Annex 0

Reinforcement Configurations of specimens Slender and Deep Beams

Slender Beams

Important Note:

For detailed elaborated Scia Engineer design step refers to the following chapters,

- Specimen 1 is the specimen with reinforcement configuration based on applied SLS load of 200 kN (SLS factor is 1).
- Specimen 2 is the specimen with reinforcement configuration based on applied SLS load of 400 kN (SLS factor is 1).
- Specimen 3 is the specimen with reinforcement configuration based on applied SLS load of 580 kN (SLS factor is 1).
- Specimen 4 is the specimen with reinforcement configuration based on applied SLS load of 450 kN (SLS factor is 1).
- Specimen 5 is the specimen with reinforcement configuration based on applied SLS load of 540 kN (SLS factor is 1).
- This chapter is also include the method of optimization

Naming of the different reinforcement configurations

- All reinforcement configurations are based on 2D finite element model in SCIA engineer.
- After optimization which is done by using Beam 1D model in SCIA Engineer. Whenever for horizontal and vertical reinforcement optimization process is done, one can call that specific horizontal or vertical reinforcement as 1d.
- In the following table the Naming of the different specimens are presented.
- Naming of the reinforcement configuration has two parts, and each part can have two values, 1d or 2d. The first part of the reinforcement configuration is about horizontal reinforcement and the second part is about shear (vertical) reinforcement (table 0-1)

Reinforcement configuration	Description
1d1d	In which both horizontal and vertical reinforcements are optimized
1d2d	In which only horizontal reinforcements are optimized (1d) and vertical reinforcements are still based on (2D) Scia finite element model
2d1d	In which only Vertical reinforcements are optimized (1d) and horizontal reinforcements are still based on (2D) Scia finite element model
2d2d	In which none of the horizontal and vertical reinforcements are optimized can be called 2d2d.(this is directly comes from 2D finite element model in SCIA.

Table 0-1

Specimen	Rein. config	Length[mm]	a=L/2 [mm]	Height(h)[mm]or depth(d)	L/h	App a/d	Width[mm]
1-1-1 1-2-1 1-3-1 1-4-1 1-5-1	1d1d	4000	2000	1000	4	2	200
1-1-2 1-2-2 1-3-2 1-4-2	1d2d						
1-1-3 1-2-3 1-3-3 1-4-3	2d1d						
1-1-4 1-2-4 1-3-4 1-4-4	2d2d						

Table 0-2

Specimen	**Applied point load (SLS)[kN]**	**Reinforcement configuration**	**Skin reinforcements**	**Distance shear reinforcements**
1-1-1	**200**	**1d1d**	**NO**	**10-300**
1-1-2		**1d2d**	**NO**	**10-250**
1-1-3		**2d1d**	**YES**	**10-300**
1-1-4		**2d2d**	**YES**	**10-250**
1-2-1	**400**	**1d1d**	**NO**	**10-200**
1-2-2		**1d2d**	**NO**	**10-130**
1-2-3		**2d1d**	**YES**	**10-200**
1-2-4		**2d2d**	**YES**	**10-130**
1-3-1	**580**	**1d1d**	**NO**	**12-150**
1-3-2		**1d2d**	**NO**	**12-130**
1-3-3		**2d1d**	**YES**	**12-150**
1-3-4		**2d2d**	**YES**	**12-130**
1-4-1	**450**	**1d1d**	**NO**	**10-170**
1-4-2		**1d2d**	**NO**	**12-150**
1-4-3		**2d1d**	**YES**	**10-170**
1-4-4		**2d2d**	**YES**	**12-150**
1-5-1	**540**	**1d1d**	**NO**	**-**

Table 0-3

SPECIMENS

Applied SLS load (factor 1) of 200 kN

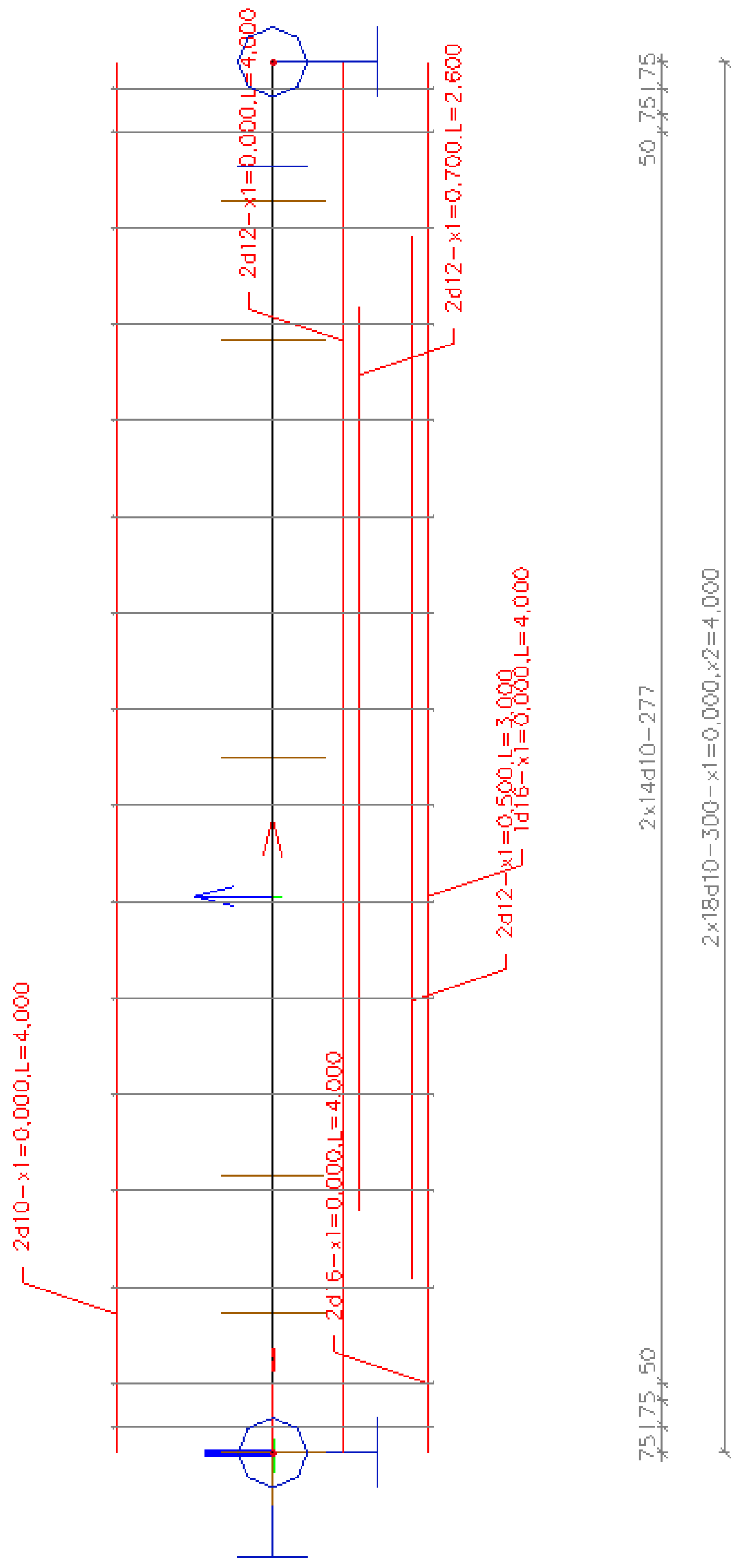
1-1-1

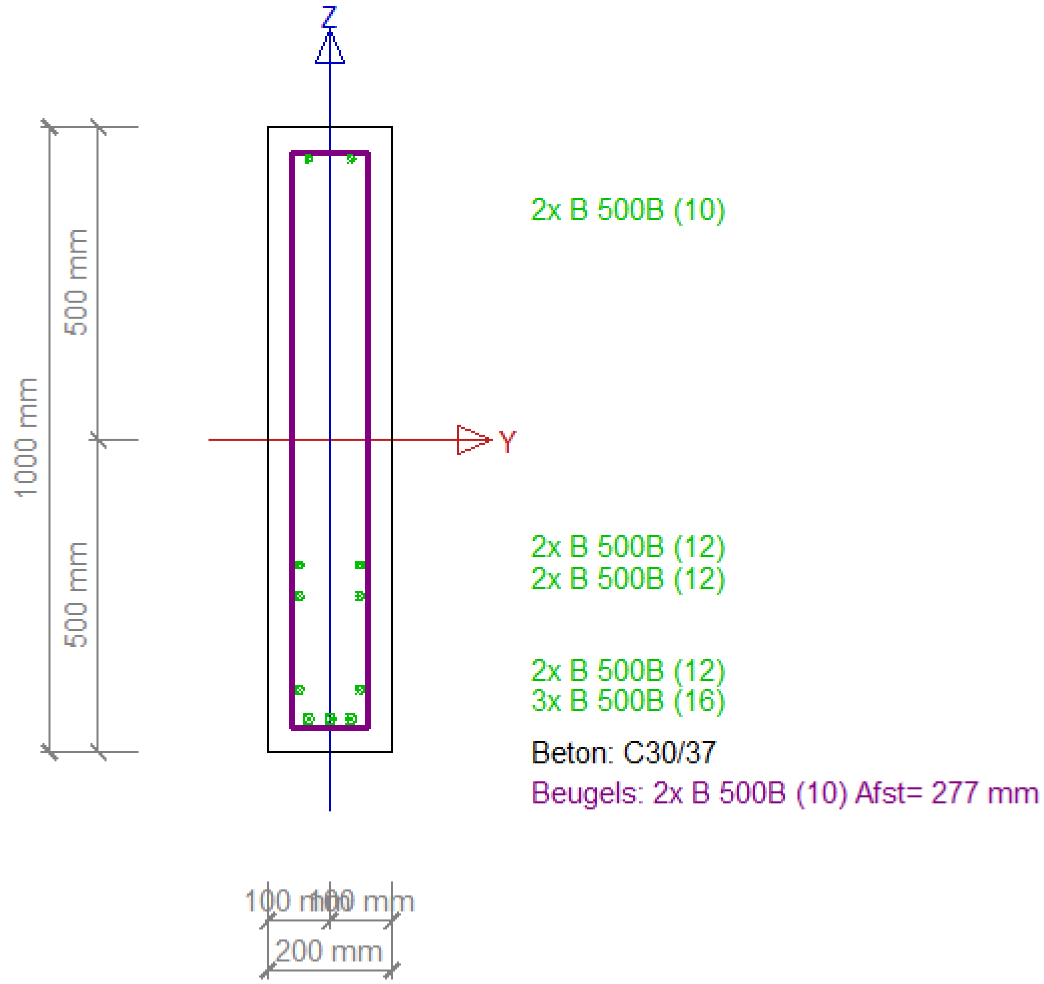
1-1-2

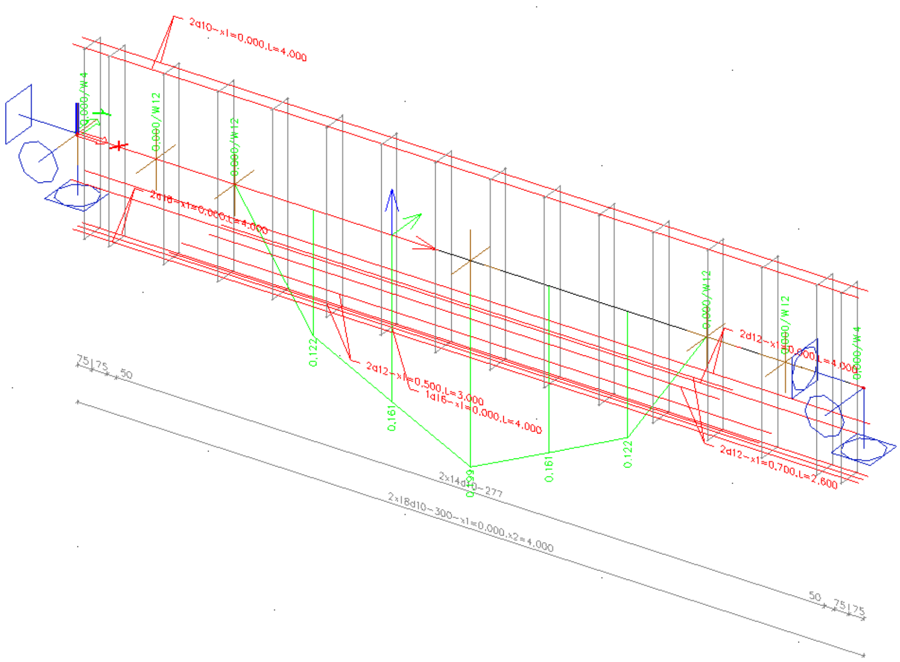
1-1-3

1-1-4

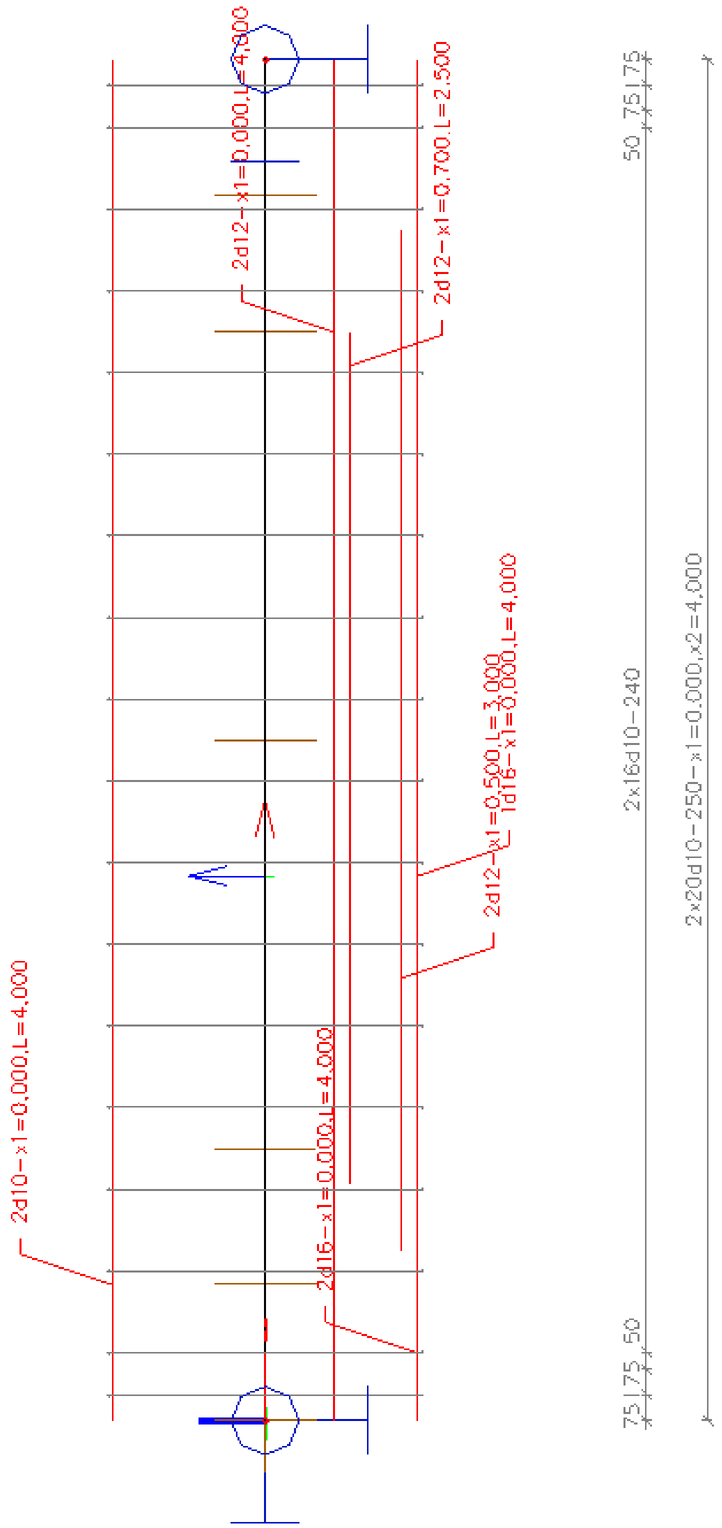
Specimen 1-1-1   reinforcement configuration 1d1d

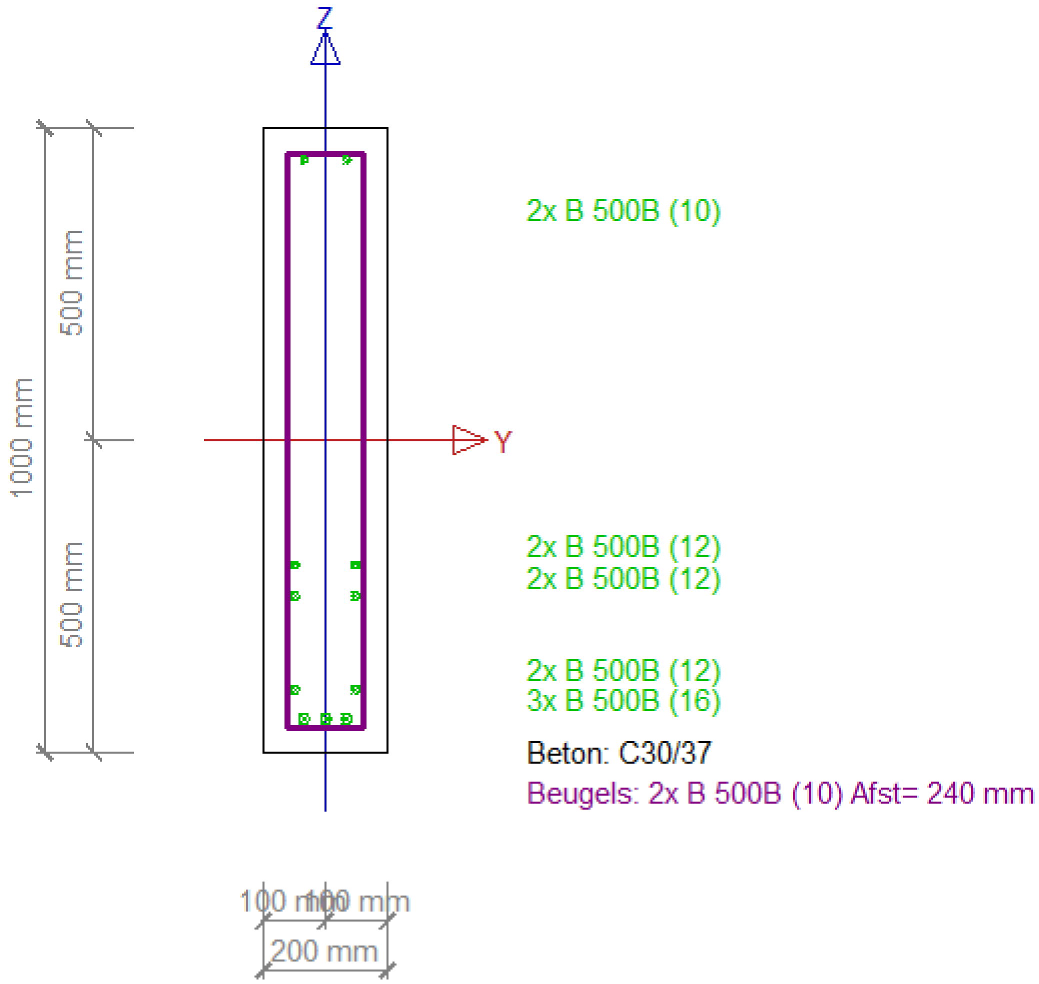



Z
Y
1000 mm
500 mm
500 mm
2x B 500B (10)
2x B 500B (12)
2x B 500B (12)
2x B 500B (12)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 277 mm
100 mm
100 mm
200 mm

