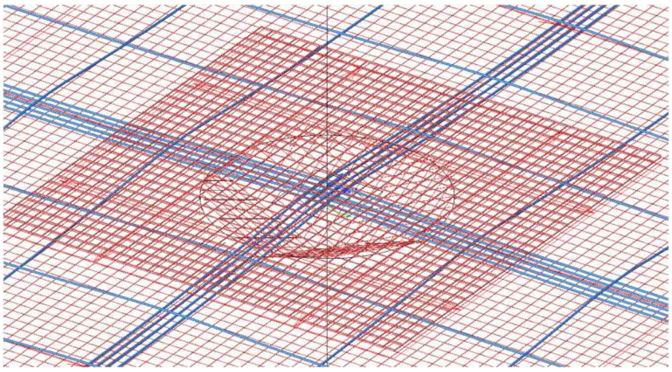


Fig. 55 Detail of the internal column

8 Check punching

Punching check is another check which is needed to fulfil for 2D members (**Concrete> Punching**). As first the punching data are required to be defined in the node where columns are defined.

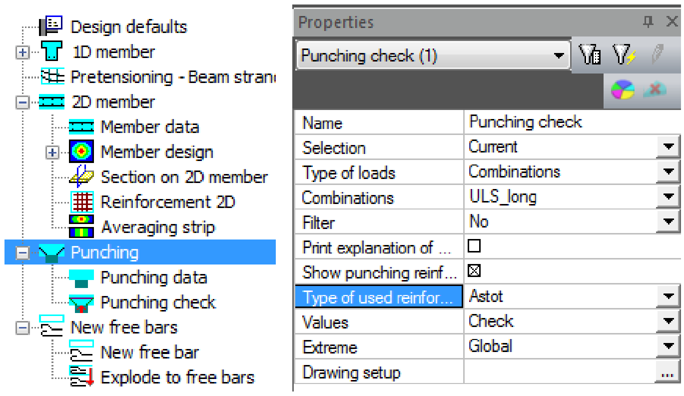


Fig. 56 Punching check

8.1 Punching data

The punching data are required to input for performing of punching check. The four types of punching data are used in this example for different type of column support.

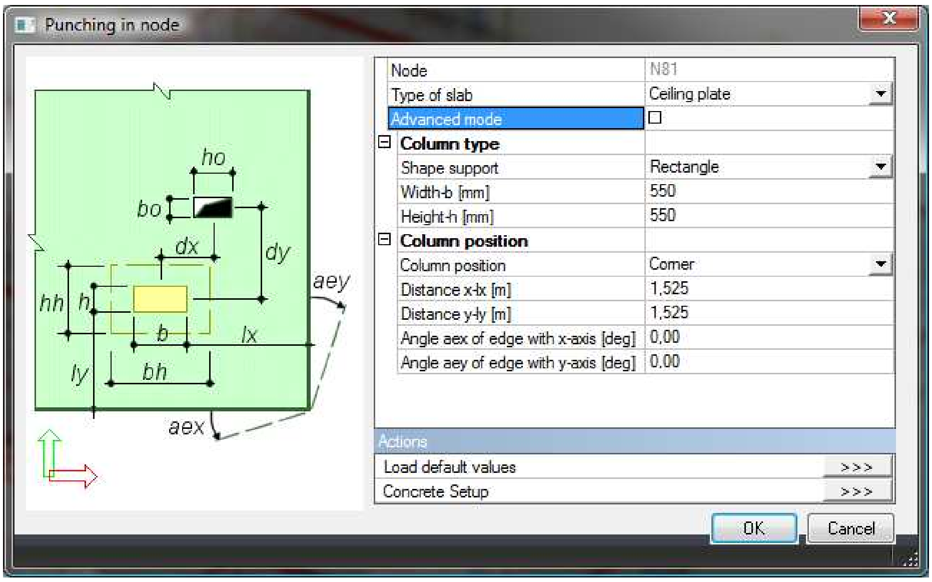


Fig. 57 Punching data – general shape

The settings of punching data for each type of column are the displayed in the table:

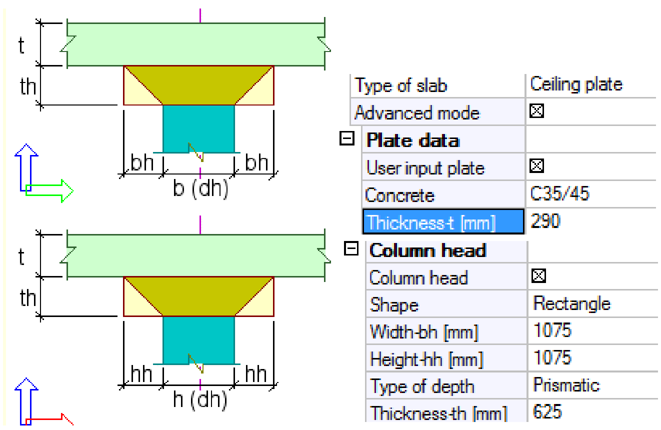
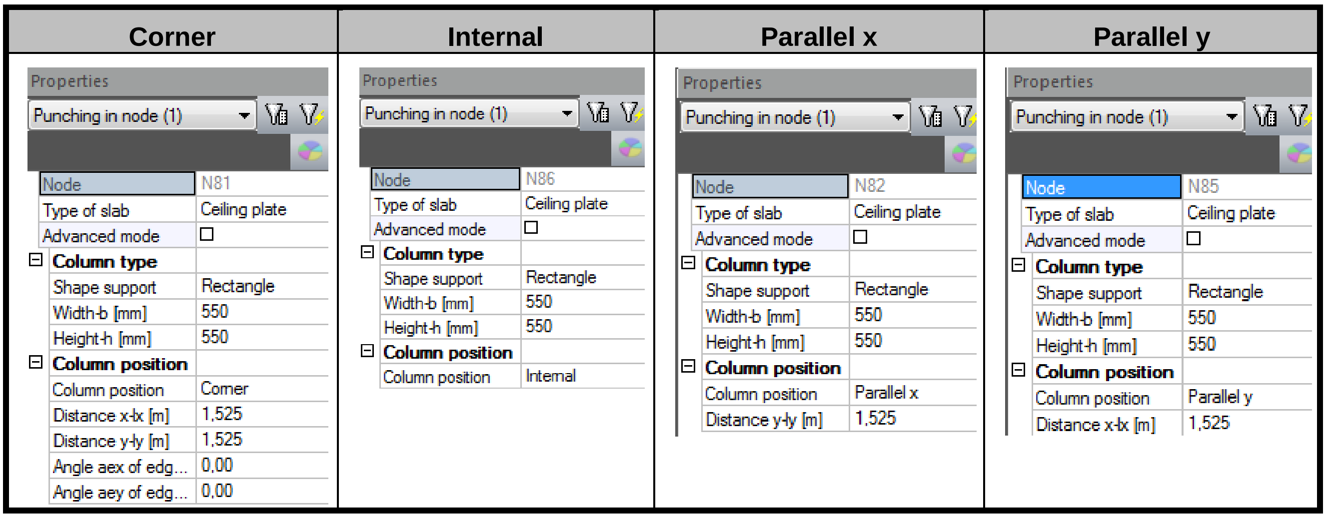


Fig. 58 Column head definition in punching data



With respect of the column head the values related to the column head should be defined also for punching check in punching data. The thickness of the slab has to be adapted manually in punching data because we defined real column head on the slab (see figure Fig. 58).

8.2 Punching check

Punching check is performed for selected node. The difference between punching check for nonprestressed and prestressed concrete is only in calculation of σ_{cp} where the effect of the prestress normal force should be taken into account. It is recommended to verify setting in concrete setup for punching mainly if the effect of the prestressing (normal force) is taken into account or not. For concrete setup see ***Concrete > ULS > Punching***.

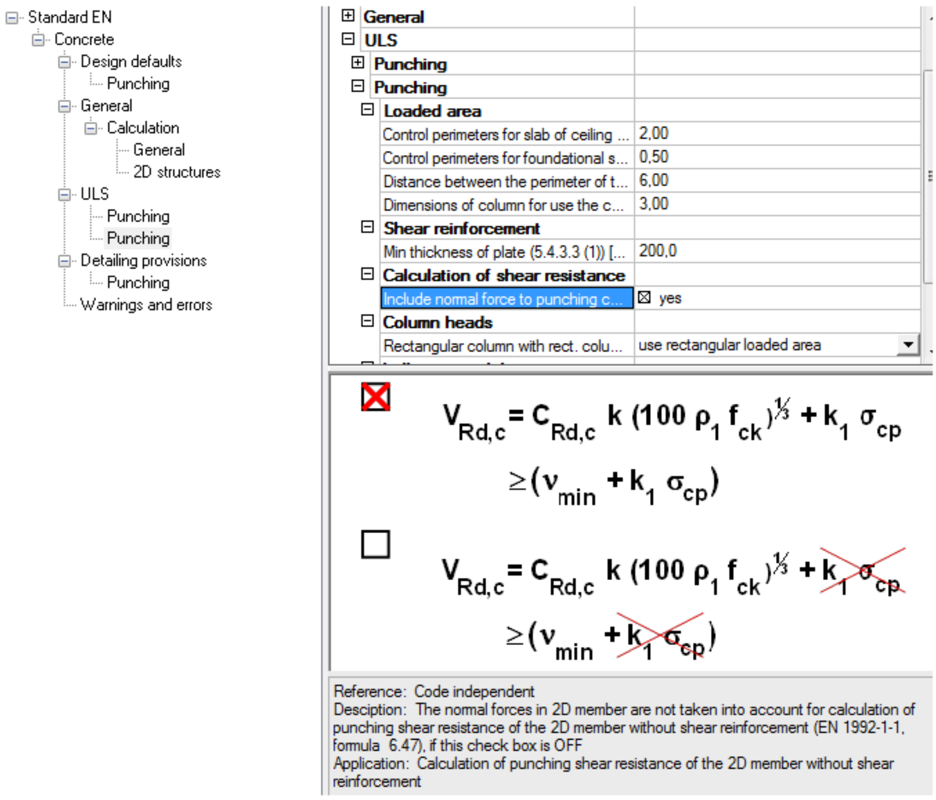


Fig. 59 Concrete setup for punching

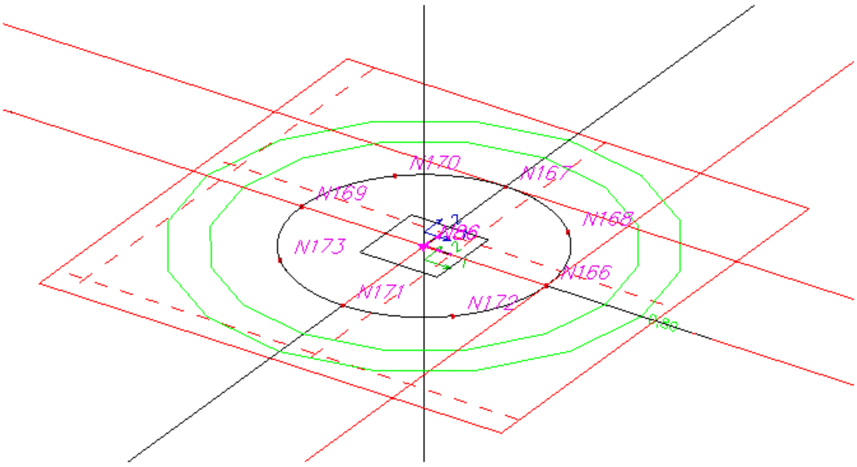


Fig. 60 Punching check for node N88

The detailed output for the node N88 is displayed in the following table.

Punching check

Linear calculation, Extreme : Global
Selection : N86
Combinations : ULS_long
Check maximum shear resistance

Node	Case	Per.	Ix_col [m]	Iy_col [m]	u_0 [m]	v [-]	v_{Ed0} [MPa]	$v_{Rd,max}$ [MPa]
N86	ULS_long	2	1,497	1,497	2,534	0,52	1,04	6,02

Reinforcement in plate

Node	Type of reinforcement	A_{s1+} [mm²]	A_{s2+} [mm²]	A_{s1-} [mm²]	A_{s2-} [mm²]	α_{s1+} [deg]	α_{s2+} [deg]	α_{s1-} [deg]	α_{s2-} [deg]
N86	User real	1810	3679	335	335	0,00	90,00	0,00	90,00

Load in critical section

Node	Case	f_d [kN/m²]	R_{Ed} [kN]	M_{Edx} [kNm]	M_{Edy} [kNm]
N86	ULS_long	-21,79	1913,30	-395,08	-366,21

Check punching shear resistance and design shear reinforcement

Node	σ_{cp} [MPa]	Case	Per.	d [mm]	u [m]	v_{Ed} [MPa]	$v_{Rd,c}$ [MPa]	A_{sw}/u [mm²/m]	$v_{Rdc,s}$ [MPa]	Check	Check value [-]	W/E
N86	0,00	ULS_long	2	211	13,453	0,67	0,83	0	0,83	OK	0,80	6

When punching check is satisfied (maximal shear capacity of concrete strut is not exceeded) then necessary area of additional shear reinforcement for punching can be designed (value Asw/u). This reinforcement can be converted to user reinforcement.

