

Advanced Expert Training Post-tensioning



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Introduction

All discussed topics are available in the Expert Edition or the Precast Edition of Scia Engineer.

The precast module of Scia Engineer allows the making of an analysis of pre-tensioned or posttensioned structures. The difference between calculating a pre-tensioned or post-tensioned construction is only in the input. With a pre-tensioned construction, one works with a bore hole pattern. With post-tensioned structures, one has to determine the path of the cable. This course document will treat some examples of post-tensioned constructions.

When making a linear analysis of a post-tensioned construction, there is no limitation concerning the model, which is definitely a strong point of the software. In a 'General XYZ' environment one can perfectly model and analyze the most complex post-tensioned constructions. Here analyzing is meant as a linear calculation with the finite element method of a post-tensioned construction.

The limitation is that long term losses can't be calculated, because a time dependent analysis is only possible in a 2D environment (XZ frame). This is why we shall limit the first two examples to a 2D-environment, to see how these time dependant losses can be calculated. Moreover, one can also execute the necessary Euro Code controls on a post-tensioned beam.

The first part shall cover an example on a very simple rectangular beam en has the sole purpose to explain the input en output possibilities of a post-tensioned Construction. The second part will cover a U-formed bridge (Dutch: 'trogligger') where the post-tensioned cable is inputted by means of source geometry. Next there will be a time-dependant analysis executed on it to calculate shrink, creep and relaxation by using the TDA module (time-dependant analysis). The third and fourth chapter will contain examples about a post-tensioned plate model in the 'General XYZ' environment.

Linear analysis of a post-tensioned beam

1_Input of geometry and post-tensioning

 Before starting a project with pre- or post-tensioning, the 'Prestress' option must be checked in the functionalities menu.

Initial stress Advanced Mod Subsoil Image: Concrete Fire resistance Image: Concrete Nonlinearity Image: Concrete Fire resistance Image: Concrete Stability Image: Concrete Fire resistance Image: Concrete Climatic loads Image: Concrete Fire resistance Image: Concrete Prestressing Image: Concrete Fire resistance Image: Concrete Stability Image: Concrete Fire resistance Image: Concrete Prostressing Image: Concrete Fire resistance Image: Concrete Studie Image: Concrete Fire resistance Image: Concrete Studie Image: Concrete Fire resistance Image: Concrete Studie Image: Concrete Fire resistance Image: Concrete BIM properties Image: Concrete Fire resistance Image: Concrete <tr< th=""><th>Dynamics</th><th></th><th>-</th><th>Prestressing</th><th></th></tr<>	Dynamics		-	Prestressing	
Nonlinearity Stability Climatic loads Prestressing Pipelines Structural model BIM properties Parameters Mobile loads LTA - load cases External application checks KP1 application Property modifiers	eer Initial stress			Advanced	
Stability Image: Climatic loads Image: Climatic loads Prestressing Image: Climatic loads Image: Climatic loads Prestressing Image: Climatic loads Image: Climatic loads Pipelines Image: Climatic loads Image: Climatic loads Structural model Image: Climatic loads Image: Climatic loads BIM properties Image: Climatic loads Image: Climatic loads Parameters Image: Climatic loads Image: Climatic loads LTA - load cases Image: Climatic loads Image: Climatic loads External application checks Image: Climatic loads Image: Climatic loads KP1 application Image: Climatic loads Image: Climatic loads Property modifiers Image: Climatic loads Image: Climatic loads	Subsoil		-	Concrete	
Climatic loads Climatic loads Prestressing Pipelines Structural model BIM properties Parameters Mobile loads LTA - load cases External application checks KP1 application Property modifiers	Nonlinearity			Fire resistance	
Prestressing Image: Source of the sector	Stability			Hollow core slab	
Pipelines I Structural model I BIM properties I Parameters I Mobile loads I LTA - load cases I External application checks I KP1 application I Property modifiers I	Climatic loads				
Structural model	Prestressing	M			
BIM properties BIM properties	Pipelines				
Parameters Parameters Nobile loads ITA - load cases External application checks KP1 application Property modifiers I	Structural model				
Mobile loads Image: Constraint of the second seco	BIM properties				
LTA - load cases LTA - load cases KP1 application checks Property modifiers	Parameters				
External application checks KP1 application Property modifiers	Mobile loads				
KP1 application Image: Comparison of the comparison of	LTA - load cases				
Property modifiers	External application checks	s 🗆 🗌			
The poly mean of the second seco	KP1 application				
Dideo design	Property modifiers				
bridge design	Bridge design				

• Next the beam can be modelled. In this example, we will use a rectangular beam (400mm by 800mm, in concrete quality C60/75) of 10m length, which is carried by hinged supports at both ends.

· · · ·			
B1/Recta	ngle (800; 400)/10,000 n	n	

Adding the post-tensioning is done in the structure menu. Under 'tendons' you will find the
possibility to input 'Post-tensioned tendons'.
 (Remark: inputting pre-tensioned tendons is done in the concrete menu)

The input of post-tensioned tendons can be done in three ways:

- Through direct input, where the user insert the cable himself into the model.
- Through direct input, where the user imports the cable path through dwg/dxf and converts it into a cable.
- Through source geometry where the user inputs coordinates for the cable and the program will interpolate between these point through possible geometric methods (which the user also indicates).

None of these three options will calculate the optimal cable path. The responsibility for the input lies completely with the user. The software will do the analysis after the input. Most users use option 2 for the input of the cable line. The dwg/dxf usually comes from a graphical design program (like AutoCad, ...).

In the first example we start with the most simple method and insert to straight cables by using option 1.

- Before a tendon can be inputted, a load case of the type 'Prestress' is made. This is needed to store the loads that are caused by the tensioning. Adding tensioning to a structure is seen as a (favourable) load on the model. By making multiple load cases of the type 'prestress', one can model the sequentionnaly tensioning of the cables and the complementary losses. The sequentional post-tensioning can also be modelled with linear construction stages. The load cases 'prestress' will have to be added to each construction phase.
- In the next step, one can indicate the properties of the tendon:

Post-tensioned tendon		
	Name	Cable
	Description	
d 80008	Number	1
	Туре	Internal
ns 🖤 ng	Layer	Layer1
	Geometry input	Direct input -
	Projection of intermediate points	Perpendicularly -
	LCS	standard -
	Material	
	Material	Y1860C-3,0
	2 Number of tendon elements in tendon (ns)	1
	Number of tendons in group (ng)	1
	Area [mm^2]	7
	Diameter of duct [mm]	60,00
	3 Load Case	LC1 - Prestress
	E Stressing	
	4 Type of stressing	Туре 1 🔹
	Prestressing from	Begin 🔹
	Coefficient of friction in curved part of tendon [-]	0,3
	Unintentional angular displacement (per unit length) [-/m]	0,003
	5 Duration of short-term relaxation [sec]	0,00
	Anchorage set - begin [mm]	6,00
	Stress during correcting - begin [MPa]	1440,00
	Duration of keeping stress [sec]	300,00
	Initial stress - begin [MPa]	1440,00
	6 Overhang of tendon not included in analysis model - begin [m]	0,000
	Overhang of tendon not included in analysis model - end [m]	0,000
	Distance between sections for output [m]	0,500
	⊟ Arc	
	Curve type	Circle + radius 🔹
	Curve parameter [m]	1,00
	Actions	
	Default values	>>>
		OK Cancel

Part 1. This indicates how you will input the tendon.

- Part 2. What is the choice of material and number of tendon elements for each tendon.
- Part 3. To which load case of type 'Prestress' will the tendon be added.
- Part 4. The type of prestressing.
- Part 5. What are the parameters for the specified type of prestressing.
- Part 6. To model a certain amount of overhang.

• <u>Part 2:</u> The choice of material:

a 💱 🗶 👬 🖬		2 C 🖨 🖻 🖆 🖬		
L860C-3,0		Name	Y1860C-3,0	
L860C-4,0		Code independent		
860C-5,0		Material type	Plain round wire	
770C-3,2			0.00	
770C-5,0		Thermal expansion [m/mK]		
770C-6,0		Unit mass [kg/m ³]	7850,0	
670C-6,9	≡	E modulus [MPa]	2,0500e+05	
670C-7,0		Poisson coeff.	0,15	
670C-7,5		Independent G modulus		
670C-8,0		G modulus (MPa)	8,9130e+04	
570C-9,4 570C-9,5		Log. decrement	0,15	
570C-9,5 570C-10,0		Colour		
860C-3.0-I		Specific heat [J/gK]	6.0000e-01	
860C-4,0-I		Thermal conductivity [W/mK]	4.5000e+01	
860C-5,0-I		Diameter [mm]	3.0	
770C-3,2-I			-1-	
770C-5,0-I		Area [mm^2]	7	
770C-6,0-I		□ prEN 10138		
670C-6,9-I		Characteristic value of maximum force (Fm) [kN]	13,10	
670C-7,0-I		Characteristic 0,1% proof force (Fp0,1) [kN]	11,30	
670C-7,5-I		Total elongation at maximum force (Agt) [1e-4]	350,0	
670C-8,0-I		Fatigue stress range (Fr) [MPa]	0,2	
570C-9,4-I		□ EN 1992-1-1		
570C-9,5-I 570C-10,0-I		Characteristic tensile strength (fpk) [MPa]	1850.0	
770S2-5,6		Characteristic 0,1% proof stress (fp0,1k) [MPa]	1600.0	
77052-6,0			350.0	
77053-7,5		Characteristic strain at maximum load (eps uk) [1e-4]		
860S2-4,5		Ductility factor (k = fpk / fp01k) [-]	1,16	
86053-4,85		Design yield strength - persistent (fpd = fp0,1k / gamma p_p) [MPa]	1391,3	
86053-6,5		Design yield strength - accidental (fpd = fp0,1k / gamma p_a) [MPa]	1600,0	
86053-6,9		Design strain limit (eps ud) [1e-4]	315,0	
860S3-7,5		Surface characteristics	Plain	
860S3-8,6		Relaxation class	Class 2 - low relaxation wires and strands	
92053-6,3		Production	Stress-relieved	
92053-6,5		User relaxation		
960S3-4,8		Relaxation table		>>
960S3-5,2 960S3-6,5				
96053-6,85 96053-6,85		Stress-strain diagram	Difference with the fact that the state of	
060S3-5,2		Type of diagram	Bi-linear with an inclined top branch	
160S3-5,2	-	Picture of Stress-strain diagram		

The material properties also contain the diametre of the pretensioning material. In the properties of the tendon itself, you can only change the number of the principal tendon.