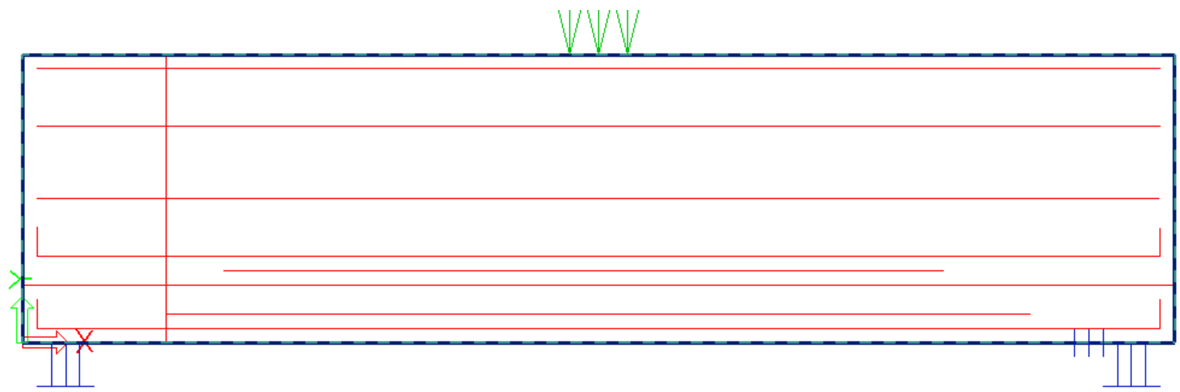


Specimen 1-1-2 reinforcement configuration 1d2d

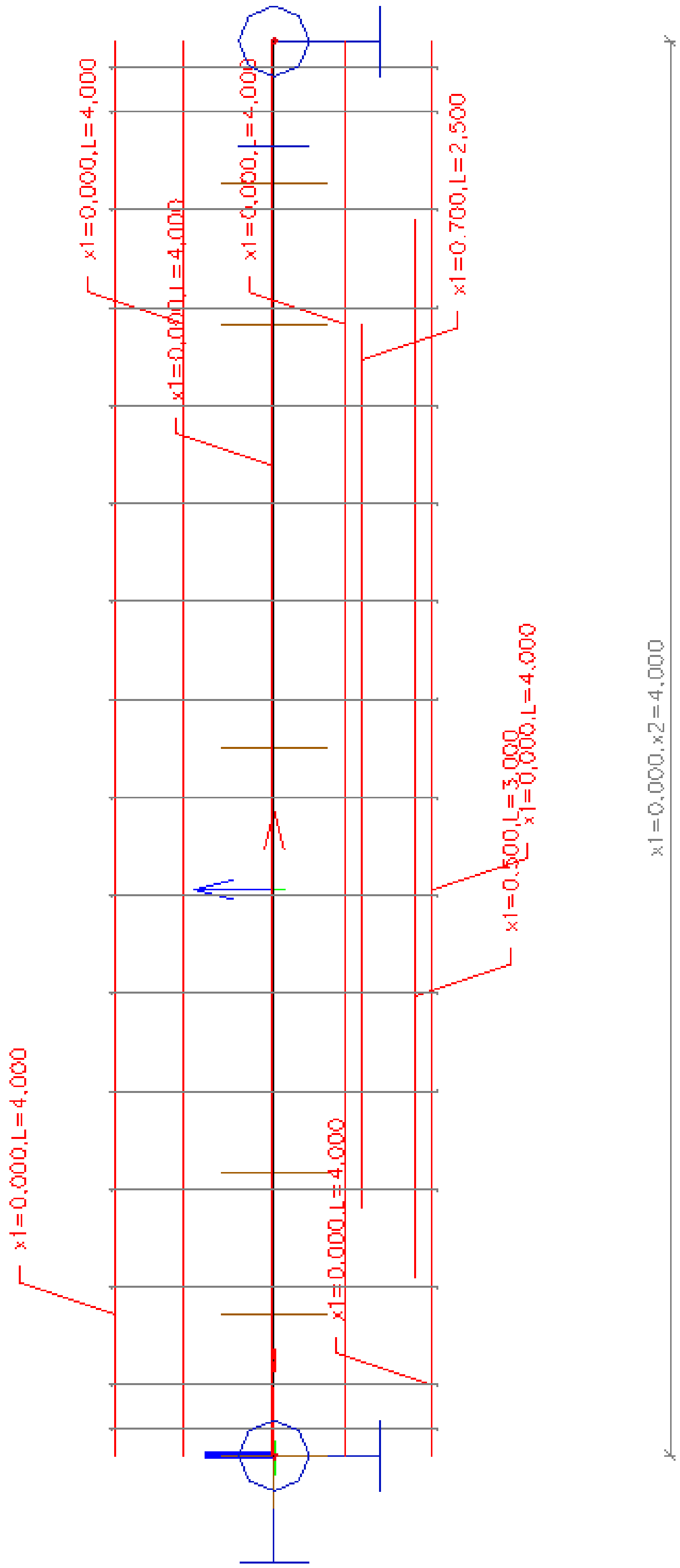


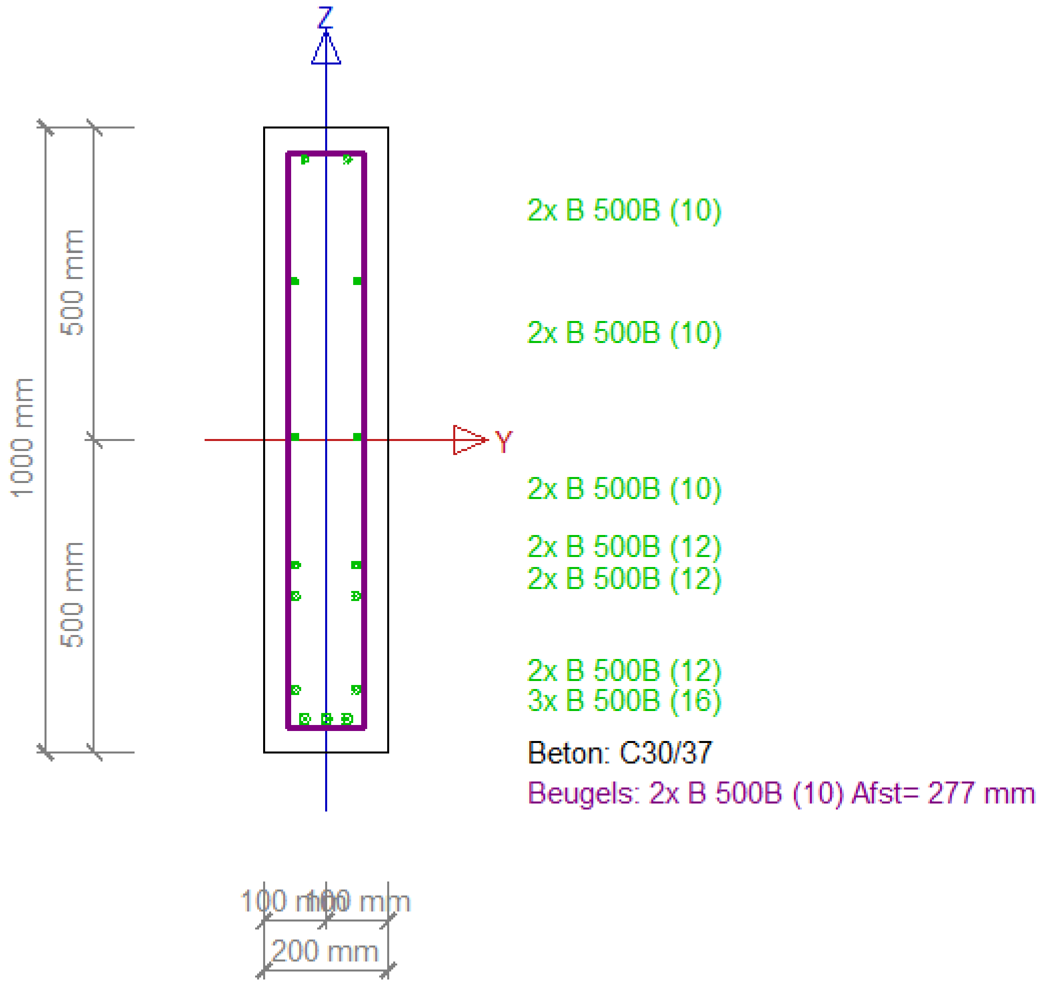


(2D finite element model)

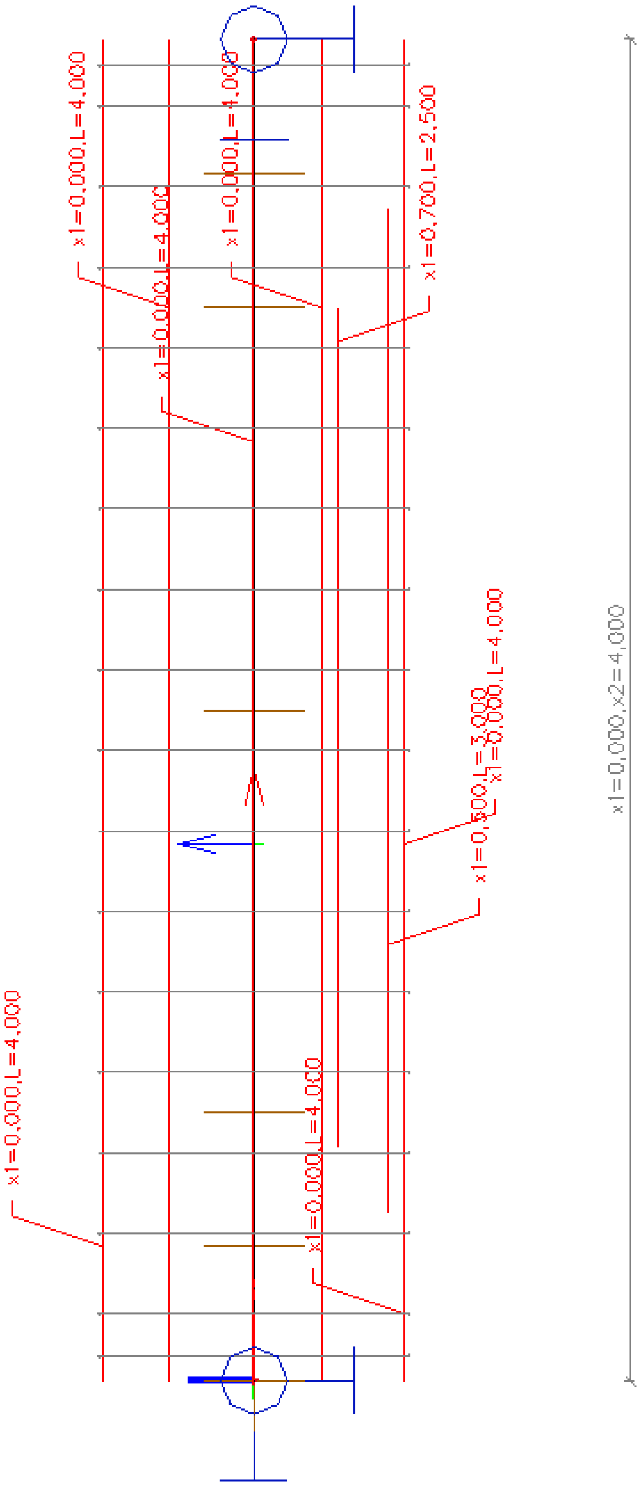


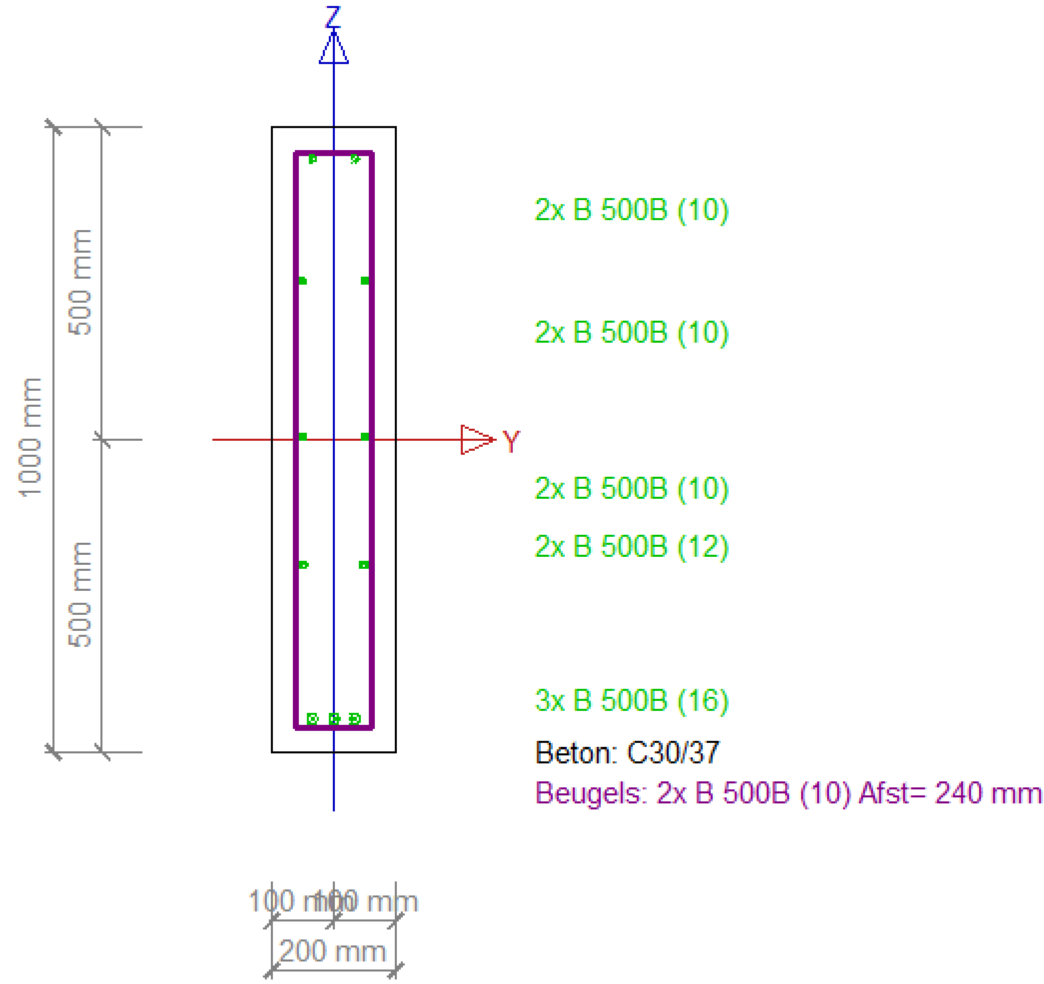
Specimen 1-1-3   reinforcement configuration 2d1d




Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (10)
2x B 500B (10)
2x B 500B (10)
2x B 500B (12)
2x B 500B (12)
2x B 500B (12)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 277 mm

Specimen 1-1-4 reinforcement configuration 2d2d




Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (10)
2x B 500B (10)
2x B 500B (10)
2x B 500B (12)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 240 mm