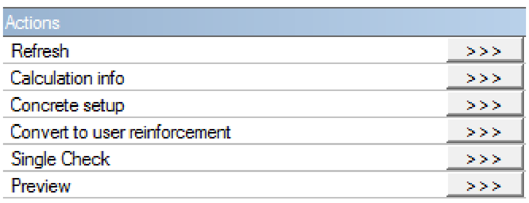


Fig. 61 Action button convert to user reinforcement

You can see the model without column head where additional shear reinforcement for punching is necessary. The real shear reinforcement for punching used in this example can be as following for node N86.

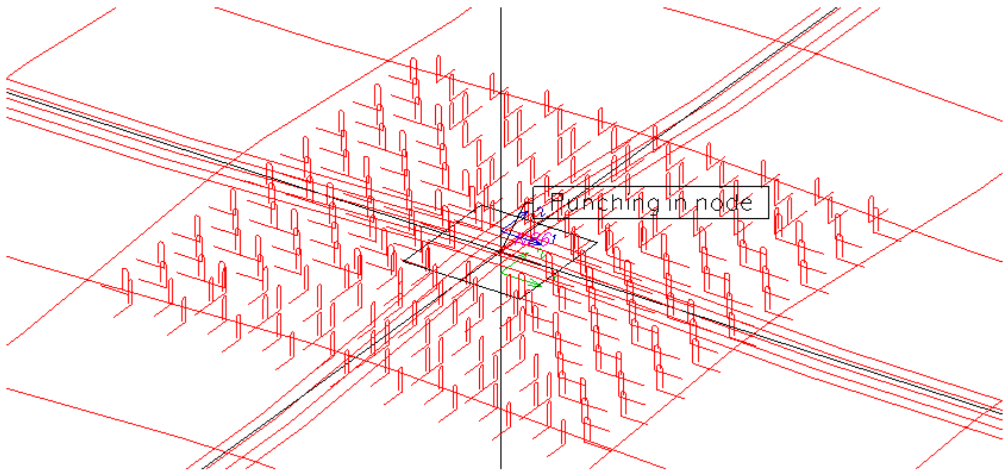


Fig. 62 Converted shear reinforcement for punching to user reinforcement

Punching check

Linear calculation, Extreme : Global
Selection : N86
Combinations : ULS_long
Check maximum shear resistance

Node	Case	Per.	Ix_col [m]	Iy_col [m]	u_0 [m]	v [-]	v_{Ed0} [MPa]	$v_{Rd,max}$ [MPa]
N86	ULS_long	1	0,396	0,396	2,200	0,52	2,22	6,02

Reinforcement in plate

Node	Type of reinforcement	A_{s1+} [mm²]	A_{s2+} [mm²]	A_{s1-} [mm²]	A_{s2-} [mm²]	α_{s1+} [deg]	α_{s2+} [deg]	α_{s1-} [deg]	α_{s2-} [deg]
N86	User real	1879	1503	785	785	0,00	90,00	0,00	90,00

Load in critical section

Node	Case	f_d [kN/m²]	R_{Ed} [kN]	M_{Edx} [kNm]	M_{Edy} [kNm]	N_{Edx} [kN]	N_{Edy} [kN]
N86	ULS_long	-9,79	839,53	-79,88	-63,99	-705,51	-563,42

Check punching shear resistance and design shear reinforcement

Node	σ_{cp} [MPa]	Case	Per.	d [mm]	u [m]	v_{Ed} [MPa]	$v_{Rd,c}$ [MPa]	A_{sw}/u [mm²/m]	v_{Rdcs} [MPa]	Check	Check value [-]	W/E
N86	2,19	ULS_long	1	198	4,684	1,02	0,96	99	1,02	OK	1,00	226

Punching reinforcement

Node	Row	Line	Per.	Number	s_t [m]	Height [m]	Length [m]	x_{beg} [m]	y_{beg} [m]	x_{beg} [m]	y_{beg} [m]
N86	1	1	1	3	0,297	0,158	0,669	0,334	-0,334	0,334	0,334
N86	1	2	1	3	0,297	0,158	0,669	0,334	0,334	-0,334	0,334
N86	1	3	1	3	0,297	0,158	0,669	-0,334	0,334	-0,334	-0,334
N86	1	4	1	3	0,297	0,158	0,669	-0,334	-0,334	0,334	-0,334
N86	2	1	1	4	0,297	0,158	0,965	0,483	-0,483	0,483	0,483
N86	2	2	1	4	0,297	0,158	0,965	0,483	0,483	-0,483	0,483
N86	2	3	1	4	0,297	0,158	0,965	-0,483	0,483	-0,483	-0,483
N86	2	4	1	4	0,297	0,158	0,965	-0,483	-0,483	0,483	-0,483
N86	3	1	1	5	0,297	0,158	1,262	0,631	-0,631	0,631	0,631
N86	3	2	1	5	0,297	0,158	1,262	0,631	0,631	-0,631	0,631
N86	3	3	1	5	0,297	0,158	1,262	-0,631	0,631	-0,631	-0,631
N86	3	4	1	5	0,297	0,158	1,262	-0,631	-0,631	0,631	-0,631
N86	4	1	3	4	0,396	0,158	1,559	0,779	-0,779	0,779	0,779
N86	4	2	3	4	0,396	0,158	1,559	0,779	0,779	-0,779	0,779
N86	4	3	3	4	0,396	0,158	1,559	-0,779	0,779	-0,779	-0,779
N86	4	4	3	4	0,396	0,158	1,559	-0,779	-0,779	0,779	-0,779
N86	5	1	3	5	0,396	0,158	1,855	0,928	-0,928	0,928	0,928
N86	5	2	3	5	0,396	0,158	1,855	0,928	0,928	-0,928	0,928
N86	5	3	3	5	0,396	0,158	1,855	-0,928	0,928	-0,928	-0,928
N86	5	4	3	5	0,396	0,158	1,855	-0,928	-0,928	0,928	-0,928
N86	6	1	3	6	0,396	0,158	2,152	1,076	-1,076	1,076	1,076
N86	6	2	3	6	0,396	0,158	2,152	1,076	1,076	-1,076	1,076
N86	6	3	3	6	0,396	0,158	2,152	-1,076	1,076	-1,076	-1,076
N86	6	4	3	6	0,396	0,158	2,152	-1,076	-1,076	1,076	-1,076
N86	7	1	3	7	0,396	0,158	2,448	1,224	-1,224	1,224	1,224
N86	7	2	3	7	0,396	0,158	2,448	1,224	1,224	-1,224	1,224
N86	7	3	3	7	0,396	0,158	2,448	-1,224	1,224	-1,224	-1,224
N86	7	4	3	7	0,396	0,158	2,448	-1,224	-1,224	1,224	-1,224
N86	8	1	3	7	0,396	0,158	2,745	1,373	-1,373	1,373	1,373
N86	8	2	3	7	0,396	0,158	2,745	1,373	1,373	-1,373	1,373
N86	8	3	3	7	0,396	0,158	2,745	-1,373	1,373	-1,373	-1,373
N86	8	4	3	7	0,396	0,158	2,745	-1,373	-1,373	1,373	-1,373
N86	9	1	4	8	0,396	0,158	3,042	1,521	-1,521	1,521	1,521
N86	9	2	4	8	0,396	0,158	3,042	1,521	1,521	-1,521	1,521
N86	9	3	4	8	0,396	0,158	3,042	-1,521	1,521	-1,521	-1,521
N86	9	4	4	8	0,396	0,158	3,042	-1,521	-1,521	1,521	-1,521
N86	10	1	4	9	0,396	0,158	3,338	1,669	-1,669	1,669	1,669
N86	10	2	4	9	0,396	0,158	3,338	1,669	1,669	-1,669	1,669
N86	10	3	4	9	0,396	0,158	3,338	-1,669	1,669	-1,669	-1,669
N86	10	4	4	9	0,396	0,158	3,338	-1,669	-1,669	1,669	-1,669

9 Check of prestressed concrete

9.1 Check of prestressing reinforcement

Check of prestressing reinforcement is available in version 2011 if the prestressing tendon is defined on rib of the slab (on the 1D member). This is the third type of modelling (see chapter 4.1.2). Then Check of prestressing from the branch **Concrete > 1D members > Check of prestressed concrete > Check of prestressing reinforcement** can be used. This check

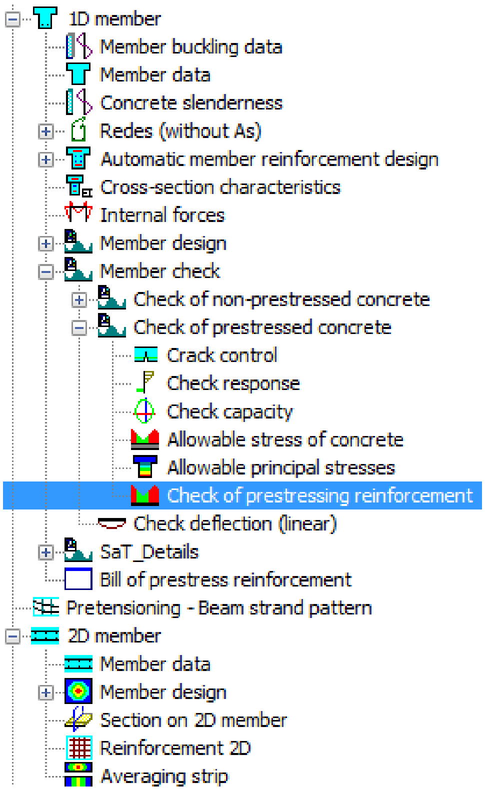


Fig. 63 Check of prestressing reinforcement

When we use the model with real tendon on the slab directly then the service for 1D element cannot be used. There is possibility to display in the ***Results > Beams > Tendon stresses***.

These values are code independent. It means without proper calculation with coefficients (e.g. r_{sup}, r_{inf} etc)

The structure is 2D. It means time dependent looses are not covered in the calculation. That why we receive zero losses (LCS) and higher maximal stresses (MaxStress)

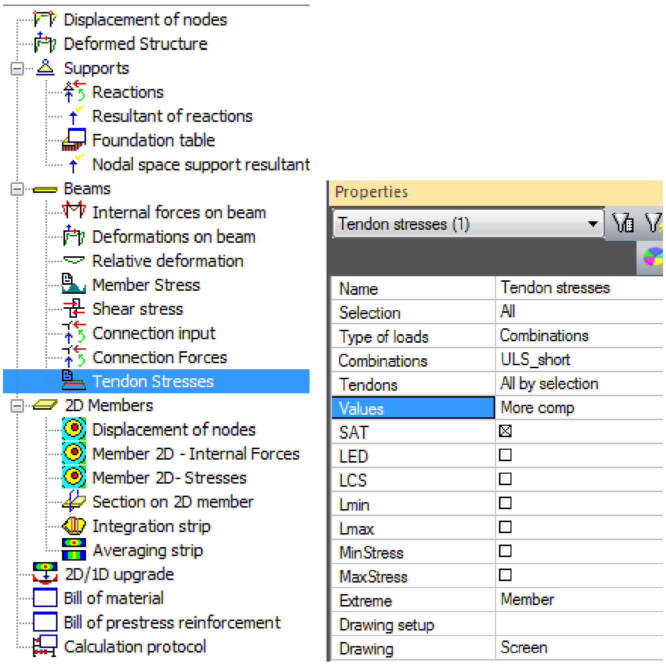


Fig. 64 Tendon stresses

The following checks should be performed according to [1]. These are the required checks:

- Stress prior anchoring (chapter 5.10.2.1 from [1])
- Stress after anchoring (chapter 5.10.3(3) from [1])
- Stress limitation due to cracks or deformation from characteristic combination (7.2(5) from [1])

9.1.1 Stress prior an after anchoring (chapters 5.10.2.1 and 5.10.3(3) from [1])

SEN provides only values named as “after anchoring” in the service tendon streses. Stress in the prestressing tendon prior and after anchoring is evaluated for combination ***ULS_short***. The detailed results are shown in the following table. The maximal value of concrete stress after anchoring is according to 5.10.2.1.