The relaxation table can also be reviewed in the material properties. It is copied from the code, but can also be inserted or changed by the user himself. The relaxation properties will obviously only have an influence on the time dependant analysis.

In this example, we chose the material **Y1860C -5,0** with **20 tendons** in one principle tendon and **4** principle tendons in one tendon group.

• Part 4: The type of stressing:

Post-tensioned tendon	
	3

The type chosen depends on the way the tendon will be post-tensioned.

The indicated diagram will be used to calculate immediate losses. For all 5 types there is anchorage set loss (in type 4, this is the only immediate loss).

In the types 1, 2, 3 and 5, there are also other losses, such as short term relaxation, etc ... The long term losses, as shown in the 5 types, can only be determined by time dependant analysis.

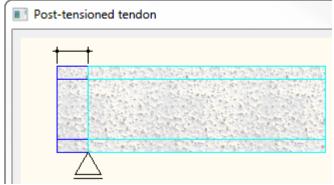
In this example we will use type 4.

Part 5: The other parameters are used to further define the type of post-tensioning. This is all
indicated as a property of the tendon.
 So for example, the amount of losses due to anchorage set loss is inputted here. Also the initial

stress in the tendon is a very important input value. In this examle it is taken equal to 1440 MPa.

With post-tensioned cables, the loss due to friction is also taken into account. So therefore it becomes important wether the cable is stressed at the beginning or end.

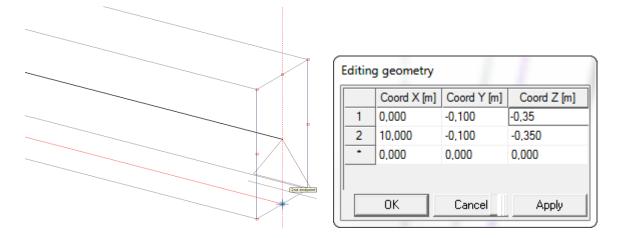
• Part 6: The possibilities to define the overhang can be seen in the following image:



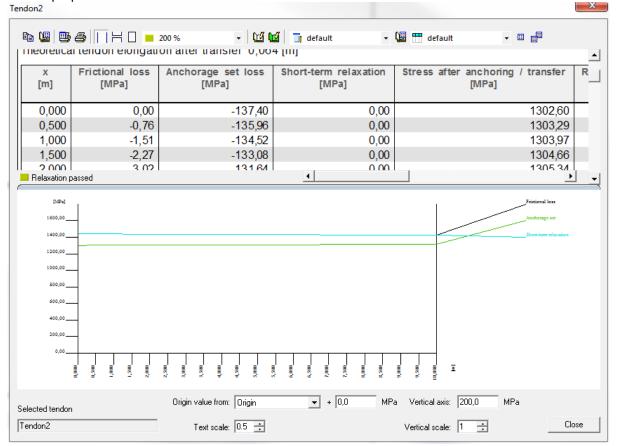
This overhang is not taken into account for the FEM analysis, but it is used for the calculation of the losses in the cable.

The next step is inserting the cable. Even after inserting the cable, it will still be possible to review and change the properties set in the previous steps.

The user can use the 'snap settings' to place the cable and afterwards use more precision for the placement of the tendon by using the 'Table edit geometry' button (for the action buttons in the properties of the tendon).



Even before the analysis is executed, it is possible to look at the immediate losses in the stressing
of the tendon. To see these, the user can click on 'Tendon losses' between the action buttons in
the properties menu of the tendon:



If tensioning is done at the beginning of a tendon, then there is a big anchorage set loss which becomes smaller towards the end. The loss due to friction increases towards the end of the cable.

Each 0,5m (which is configured in the properties of the tendon), the stress after transfer is determined. This is the stress found after substraction of anchorage set loss and the friction loss from the initial stress.

This stress af transfer (SAT) is the stress which is sent to the solver to execute the analysis.

• Similar to the input of the first tendon, we will also add a second tendon in the other bottom corner. This can be simply copied from the original tendon. And after which you will have to assigne the second cable to a certain load case (now a different one due to construction stages).

2_Construction stages (and loads)

Three linear construction stages will be made.

Stage 1: Only 'Self weight'

```
Stage 2: Tensioning tendon 1 in 'LC 1 – Prestress cable 1' (with an additional empty load case)
```

Stage 3: Tensioning tendon 2 in 'LC 2 – Prestress cable 2' (with an additional empty load case)

In this simple example, time dependant analysis will not be used. There will also not be any other stage which includes service loads.

3_Calculation

Before a calculation with prestressed tendons can be performed, the mesh and solver setups will have to be modified.

<u>Mesh</u>: It is very important that the tendons are divided in sufficient finite elements to ensure an accurate analysis.

Name	
Mesh	
Minimal distance between two points [m]	0,001
Average number of tiles of 1D element	1
Average size of 2D element/curved element [m]	1,000
Definition of mesh element size for panels	Automatic -
Average size of panel element [m]	1,000
1D elements	
Minimal length of beam element [m]	0,100
Maximal length of beam element [m]	100,000
Average size of cables, tendons, elements on subsoil, nonlinear soil spring [m]	1,000
Generation of nodes in connections of beam elements	M
Generation of nodes under concentrated loads on beam elements	M
Generation of eccentric elements on members with variable height	
Division on haunches and arbitrary members	5
Division for 2D-1D upgrade	50
Apply the nodal refinement	Only 2D members -
Hanging nodes for prestressing	M

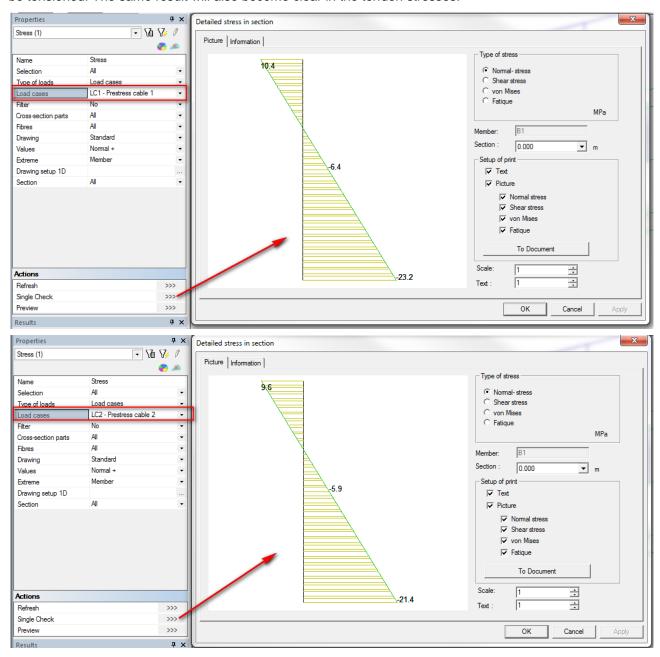
<u>Solver</u>: If the size of the mesh is sufficiently small, then the number of sections on average member can be set to 1. This will benefit the speed of postprocessors, such as Euro Code checks.

Number of sections on average member 1 Maximal acceptable translation [mm] 1000,0 Maximal acceptable rotation [mrad] 100,0 Print time in Calculation Protocol Imit for the section of t	Name	
Neglect shear force deformation (Ay, Az >> A) Image: Content and the second s		
Type of solver Direct Number of sections on average member 1 Maximal acceptable translation [mm] 1000,0 Maximal acceptable rotation [mrad] 100,0 Print time in Calculation Protocol Imit and the solution of	Run one nonlinear combination	
Number of sections on average member 1 Maximal acceptable translation [mm] 1000,0 Maximal acceptable rotation [mrad] 100,0 Print time in Calculation Protocol Imiliar Nonlinearity Solver precision ratio Solver precision ratio 1	Neglect shear force deformation (Ay, Az >> A)	
Maximal acceptable translation [mm] 100,0 Maximal acceptable rotation [mrad] 100,0 Print time in Calculation Protocol Image: Calculation Protocol Nonlinearity Maximum iterations Solver precision ratio 1	Type of solver	Direct -
Maximal acceptable rotation [mrad] 100,0 Print time in Calculation Protocol Image: Colorad state	Number of sections on average member	1
Print time in Calculation Protocol Image: Coloradia structure Nonlinearity Maximum iterations 50 Solver precision ratio 1	Maximal acceptable translation [mm]	1000,0
Nonlinearity 50 Navimum iterations 50 Solver precision ratio 1	Maximal acceptable rotation [mrad]	100,0
Maximum iterations 50 Solver precision ratio 1	Print time in Calculation Protocol	M
Solver precision ratio 1	Nonlinearity	
· ·	Maximum iterations	50
Coefficient for reinforcement 1	Solver precision ratio	1
	Coefficient for reinforcement	1

4_Results

In the results menu the 'Internal forces' and 'Tendon Stresses' can be viewed. Also for each individual load case, as for each class that is made for a construction stage, the results can be viewed.

We will compare the results from 'LC1 – Prestress cable 1' with 'LC2 – Prestress cable 2': \rightarrow In the stresses on beam, there is a slightly bigger stress for 'LC1', then for 'LC 2'. \rightarrow This is logical considering that cable 2 will lose some tendon stress since cable 1 will be the first to be tensioned. The same result will also become clear in the tendon stresses.



If we would consider the normal forces (under internal forces), then we would see that these are lower for LC2 than for LC1.

Note: There is an option 'Prestress' in the property menu of 'Internal forces'. If this is ticked on, then the section will be calculated as possibly already prestressed. For LC1 this will not make a difference, but for LC2 this can give different results, because at the time of tensioning for cable 2, there is already stress in the section due to cable 1. This will make the equivalent section (and the moment of inertia) bigger, which causes the results for LC2 not to be the same as those of LC1 for a regular section.