Applied SLS load (factor 1) of 400 kN

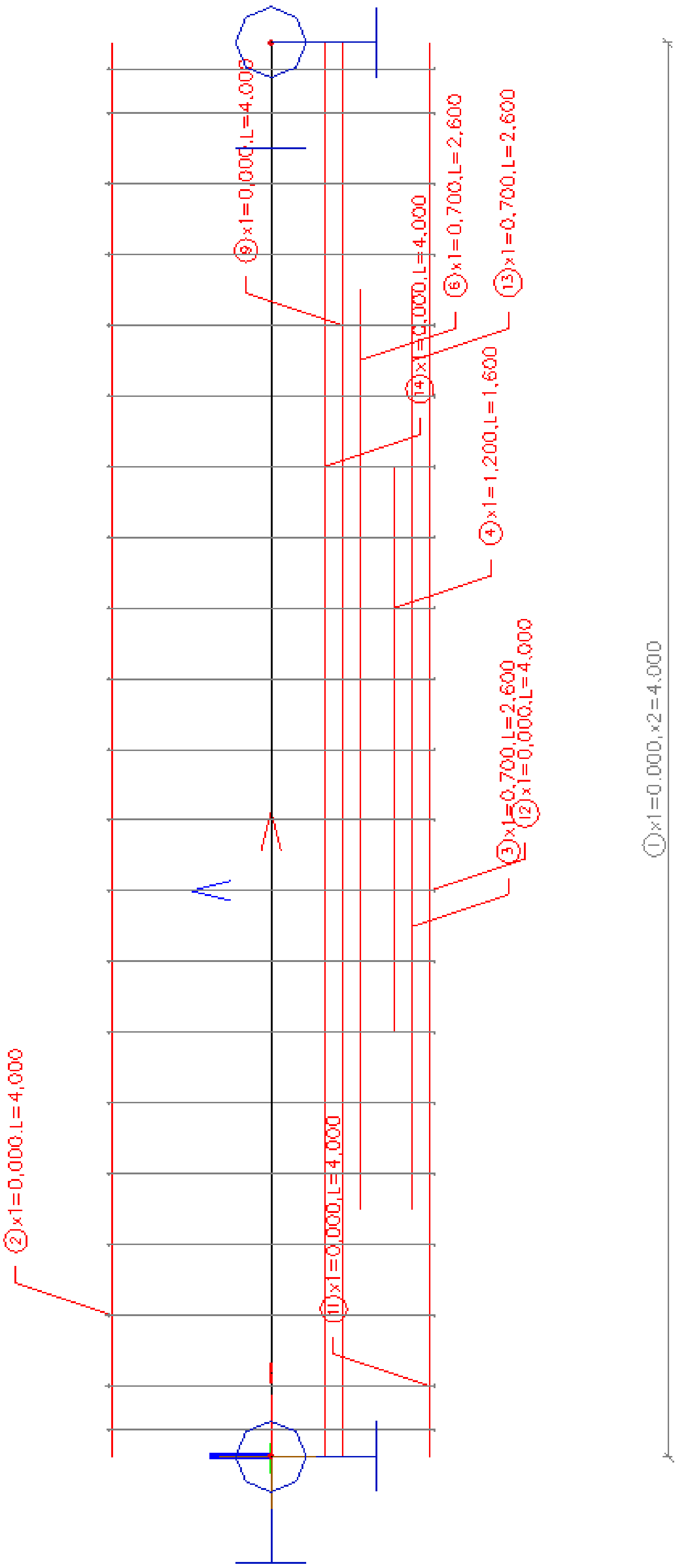
1-2-1

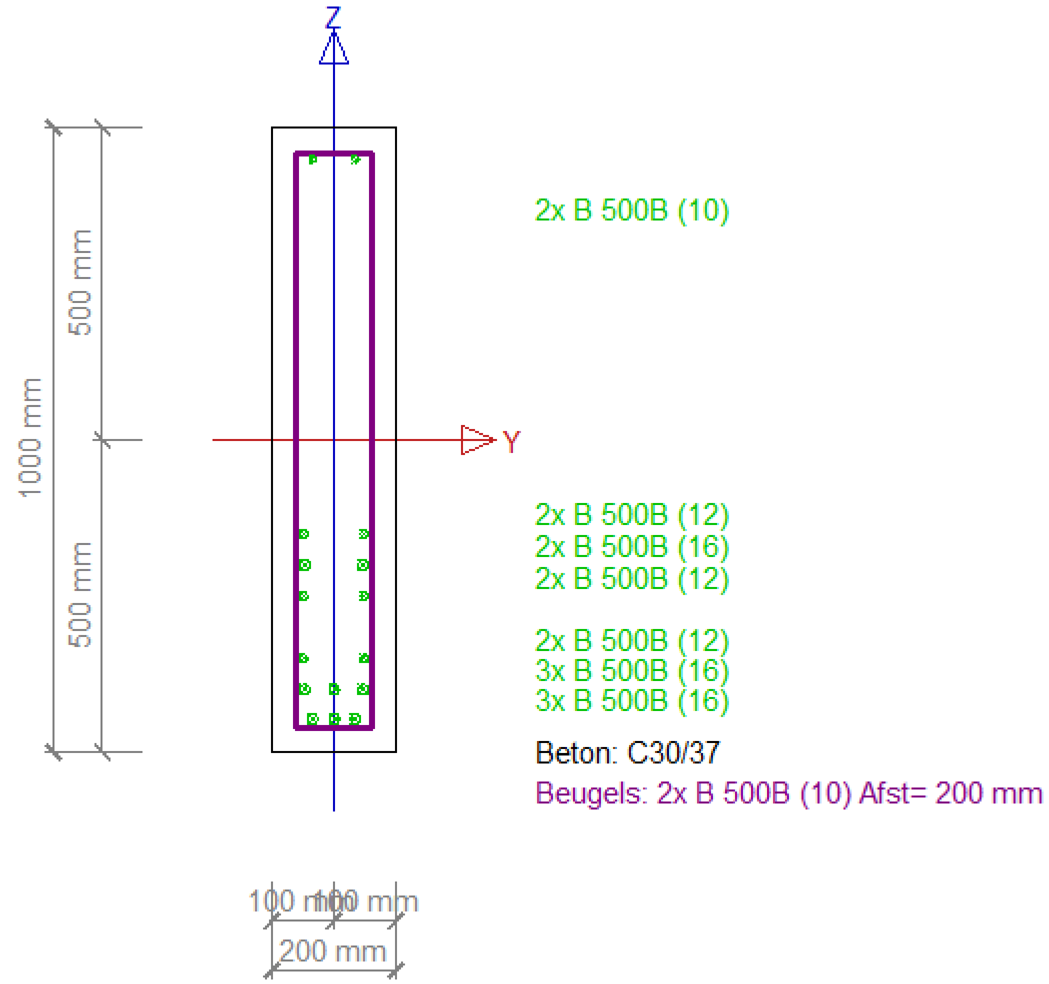
1-2-2

1-2-3

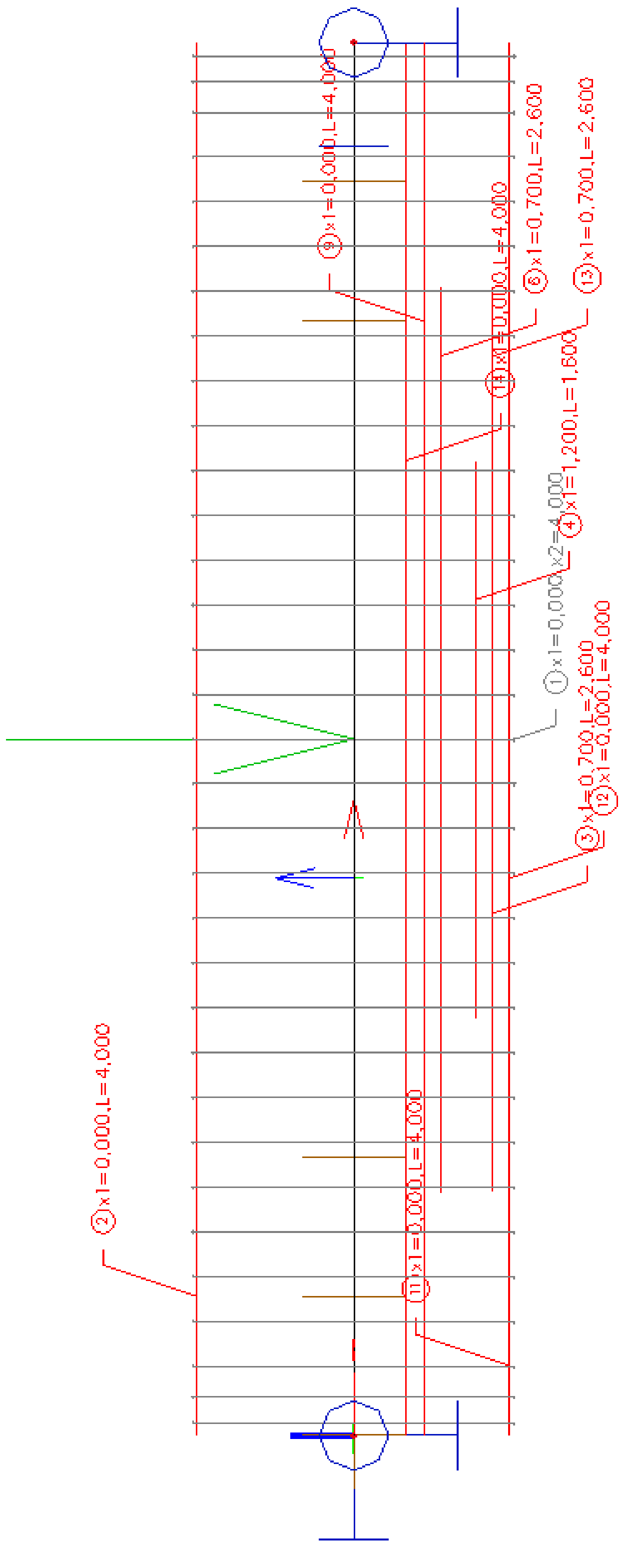
1-2-4

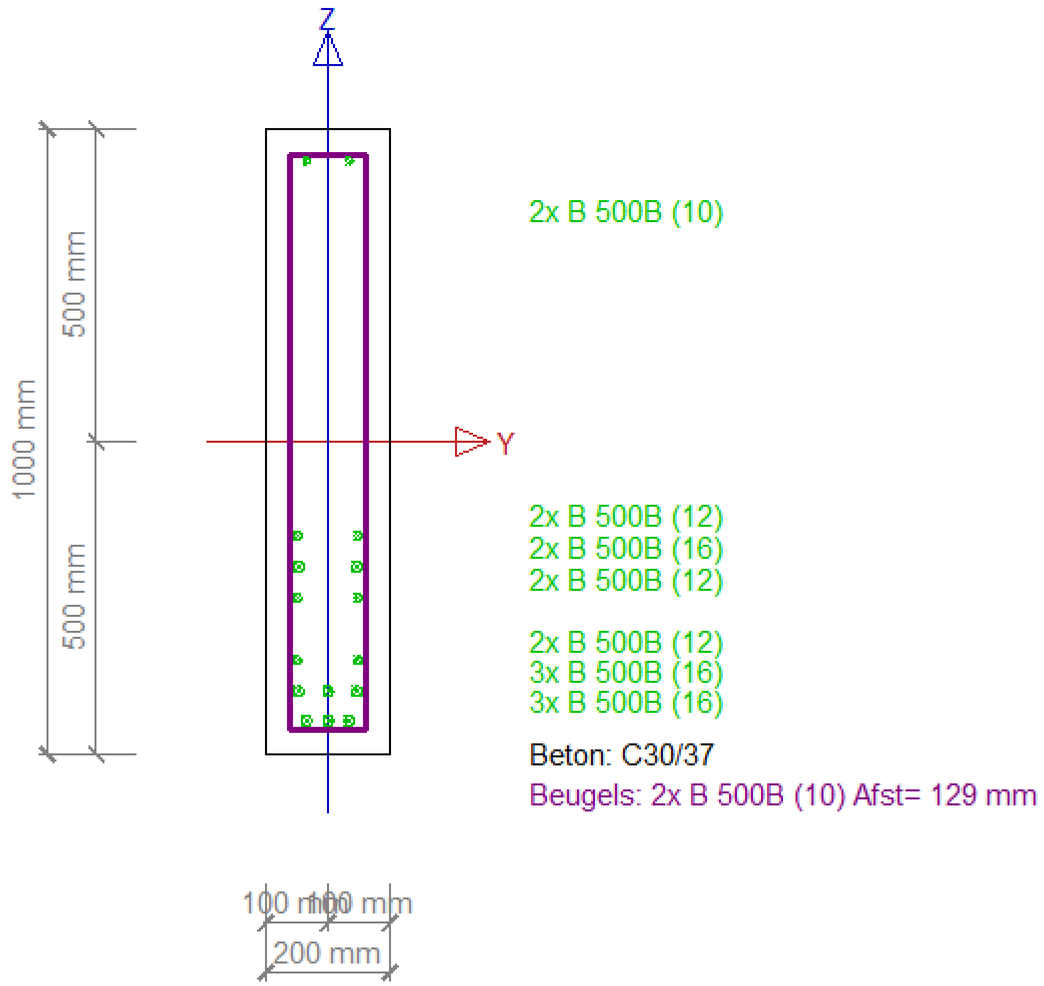
Specimen 1-2-1 Reinforcement configuration 1d1d



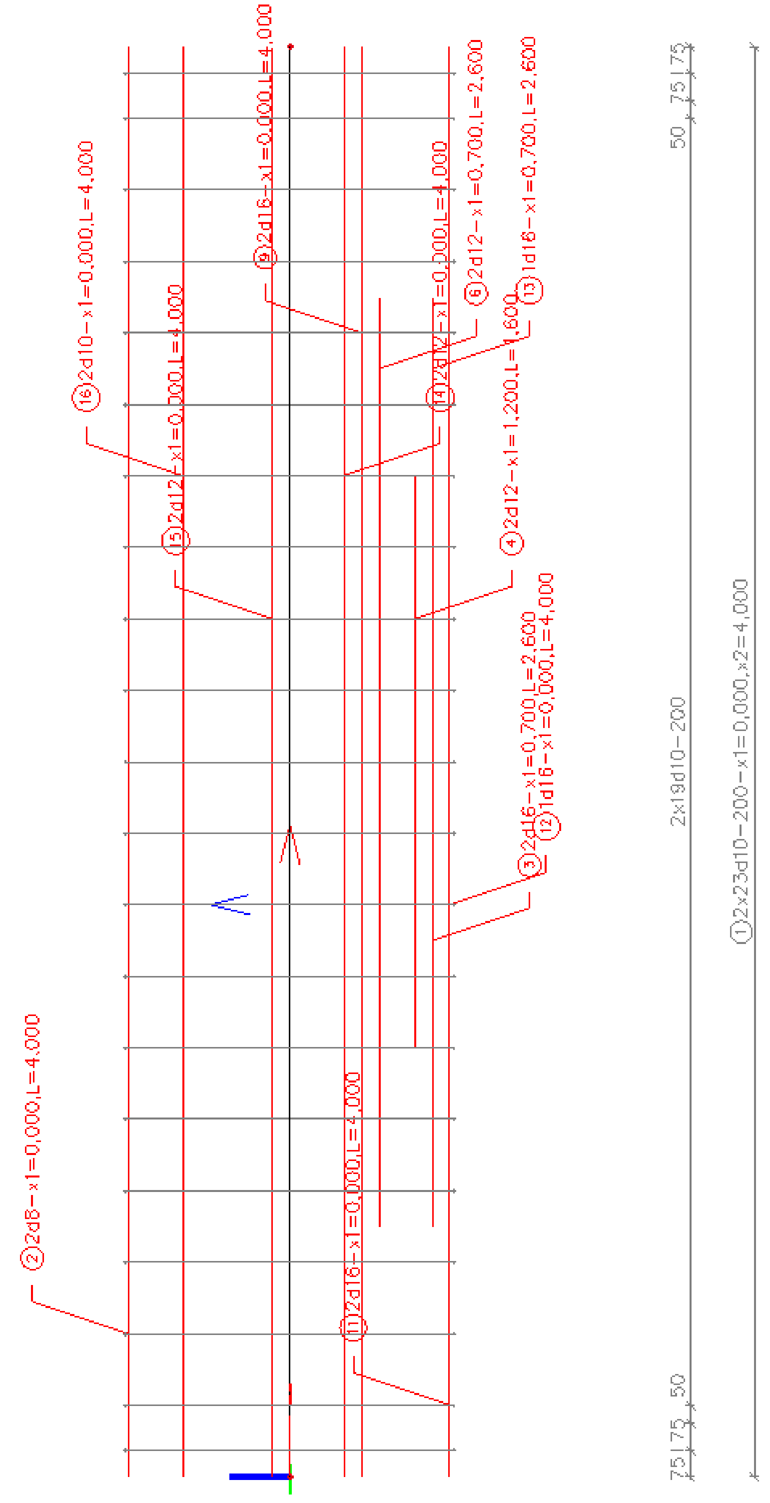

Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (10)
2x B 500B (12)
2x B 500B (16)
2x B 500B (12)
2x B 500B (12)
3x B 500B (16)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 200 mm

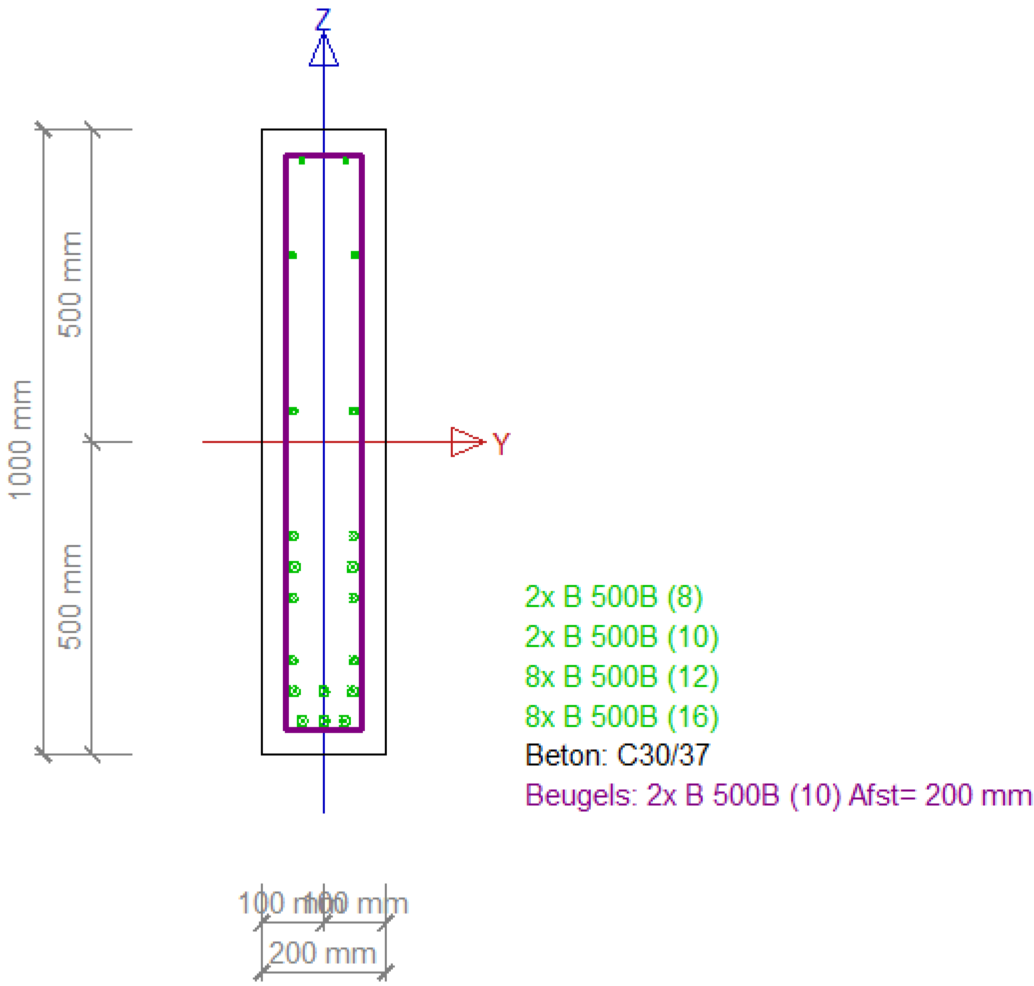
Specimen 1-2-2 reinfrocment configuration 1d2d