- ***Stress prior anchoring***

$$\sigma_{p,max} = min(k_1 \cdot f_{pk}; k_2 \cdot f_{p01k}) = min(0{,}8 \cdot 1860; 0{,}9 \cdot 1670) = 1488MPa$$
$$\sigma_{p,pa} = 1450MPa < 1488MPa = \sigma_{p,max} \rightarrow OK$$

- ***Stress after anchoring***

$$\sigma_{p,m0} = \min(k_7 \cdot f_{pk}; k_8 \cdot f_{p01k}) = \min(0{,}75 \cdot 1860; 0{,}85 \cdot 1670) = 1395MPa$$
$$\sigma_{p,aa} = 1407{,}43MPa > 1395MPa = \sigma_{p,m0} \rightarrow NOTOK$$

The results of the stress after anchoring are bit higher in the table below so probably the decreasing of the initial stresses for prestressing tendons should be adapted to less value than original 1450MPa.

Tendon stresses

Tendon stresses
Linear calculation, Extreme : Global
Selection : All
Tendons: All by selection
Combinations : ULS_short

Case	Tendon	x [m]	Stress after anchoring / transfer [MPa]	LED [MPa]	LCS [MPa]	Lmin [MPa]	Lmax [MPa]	MinStress [MPa]	MaxStress [MPa]
ULS_short	4ycA2	0,000	1339,44	0,00	0,00	0,00	0,00	1339,43	1339,43
ULS_short	4xcA4	28,500	1407,43	-0,61	0,00	0,00	0,00	1406,82	1406,82

9.1.2 Stress limitation due to cracks or deformation from characteristic combination (7.2(5) from [1])

Stress in the prestressing tendon due to cracks or deformation is evaluated for combination ***SLS_Char_long***. The detailed results are shown in the following table. The maximal value of concrete stress from characteristic combination is according to 7.2(5).

$$\sigma_{pm} = k_5 \cdot f_{pk} = 0{,}75 \cdot 1860 = 1395MPa$$

Tendon stresses

Tendon stresses
Linear calculation, Extreme : Global
Selection : All
Tendons: All by selection
Combinations : SLS_Char_long

Case	Tendon	x [m]	Stress after anchoring / transfer [MPa]	LED [MPa]	LCS [MPa]	Lmin [MPa]	Lmax [MPa]	MinStress [MPa]	MaxStress [MPa]
SLS_Char_long	4ysA3	0,000	1339,44	-0,06	0,00	0,00	0,00	1339,38	1339,38
SLS_Char_long	4xcA5	28,500	1407,43	-0,51	0,00	0,00	0,00	1406,92	1406,92

The maximal value sis higher than allowed but due to fact the losses from creep and shrinkage are not covered in this calculation the maximal value will be probably less than allowed 1395MPa.

Detailed calculation of the losses for each tendon is possible when you use action button ***Tendon losses*** when you select some tendon from the property window.

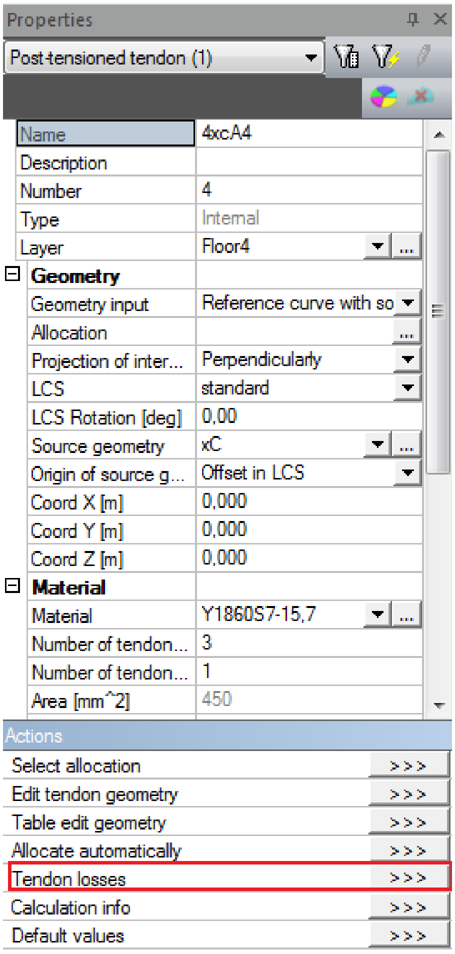
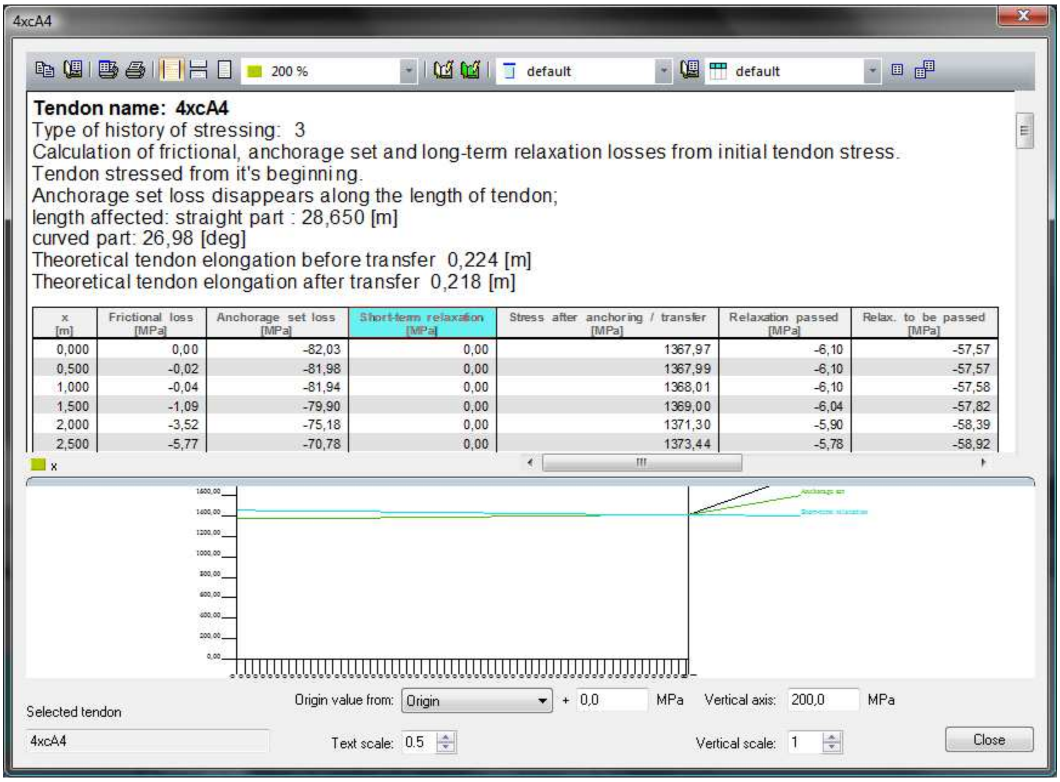


Fig. 65 Action button tendon losses



Tendon name: 4xcA4
Type of history of stressing: 3
Calculation of frictional, anchorage set and long-term relaxation losses from initial tendon stress.
Tendon stressed from it's beginning.
Anchorage set loss disappears along the length of tendon;
length affected: straight part : 28,650 [m]
curved part: 26,98 [deg]
Theoretical tendon elongation before transfer 0,224 [m]
Theoretical tendon elongation after transfer 0,218 [m]

x [m]	Frictional loss [MPa]	Anchorage set loss [MPa]	Short-term relaxation [MPa]	Stress after anchoring / transfer [MPa]	Relaxation passed [MPa]	Relax. to be passed [MPa]
0,000	0,00	-82,03	0,00	1367,97	-6,10	-57,57
0,500	-0,02	-81,98	0,00	1367,99	-6,10	-57,57
1,000	-0,04	-81,94	0,00	1368,01	-6,10	-57,58
1,500	-1,09	-79,90	0,00	1369,00	-6,04	-57,82
2,000	-3,52	-75,18	0,00	1371,30	-5,90	-58,39
2,500	-5,77	-70,78	0,00	1373,44	-5,78	-58,92

Fig. 66 Tendon losses

9.2 Check of allowable concrete stresses

This check is not possible for 2D members in Scia Engineer 2011 at all. User can evaluate only concrete stresses in menu **Results > 2D members > Member 2D stresses**.

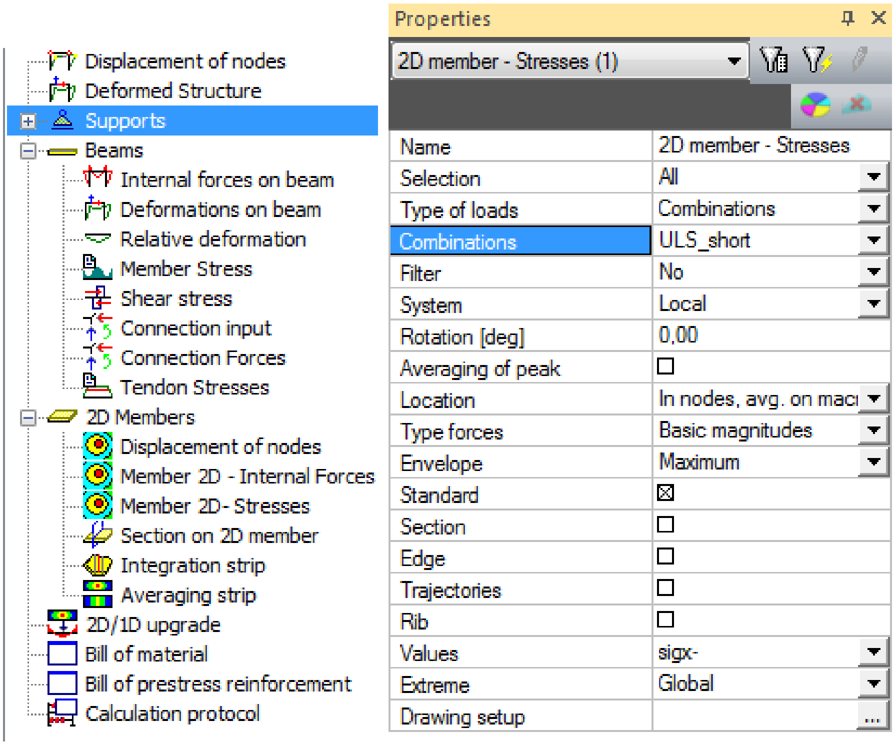


Fig. 67 Member 2D - Stresses

For each combination the results are displayed and user can check the values with limited values from the code [1]. The check is performed in three steps. These are the required checks:

- Concrete stress after anchoring
- Concrete stress under characteristic combination – longitudinal cracks (7.2(2))
- Concrete stress under quasi permanent combination – nonlinear creep (7.2(3))

Values from the next chapters are evaluated for the model with column heads with real defined tendon.

> **The calculation of the stresses do not cover the user defined or designed reinforcement. The obtained results can be higher than calculated with reinforcement.**

9.2.1 Concrete stress after anchoring

Concrete stress after anchoring is evaluated for combination ***ULS_short*** (After anchoring). The detailed results are shown in the following table. The maximal value of concrete stress after anchoring is according to 5.10.2.2(5).