Remark: If the option 'Prestress' is ticked on, then it will be possible to chose for 'Total resultants' or just 'Primary forces' or 'Secondary forces'. In an isostatic beam, the secondary forces will be zero, because these only appear with isostatic structure (example 5). A background about these secondary forces is given at p86 of the book 'Navrátil, J.: Prestressed concrete structures'.

The tendon stresses shows the course of the stresses over the length of the tendon.

- **SAT** = Stress of transfer. This is the initial stress, reduced by the immediate losses.

- LED (= Loss due to elastic deformation): These losses are due to sequential post-tensioning and

elastic deformation of the concrete. These losses will only appear in stage 3 (tensioning 2nd cable). - **LCS** (= Loss due to creep & shrinkage): These are the long term losses due to creep, shrinkage and long term relaxation. They are only calculated in a time dependent analysis (and so they are now 0).

The preview of these losses can be seen in the image below.

Tendon stresses

Tendon stresses Linear calculation, Extreme : Global Selection : All Tendons: All by selection Class : ST3 (ULS)

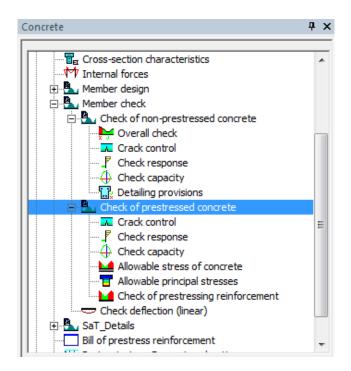
Case	Tendon	x [m]	Stress after anchoring / transfer [MPa]	LED [MPa]	LCS [MPa]	Min Stress [MPa]	MaxStress [MPa]
ST3 (ULS)	Tendon1	0,000	1302,60	-101,88	0,00	1200,72	1200,72
ST3 (ULS)	Tendon1	10,000	1316,35	-102,96	0,00	1213,40	1213,40

5_Controles in the concrete menu and design of passive reinforcement

In the concrete menu you can check if the post-tensioned beam will suffice. This concerns the design of passive reinforcement, as well as the specific Euro Code checks for the prestress steel.

The steps to execute the design of the passive reinforcement and to use the complementary checks (crack control, response control and capacity control) are completely consistent with the design of reinforcement of 1D elements. This is why a reference will be made to the workshop concrete.

The Euro Code checks which are specific for prestress elements are the check of 'Allowable stress of concrete', 'Allowable principal stress' and the 'Check of prestressing reinforcement'.



Check of the 'Allowable stress of concrete

There are multiple checks (three) to perform for the allowable stress of concrete.

Stage 3 \rightarrow Ultimate Limit State combination (ULS): $\sigma_{cc.max}$

The value $\sigma_{cc,aa}$ will be checked (maximum stress of concrete in compression after anchorage). This stress should be smaller than $\sigma_{cc,max}$ (maximum allowable stress of the concrete) in order for the concrete not to be crushed. The value $\sigma_{cc,aa}$ obviously exceeds $\sigma_{cc,max}$.

Properties	4 >	C Previe	ew								
Allowable stress concrete	e EN 1992-1-1 (1) 🔹 🖓 🗸	Ē	4 5 4 1	□ ■ 200 %	- 🖬 🕯	🖆 📑 de	fault	- (
	🐔 🍝		owable s	tress concrete El	1992-	1.1					
Name	Allowable stress concrete EN 1992-1-1	יייך וון	owabie 3		1002-	1-1					
Selection	All 🗸	Lin	ear calculatio	on, Extreme : Member							
Type of loads	Combinations -		Selection : All Combinations : F3-EN-ULS (STR/GEO) Set B								
Combinations	F3-EN-ULS (STR/GEO) Set B										
Filter	No 🝷			k of allowable stress c		r selecte	d memb	ers			
Print explanation of err	V										
Use named fibres		M	ember d _x [m]	Case	Fibre	N [kN]	M [kNm]	o MPai			
Use named CSS parts			100			[kii]	M,				
Values	sigma cc,max 🔹				2 7		[kNm]	[MPa]			
Extreme	Member -	B1	0,000	F3-EN-ULS (STR/GEO) Set B/2	2 7	-4913,2	-1719,6				
Drawing setup 1D							0,0	-36,00			

Stage 3 \rightarrow Characteristic Service Limit State combination (SLS): $f_{ct.eff}$

The value $\sigma_{cq,max}$ (maximum concrete stress after application of self-weight and all loads) must not exceed the allowable tension in the concrete, $f_{ct,eff}$ in an SLS combination.

This value is strongly exceeded when all loads are applied because in this example, the upper fibre of the beam is subjected to tension (due to the prestressed tendons). In a practical case, there will be more loads present, and thus the value of $\sigma_{cq,max}$ will be much smaller.

Properties		φ ×	Preview									
Allowable stress concrete	EN 1992-1 🔹 🏹 🌾	Ø	Þa 😃 📑	6	i H D 📕	200 %	-	w 🖬 📋	j default		- 🛄	Ð
	e 1	×	Allowal	nle s	tress c	oncrete E	N 19	92-1-1				
Name	Allowable stress concrete	E		510 3	1033 0			JZ-1-1				
Selection	All	-	Linear ca	Iculatio	n Extrem	ne : Member						
Type of loads	Combinations	-	Selection		in, Extrem							
Combinations	F3-EN-SLS Characteristic	-			F3-EN-SL	S Characteri	stic					
Filter	No	-	Prestres	s chec	k of allov	vable stress	concret	te for sele	ected me	mbers		
Print explanation of err	M											
Use named fibres			Member	d , [m]		Case	Fibre	N [kN]	My [kNm]	σ (MPa)	σ _{cg,min} [MPa]	σ _{cgmax} [MPa]
Use named CSS parts				tool.				food	M _z [kNm]			
Values	f ct,eff	-								occ.max [MPa]	σ _{ccch} [MPa]	^T ct.eff [MPa]
Extreme	Member	-	B1	0,000	F3-EN-SLS	Characteristic/3		-4094,3	-1433,0 0.0	-54,94 -36,00 (-60,43	-14,25
Drawing setup 1D									0,0	-30,00	0,00	4,40
Section	All	•										

Remark: The value $\sigma_{cc,ch}$ (allowable compression in concrete in SLS characteristic combinations) is not calculated because this check is only needed for the environmental classes XD, XF and XS.

Stage 3 \rightarrow Quasi permanent Service Limit State Combination (SLS): $\sigma_{cc,qp}$ and $f_{ct,eff,qp}$

Here the values of $\sigma_{cc,qp}$ and $f_{ct,eff,qp}$ (respectively the allowable compressive and tensile concrete stress in SLS quasi permanent combinations) are being checked. The values of $\sigma_{lt,min}$ and $\sigma_{lt,max}$ (respectively the minimal and maximal concrete stress caused by long term loads) may not exceed the allowable stresses indicated by $\sigma_{cc,qp}$ and $f_{ct,eff,qp}$. The user can modify $f_{ct,eff,qp}$ manually in the concrete setup. By default it is set to zero. So since there is tension in some of the fibres, the check will not pass.

Properties	ተ >	×	Preview											
Allowable stress concrete	e EN 1992-1-1 (1) 🔹 🏹 🌾 🖉		🖻 🛄 📑	6	片 🗌 📕 200 %	-	1	🖆 📑 de	fault	•	VIII		•	•
	🥐 🥔	١ſ	Allowal	hle st	ress concrete	EN 1	992.	1-1						
Name	Allowable stress concrete EN 199	יוור	Allowa	510 30			552	1-1						
Selection	All 🗸		Linear ca	Iculatio	n. Extreme : Membe	er	******							*****
Type of loads	Combinations -		Selection			0.								
Combinations	F3-EN-SLS Quasi-permanent 🔹			Combined in State Stat										
Filter	No -				of allowable stres		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	r selecte	d memb	oers	******	*****************************	******	*****************************
Print explanation of err	\checkmark													
Use named fibres			Member	d x [m]	Case		Fibre	N [kN]	My [kNm]	o MPa	o MPajn	o MPaj	σ _{clt.min} IMPal	oclt max MPa
Use named CSS parts				6.0				1	M	σ _{cc.max}	σ _{cc.ch} IMPal	f _{ct.eff}	or Internation	f ct.eff.qp
Values	sigma clt,max 👻								[kNm]				from of	[initia]
Extreme	Member -		B1	10,000	F3-EN-SLS Quasi-perman	ient/3	3	-4133,4	-1446,7 0.0	-55,46 -36,00	-55,46 0,00	23,49 0,00	-61,01 -27,00	25,84 0,00
Drawing setup 1D					1				0,0	-30,00	0,00	0,00	-27,00	0,00

Check of allowable principal stresses

Properties

This check is described in the Euro Code EN1992, art 12.6.3 (3):

<< A concrete member may be considered to be uncracked in the ultimate limit state if either it remains completely under compression or if the absolute value of the principal concrete tensile stress σ_{ct1} does not exceed f_{ctd} .>>

In the check of allowable principal stresses it can be seen that this check is not alright:

riopenties		1 24	FIEVIEW								
Prestress check allowable	e principal stresses 🔹 🏹 🌾	Ø	n 🛯 🖪 4) H D	200 %	- 🖬 🖬	📑 default	- 🕮 🕇	default	- 11	
	*	*	Prestress	s check	allowable p	incinal st	tresses Fl	1992-1-	1		
Name	Prestress check allowable princip	oal	11000000	onoon	anonabio p	morpur o	100000 E	10021	•		
Selection	All	•	Linear calcu	lation Extr	reme : Member						
Type of loads	Combinations	•	Selection :		enie : Menioer						
Combinations	F3-EN-ULS (STR/GEO) Set B	•			-ULS (STR/GEO)	Set B					
Filter	No	•			lowable principa		r selected mer	nbers			
Print explanation of err				incont of all							
Use named cuts			Member	d _x	С	ase	N _d	V _{vd}	M _{xd}	M _{yd} [kNm]	σ ₁
Use named CSS parts				[m]			[kŇ]	[ĸŇ]	[kNm]	[kNm]	[MPa]
Values	Check value	-						V _{zd}		Mzd	f [MPa]
Extreme	Member	-						[kN]		[kNm]	
Drawing setup 1D			B1	10,000	F3-EN-ULS (S	R/GEO) Set	B/2 -496	60,1 0,0	0,0	-1736,0	26,89
Section	All	-						-53,0		0,0	2,07

Check of stress in the prestressing reinforcement

This option is used to check the stress in the post-tensioned tendons for an ULS combination.