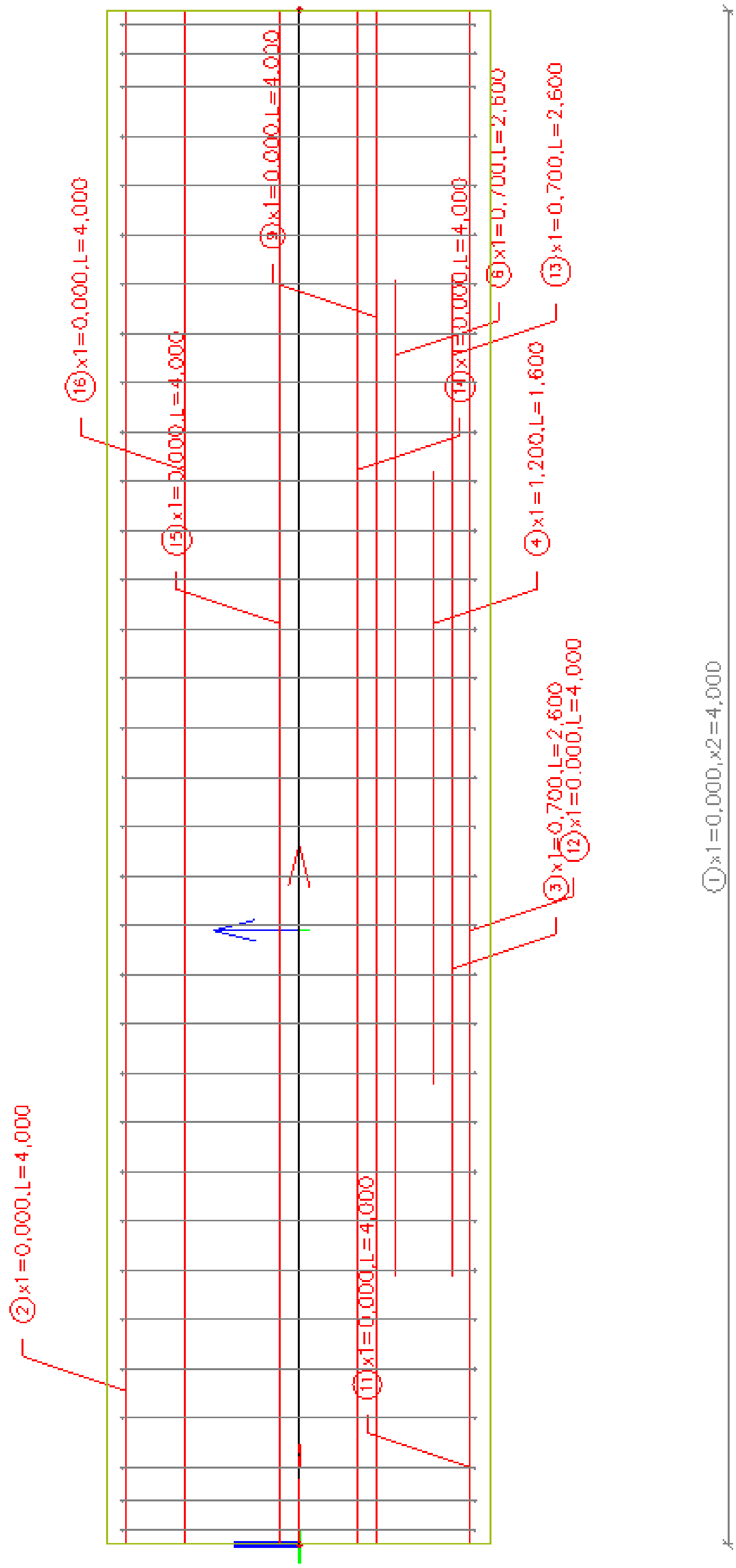

Z
Y
500 mm
1000 mm
500 mm
2x B 500B (10)
2x B 500B (12)
2x B 500B (16)
2x B 500B (12)
2x B 500B (12)
3x B 500B (16)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 129 mm
100 mm
100 mm
200 mm

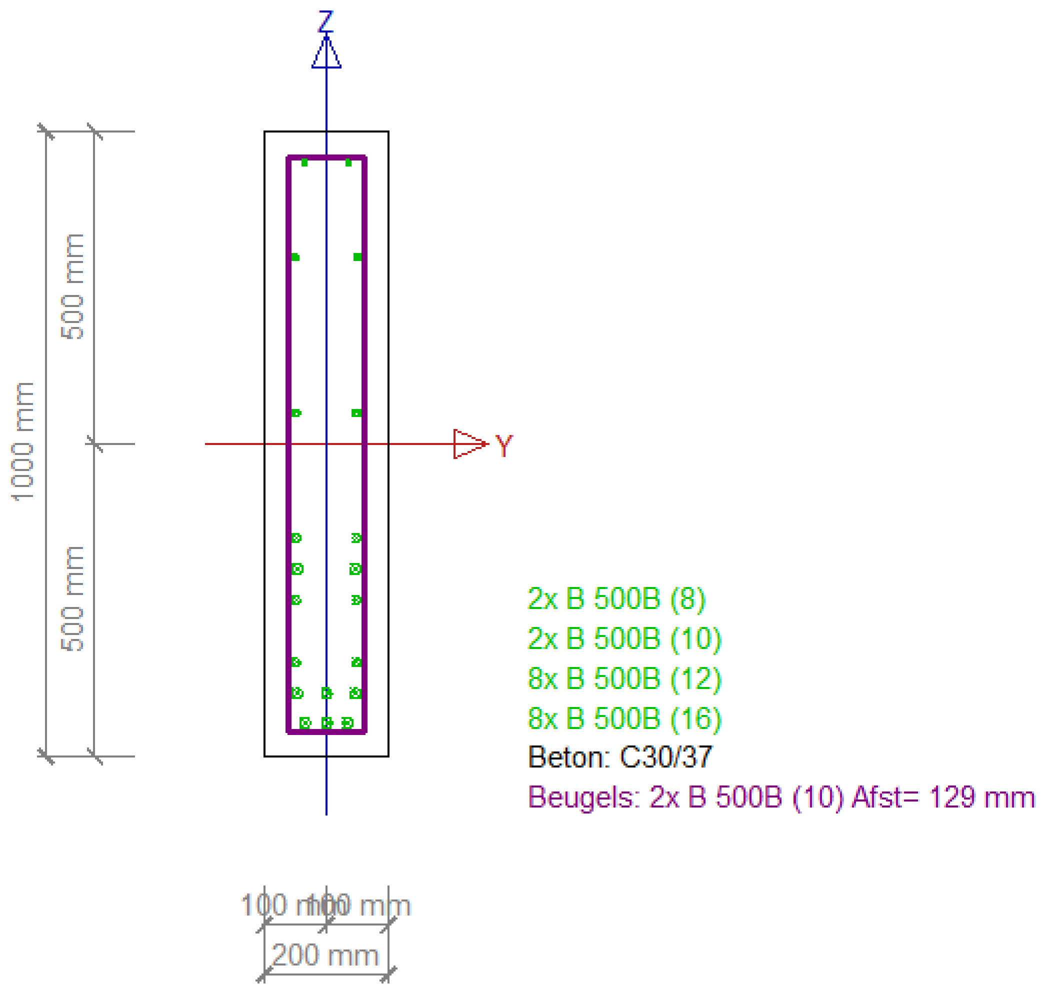
Specimen 1-2-3 2d1d




Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (8)
2x B 500B (10)
8x B 500B (12)
8x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 200 mm

Specimen 1-2-4   2d2d




Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (8)
2x B 500B (10)
8x B 500B (12)
8x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 129 mm