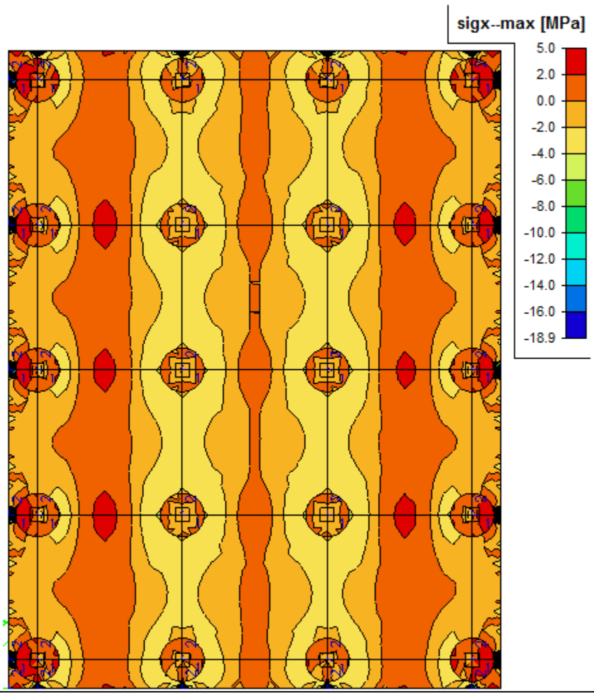
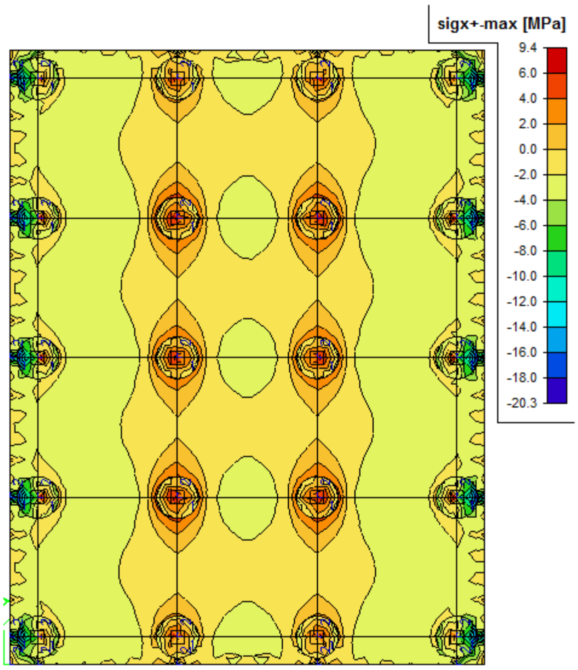
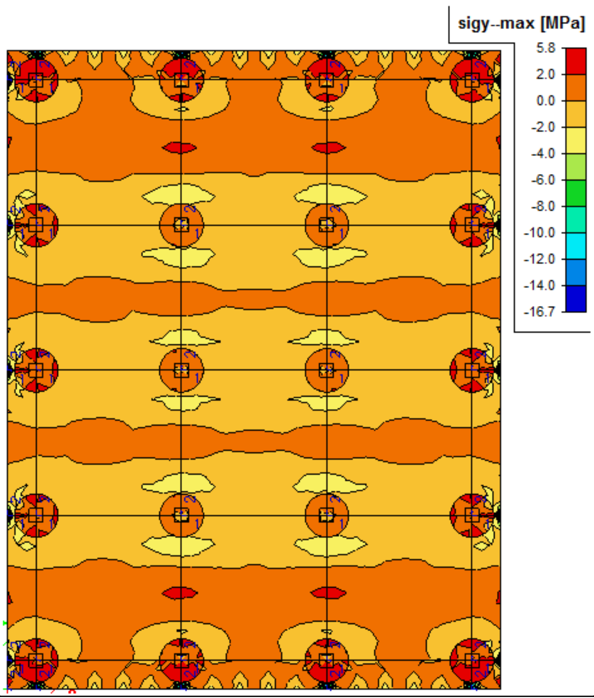
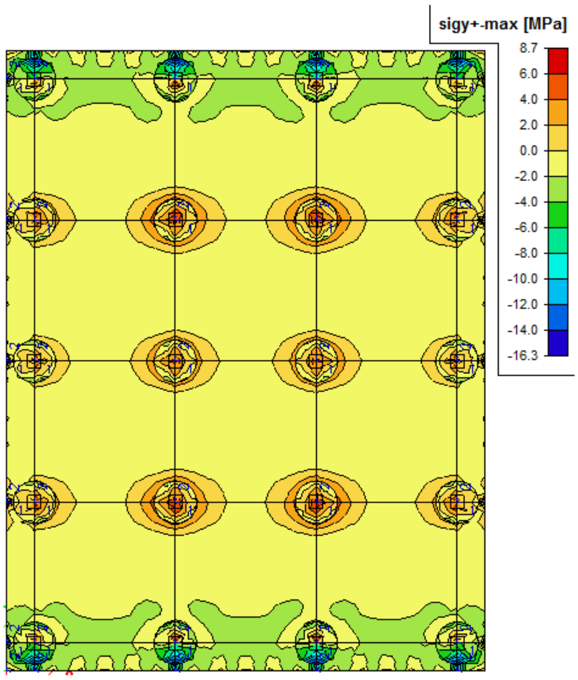
$$\sigma_{c,aa} = 0{,}6 \cdot f_{ck}(t)$$

The time dependent analysis is available only for 1D (plane XZ) element but it is not possible for 2D member. It means the current strength of concrete after anchoring has to be calculated manually. We supposed the anchoring of the postensioned tendons in 3 days.

$$f_{ck}(t=3) = \beta_{cc}(t) \cdot f_{cm} - 8MPa = e^{\left\{s\left[1-\left(\frac{28}{t}\right)^{0,5}\right]\right\}} \cdot f_{cm} - 8 = e^{\left\{0,2\left[1-\left(\frac{28}{3}\right)^{0,5}\right]\right\}} \cdot 43 - 8 = 20{,}51MPa$$

The maximal value of concrete strength after anchoring is then

$$\boldsymbol{\sigma_{c,aa}} = 0{,}6 \cdot f_{ck}(t) = 0{,}6 \cdot 20{,}51 = \mathbf{12{,}3}\boldsymbol{MPa}$$

<table>
<tr><th>Sigma</th><th>Lower (-)</th><th>Upper (+)</th></tr>
<tr><td>x</td><td></td><td></td></tr>
<tr><td>y</td><td></td><td></td></tr>
</table>

9.2.2 Concrete stress under characteristic combination – longitudinal cracks (7.2(2))

Concrete stress under characteristic combination is evaluated for combination ***SLS_Char_long***. The detailed results are shown in the following table. For this combination we check the stress in

- ***Compression***
  - The maximal value of concrete compressive stress is according to 7.2(2).

$$\sigma_{cc,ch} = k_1 \cdot f_{ck}(t); k_1 = 0{,}6$$

- ***Tension***
  - The maximal value of concrete tensile stress is according to 7.1(2).

$$\sigma_{ct,ch} = f_{ct,eff}(t) = f_{ctm}(t)$$

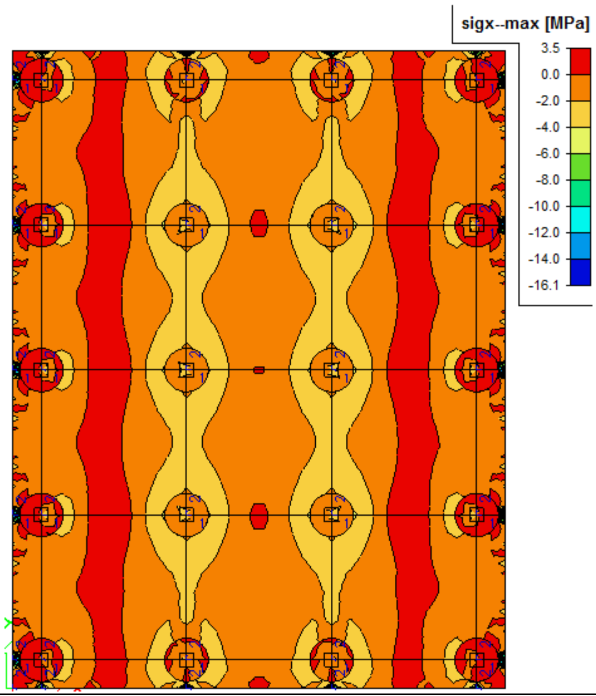
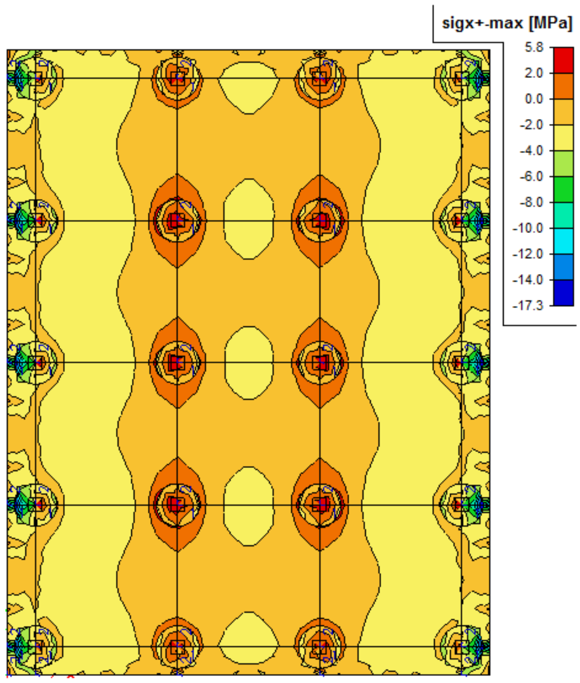
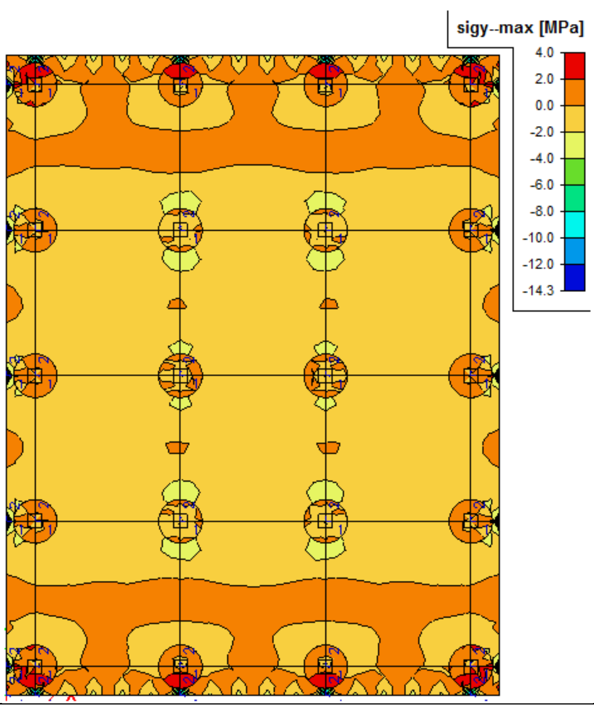
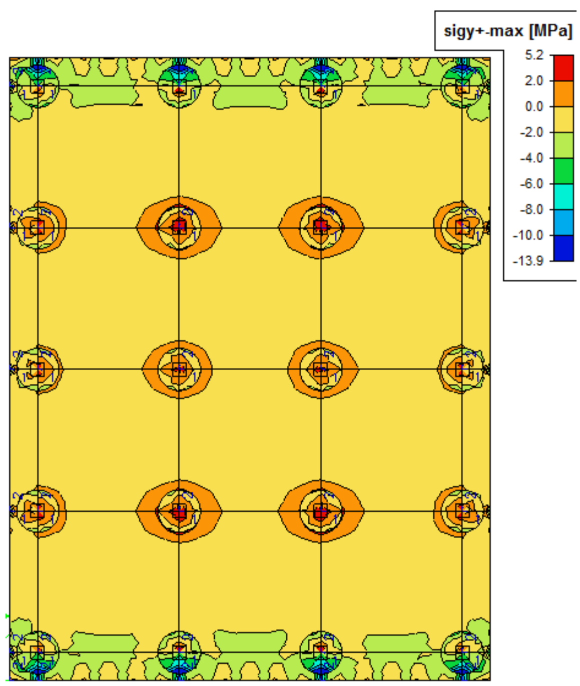
Strength of concrete in working life 50years has to be calculated manually. We supposed the working life 50 years (18250days).

$$f_{ck}(t=18250)=\beta_{cc}(t)\cdot f_{cm}-8MPa=e^{\left\{s\left[1-\left(\frac{28}{t}\right)^{0,5}\right]\right\}}\cdot f_{cm}-8=e^{\left\{0,2\left[1-\left(\frac{28}{18250}\right)^{0,5}\right]\right\}}\cdot 43-8=44{,}11MPa$$

The maximal values of concrete strength are the following

$$\boldsymbol{\sigma_{cc,ch}}=0{,}6\cdot f_{ck}(t)=0{,}6\cdot 44{,}11=\mathbf{26{,}47}\boldsymbol{MPa}$$

$$\boldsymbol{\sigma_{ct,ch}}=f_{ctm}(t)=0{,}3\cdot\left(f_{ck}(t)\right)^{2/3}=0{,}3\cdot(44{,}11)^{2/3}=\mathbf{3{,}74}\boldsymbol{MPa}$$

Sigma	Lower (-)	Upper (+)
x		
y		

You can see all compressive stress in concrete are less than limit value $\boldsymbol{\sigma_{c,ch}}=\mathbf{26{,}47}\boldsymbol{MPa}$. When you look on tensile concrete stress there are higher values (max 5,8MPa) These stresses will be probably transferred by the reinforcement because the calculation of the stresses do not cover the user defined or designed reinforcement.