Combinations : F3-EN-ULS (STR/GEO) Set B Check of prestressing reinforcement for selected tendons

	d _x [m]	Case	σ _{p.pa} [MPa]	σ _{paa} [MPa]	σ _{pa,min} [MPa]	σ _{pq.max} [MPa]	σ _{p.iti} [MPa]	Check _{cal} [-]	Check
Tendon			σ _{p,max} [MPa]	σ _{pm0} [MPa]	σ _{pm} [MPa]	σ _{pm} [MPa]	σ _{pm} [MPa]	Check _{lim} [-]	
	0,00	F3-EN-ULS (STR/GEO) Set B/2	1440,00	1302,60	1180,35	1180,35	1180,35	1,00	ОК
Tendon1		ST3	1440,00	1360,00	1395,00	1395,00	1395,00	1,00	

These checks pass. No stress is exceeded. In the image below there is more explanation about the symbols used in the preview. This way it becomes easier to manually see what is checked.

σp,pa	Stress of prestressing reinforcement prior anchoring (during tensioning)
σр,аа	Stress of prestressing reinforcement after anchoring/transferof prestress
σpq,min	Minimum stress of prestressing reinforcement after application of self-weight, all permanent, and variable loads
σpq,max	Maximum stress of prestressing reinforcement after application of self-weight, all permanent, and variable loads
σp,ltl	Stress of prestressing reinforcement after long-term losses (LTL)
Checkcal	Maximum value of check of all performed checks of allowable stress of tendon
σp,max	Allowable stress of prestressing reinforcement prior anchoring (during tensioning)
σpm0	Allowable stress of prestressing reinforcement after anchoring/transferof prestress
σpm	Allowable stress of prestressing reinforcement caused by SLS combinations

The allowable stresses before and after anchorage ($\sigma_{p,max}$ and $\sigma_{p,m0}$) are calculated according to chapter 5.10.2 and 5.10.3 of the Euro Code EN1992. The allowable stress $\sigma_{p,m}$ in the tendons under the service limit state combinations are given in chapter 7.2.

The factors used in these formula can be configured in the national annex for Euro Code 2, in the part which indicates national dependent values for EN1992-1-1. The parameters can be found under the part 'Allowable stress'.

Name	Standard EN
Concrete	
* General	
E ULS	
± SLS	
☐ Allowable stress	
Stress limitation during tensioning	
National annex	_
$^{\Box}$ k1; k2 to calculate the maximum stress applied to the tendon during tensioning	
Values [-]	0,80 / 0,90
□ k3 - increased factor for maximum stress in prestressing reinforcement during tensioning 5.10.2.1(2)	
Value [-]	0,95
k6 - increased factor for maximum compressive stress in pre-tensioned concrete after transfer of prestress 5.10.2.2(5)	
Value [-]	0,70
k7 - factor for maximum stress in prestressing reinforcement after anchoring/transfer of prestress 5.10.3 (2)	
Value [-]	0,75
k8 - factor for maximum stress in prestressing reinforcement after anchoring/transfer of prestress 5.10.3 (2)	
Value [-]	0,85
SLS stress limitation	
National annex	
k1 - factor for maximum compressive stress in concrete under SLS characteristic combi	
Value [-]	0,60
E k2 - factor for maximum compressive stress in concrete under SLS quasi-permanent combi (linearity of creep condition) 7.2(3)	
Value [-]	0,45
k5 - factor for maximum stress in prestressing reinforcement under SLS combi 7.2(5)	
Value [-]	0,75
Detailing provisions	
Common detailing provisions	
Columns	
Beams	

The stresses indicated in the preview of this check can easily be calculated manually:

→ 5.10.2 Maximum Stressing Force

- $\circ k_1 = 0,80$
- $\circ k_2 = 0,90$

$$\circ \quad \sigma_{p,max} = \min(k_1 \cdot f_{pk}; k_2 \cdot f_{p,01k}) = 1440 \ N/_{mm^2}$$

➔ 5.10.3 Prestressing Force

- $\circ k_7 = 0,75$
- $\circ k_8 = 0.85$
- $\circ \quad \sigma_{p,m0} = \min(k_7 \cdot f_{pk}; k_8 \cdot f_{p,01k}) = 1360 \ N/mm^2$

Summary

The checks concerning allowable stresses in the concrete were not all right, but the checks for allowable stress in the prestress tendons did pass.

Now the user will have to modify his design to ensure that the check for allowable concrete stresses pass the unity check. It can be done by increasing the size of the cross section or by augmenting the quality of the concrete used in the beam.

Time dependant analysis of a post-tensioned beam

This goal of this chapter is to show how the time dependant analysis can be executed in Scia Engineer. A calculation with time dependant analysis is necessary to determine the time dependant losses of the tendons. This can only be applied in a 2D environment.

sic data F	unctionality Lo	ads Protection		
Scia	Data		Material	
Scia II	Name:		Concrete	M
		1	Material	C60/75 •
	Part:		Reinforcement	
			Steel	
	_		Timber	
	Description:	-	Masonry	
			Other	
	Author:	-	Aluminium	
	Date:	04. 12. 2012		
	a .		Code	
	Structure:		National Code:	
	Frame XZ		🔹 🏹 EC - EN	•
	Truss XZ Frame XZ			
	Truss XYZ		National annex:	
	Frame XYZ Grid XY Plate XY Wall XY General XYZ		Standard	ien ▼

It is possible and in most cases also acceptable to simplify a 3D plate model to a 2D beam model. It is most definitely acceptable if the length is much larger than the width of the plate. In such cases the analysis in longitudinal direction is much more important. The advantage of a 3D-model would be the forces that can be investigated in transverse direction. This will also be shown in the next chapters.

1_Input geometry and post-tensioning

NI.

The TDA analysis of post tensioned bridges is a much used application of the program. This is why there are many pre-parameterized bridges to be found in the cross-section library, which also makes the input of typical decks of bridges much easier.

Available groups	Available items of this group
Concrete Geometric shapes Numerical	
General Precast	uvîî
	- TTT - T
	ਾ ਹਿ ਦ

Because this list is far from complete and does not contain all types of bridges, it is also possible to create a profile using 'General' cross-sections. The general cross-section opens a section-editor in where it is possible to manually create a cross-section, or to import one from dwg/dxf.

Parameters b0 1200 88 C60/75 Material 8000 Ξ b [mm] 1200 b0 [mm] 1 b1 [mm] 2500 h [mm] y 2500 h1 [mm] 1 s [mm] h2500 8 bl 1 500 d [mm] ь 8000 General

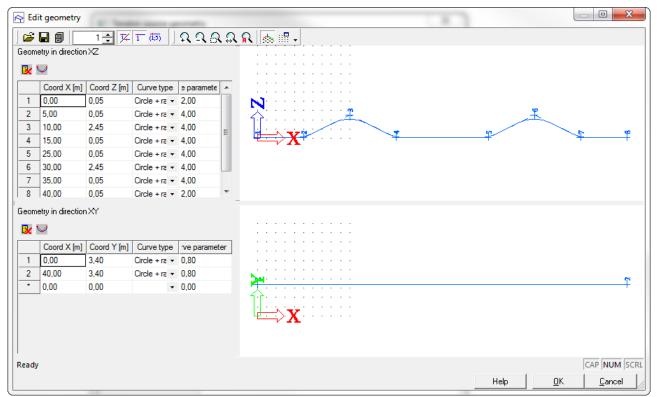
In this example we will use one of the predefined parametric bridges. The section used has the following measurements:

We will insert the beam over a total length of 40m with intermediate supports at 10m and 30m.

Adding the prestressed tendons is the most difficult part of the modeling. In the previous example this has been kept simple because it was possible to do this manually. In this example the input by source geometry will be used. This geometry can be inserted under : *'Libraries -> Prestressing -> Tendon source geometry'*

In practice one usually starts from a dwg file which can be imported in Scia Engineer and converted to a post-tensioned tendon. There is also more explanation about this as a demonstration movie on the site www.scia-online.com.

The source geometry allows us to determine the geometry of a post-tensioned tendon by using several points. The course of the tendon will be determined by means of interpolation between the points indicated by the user. For more explanation about the interpolation that takes place in the software, a reference is made to the documents for prestress under the help of Scia Engineer.



The source geometry used in this example is shown in the image below.

We will model two tendons in the bridge (one on the left side and one on the right side), and these two cables will be placed in the same load case 'LC1 – Prestress'. This means that the two cables will be tensioned at the same time.

Remark: For source geometry it can be very usefull to use parameters. By using parameters the points of the source geometry can be easily determined with very limited input. An example of these input values can be seen in the image just below.

Project		Pro	oject	
Sjabloondialoog 	G	eon	netrie	
 ■ ↓ ▲ Belastinggevallen, Combinaties ■ ■ ■		Ð	Cross-Section	
Beton			hcss - Depth of the Cross-Section [mm]	2000,0
Document			boss - Width of the Cross-Section [mm]	6000,0
			cb - Upper cover [m]	0,05
i Bibliotheken			co - Lower cover [m]	0,05
		Ð	Spans	
Lijnraster			L1 - Span 1 [m]	12,00
Parameters			L2 - Span 2 [m]	12,00
📲 Parameters sjablooninstellingen			L3 - Span 3 [m]	12,00
Lagen		Ð	Prestressing	
📲 Door gebruiker gedefinieerde sele			PS1_Rmin - Minimal Radius [m]	2,00
			SP_Ls - Lengte van het rechte deel [m]	1,00

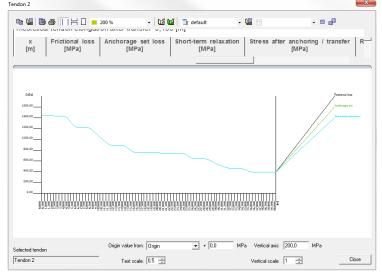
These input values are then linked to parameters that determine the coordinates of the source geometry.