Applied SLS load (factor 1) of 580 kN

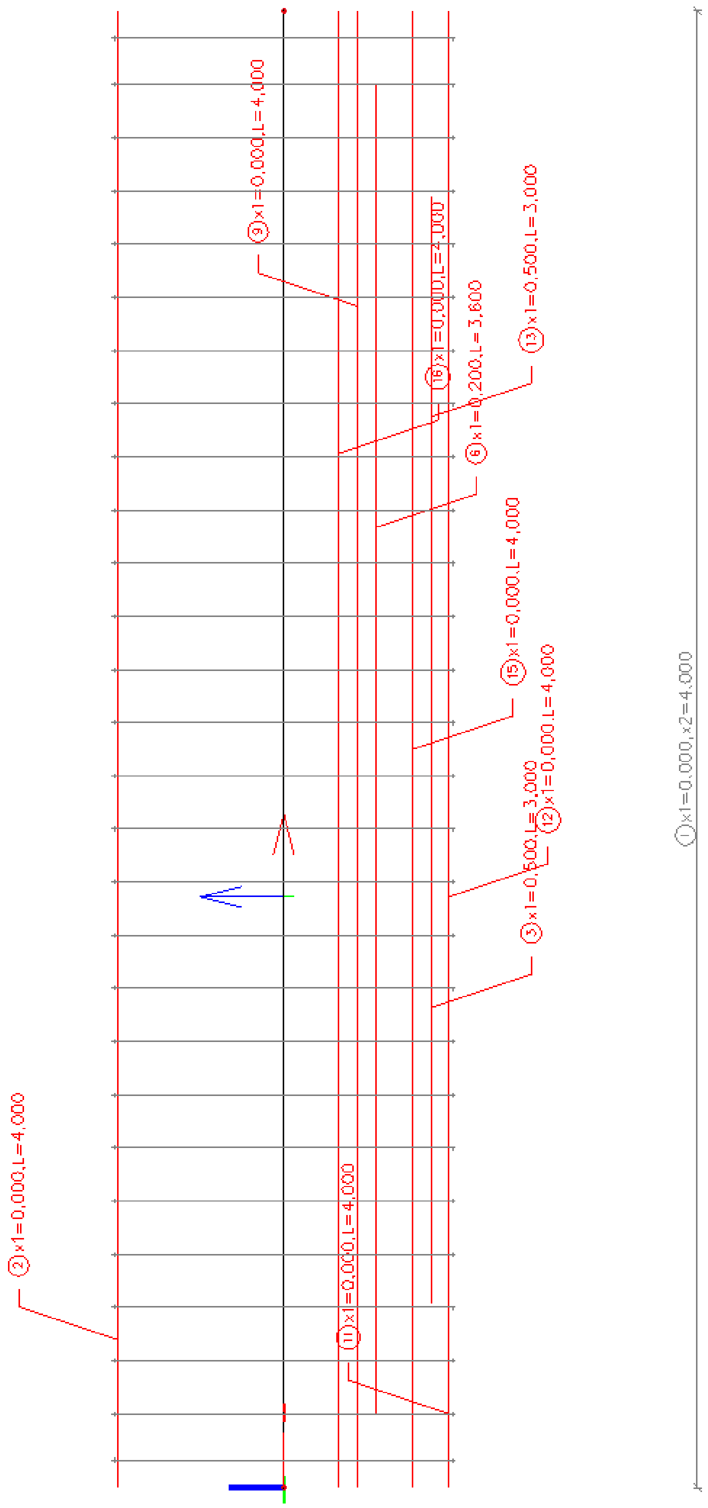
1-3-1

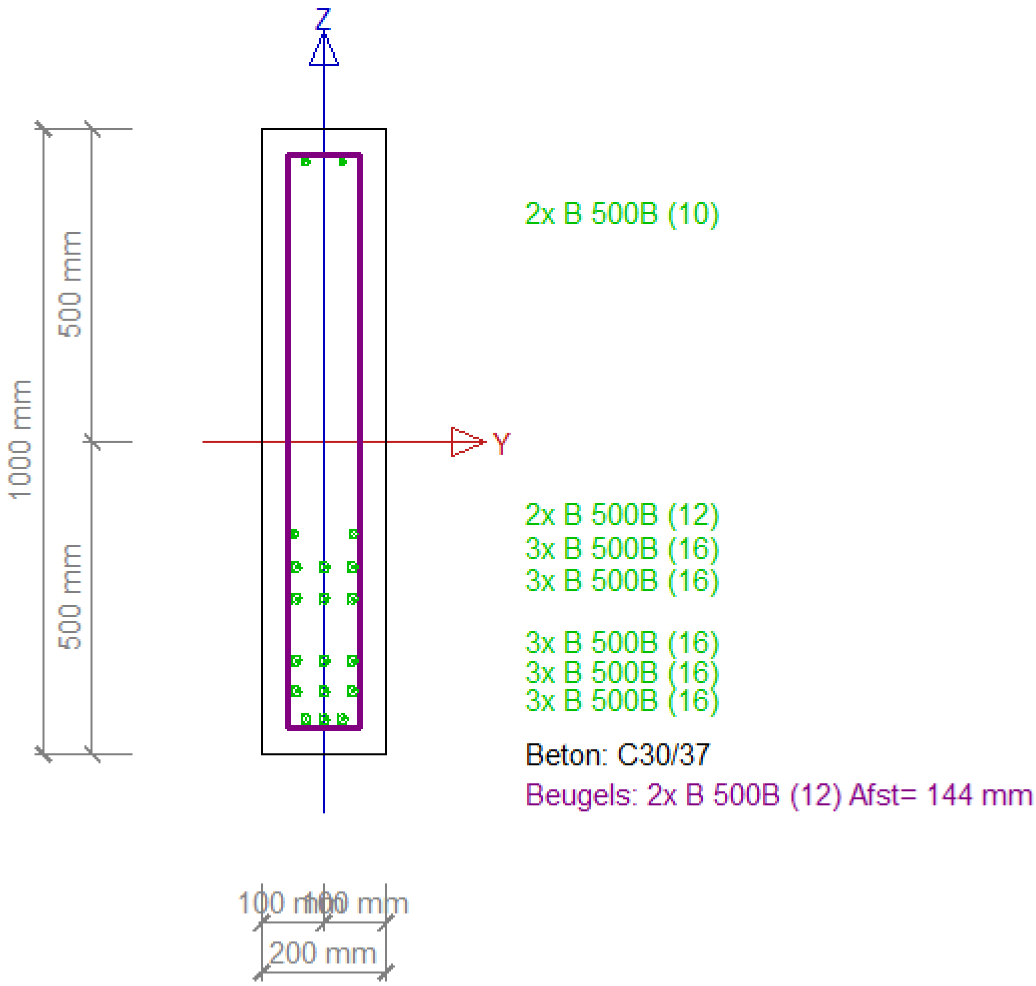
1-3-2

1-3-3

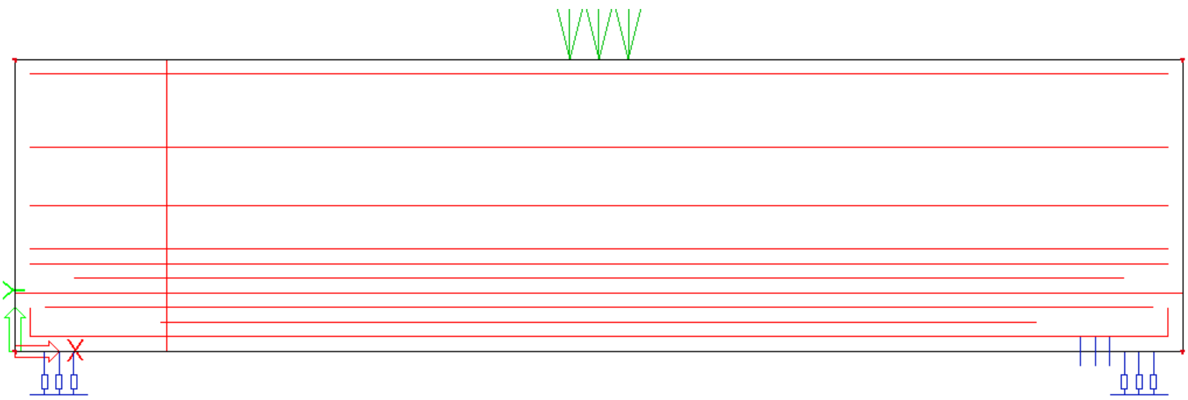
1-3-4

Specimen 1-3-1 1d1d

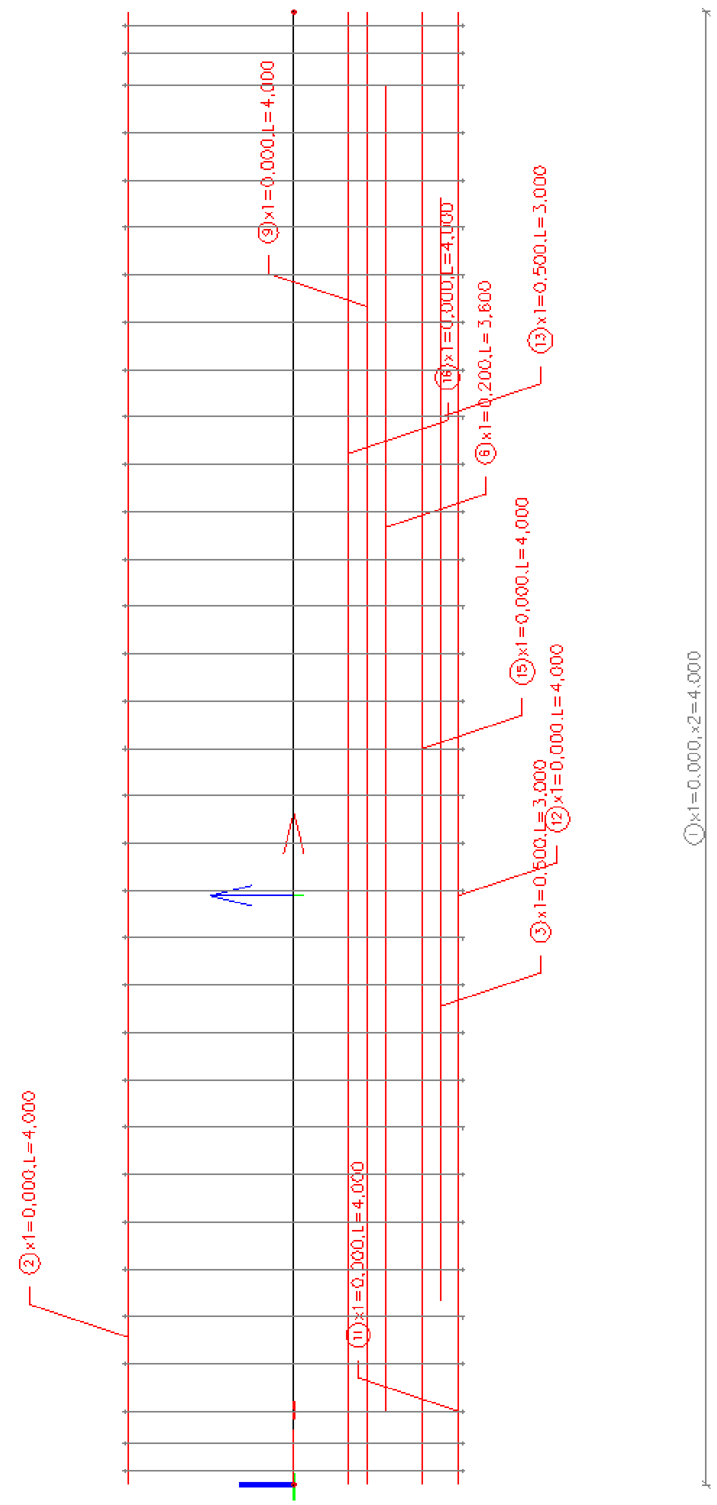


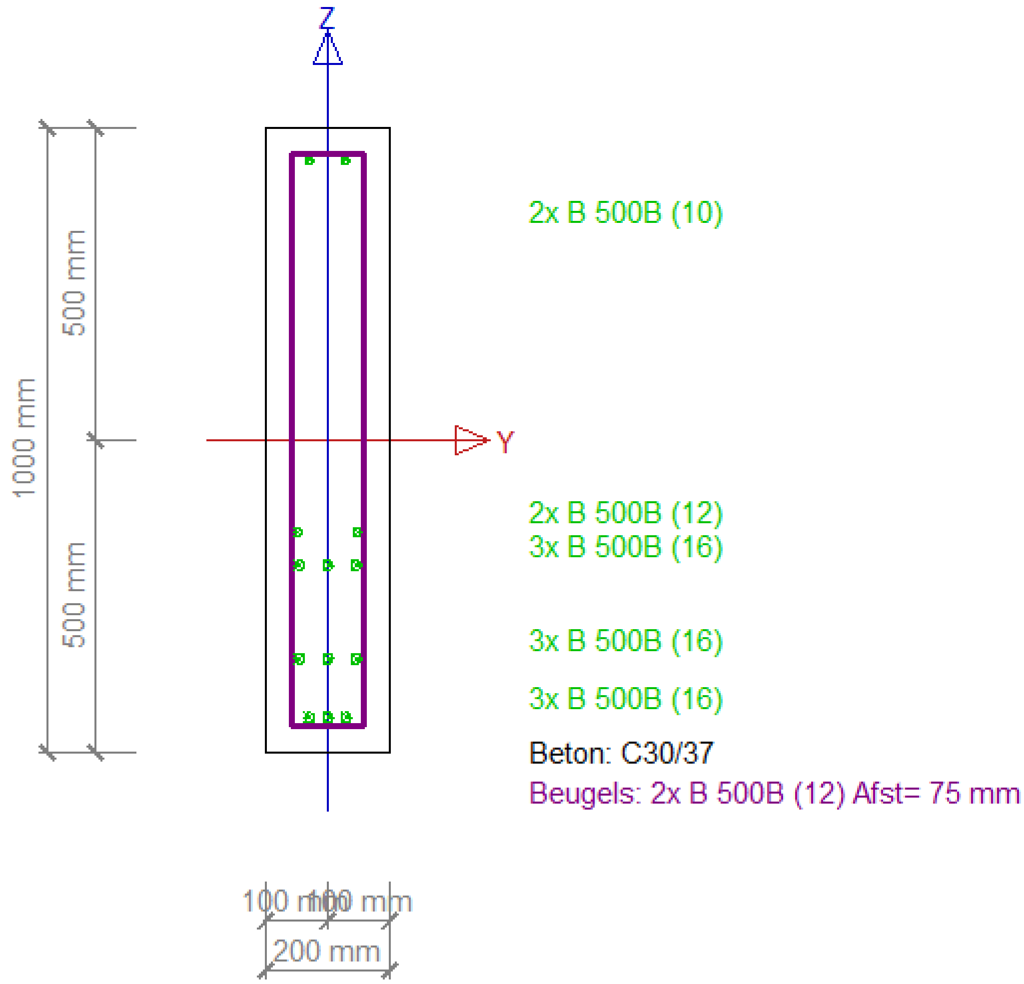


2d finite element model

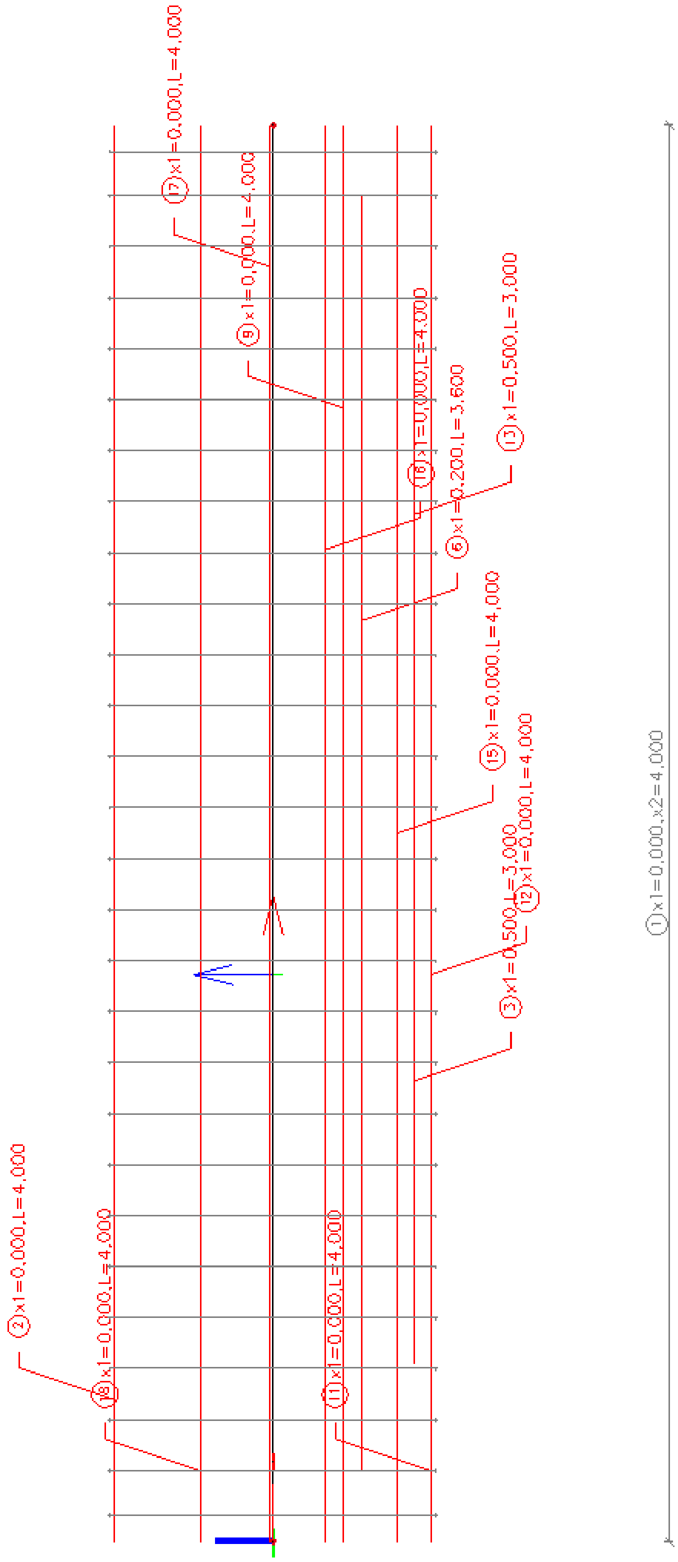


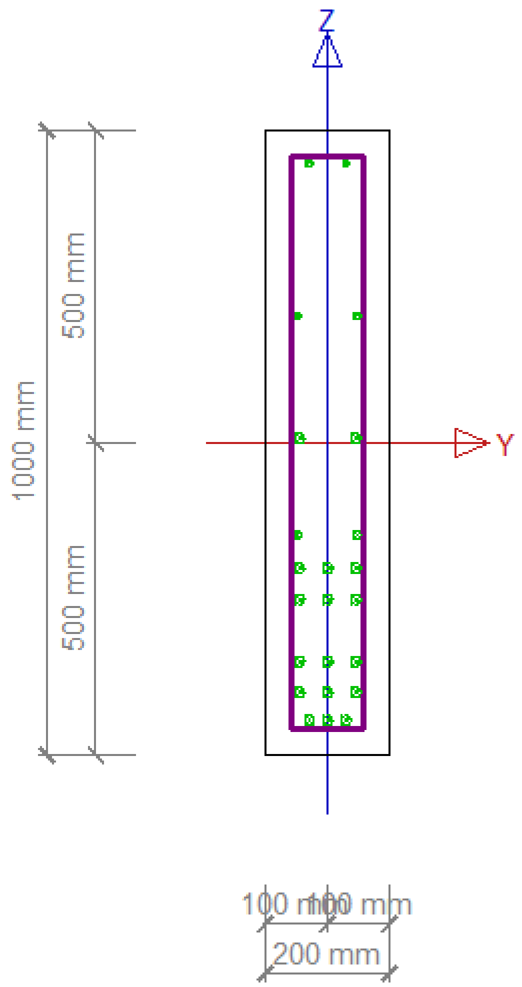
Specimen 1-3-2 1d2d




Z
Y
2x B 500B (10)
2x B 500B (12)
3x B 500B (16)
3x B 500B (16)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (12) Afst= 75 mm
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm

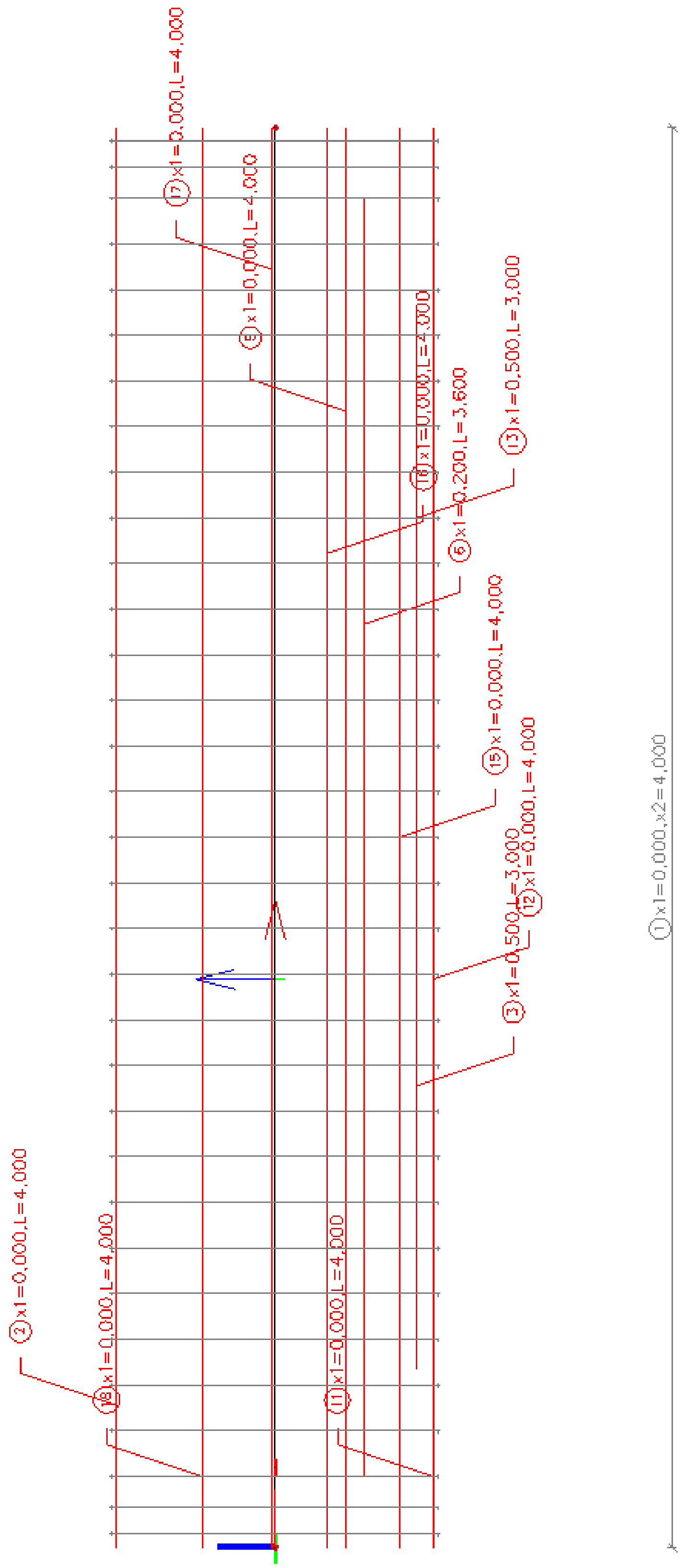
Specimen 1-3-3   2d1d

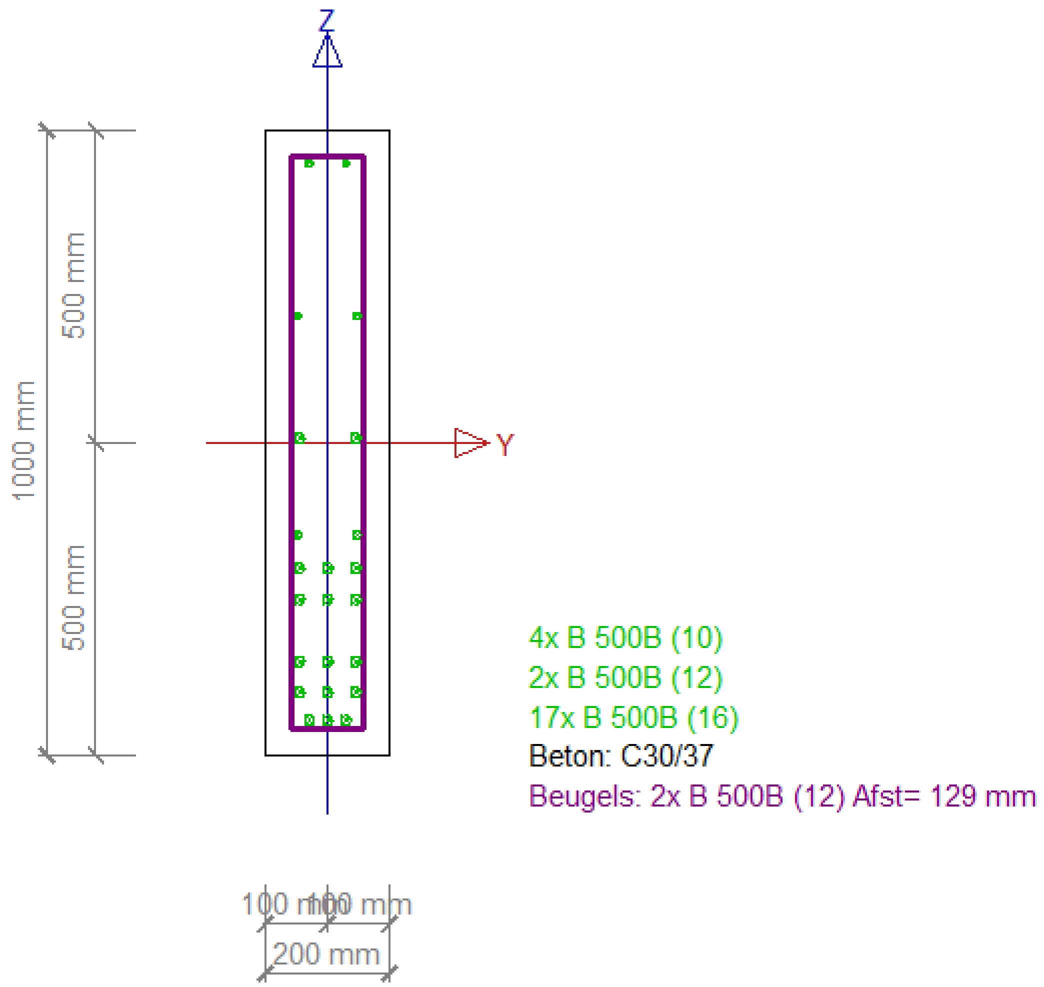




4x B 500B (10)
2x B 500B (12)
17x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (12) Afst= 144 mm

Specimen 1-3-4 2d2d




Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
4x B 500B (10)
2x B 500B (12)
17x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (12) Afst= 129 mm