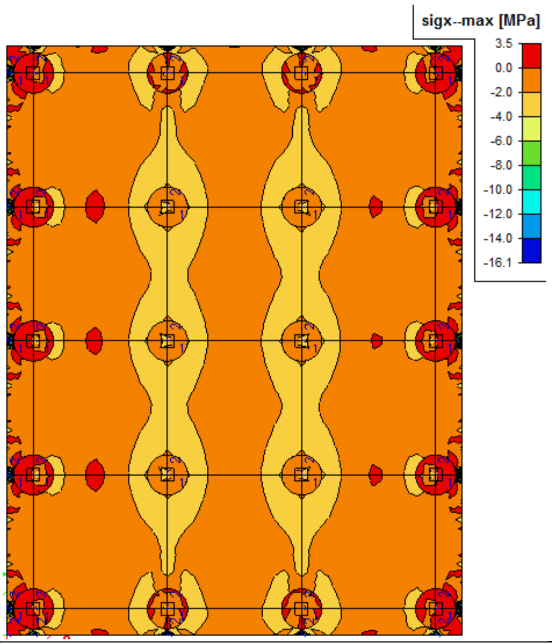
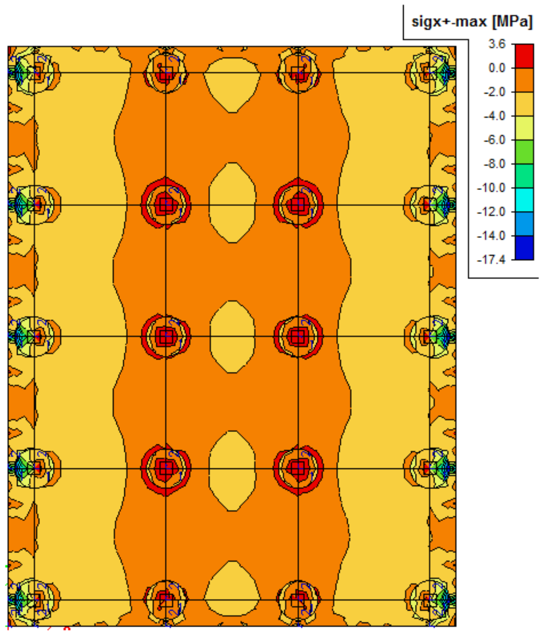
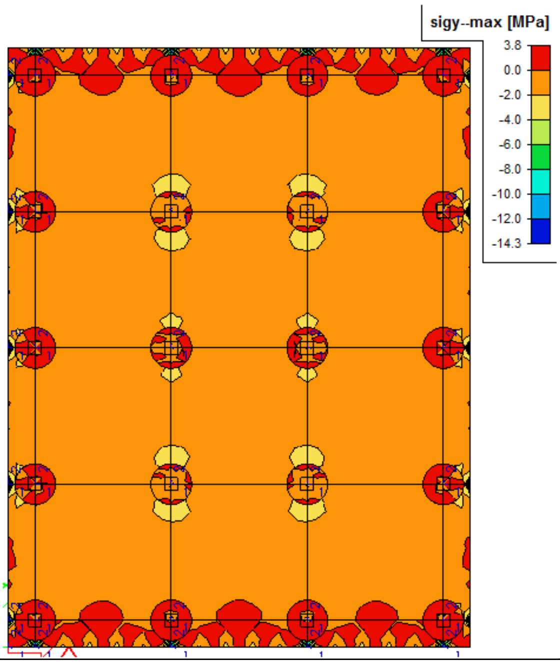
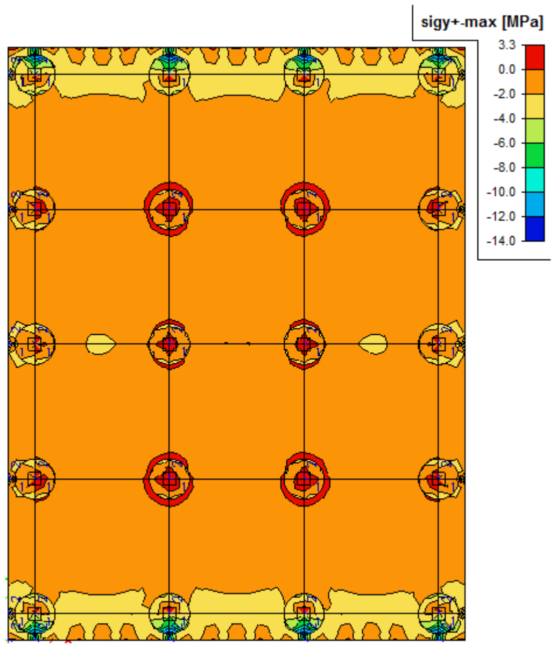
9.2.3 Concrete stress under quasi permanent combination – nonlinear creep (7.2(3))

Concrete stress under quasi permanent combination is evaluated for combination ***SLS_QP_long***. The detailed results are shown in the following table. The maximal value of concrete compressive stress is according to 7.2(3).

$$\sigma_{cc,ch} = k_2 \cdot f_{ck}(t); k_2 = 0{,}45$$

The maximal values of concrete strength are the following

$$\boldsymbol{\sigma_{cc,qp}} = 0{,}45 \cdot f_{ck}(t) = 0{,}6 \cdot 44{,}11 = \mathbf{19{,}85}\boldsymbol{MPa}$$

Sigma	Lower (-)	Upper (+)
x		
y		

You can see all compressive stress in concrete are less than limit value $\boldsymbol{\sigma_{cc,qp}} = \mathbf{19{,}85}\boldsymbol{MPa}$**.**

9.3 Check capacity

There is not special service for Capacity check. The capacity of the slab in ULS can be verify by calculation of the **Additional reinforcement** in service **Design ULS**. If Additional reinforcement is equal to zero then capacity of the slab is OK and no additional reinforcement is required.

9.4 Check crack width

Check of cracks on 2D members is not available in Scia Engineer 2011 but only design of necessary area of nonprestressed reinforcement is done with respect of the effects of the prestressing. This procedure should satisfy the fulfilling of the code required limited cracks widths.
Design of the nonprestressed reinforcement for serviceability limit state is done together with design for ultimate limit state in one service **Concrete > 2D members >Design ULS+SLS**.

New service of Member check for 2D has been implemented in version Scia Engineer 2011 and will not be commented more in this tutorial

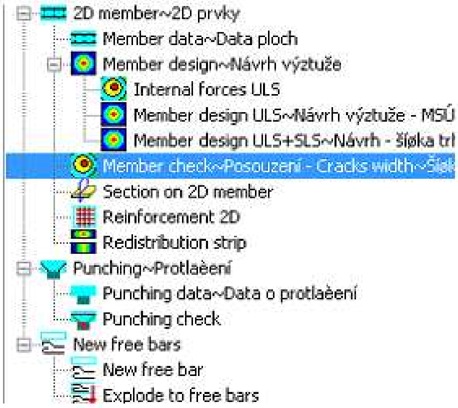


Fig. 68 New service crack width

10 Check deflection – code dependent calculation (CDD)

With respect of the different modelling of the postensioned slab (see 4.1) the evaluation of CDD deflection is available only for one of them. Code dependent calculation with real postensioned tendons modelled by hanging nodes or allocated on the ribs is not possible in version Scia Engineer 2011. Code dependent deflection is available only for the prestressing defined by the equivalent load. The background of the CDD calculation is more explained in the [6].

10.1 Concrete combinations

Concrete combinations are special combinations which are used only for calculation of code dependent deflection (CDD). We have to prepare combinations with the same prescription as EN SLS quasi permanent. There is not special tool for preparation of the code dependent concrete combination in the program. All combinations have to be prepared manually.

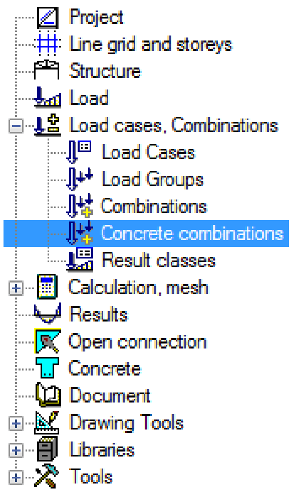


Fig. 69 Concrete combination

We need to calculate total and additional deflection for this slab according to 7.4.1 (4)(5) from [1]. That's why we have to prepare two concrete combinations. The first combination (CC1) will be used for calculation of the ***Total deflection*** and also deflection caused by the creep and longterm loads will be calculated from this combination. The second combination (CC2) will be used for evaluation of the ***immediate deflection*** which will be used for calculation of the ***additional deflection***

The prescription for preparation of both combinations abased on EN SLS quasi-permanent combination with respect of the longterm losses is the following:

$$CC1 = 1{,}0 * SW + 1{,}0 * DL + 0{,}9 * 0{,}85 * P$$

$$CC2 = 1{,}0 * SW + 1{,}0 * DL + 0{,}9 * 0{,}85 * P + \Psi_2 * LL$$

SW selfweight
DL dead load
P prestressing
LL life load

Factors for prestressing mean shorterm (0,9) and longterm losses (0,85)

Life load is from category F ➔ Ψ_2 =0,6

Only one variable load can be insert into concrete combination for calculation of the nonlinear deflection with creep. There is not combinatory for preparation of extreme combination from more variable loadcases fro CDD calculation. We could prepare new combination for each variable loadcase.

The combinations look as the following in the program

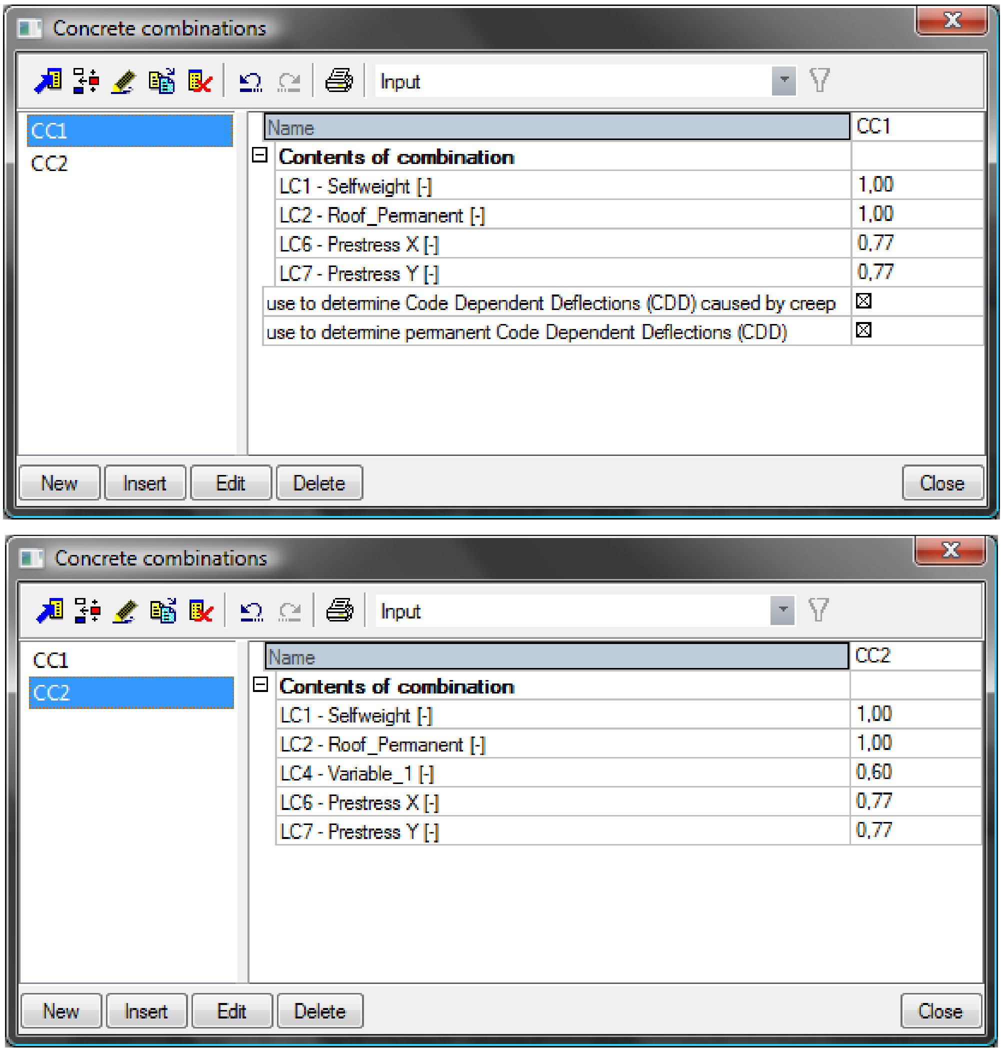


Fig. 70 Concrete combinations

10.2 Code dependent calculation

The nonprestressed reinforcement (user defined or designed) is needed for the calculation of CDD. There is more option in ***Concrete solver > SLS > Code dependent deflection*** how to deal with the reinforcement. The area of the user defined reinforcement (bars representing prestressing and 2D mesh reinforcement) will be taken into account for the calculation of the CDD as we set in concrete solver (se following figure) – ***As,user***. The same designed and defined user reinforcement was used in this calculation as was used for model with real tendon and column head (see chapter 7.3.3).