The parameters of the tendon are determined as followed.

		Name	Tendon 1	
		Description		
d 80008		Number	1	
		Туре	Internal	
🗕 🕶 ns 🖤 🖤 ng		Layer	Layer1	·
<u>x x</u>	E	Geometry		
		Geometry input	Source geometry	-
		Allocation		
		LCS - X	B1	-
		Projection of intermediate points	Perpendicularly	•
		LCS	standard	•
		Source geometry	Tendon 1	•
		Origin of source geometry	Offset in LCS	•
		Coord X [m]	0,000	
		Coord Y [m]	0,000	
		Coord Z [m]	0,000	
	Ξ	Material		
		Material	Y1670C-7,0	·
		Number of tendon elements in tendon (ns)	20	
		Number of tendons in group (ng)	1	
		Area [mm^2]	770	
		Diameter of duct [mm]	60,00	
		Load Case	LC1	·
	Ξ	Stressing		
		Type of stressing	Type 4	
		Prestressing from	Begin	•
		Coefficient of friction in curved part of tendon [-]	0,3	
		Unintentional angular displacement (per unit length) [-/m]	0,003	
		Initial stress - begin [MPa]	1440,00	
		Overhang of tendon not included in analysis model - begin [m]	0,000	
		Overhang of tendon not included in analysis model - end [m]	0,000	
		Distance between sections for output [m]	0,500	
	A	ctions		
	1	Fendon losses		>>>
	C	Calculation info		>>>
	0	Default values		>>>

The system line of the member also has to be set at 'bottom'.

As the tendons are placed, it becomes possible to look at the immediate losses in the cable. This is in the assumption that the post-tensioning would be done at the beginning of the tendon.

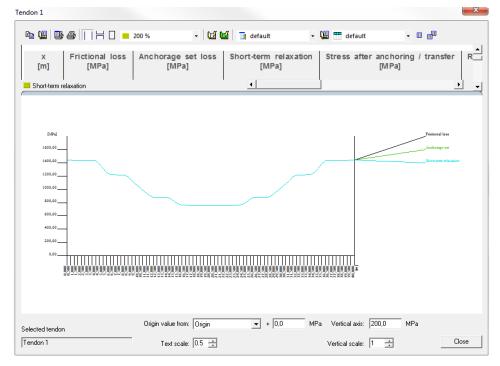


It is obvious that the loss due to friction has become too big at the end of the 40m long bridge. This is why it is advised that these cable are tensioned at both ends.

The following setting will be used for the tendons (in order to reduced the losses due to friction).

-	Stressing		
	Type of stressing	Type 4	
	Prestressing from	Both ends, anchored at the end, restresssed at the beginning 📼	
	Coefficient of friction in curved part of tendon	0,3	
	Unintentional angular displacement (per unit I	0.003	
	Initial stress - begin [MPa]	1440.00	
	Initial stress - end [MPa]	1440.00	
	Overhang of tendon not included in analysis	0,000	
	Overhang of tendon not included in analysis	0,000	
	Distance between sections for output [m]	0.500	

This results in the following losses:



2_Construction stages (and loads)

The construction stages of this project will not be normal linear construction stages, but will be part of a time dependant analysis. So for each construction stage, a certain time indication will be necessary.

Stage 1: Casting of the concrete bridge:	day 0
Stage 2: Adding the post-tensioned cable:	day 28
Stage 3: Adding the service load:	day 100
Stage 4: Check of the structure after 50 years	day 18000

The load cases taken into account will only be the self-weight and a service load. Also in accordance to the construction stages, which need a load case for each stage, we will need the following load cases.

(LC 1: Prestress)

- LC 2: Self weight
- LC 3: Empty load case (for stage 2, where the post-tensioned cable will be added)
- LC 4: Service load (variable load case, but of the type 'long term') → Line load of 10 kN/m
- LC 5: Empty load case (for stage 5, the check after 50 years)

🖊 🤮 🗶 🛍 🔽 🥍	Ω 🖂 🚭 🗃 🔚 AI	- [7
.C1 - Prestress	Name	LC4	
.C2 - Self Weight	Description	Service load	
.C3 - Empty (stage 2)	Action type	Variable	
.C4 - Service load	LoadGroup	LG2	· .
LC5 - Empty (stage 4)	Load type	Static	
	Specification	Standard	
	Duration	Long	
	Master load case	None	
	Actions		
	Delete all loads		>>>
	Copy all loads to another loadca		>>>

Remark: It is also possible to use mobile loads to create the load case. This is done to create the maximal moment in the middle of the span, or at the sides. For more information about mobile loads, a reference is made to the workshop about mobile loads.

The configuration for the time dependant analysis has to be as shown in the image below.

Name		
Туре	Time dependent analysis	•
Load factors(Code independent combinations only)		
 Permanent (long-term) load cases 		
Prestressed load cases		
Long-term part of variable loads		
Factor Psi [-]	0,30	
TDA		
Load factors for generated load cases		
gamma-creep min [-]	1.00	
gamma-creep max [-]	1.00	
Time - History		
Number of subintervals	1.0	
Ambient humidity [%]	70,00	
Automatic calculation of subintervals	no no	
Local time axis		
Time of casting [day]	-1,00	
Time of curing [day]	0.00	
Duration of curing of composite parts of cross-section [day]	0,00	
Line support (formwork)		
Time of releasing of displacements in X direction [day]	14,00	
Time of releasing of displacements in Z direction [day]	14,00	
Generate output text file		
Results		

The most important properties are summed up.

Long-term part of the variable load: $\Psi = 0, 3$

The variable loads are also taken into account for the time dependant analysis, but only for 30% (permanent loads are taken into account for 100%). This is only valid for variable loads of duration 'long'. The duration of a certain load case can be indicated in the configuration of the load case.

Number of subintervals (between 2 construction stages)

The numerical TDA method becomes more accurate if there are more subintervals between two construction stages. In return, more computational time is necessary. The number of subintervals is preferable given for each construction stage separately. For example, between the 3rd and 4th construction stage more subintervals are necessary because the time between them is much bigger.

Ambient humidity [%]

This property will affect the shrinkage. For higher ambient humidity, there will be less shrinkage.

Local time axis

The local time axis introduces extra times for which no construction stage has to be defined:

- *Time of casting*: This is preferably taken on day -1 to prevent the possibility that on day 0 an element without stiffness is sent to the solver (newly cast concrete has no stiffness).
- *Time of curing:* This is a special treatment of the concrete, which possitively affects the shrinkage. It is mostly applied in the prefab industry.
- Line support (formwork): This property assumes that the concrete stays in the formwork after casting the concrete in order to build up stiffness before carrying any loads.
 Remark: During this period the structure is completely supported and the deformations and internal forces do not occur.

The different construction stages are configured in the following manner.

🎜 🏣 🗶 🗽 😂 🖉	All	• 7	
T1 - Casting of the concrete	Name	ST1	
-	Order of stage	1	
	Description	Casting of the concrete	
	Global time [day]	0.00	
	Number of subintervals	1	
	Ambient humidity [%]	100,00	
	Last construction stage		
	Load case permanent or long-term		
	Load case	LC2 - Self Weight	-
	Load case prestress		
	Load case	None	
	Type of generated combinations	All code dependent	
	Actions		
	Variable load cases		>>
New Insert Edit Delet	1		Clos
Construction stages	e	7	>> Clos
Construction stages	e	• \7	Clo
Construction stages	e	ST2	Clo
Construction stages	Al		Clo
Construction stages	All	ST2	Clo
Construction stages	All Name Order of stage	ST2 2	Clo
Construction stages	All Name Order of stage Description	ST2 2 Adding the post-tensioning	Clo
Construction stages	All Name Order of stage Description Global time (day)	ST2 2 Adding the post-tensioning 28,00 3 70,00	Clo
Construction stages	All All Name Order of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage	ST2 2 Adding the post-tensioning 28,00 3	Clo
Construction stages	All All Order of stage Description Global time (day) Number of subintervals Ambient humidity [%]	ST2 2 Adding the post-tensioning 28,00 3 70,00	Clo
Construction stages	All All All Conder of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case	ST2 2 Adding the post-tensioning 28,00 3 70,00	
Construction stages	All All Order of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term	ST2 2 Adding the post-tensioning 28,00 3 70,00 \overleftarrow{r}	
Construction stages	All All All Conder of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case	ST2 2 Adding the post-tensioning 28,00 3 70,00 \overleftarrow{r}	
Construction stages	All All All All Conder of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case Load case prestress	ST2 2 Adding the post-tensioning 28,00 3 70,00 IC LC3 - Empty (stage 2)	
	All All All All Conder of stage Description Global time (day) Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case Load case Load case Load case Load case	ST2 2 Adding the post-tensioning 28,00 3 70,00 IC3 - Empty (stage 2) LC1 - Prestress	

Note that after stage 2 the structure will not be changed anymore ('Last construction stage'). After this stage, long term variable load cases can be used as base for the construction stage.