Applied SLS load (factor 1) of 450 kN

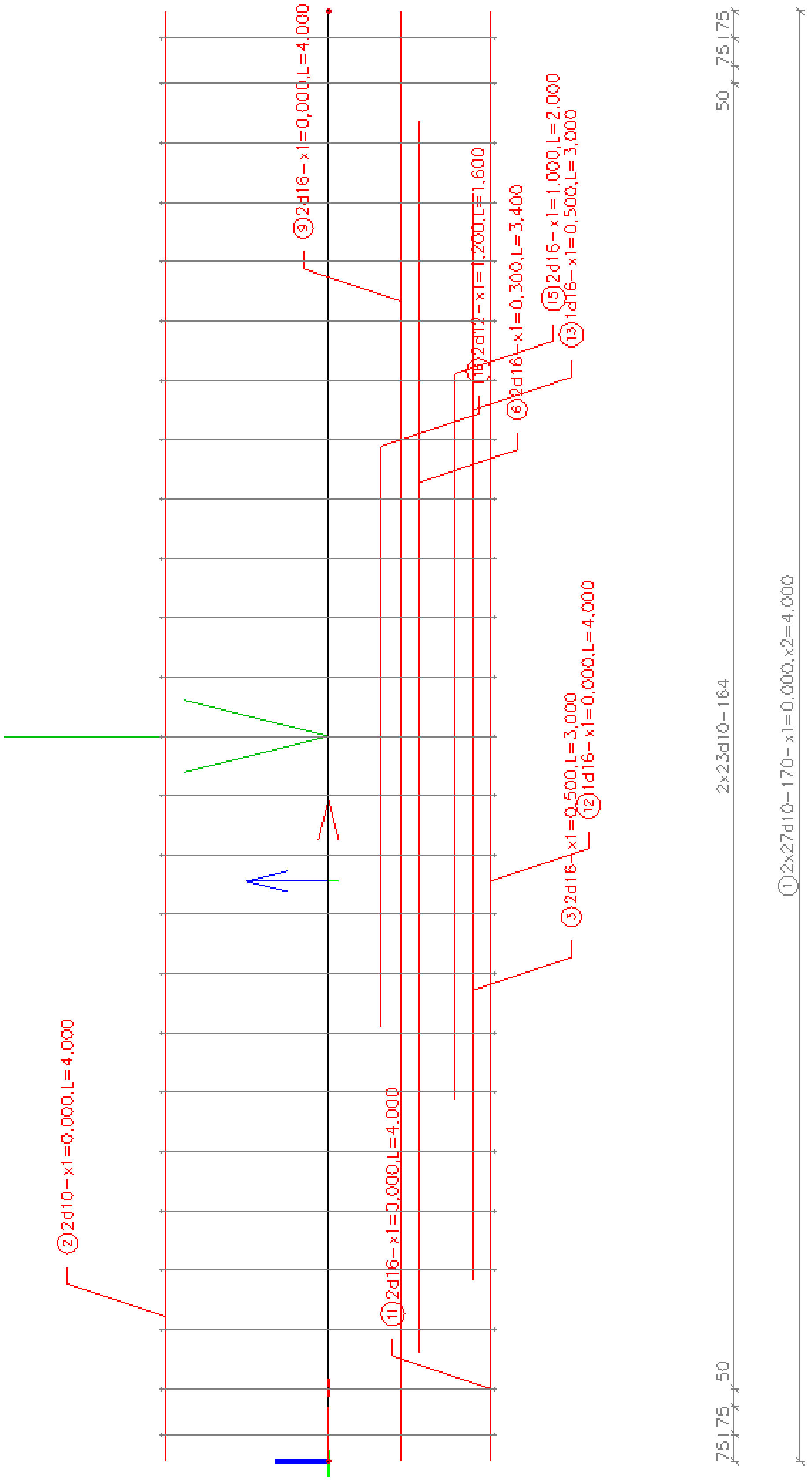
1-4-1

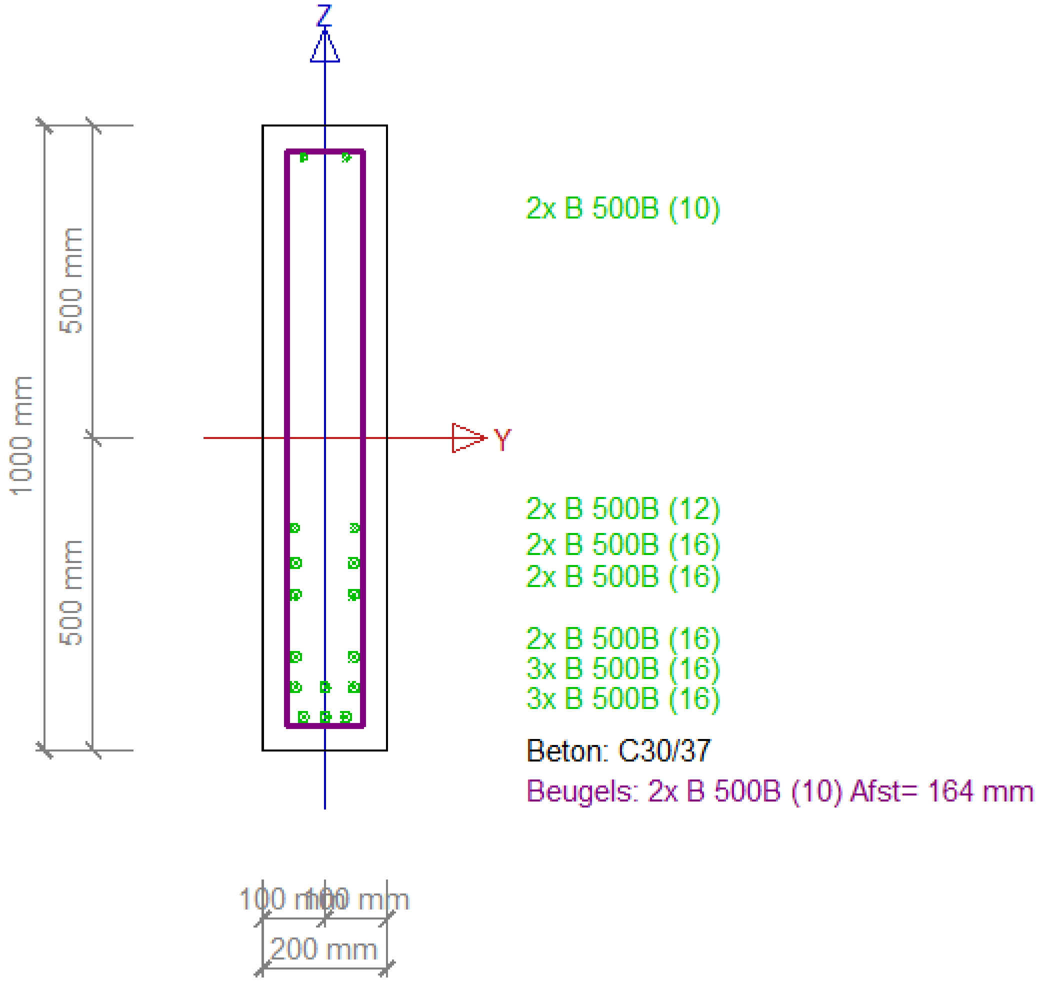
1-4-2

1-4-3

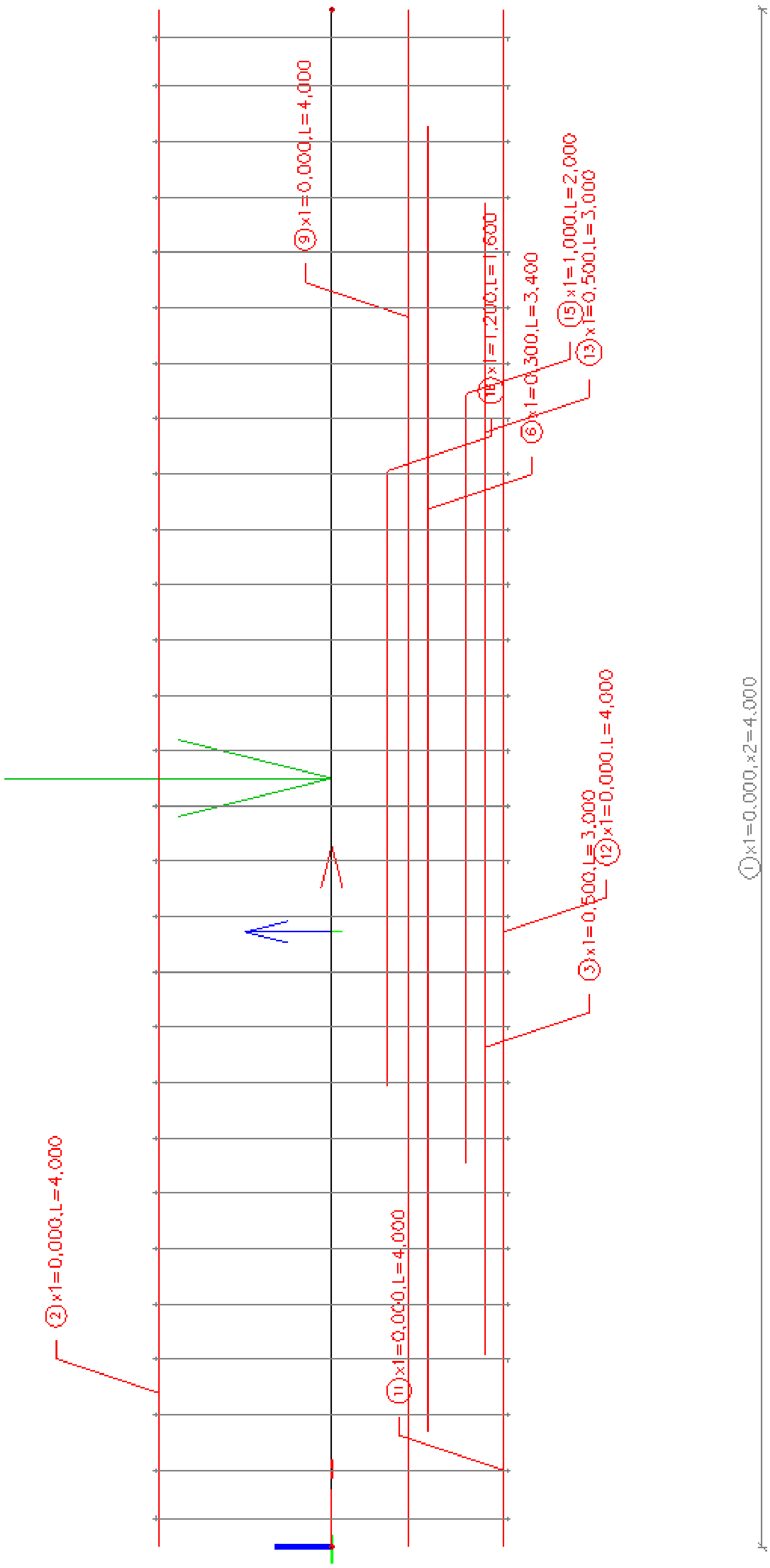
1-4-4

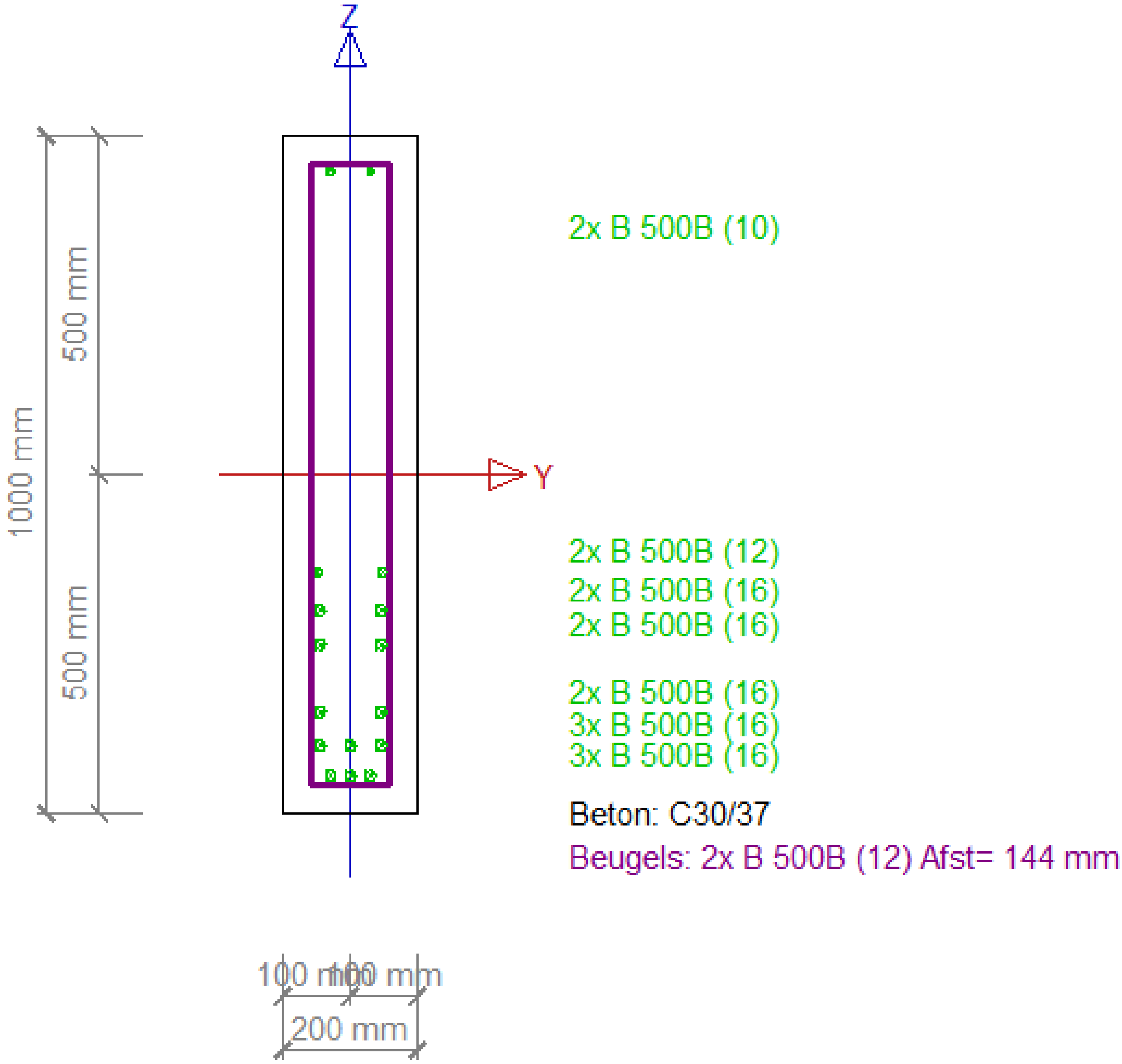
SPECIMEN 1-4-1 1d1d



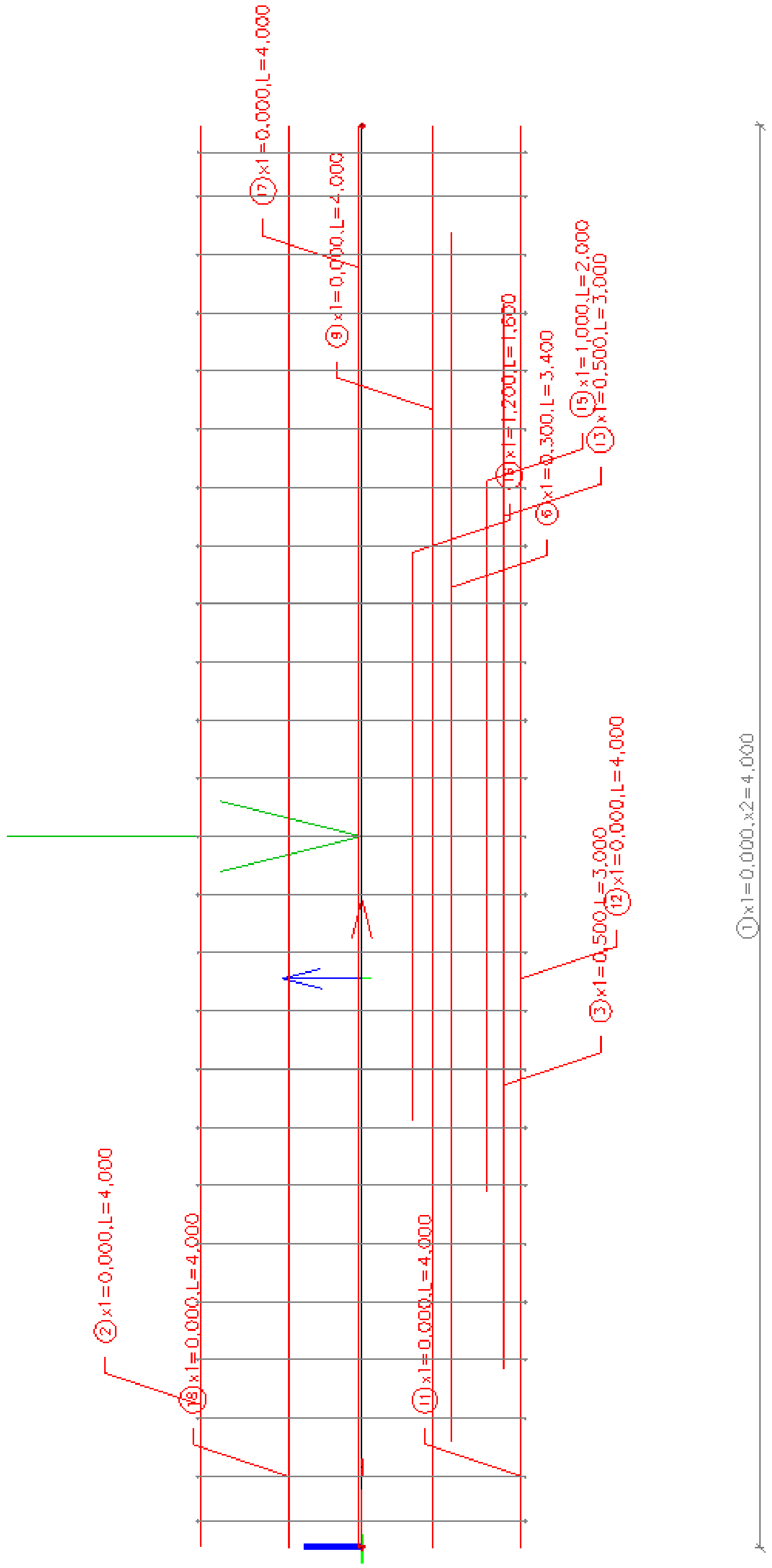

Z
Y
2x B 500B (10)
2x B 500B (12)
2x B 500B (16)
2x B 500B (16)
2x B 500B (16)
3x B 500B (16)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 164 mm
500 mm
1000 mm
500 mm
100 mm
100 mm
200 mm