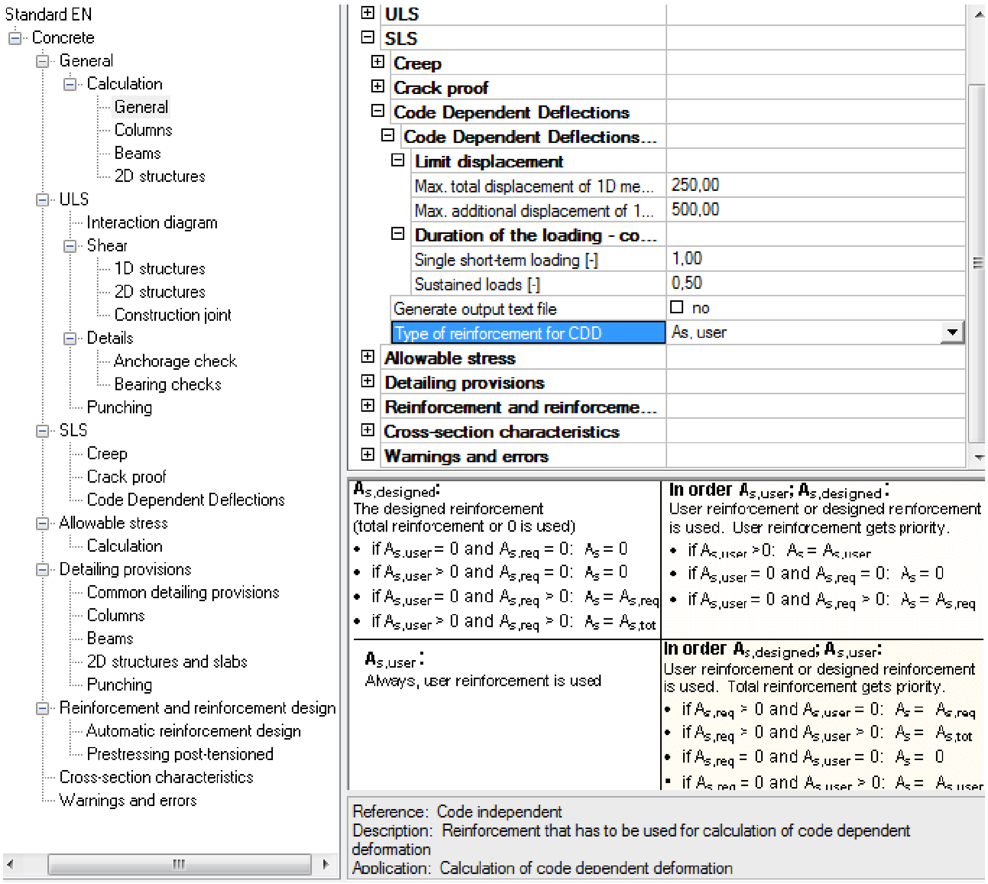


Fig. 71 Settings in Concrete solver

Then everything is prepared for the CDD calculation. The first step is run linear calculation. When linear calculation is finished then CDD calculation can be run.

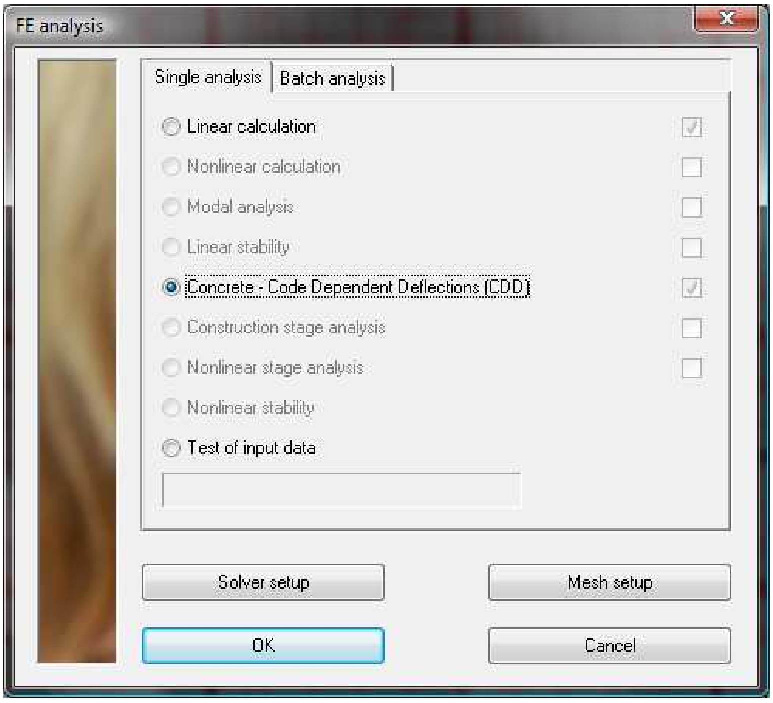


Fig. 72 Dialogue for running CDD

Afterwards we get the confirmation dialogue about general deflections.

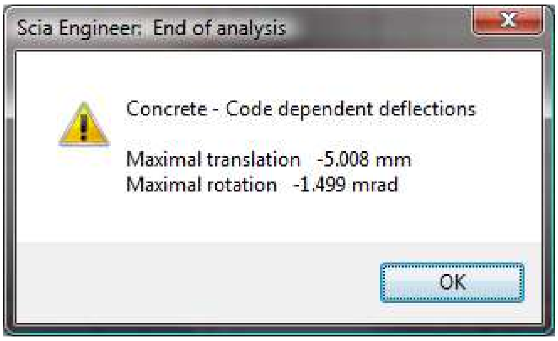


Fig. 73 Confirmation dialogue after CDD calculation

10.3 Stiffness presentation

The service for stiffness presentation is the first service which appears only after CDD calculation. This service is in concrete tree (***2D Member > Member check > Stiffness presentation***).

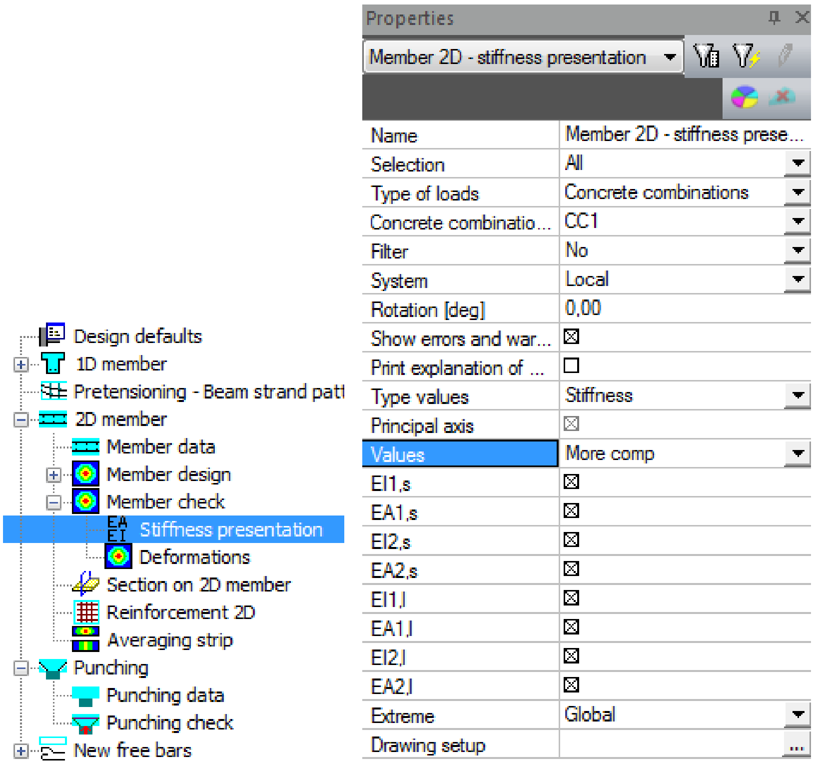
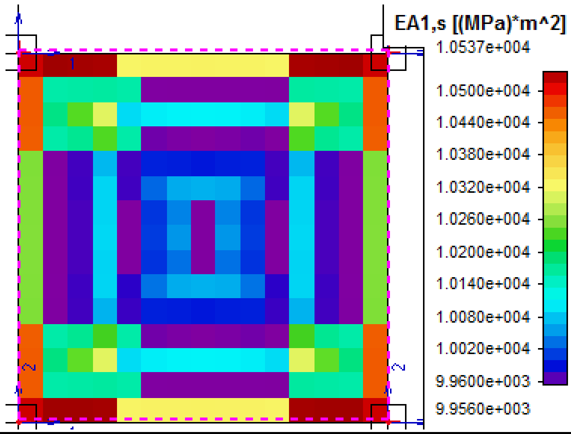
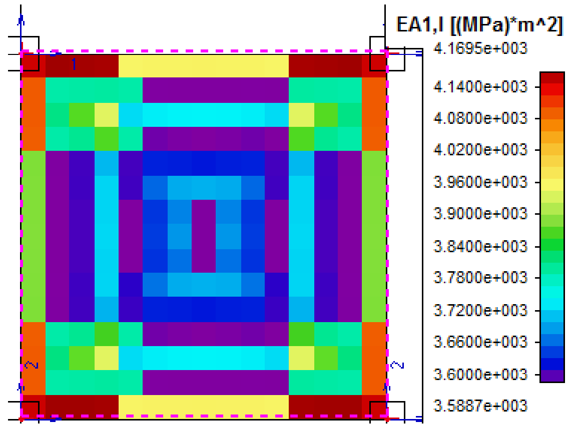
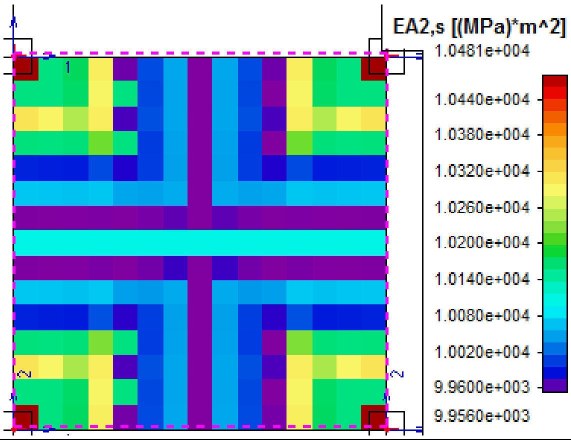
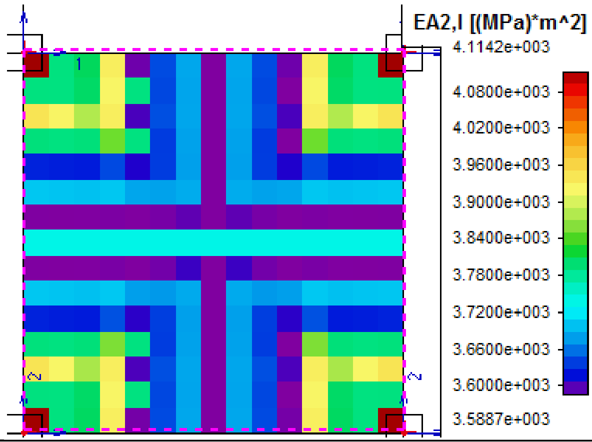
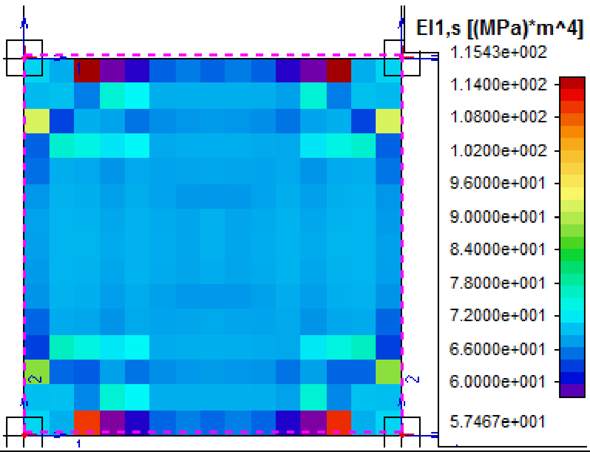
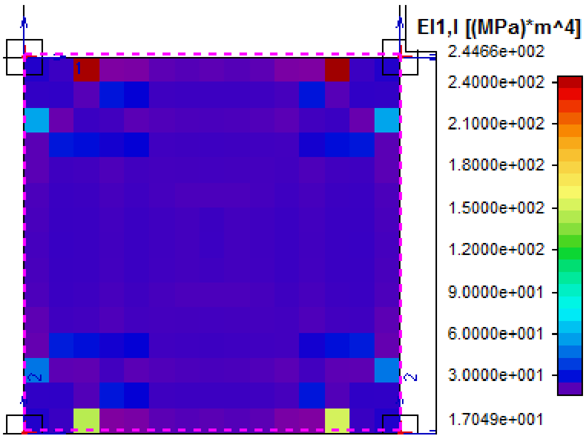
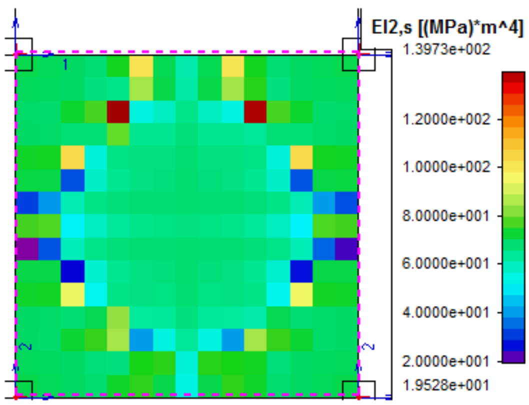
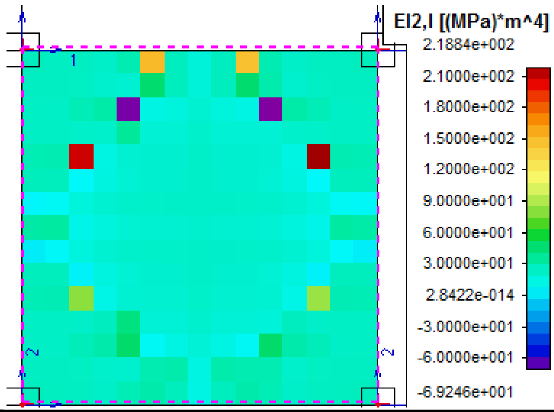