Construction stages			×
Construction stages			
🎜 🤮 🗶 🖳 😂 🖨 🗌	All • 🖓		
ST1 - Casting of the concrete	Name	ST3	
ST2 - Adding the post-tensioning	Order of stage	3	
ST3 - Adding the service load	Description	Adding the service load	
	Global time [day]	100,00	
	Number of subintervals	5	
	Ambient humidity [%]	70,00	
	Last construction stage		
	Load case permanent or long-term		
	Load case	LC4 - Service load	·
	Psi [-]	0,30	
	Type of generated combinations	All code dependent	-
	Actions		
	Variable load cases		
	vanable load cases		>>>
New Insert Edit Dele	te		Close
			×
Construction stages			
🏓 🤮 🗶 😰 😂 🛛	AI • 🖓		
ST1 - Casting of the concrete	All • 7	ST4	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning		ST4 4	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name		
ST1 - Casting of the concrete ST2 - Adding the post-tensioning	Name Order of stage	4	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description	4 Check after 50 years	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day]	4 Check after 50 years 18000,00	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals	4 Check after 50 years 18000,00 10	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%]	4 Check after 50 years 18000,00 10 70,00	
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage	4 Check after 50 years 18000,00 10 70,00	·
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case	4 Check after 50 years 18000,00 10 70,00	· · · · · · · · · · · · · · · · · · ·
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [½] Last construction stage □ Load case permanent or long-term	4 Check after 50 years 18000,00 10 70,00 LC5 - Empty (stage 4)	×
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case	4 Check after 50 years 18000,00 10 70,00 LC5 - Empty (stage 4)	× ×
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case Type of generated combinations	4 Check after 50 years 18000,00 10 70,00 LC5 - Empty (stage 4)	×
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case Type of generated combinations	4 Check after 50 years 18000,00 10 70,00 LC5 - Empty (stage 4)	T
ST1 - Casting of the concrete ST2 - Adding the post-tensioning ST3 - Adding the service load	Name Order of stage Description Global time [day] Number of subintervals Ambient humidity [%] Last construction stage Load case permanent or long-term Load case Type of generated combinations Actions Variable load cases	4 Check after 50 years 18000,00 10 70,00 LC5 - Empty (stage 4)	•

3_Calculation

After the setup of the mesh and solver, the time-dependant analysis can be executed.

	Single analysis Batch analysis	
Engineer	C Linear calculation	V
	C Nonlinear calculation	
	C Modal analysis	
	C Linear stability	
	C Concrete - Code Dependent Deflection	s (CDD)
	 Construction stage analysis 	
	C Nonlinear stage analysis	
	C Nonlinear stability	
	C Test of input data	
	Number of stages: 4, TDA	
	,	
	Solver setup	Mesh setup
	ОК	Cancel

\$2

4_Results

The results which can be viewed are the in the same options as in the previous example.

Tendon stress

However, now it will also be possible to find long term losses. This effect is obvious in the tendon stresses for stage 3 and stage 4. The results are compared below.

Tendon stresses

Tendon stresses Linear calculation, Extreme : Global Selection : All Tendons: All by selection Class : ST3 (ULS)

Case	Tendon	x [m]	Stress after anchoring / transfer [MPa]	LED [MPa]	LCS [MPa]	Min Stress [MPa]	MaxStress [MPa]
ST3 (ULS)	Tendon 1	20,000	753,61	0,19	-13,37	740,43	740,43
ST3 (ULS)	Tendon 1	0,000	1440,00	0,00	-60,07	1379,93	1379,93

Tendon stresses

Tendon stresses Linear calculation, Extreme : Global Selection : All Tendons: All by selection Class : ST4 (ULS)

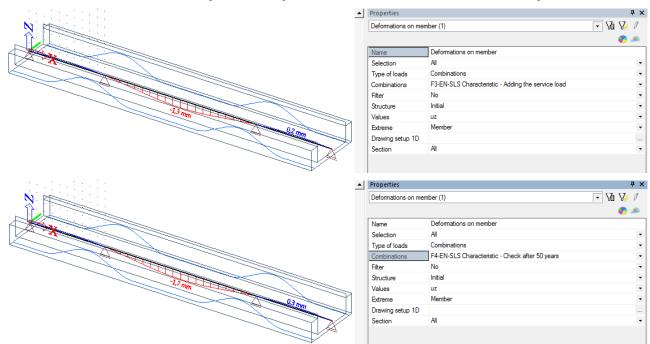
Case	Tendon	x [m]	Stress after anchoring / transfer [MPa]	LED [MPa]	LCS [MPa]	Min Stress [MPa]	MaxStress [MPa]
ST4 (ULS)	Tendon 1	20,000	753,61	0,19	-52,50	701,30	701,30
ST4 (ULS)	Tendon 1	0,000	1440,00	0,00	-159,20	1280,80	1280,80

It can be clearly seen that the long term losses, LCS (loss due to creep and shrinkage), are significantly higher after 50 years in comparison with the beginning of the last stage at 100 days.

The long term losses are also smaller at the middle part of the beam. This is because the tensioning after anchorage is lower in the middle part (due to anchorage losses), and the losses due to relaxation depend on the amount of stress in the tendon. So higher stress in the cable means higher long term losses.

Deformations

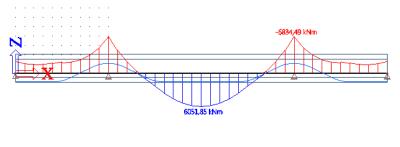
Aside from the tendons stresses, the deformations can also be inspected. Here we will also look at the difference between stage 3 and stage 4, to see the effects of the increased long term losses.



The deformation in the middle of the beam is 1,3mm at the beginning of the stage with the service load, and it is 1,7mm at the end of the same stage.

Moment diagram

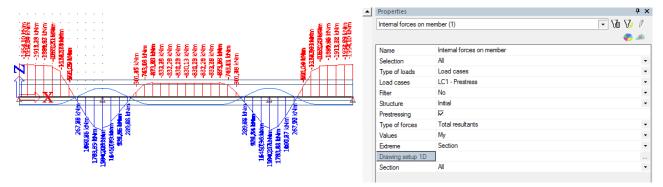
The moment diagram after 50 years will look like:



Properties	
Internal forces on	member (1)
Name	Internal forces on member
Selection	All
Type of loads	Combinations
Combinations	F4-EN-ULS (STR/GEO) Set B - Check after 50 years
Filter	No
Prestressing	
Values	My
Extreme	Global
Drawing setup 1D	
Section	All

With a moment of 6051.85kNm in the middle of the span and 6834,49kNm at the supports. The result comes from the combined loads of the self weight, service load and tensioning after 50 years.

The stress in the tendons creates an opposite moment (at day 100) of 830kNm in the middle of the span and 1994kNm at the supports (not including losses of stress in the tendon).



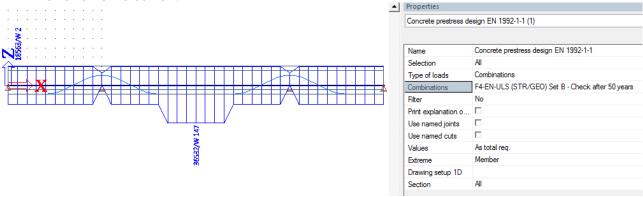
From these results we can expect that more post-tensioning will have to be added or more passive reinforcement will probably be required.

5_Checks in the concrete menu

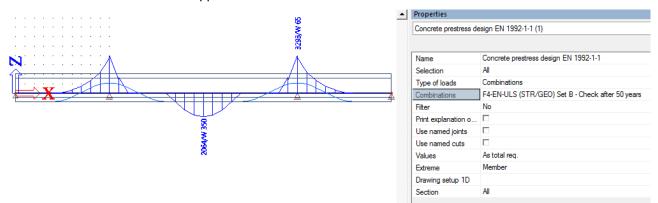
Passive reinforcement

In the concrete menu the amount of passive reinforcement can be calculated.

The 'Concrete prestress design' of the prestressed beam will give the following result (while respecting the minimum reinforcement demand): 18 563 m³ of upper reinforcement and 36 532 mm³ of lower reinforcement.



If the minimum reinforcement is not repected, then the following amount of reinforcement is calculated: 2 064 m³ of upper reinforcement and 3 293 mm³ of lower reinforcement.



In the middle of the beam there will still be a certain amount of lower reinforcement necessary and above the supports there is still some upper reinforcement necessary. This means that the construction will become instable without any passive reinforcement.

Allowable stresses

The stresses in both the cables and the concrete must be checked to see if the prestress does not exceeds the maximal concrete pressure or the maximal tension in the tendons.

A. The check of allowable stress in the concrete after anchorage is easily suffices.

Allowable stress concrete EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : F2-EN-ULS (STR/GEO) Set B **Prestress check of allowable stress concrete for selected members**

Case	M _z [kNm]	Member	d _x [m]	N [kN]	My [kNm]	σ _{c.aa} [MPa]	σ _{cg.min} [MPa]
					M _z [kNm]	occ.max [MPa]	σ _{cc.ch} [MPa]
F2-EN-ULS (STR/GEO) Set B/1	0,00	B1	14,000	-1476,97	556,01	-0,39	-0,39
					0,00	-36,00	0,00

B. The check of allowable tensile stress in the concrete of quasi-permanent loads also suffices.

Allowable stress concrete EN 1992-1-1

Linear calculation, Extreme : Member Selection : All Combinations : F4-EN-SLS Characteristic Prestress check of allowable stress concrete for selected members

Case	M _z [kNm]	Member	d _x [m]	N [kN]	My [kNm]	σ _{c.aa} [MPa]	σ _{cg.min} [MPa]	σ _{cg.max} [MPa]	σ _{clt.min} [MPa]
					M _z [kNm]	σ _{cc.max} [MPa]	σ _{cc.ch} [MPa]	f _{ct.eff} [MPa]	σ _{cc.qp} [MPa]
F4-EN-SLS Characteristic/2	0,00	B1	10,000	-1523,83	-4450,57	-1,00	-1,01	1,78	-1,00
					0,00	0,00	0,00	5,16	0,00

The tensile stress occurs above the supports ($d_x = 10m$), but is not too big ($\sigma_{cq,max} < f_{ct,eff}$).

C. The check of allowable tendon stress is also investigated.

Check of prestressing reinforcement

Linear calculation, Extreme : Global Selection : All Tendons: All by selection Combinations : F2-EN-ULS (STR/GEO) Set B

Check of prestressing reinforcement for selected tendons

	d _x [m]	Case	σ _{p,pa} [MPa]	σ _{p,aa} [MPa]	σ _{pq,min} [MPa]	σ _{pq,max} [MPa]	σ _{p,ltl} [MPa]	Check _{cal} [-]
Tendon			σ _{p,max} [MPa]	σ _{pm0} [MPa]	σ _{pm} [MPa]	σ _{pm} [MPa]	σ _{pm} [MPa]	Check _{lim} [-]
	0,00	F2-EN-ULS (STR/GEO) Set B/1	1440,00	1440,00	1440,00	1440,00	1440,00	1,18
Tendon 1		ST2	1296,00	1224,00	1252,50	1252,50	1252,50	1,00

The tendon stress before and after anchorage exceeds the allowable stresses. In such a case we will want to keep the total compressive stress in the concrete, but we want to stay under the maximum allowed.