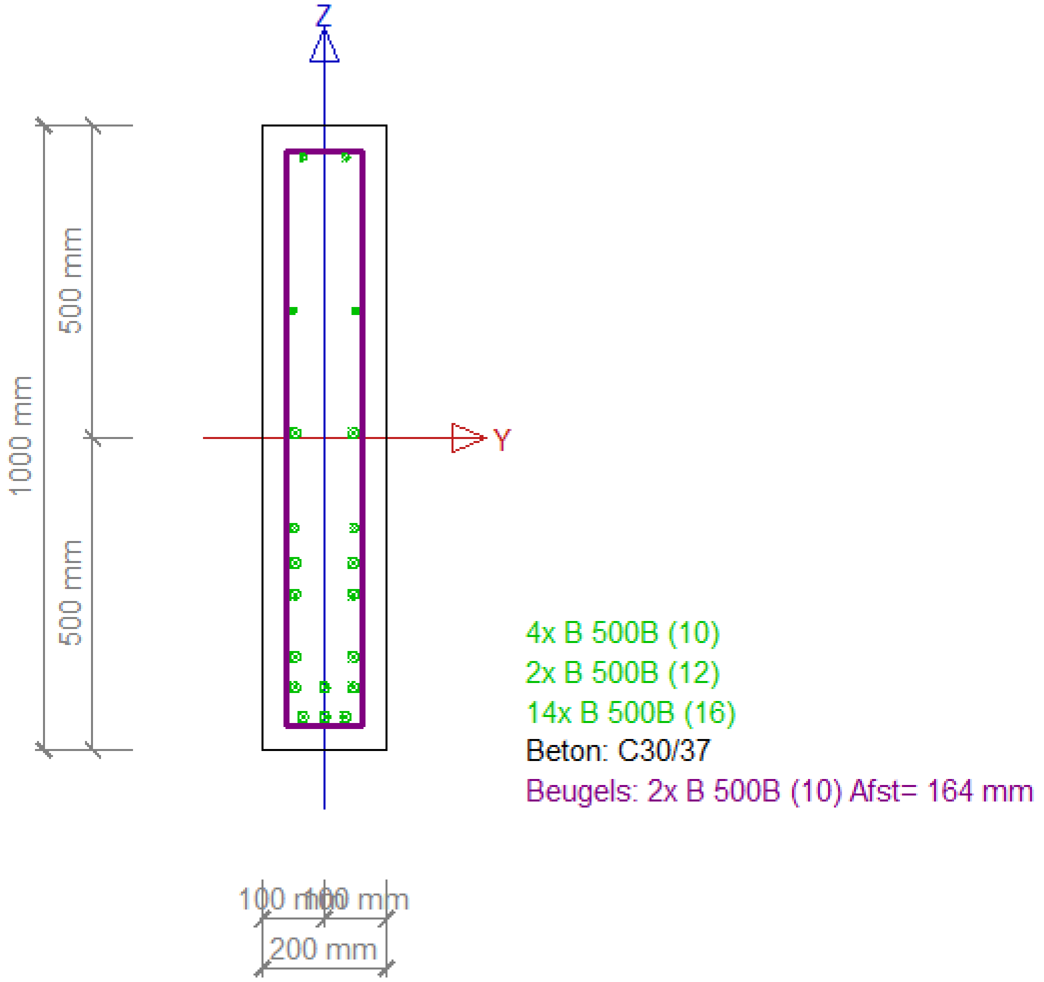
SPECIMEN 1-4-1 1d2d



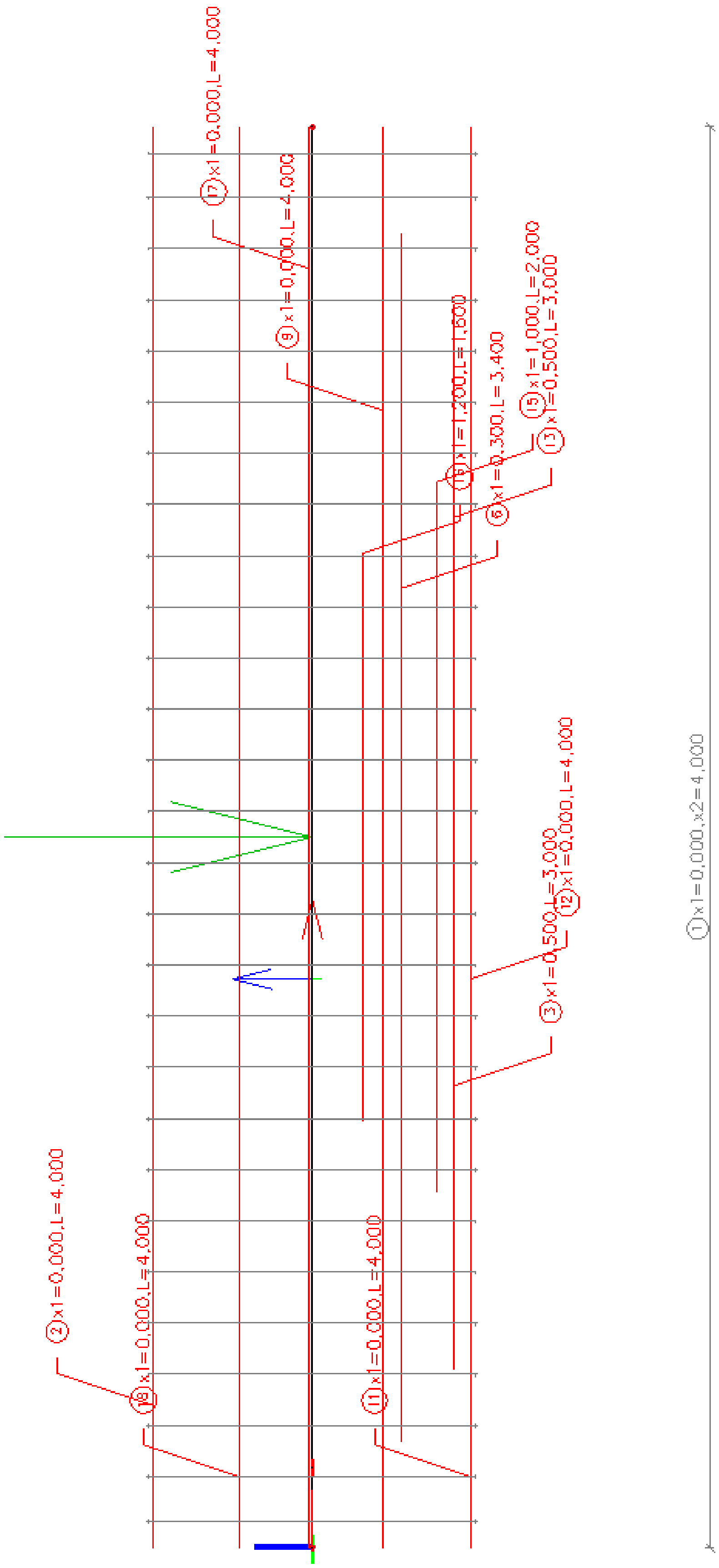

Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
2x B 500B (10)
2x B 500B (12)
2x B 500B (16)
2x B 500B (16)
2x B 500B (16)
3x B 500B (16)
3x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (12) Afst= 144 mm

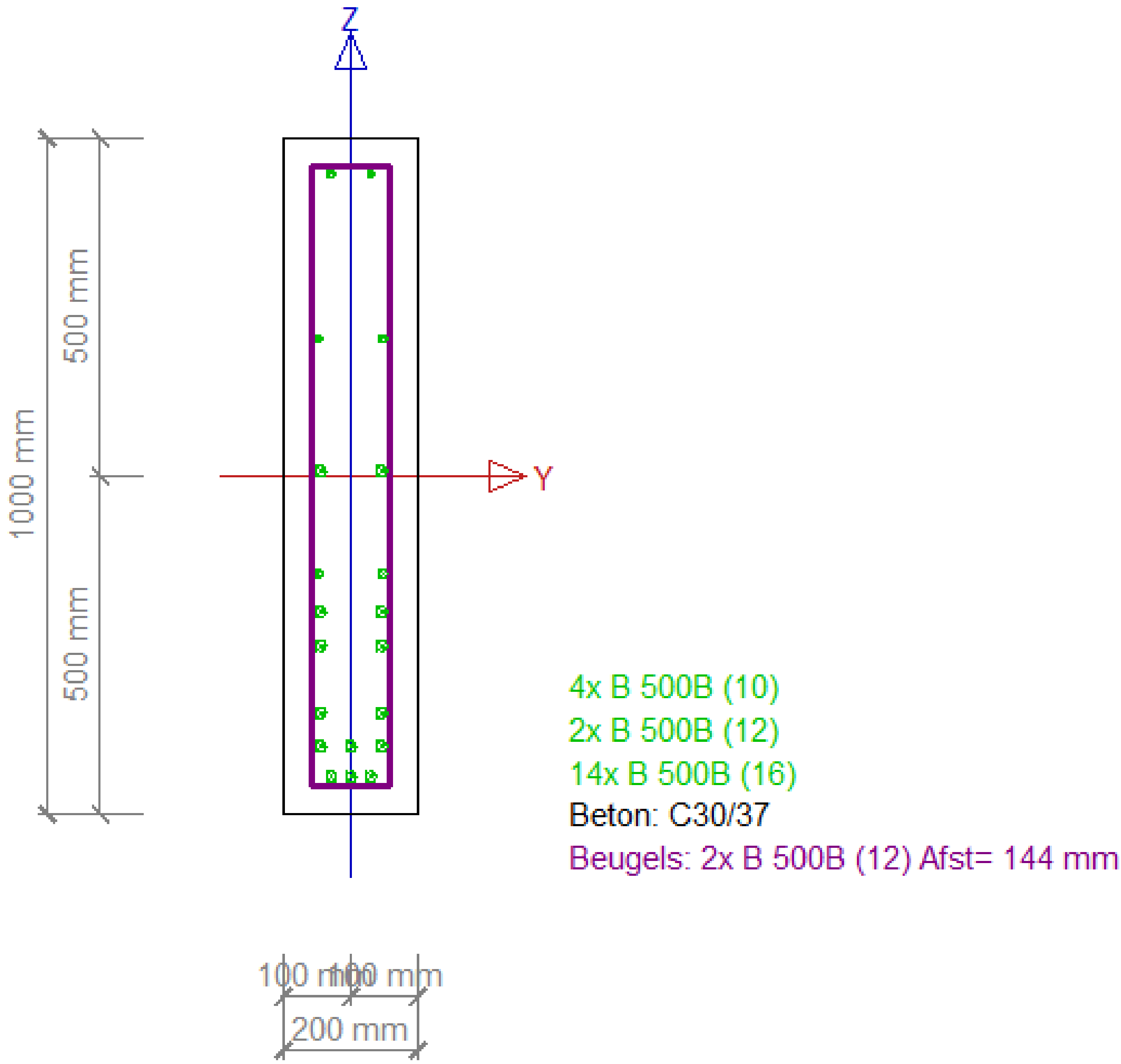
SPECIMEN 1-4-1 2d1d



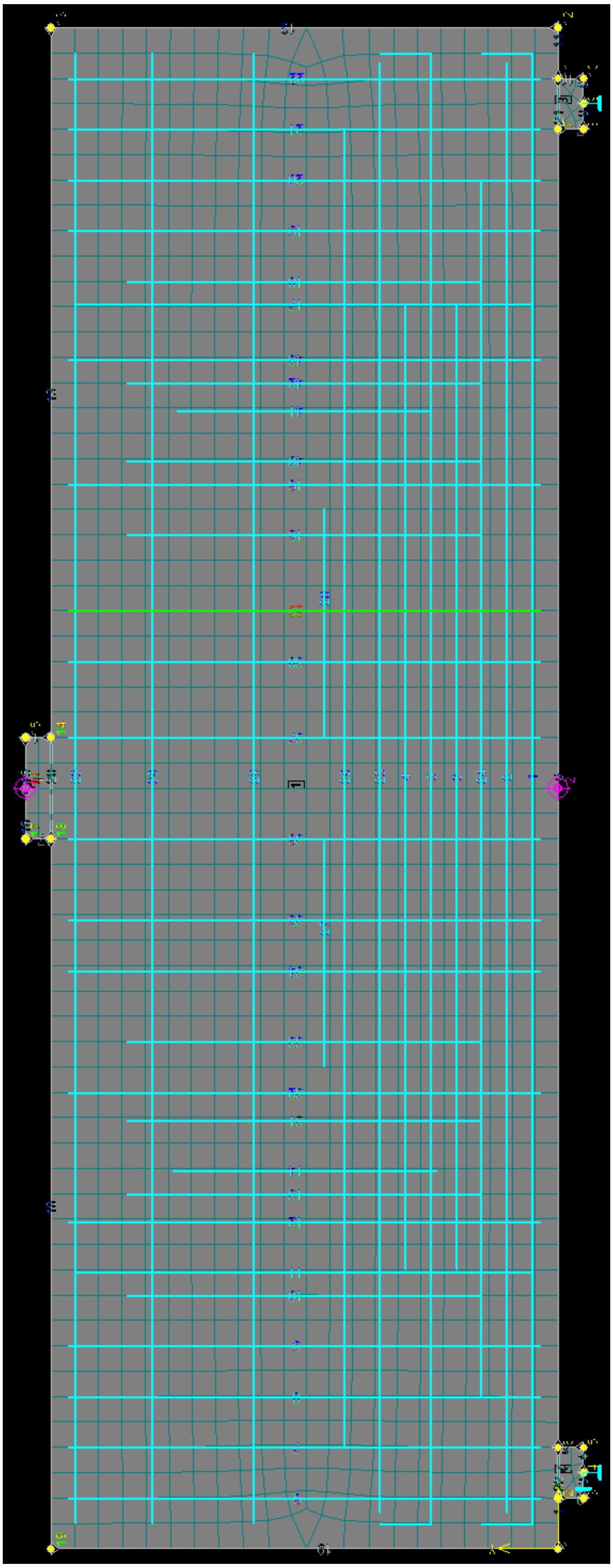

Z
Y
500 mm
500 mm
1000 mm
100 mm
100 mm
200 mm
4x B 500B (10)
2x B 500B (12)
14x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (10) Afst= 164 mm

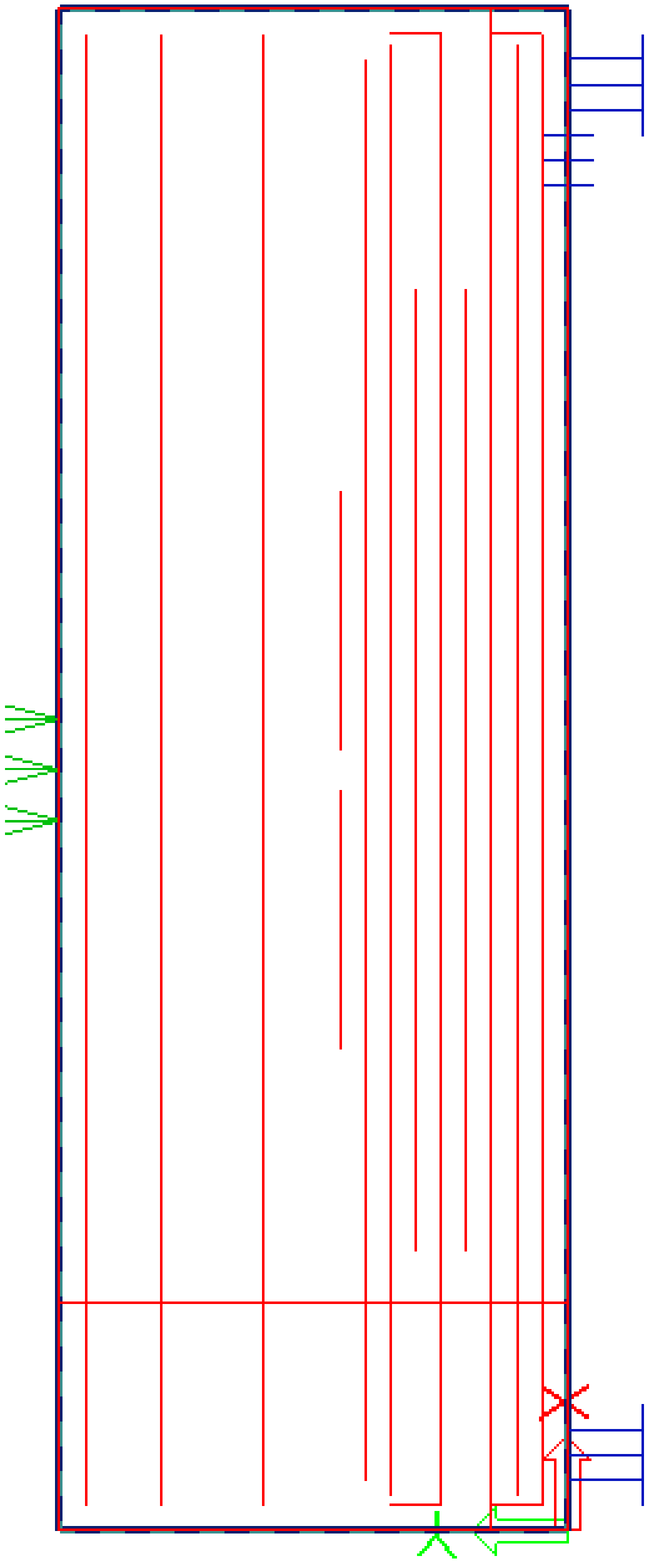
SPECIMEN 1-4-1 2d2d

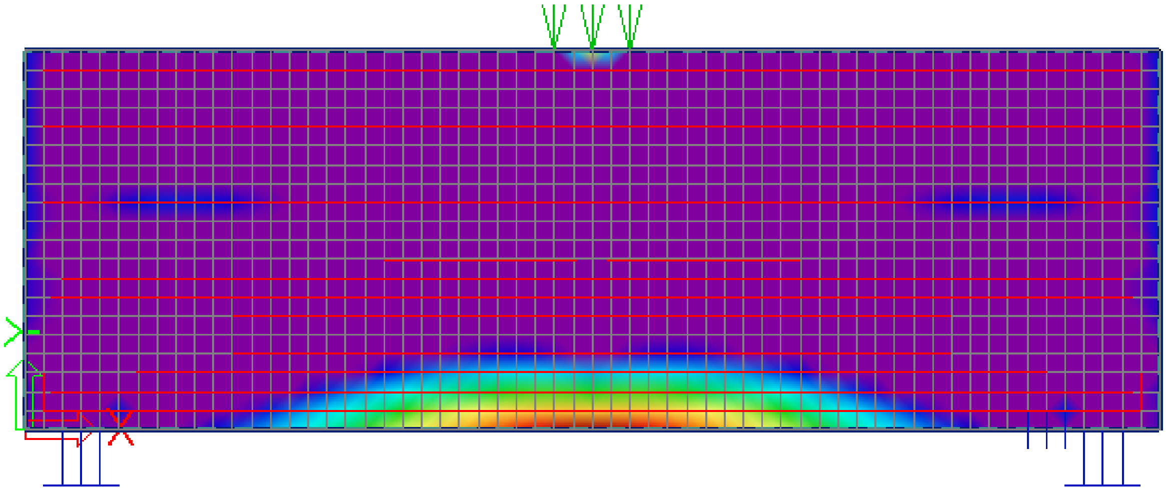



Z
Y
1000 mm
500 mm
500 mm
100 mm
100 mm
200 mm
4x B 500B (10)
2x B 500B (12)
14x B 500B (16)
Beton: C30/37
Beugels: 2x B 500B (12) Afst= 144 mm

SPECIMEN(mesh net of 5-150 is also in the specimen)S-4-2







At 464kN applied load design load off 646 kN chek kon

Design of reinforcements Slender BEAMS

Process of reinforcing

1-First by using 2D finite element model in Scia engineer, the needed reinforcement configuration is found

"Scia Engineer gives its output per element for required reinforcement mm^2/m. To obtain the actual required reinforcement area A_s in longitudinal direction, the output must be multiplied by the height of the finite element in the specific height. For the transversal direction the output must be multiplied by the width of the finite element at the specific width.