Fig. 74 Service for stiffness presentation

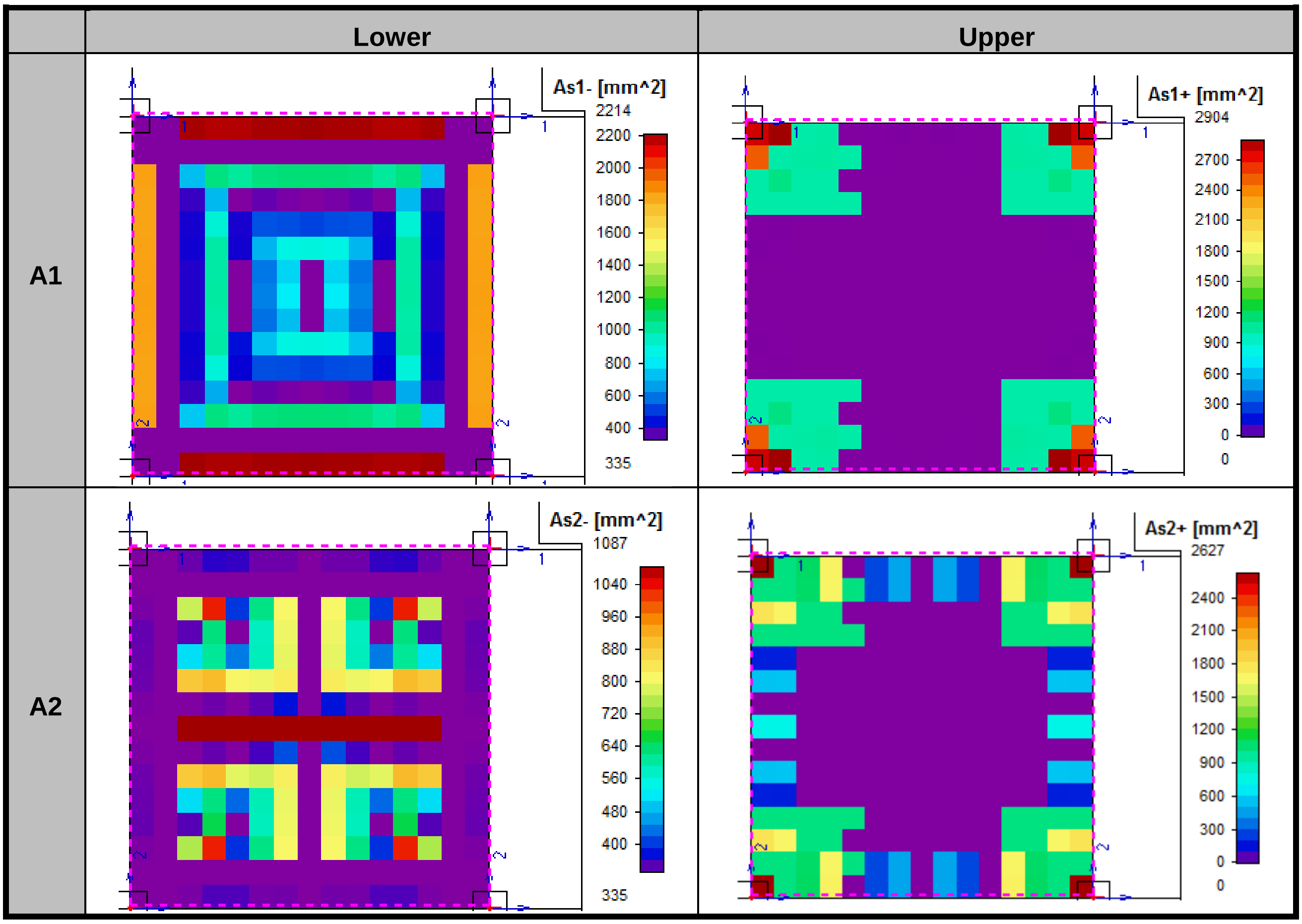
There is possible to evaluate two types of values in this service:

- ***Required areas*** – areas of the reinforcement which are used for the CDD calculation (user or required areas)
- ***Stiffness's*** – shorterm (s) and longterm (l) axial (EA) and bending (EI) stiffness's in both directions (1,2)

The stiffness's are the following. Graphical presentation is done for better overview again for the slab S138.

	Shorterm	Longterm
EA 1		
EA 2		
EI1		
EI2		

The required areas are the following. Graphical presentation is done for better overview again for the slab S138. The values correspond with user defined reinforcement (freebars representing prestressing and designed user defined 2D reinforcement).



Member 2D - stiffness presentation 2D (stiffness - principal axis)

Member 2D - stiffness presentation 2D (stiffness - principal axis)
Member 2D - stiffness presentation 2D (required area - member axis)

Member elem	Case	n_1 [kN/m] n_2 [kN/m]	m_1 [kNm/m] m_2 [kNm/m]	$n_{r1,s}$ [kN/m] $n_{r2,s}$ [kN/m]	$m_{r1,s}$ [kNm/m] $m_{r2,s}$ [kNm/m]	$n_{r1,l}$ [kN/m] $n_{r2,l}$ [kN/m]	$m_{r1,l}$ [kNm/m] $m_{r2,l}$ [kNm/m]	$EI_{1,s}$ [(MPa)*m^4] $EI_{2,s}$ [(MPa)*m^4]	$EA_{1,s}$ [(MPa)*m^2] $EA_{2,s}$ [(MPa)*m^2]	$EI_{1,l}$ [(MPa)*m^4] $EI_{2,l}$ [(MPa)*m^4]	$EA_{1,l}$ [(MPa)*m^2] $EA_{2,l}$ [(MPa)*m^2]
S155	CC2	-607,38	1,53	-10557,44	26,57	-10411,81	26,21	**-1,0205e+03**	1,0325e+04	-1,5974e+01	3,9574e+03
3361		-801,76	-1,85	-9761,07	-22,57	-9907,08	-22,91	5,5459e+01	1,0093e+04	1,5082e+01	3,7259e+03
S139	CC2	-481,95	-1,39	-10749,44	-31,02	-10823,03	-31,23	**3,2438e+04**	1,0474e+04	-1,9412e+01	4,1071e+03
1626		-416,17	-30,18	-1928,48	-139,84	-2061,12	-149,45	7,1813e+01	1,0239e+04	2,7189e+01	3,8716e+03
S127	CC2	-451,50	15,79	-5875,77	205,50	-5853,38	204,71	6,8664e+01	**9,9560e+03**	2,4065e+01	**3,5887e+03**
14		-114,59	1,05	-8485,62	77,77	-8406,40	77,04	6,5088e+01	9,9560e+03	2,0985e+01	3,5887e+03
S142	CC2	-503,59	-27,40	-4850,02	-263,87	-3910,20	-212,74	6,8857e+01	**1,0537e+04**	2,4490e+01	**4,1697e+03**
1952		-399,83	-43,03	-774,72	-83,37	-807,07	-86,85	7,0649e+01	1,0161e+04	2,6022e+01	3,7940e+03
S147	CC2	-492,47	11,22	-6802,86	154,97	-6678,00	152,13	6,3565e+01	1,0240e+04	2,0271e+01	3,8730e+03
2713		-354,36	-0,55	-10357,34	-15,93	-10180,18	-15,66	**-1,9873e+03**	1,0103e+04	-1,4957e+01	3,7353e+03
S137	CC2	-482,32	0,53	-9676,79	10,57	-9315,79	10,18	2,2664e+01	1,0106e+04	3,9742e+00	3,7382e+03
1078		-410,05	-0,53	-10270,97	-13,26	-10046,02	-12,97	**3,6664e+03**	1,0012e+04	-1,5341e+01	3,6447e+03
S147	CC2	-469,99	-56,31	-641,28	-76,83	-665,52	-79,73	7,0672e+01	1,0498e+04	2,6052e+01	4,1309e+03
2508		-448,95	-77,76	-372,44	-64,51	-395,05	-68,42	3,2357e+01	**7,2072e+03**	1,3944e+01	**2,7581e+03**
S144	CC2	-427,92	-59,42	-512,58	-71,17	-541,64	-75,21	7,0990e+01	1,0483e+04	2,6340e+01	4,1156e+03
2389		-469,65	-67,99	-477,18	-69,08	-498,19	-72,12	7,0787e+01	**1,0516e+04**	2,6158e+01	**4,1487e+03**
S139	CC2	-414,29	-1,81	-10173,97	-44,50	-11717,23	-51,25	1,2277e+02	1,0441e+04	**-1,3567e+03**	4,0735e+03
1594		-481,83	-30,00	-3116,72	-194,05	-2992,35	-186,31	7,0848e+01	1,0333e+04	2,6241e+01	3,9654e+03
S137	CC2	-428,15	1,21	-10113,05	28,46	-11073,47	31,17	1,1400e+02	1,0211e+04	**4,9964e+03**	3,8433e+03
1007		-469,75	-32,73	-2069,35	-144,18	-2030,09	-141,45	7,0150e+01	1,0262e+04	2,5555e+01	3,8950e+03
S142	CC2	-556,69	18,72	-5902,23	198,44	-5793,20	194,77	6,5300e+01	1,0330e+04	2,1579e+01	3,9631e+03
1943		-370,25	-0,72	-9969,51	-19,28	-10340,36	-20,00	1,1053e+02	9,9574e+03	**-1,5636e+03**	3,5901e+03
S137	CC2	-466,11	6,75	-7708,43	111,56	-7551,29	109,29	6,2832e+01	1,0073e+04	1,9468e+01	3,7060e+03
1102		-397,42	-2,21	-9665,46	-53,85	-10716,45	-59,71	1,1301e+02	1,0087e+04	**8,5927e+03**	3,7195e+03

Member 2D - stiffness presentation 2D (required area - principal axis)

Member 2D - stiffness presentation 2D (required area - principal axis)
Member 2D - stiffness presentation 2D (required area - member axis)

Member	Case	elem	n_1 [kN/m] n_2 [kN/m]	m_1 [kNm/m] m_2 [kNm/m]	A_{s1+} [mm²] A_{s2+} [mm²]	A_{s1-} [mm²] A_{s2-} [mm²]	A_{s1} [mm²] A_{s2} [mm²]	A_{st1} [mm²] A_{st2} [mm²]	A_{sc1} [mm²] A_{sc2} [mm²]
S126	CC2	1	13,78	7,46	513	**335**	848	335	513
			-26,11	-0,91	513	**335**	848	0	848
S138	CC2	1406	-492,54	15,49	0	**2214**	2214	0	2214
			-402,47	2,06	0	335	335	0	335
S128	CC2	87	-512,71	1,57	579	574	1153	0	1153
			-446,97	-5,50	523	**1975**	2498	0	2498
S127	CC2	14	-451,50	15,79	**0**	335	335	0	335
			-114,59	1,05	**0**	335	335	0	335
S144	CC2	2390	-503,59	-27,40	**2905**	335	3240	0	3240
			-399,83	-43,03	1026	335	1361	1026	335
S144	CC2	2389	-427,92	-59,42	2634	335	2970	2634	335
			-469,65	-67,99	**2800**	335	3135	2800	335

10.4 Deformation check

After successful running of CDD new service for evaluation of deflection appears in concrete tree (***2D Member > Member check > Deformations***).