A possible solution is to use a material which has a higher maximal tendon stress, or to lower the tendon stress in the tendons themselves. This can be done by using more tendons than in the current situation.

The tendon stress after 50 years will be lower, so it is advisable to keep the same total amount of prestress, because if the total amount of prestress would be lowered, it is possible that the previous checks (especially the allowable tensile stress in the concrete) will not pass anymore.

Linear analysis of a post-tensioned bridge deck

In this chapter post-tensioned cables are introduced on a bridge deck. This deck will be modeled as a 2D-element, allowing the calculation to run in a general XYZ environment. As previously mentioned a time dependent analysis cannot be performed in the general XYZ environment. In order to take into account a certain long-term loss, the user itself would be able to make an estimate of this loss and simply include this by giving the prestressed cables a lower initial stress.

It might be possible to tension the cables sequentially and to calculate these losses by using linear construction stages. The process is analogous to example 4.

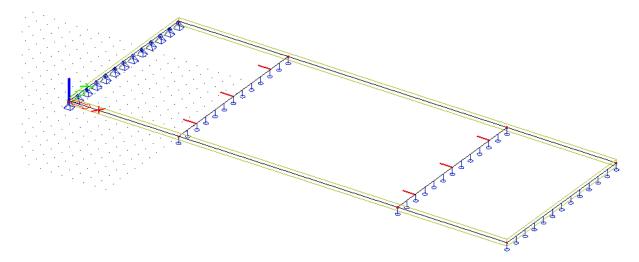
This example will be restricted to a linear analysis of a post-tensioned bridge deck without working with construction phases.

1_Input geometry and post-tensioning

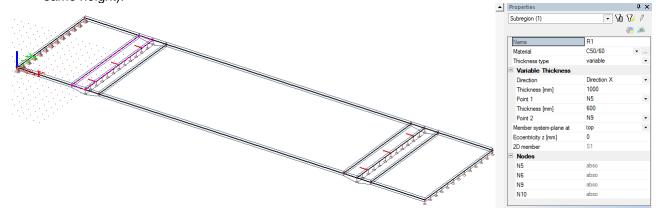
Before the modeling can start, the project data must be inputted. We will choose for a general XYZ environment with material concrete C50/60. In the functionalities the option 'Prestressing' is ticked on (and on the right side, 'Advanced parameters', to indicate for example anchorage losses).

The plate has a size of 40 by 15 meters and a thickness of 600mm.

It is supported by supports at the ends and at 10m distance from the ends. To introduce a line support at 10m distance from the ends, you will first have to introduce an internal edge. These steps result in the following structure:



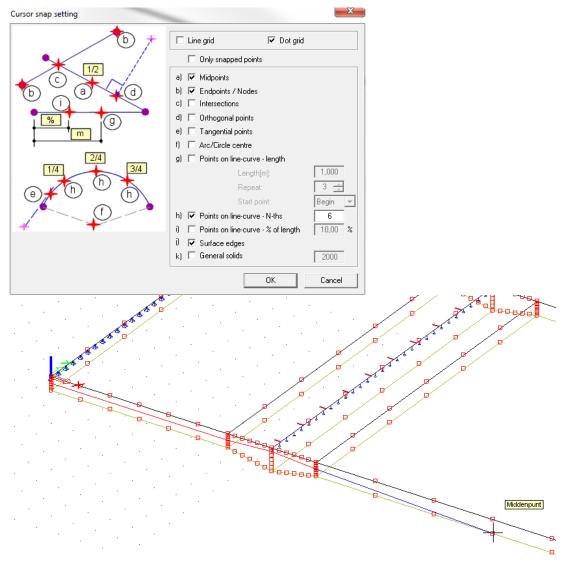
The next step is to create subregions above the internal supports in order to locally thicken the plate. At a distance of 2m from the intermediate support, the thickness is increased from 600mm to 1000mm (towards the support in question). Also the alignment is set to 'top' (so that the top surfaces are at the same height).



Applying the post-tensioned cables is completely analogous as in 1D elements. Again, there is a possibility of direct input, input via source geometry or starting from a dwg-file. The direct input or import via source geometry could be simplified by means of parameters.

Material			
Material	Y1770S7-9	•	
Number of tendon elements in tendon (ns)	20		
Number of tendons in group (ng)	1		
Area [mm^2]	1000		
Diameter of duct [mm]	60,00		
.oad Case	LC1 - Prestress	•	
Stressing			
Type of stressing	Type 4	•	
Prestressing from	Both ends, anchored at the end, restresssed at the beginning		•
Coefficient of friction in curved part of tendon [-]	0,3		
Unintentional angular displacement (per unit length) [-/m]	0,003		
Anchorage set - begin [mm]	6,00		
Anchorage set - end [mm]	6,00		
Initial stress - begin [MPa]	1440.00		
Initial stress - end [MPa]	1440,00		
Overhang of tendon not included in analysis model - begin [m]	0,000		
Overhang of tendon not included in analysis model - end [m]	0,000		
Distance between sections for output [m]	0,500		

In this example, 1 cable is inserted through direct input. Then this cable is copied several times over the width of the plate. The direct input is done using snapped points. The coordinates of the snapped points may subsequently be adjusted according to 'table edit geometry'.



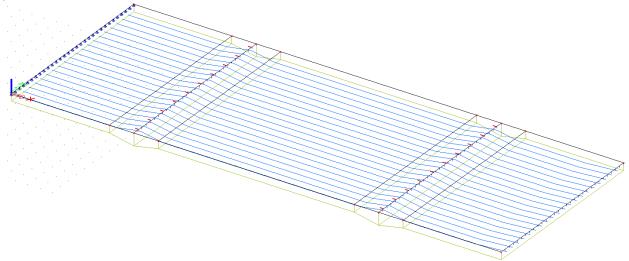
The coordinates of the snapped points may subsequently be adjusted according to 'table edit geometry'. This way the course of the tendon can be numerically perfected.

	Coord X [m]	Coord Y [m]	Coord Z [m]	Curve type		Curve parameter [m]	
1	0,000	0,000	-0,300				1
2	8,000	0,000	-0,300	Circle + radius	•	1,000	
3	10,000	0,000	-0,167	Circle + radius	•	1,000	
4	12,000	0,000	-0,300	Circle + radius	•	1,000	
5	20,000	0,000	-0,550	Circle + radius	•	1,000	
6	28,000	0,000	-0,300	Circle + radius	•	1,000	
7	30,000	0,000	-0,167	Circle + radius	•	1,000	
8	32,000	0,000	-0,300	Circle + radius	•	1,000	l
9	40,000	0,000	-0,300				

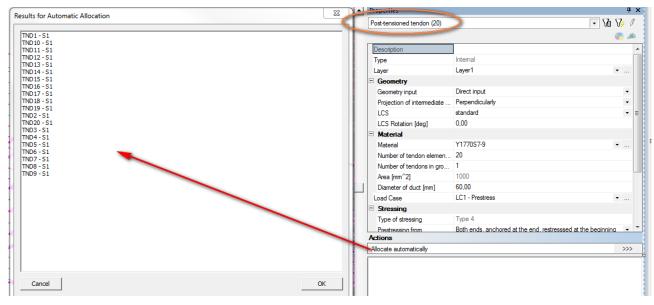
If the first tendon is placed according to wish, it can be copied 20 times over the width of the plate.

Multicop	у			×
	per of copies 21	÷	Connect selected nodes with new beams Copy additional data	<u>د</u>
Distan	ice vector		How to define the distance ?	
Define	e distance by cursor		C between two copies	
x y z	0,000 15 0,000	m m m	 from original to the last of How to define the rotation ?- between two copies from original to the last of 	
- Rotati	on		C from original to the last o Rotation around	юру
rx ry	0,00	deg deg	current UCS distance vector	
rz	0,00	deg	ОКС	ancel

After copying the tendon, there are now 22 tendons in the plate, including the tendons at Y=0 and at Y=20. These outer tendon are not present in reality, so they are deleted. The result is a plate with 20 post-tensioned tendons.



After entering the post-tensioned cables, they still need to be assigned to the plate. This can be done for all cables simultaneously through the action 'automatically assign'.



These are the tendon stress losses in one of the tendons:

TND13									
Pa 🚇	₿4	H O 🗕	200 % 🗸 🕅	🖬 📑 defa	ult	- 📜 🛙		• II II	
x [m]	Fri	ctional loss [MPa]	Anchorage set loss [MPa]		m relaxatio MPa]	n Stre	ss after ancho [MPa]		er R
0.00		0.00	-144.2	7	0.0	00		1295.	73
Anchorage set loss Image: set l									
Selected ter	ndon		Origin value from: Origin	-	+ 0,0	MPa Ver	tical axis: 200,0	MPa	
TND13			Text scale: 1.2 📫			Vertio	cal scale: 1 📫		Close

2_Input of the loads

In this example two additional load cases are created:

(LC 1: Prestress)

LC 2: Self Weight

LC 3: Service Load \rightarrow a surface load of 5 kN/m² applied over the entire plate

After the load cases and loads have been introduced, an ULS and a SLS combination are made.

3_Calculation

Before the calculation can be performed, the size of the mesh must first be set. The calculation will be done with a mesh size of 0,5 m and maintain also this mesh size for the prestressed cables.

	Mesh setup		×
	Name		
E	Mesh		
	Minimal distance between two points [m]	0,001	
	Average number of tiles of 1D element	1	
	Average size of 2D element/curved element [m]	0,500	

After changing this setting, the linear calculation can be performed.

4_Results

The results are available after executing the linear calculation.

Since no construction stages are being used, the tendon stresses will remain the same as the stress after anchoring, which already could be determined from the linear calculation.

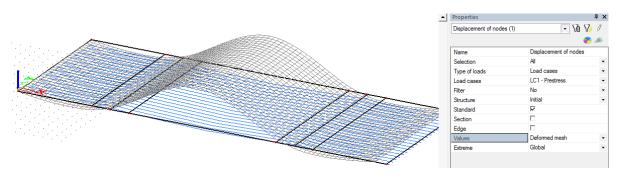
After evaluation of the results, the user can see by means of deformation and internal forces whether or not the optimal post-tensioning has been applied.

This is a general comment on the use of pre-tensioning in Scia Engineer. The program allows a very complex analysis to be carried out, but it does not design the amount of pre-tensioning itself. The program only does the analysis. It is the responsibility of the user to evaluate the results, in other words whether the applied pre-tensioning may or may not be optimal.

Viewing the deformed structure under prestressed circumstances gives the user an idea if the course of the cable is chosen optimally.

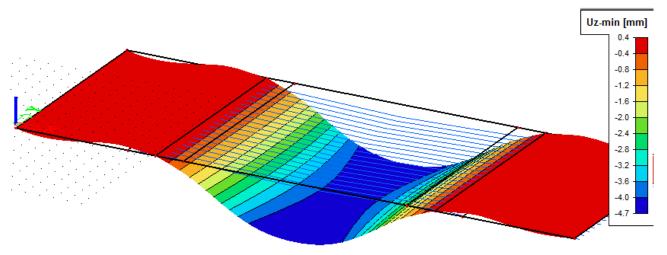
In this construction, the deflection in the middle of the field will be the most disadvantageous. Post-tensioning must be designed in such a way that the deflection in the middle of the field is prevented.

The deformation under post-tensioning is shown below:



This deformation is clearly the opposite of the deformation under its self weight.

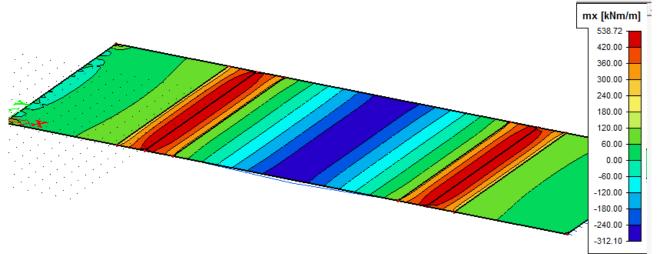
The deformation of the (characteristic) SLS combination shows the resulting deformation of the posttensioned structure in charge of its self weight and service load.

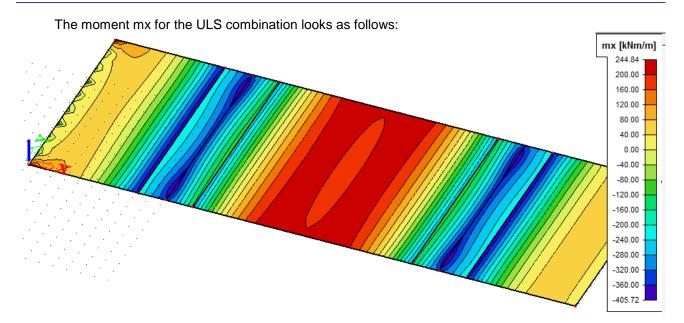


The course of the cable is well chosen because it counteracts the deformation of the self weight and the service load.

The same applies to the internal forces. The moment mx, as a result of post-tensioning, is clearly opposite to that of its self weight and service load.

The moment mx due to post-tensioning is shown below.





Remark: Because the ULS is an enveloping combination and therefore only an enveloping result would be retrieved, only the following linear ULS combination is shown here:

1*LC1 + 1,35*LC2 + 1,5*LC3

The user should continue to evaluate if the resulting internal forces can be absorbed by the concrete itself or by passive reinforcement. If he considers that this is not the case, then the prestressing force can be increased and the linear calculation can be performed again.

The design of the passive reinforcement and also the controls for allowable stresses are supported only for 1D elements.

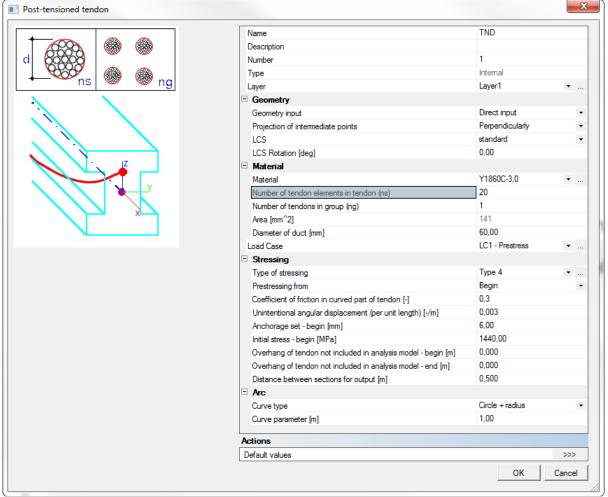
Analysis of a slab post-tensioned in 2 directions

Post-tensioned cables can also be applied on 2D elements. This means that the post-tensioning can be applied in two directions. Below, an example of a post-tensioned slab in 2 directions will be discussed.

1_Input of geometry and post-tension

A square plate with a thickness of 400mm is chosen (with 'Member system-plane at = centre'). The span is 10 meters and at each edge a hinged line support is added (so the load is carried to the supports in 2 directions). The concrete quality C30/37 is chosen.

Next the tendons have to be inputted. The properties are those as seen in the image below. The cables are tensioned from the beginning, without restressing at the end.



The cables will be placed with an interval of 1 meter in each direction. And the geometry of the cables follows the coordinates is as follows (the tendons are heightened towards the edges of the plate):

	Coord X [m]	Coord Y [m]	Coord Z [m]	Curve type		ve parameter	-
1	0,500	0,000	0,000				
2	0,500	2,000	-0,150	Circle + radius	•	1,000	Ξ
3	0,500	8,000	-0,150	Circle + radius	•	1,000	4
4	0,500	10,000	0				-

TND 🗸 🔟 🔟 🧻 default 🗸 🛄 🎹 default 🖻 💹 🎒 🎒 📔 🕂 🗌 📒 200 % Anchorage set loss appears over the whole length of tendon. Theoretical tendon elongation before transfer 0,068 [m] Theoretical tendon elongation after transfer 0,062 [m] Frictional loss Anchorage set loss Short-term relaxation Stress after anchoring / z х [MPa] [m] [m] [MPa] [MPa] transfer [MPa] 0.000 0.000 0.00 -206,74 0,00 1233,26 0,500 -0,037 -0,76 -205,34 0,00 1233,90 1,000 -0,075 -1,51 -203,94 0,00 1234,55 🔟 Ready (nl) [MPa] Frictional loss 1600,00 Anchorage set 1400,00 Short-term relaxation 1200,00 1000,00 800,00 600.00 400.00 200,00 0,00 2,000 2,500 3,000 3,500 4,000 4.500 5,000 5,500_ 6,000 6,500 7,000 7,500_ 8,000 9,500 000 ,500 000,6 0.000 0000 500 3.500 Ξ ▼ + 0,0 MPa Vertical axis: 200,0 MPa Origin value from: Origin Selected tendon TND Close Text scale: 🔝 🛨 Vertical scale: 1 🕂

This gives the following result for the course of the cable losses:

2_Input of loads

Since this is a very brief example, only the load case of 'Prestress' is shown. The effect of the prestress of each tendon is combined in load case LC1 for direction X and Y. It would also be possible to divide this in separate load cases, to examine the contribution of the pre-tensioning individually for each direction. And by using construction stages, it is also possible to simulate the tensioning sequentially.

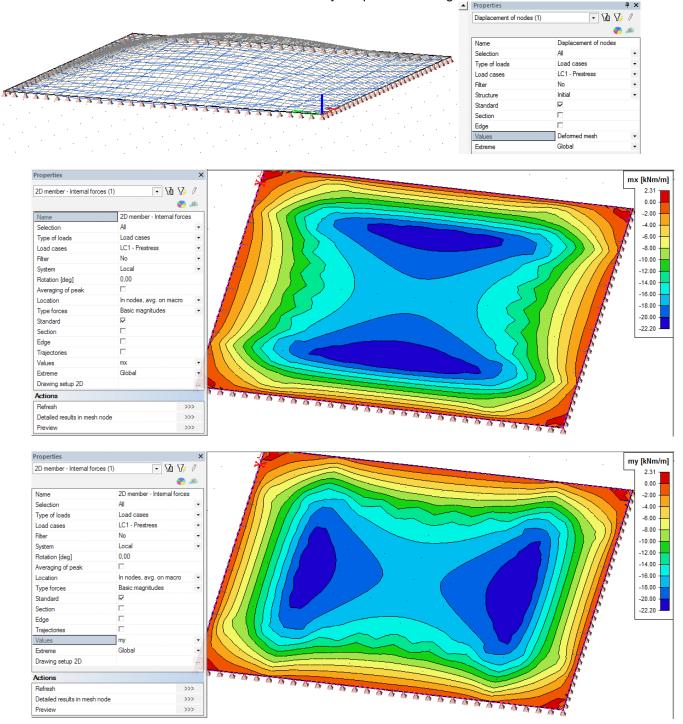
3_Calculation

The mesh size for 2D elements is set at 0,25m. Then a linear calculation is executed.

Mesh setup		×
Name		
Mesh		
Minimal distance between two points [m]	0,001	
Average number of tiles of 1D element	1	
Average size of 2D element/curved element [m]	0,250	
Different of the second second	Manual	

4_Results

The deformations and the internal forces induced by the post-tensioning are shown below.



For the moments, it is clear that symmetry is present in the prestress effects. This points out that the tendons are taken into account for both directions.

For an interpretation of the results, reference is made to the preceding examples.

Detailled documents about design and checks of post-tensioned slabs

For a more detailed document about post-tensioned plates, a reference is made to the tutorial 'Post-tensioned concrete slab EN1992-1-1'.

This tutorial elaborates on the design and checks of post-tensioned slab elements according to EN 1992-1-1. The focus is not so much on imports as in previous chapters, but on the discussion of the output.

This tutorial is only available in English.