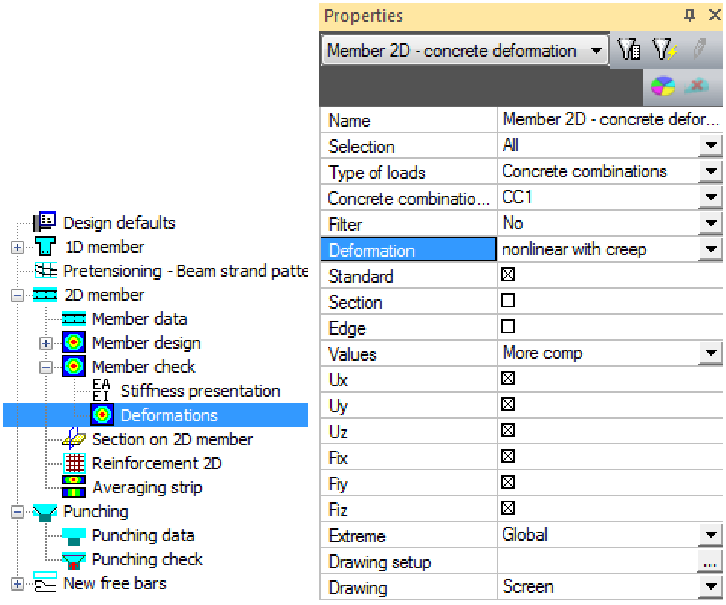


Fig. 75 Service for deformation check

Two checks of deflections are required according to 7.4.1(4)(5) from [1]. The deflections are evaluated in the following way. Two required checks are:

- ***Check of total deflection*** (7.4.1(4)) – the limit value L/250; $L_x = L_y = 9000mm$

$$\boldsymbol{\delta_{tot,lim} = L/250 = 9000/250 = 36mm}$$

- ***Check of additional deflection*** (7.4.1(5)) – the limit value L/500

$$\boldsymbol{\delta_{add,lim} = L/500 = 9000/500 = 18mm}$$

Total and additional deflections are not evaluated directly for 2D members. Special algorithm has to be applied for calculation of these deflections.

10.4.1 Total deflection

Total deflection (δ_{tot}) is calculated for combination including also variable loads (CC2) as the sum of the ***Elastic deformation*** $(\delta_{NL,CC2})$ and ***Creep deformation***(δ_{creep}). Elastic deformation is nonlinear deformation for combination CC2. Creep deformation can be evaluated as the difference between ***Nonlinear+creep*** $(\delta_{NL,creep,CC1} or \delta_{NL,creep,CC2})$ and ***Nonlinear*** $(\delta_{NL,CC1} or \delta_{NL,CC2})$ fro combination CC1 or CC2. In fact ***Total deflection*** is deflection for combination CC2 as type ***Nonlinear+creep*** $(\delta_{NL,creep,CC2})$

CC2 $\delta_{tot} = \delta_{NL,CC2} + \delta_{creep} = \delta_{NL,creep,CC2}$

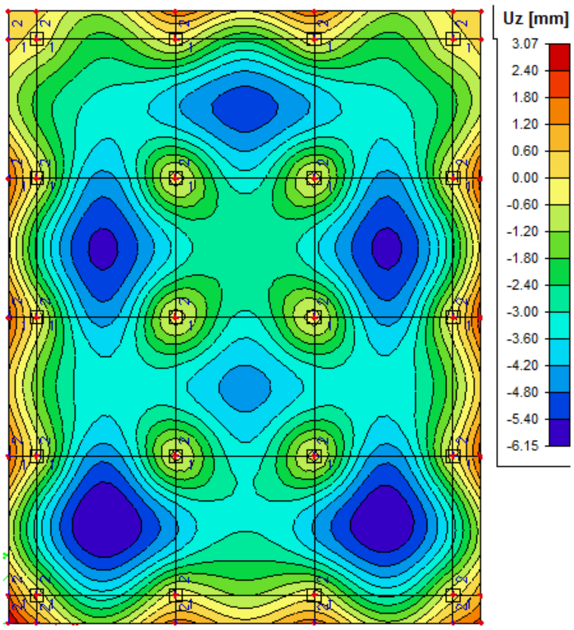
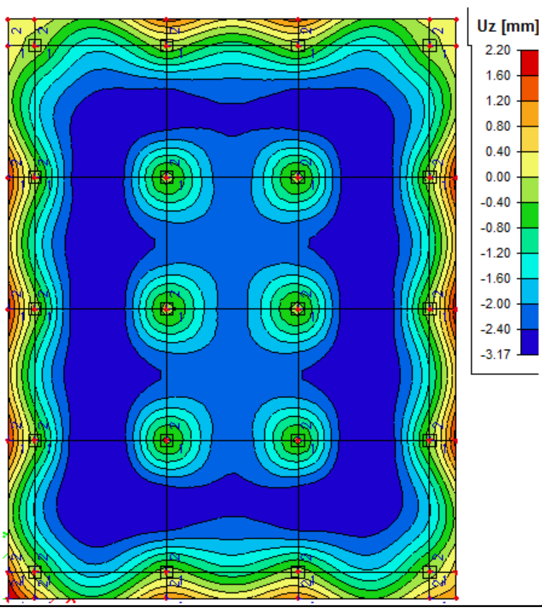
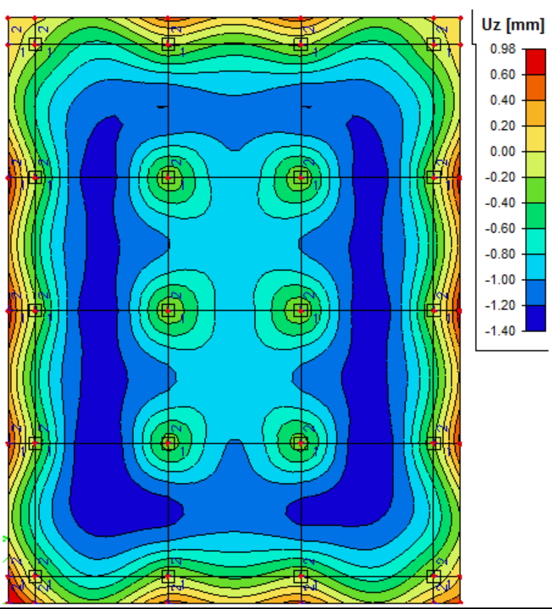


Fig. 76 Total deflection

Maximum value is $\boldsymbol{\delta_{tot,calc}} = \mathbf{6,15}\boldsymbol{mm} < 36\boldsymbol{mm} = \boldsymbol{\delta_{\text{tot,lim}}}$ ➔ **Check is satisfied.**

If the ***creep deformation*** (δ_{creep}) is also required then this value is calculated as difference between ***Nonlinear+creep*** $(\delta_{NL,creep,CC1})$ and ***Nonlinear*** $(\delta_{NL,CC1})$ deformation for combinations CC1 where checkbox calculated to creep has been switch ON:

CC1 $\delta_{creep} = \delta_{NL,creep,CC1} - \delta_{NL,CC1}$

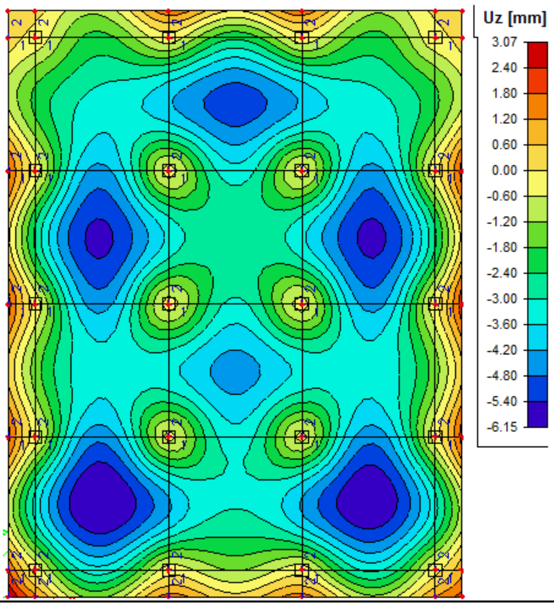
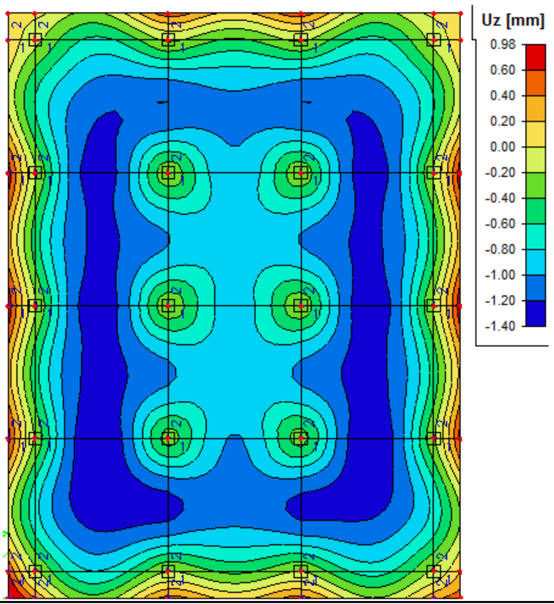
	$\boldsymbol{\delta_{NL,creep,CC1}}$	$\boldsymbol{\delta_{NL,CC1}}$
Screen		
Values	--3,17mm	-1,40mm
$\boldsymbol{\delta_{creep}}$	-3,17 - (-1,40) = **-1,77 mm**	

10.4.2 Additional deflection

Additional deflection is calculated for combination CC2 as the difference between total and immediate deflection. The ***immediate deflection*** is evaluated for combination CC1 as the ***nonlinear deflection***(δ_{NL}).

CC1 $\delta_{imm} = \delta_{NL,CC1}$

CC2 $\delta_{add} = \delta_{tot} - \delta_{imm}$

<table>
<tr><th></th><th>$\boldsymbol{\delta_{tot}}$</th><th>$\boldsymbol{\delta_{imm} = \delta_{NL,CC1}}$</th></tr>
<tr><td>Screen</td><td>
</td><td>
</td></tr>
<tr><td>Values</td><td>-6,15mm</td><td>-1,40mm</td></tr>
<tr><td>$\boldsymbol{\delta_{add}}$</td><td colspan="2">-6,15 - (-1,40) = -4,75 mm</td></tr>
</table>

Maximum value is $\boldsymbol{\delta_{add,calc} = 4,75mm < 18mm = \delta_{add,lim}}$ ➔ **Check is satisfied.**

11 Summary and conclusions

One floor of the parking house has been modelled and checked in this tutorial. We introduced two possibilities how to defined prestressing on the slab (equivalent load, real tendon). Each option has some advantages and disadvantages. General overview is possible to see in the following table.

Item	Equivalent load	Real tendon
Preparation and definition of the prestressing	Difficult	Simple
Shorterm losses	NO	YES
Longterm losses	NO	NO
Internal forces from prestressing in design	YES	YES
Area of prestressing in design	NO (freebars are used)	NO (freebars duplicate geometry of the tendons)
Design ULS(ULS+SLS)	YES	YES
Check of allowable concrete stresses	NO	NO
Check prestressed capacity or response	NO	NO
Check of prestressing reinforcement	NO	YES (partly)
Check punching with respect of prestressing	YES	YES
Code dependent deflection (CDD)	YES	NO
Is needed module postensioning?	NO	YES

The solution for postensioned slab is not 100% comfortable and it doesn't bring complete solution but with using of this tutorial you will be able to perform design of such kind of the structure and also check it.

12 Bibliography

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