- For verifications the reinforcement configuration as a result of 2D finite element model analysis by Scia Engineering, the reinforcement configuration is applied into 1D Model in Scia Engineering.
- In applying the reinforcement from 2D to 1D model the following options are investigated

  - ✓ Longitudinal and vertical reinforcement is optimized
  - ✓ Only vertical reinforcement is optimized
  - ✓ Reinforcement configuration based on 2D Scia finite element model

Note: Optimization is also elaborated in chapter 4.4.2 of the thesis.

Important design considerations in using 2D finite element model,

1)

In 2D models, it can be seen that Scia engineering required reinforcement bars almost along the whole height of the slender beams. This is because of the finite element calculations which are done by Scia in the scale of mesh elements. In this thesis the effect of these top reinforcements are going to be investigated.

2) Optimization process of the reinforcement configuration is done by the following two options

- ✓ First ignoring the longitudinal skin reinforcements
- ✓ Vertical reinforcement based on 1D beam model in Scia Engineering and hand calculations
- ✓ As it is already mentioned before, in 2D model, there is no possibility to add Stirrups for Shear stresses, so it is decided to just add vertical mesh only. As it is seen in the verification steps by hand and by 1D modeling in Scia, the results are reliable and correct.

The method of configurations

There are two possibilities for reinforcing the specimens

1. **Normal method**

Generally this method is based on "one time reinforcing", so the user based on the required reinforcement which is given by Scia, can put the reinforcements in to the specimen in one time. The following loop is the procedure for this method.

- Calculation is done by Scia Engineer
- Find required dimensions of reinforcement
- Put the reinforcement in to the specimen
- Check it again , if Scia needed more reinforcement adjust the reinforcements

2. **Step by step method or SSM**

In this method, the general argument about the calculating reinforcement which is mentioned in Normal method is also valid.

SSM is based on the behavior of the material and redistribution of stresses after putting one layer of the reinforcements. This method can be formulated as the following loop:

- Calculation
- Find dimensions of the required reinforcement at the bottom edge of the specimen, with a required specific height(depends on the stresses)
- Putting one bottom reinforcement layer
- Again calculation
- Find dimension of the additional required reinforcement at the second layer from bottom with a specific height.
- Putting another layer above the firsts layer of reinforcement
- run the calculation again
- After putting 2 or 3 layers of reinforcement, Scia might require more reinforcement in layer 1 or 2. Here user can adjust some parameters of that specific layer for example choosing higher diameter of reinforcement, or putting extra reinforcements
- Run the calculation again
- This procedure of adding reinforcement layer by layer and running the calculation after each step will be continued. At the end Scia Engineer doesn't need any more reinforcement.
- These procedure should be done both in x and y direction. (direction 1 and 2 in Scia)

Note: Sometimes in 2D FEM analysis in Scia which is based on linear finite element method. At the end of configuration Scia still require some reinforcements at the bottom edge or top edge of the specimens, which can be ignored. The reason Scia calculates the amount of reinforcement for each small finites mesh elements, so consequently also at the edge of the slender beam Scia requires reinforcement which is only due to the finite element calculations and can be safely ignored. For the same reason Scia requires also some reinforcements in the free space between bottom and top reinforcements, which also can be safely ignored. (This is based on the 1D Linear hand calculations, also 1D linear Beam calculation with Scia for SLENDER beams specimens)

(Refer also to the chapter 8 conclusions and recommendations)

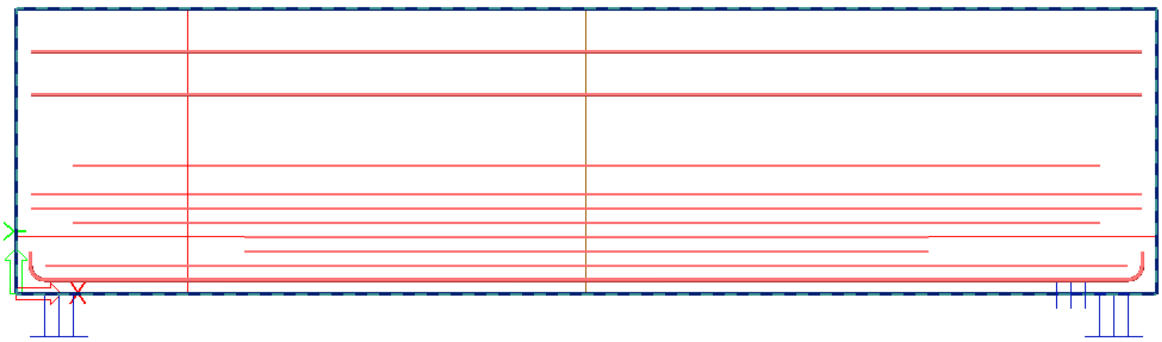
Note: for the first layer of reinforcement full anchorage is assumed based on the Eurocode and the results of the Romans work.

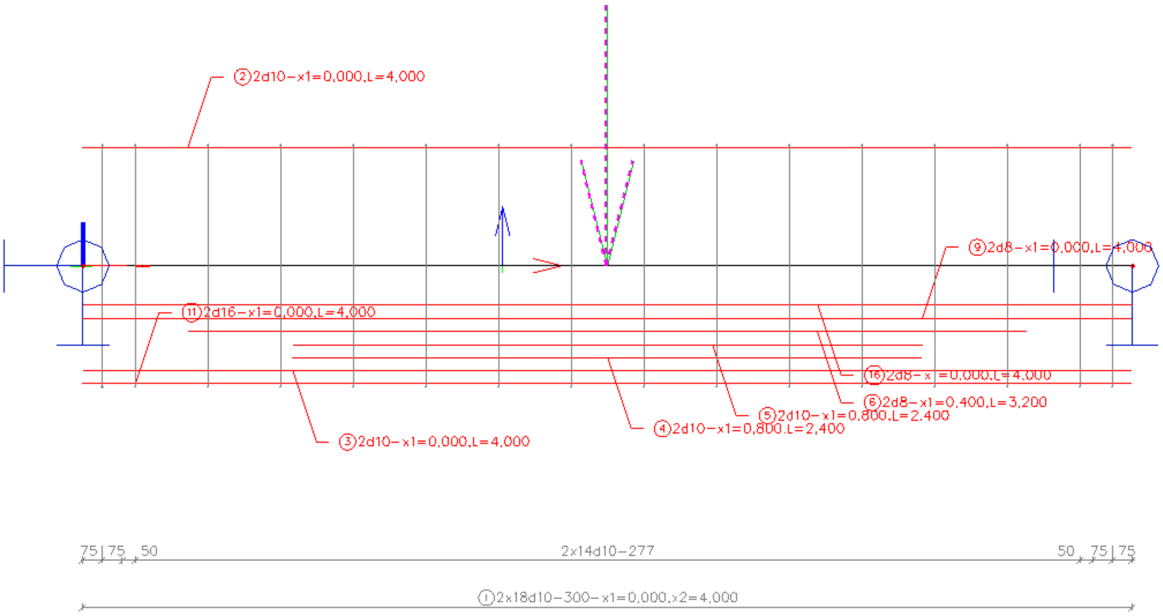
Optimization Process and defining different reinforcement configurations

Scia Engineer considers all detailing rules according to Eurocode or none-Eurocode to determine in 2D finite element model the amount of required reinforcements. In 1D beam model also Scia takes into account too many detailing provisions. Consequently theses extra measurements causes conservative results from Scia Engineer both in 2D finite element model and also in 1D beam model. One can get some errors in the results or capacity checks which should be studied and if necessary ignored.

As an example the “step by step method” is done for specimen under 200 kN SLS loading.

200 kN 1D model (normal method)





Controle - Wapeningcapaciteit EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : ULS
Methode van bezwijkdiagrammen voor geselecteerde staven

Staaf	d_x [m]	BG	Controleer type	N [kN] / $N_{(r)}$ [kN]	M_y [kNm] / $M_{y(r)}$ [kNm]	M_z [kNm] / $M_{z(r)}$ [kNm]	N_u [kN] / N_{u2} [kN]	M_{yu} [kNm] / M_{yu2} [kNm]	M_{zu} [kNm] / M_{zu2} [kNm]	$Controle_{ber}$ [-] / $Controle_{lim}$ [-]	Contr
B1	0,000	ULS/1	Mu	0,00	71,15	0,00	0,00	**284,67**	0,00	0,25	OK
				0,00	71,15	0,00	0,00	**-98,01**	0,00	1,00	
B1	0,400	ULS/1	Mu	0,00	126,04	0,00	0,00	**284,67**	0,00	0,44	OK
				0,00	126,04	0,00	0,00	**-98,01**	0,00	1,00	
B1	0,400	ULS/1	Mu	0,00	126,04	0,00	0,00	**313,48**	0,00	0,40	OK
				0,00	126,04	0,00	0,00	**-106,59**	0,00	1,00	
B1	0,400	ULS/1	Mu	0,00	126,04	0,00	0,00	**313,48**	0,00	0,40	OK
				0,00	126,04	0,00	0,00	**-106,59**	0,00	1,00	
B1	0,800	ULS/1	Mu	0,00	180,15	0,00	0,00	**313,48**	0,00	0,57	OK
				0,00	180,15	0,00	0,00	**-106,59**	0,00	1,00	
B1	0,800	ULS/1	Mu	0,00	180,15	0,00	0,00	**411,35**	0,00	0,44	OK
				0,00	180,15	0,00	0,00	**-120,34**	0,00	1,00	
B1	0,800	ULS/1	Mu	0,00	180,15	0,00	0,00	**411,35**	0,00	0,44	OK
				0,00	180,15	0,00	0,00	**-120,34**	0,00	1,00	
B1	1,200	ULS/1	Mu	0,00	233,31	0,00	0,00	**411,35**	0,00	0,57	OK
				0,00	233,31	0,00	0,00	**-120,34**	0,00	1,00	
B1	1,600	ULS/1	Mu	0,00	271,77	0,00	0,00	**411,35**	0,00	0,66	OK
				0,00	271,77	0,00	0,00	**-120,34**	0,00	1,00	
B1	2,000	ULS/1	Mu	0,00	271,77	0,00	0,00	**411,35**	0,00	0,66	OK
				0,00	271,77	0,00	0,00	**-120,34**	0,00	1,00	

Controle - Wapeningcapaciteit EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : ULS
Dwarskrachtcontrole voor geselecteerde staven

Staaf	d_x [m]	BG	V_{ED} [kN]	beugel afst [mm] / dwarsafst [mm]	diam. [mm]	A_{ss} [mm²/m]	$V_{Rd,c}$ [kN] / V_{Rdmax} [kN]	V_{Rd} [kN]	$Controle_{ber}$ [-] / $Controle_{lim}$ [-]	Controle
B1	0,000	ULS/1	141,77	125	10,0	1257	73,59	**520,36**	0,27	OK
				120			831,09		1,00	
B1	0,400	ULS/1	139,42	277	10,0	567	73,59	**234,88**	0,59	OK
				120			831,09		1,00	
B1	0,400	ULS/1	139,42	277	10,0	567	76,14	**231,49**	0,60	OK
				120			819,09		1,00	
B1	0,400	ULS/1	139,42	277	10,0	567	76,14	**231,49**	0,60	OK
				120			819,09		1,00	
B1	0,800	ULS/1	137,06	277	10,0	567	76,14	**231,49**	0,59	OK
				120			819,09		1,00	
B1	0,800	ULS/1	137,06	277	10,0	567	83,90	**228,47**	0,60	OK
				120			808,41		1,00	
B1	0,800	ULS/1	137,06	277	10,0	567	83,90	**228,47**	0,60	OK
				120			808,41		1,00	
B1	1,200	ULS/1	134,71	277	10,0	567	83,90	**228,47**	0,59	OK
				120			808,41		1,00	
B1	1,600	ULS/1	132,35	277	10,0	567	83,90	**228,47**	0,58	OK
				120			808,41		1,00	
B1	2,000	ULS/1	130,00	277	10,0	567	83,90	**228,47**	0,57	OK
				120			808,41		1,00	

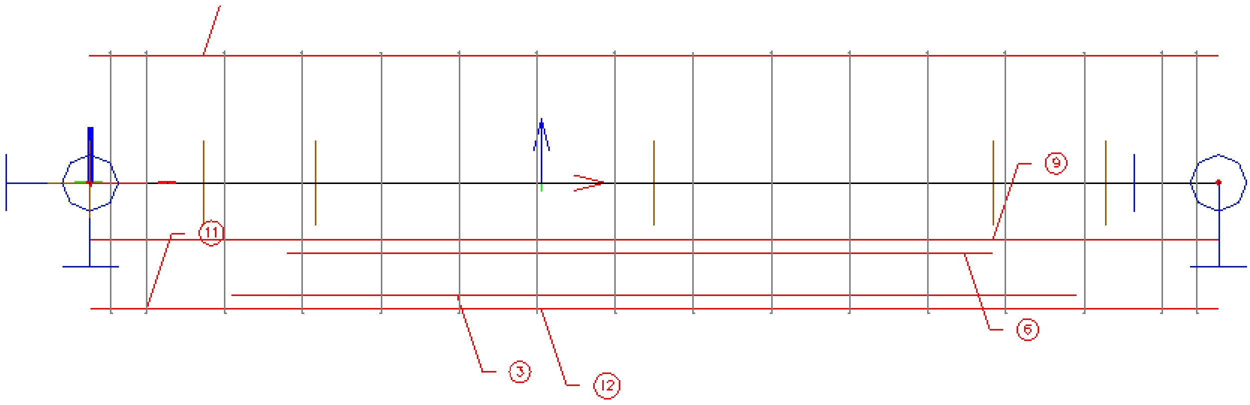
200 % default

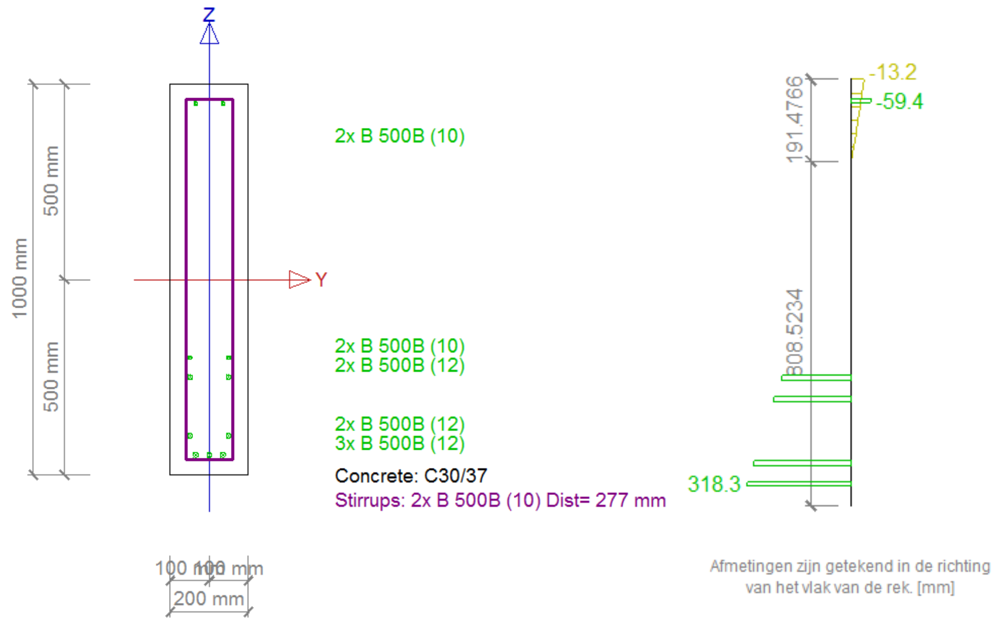
Controle - Scheurvorming EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : SLS
Scheurwijdte berekening voor geselecteerde staven

Staaf	d_x [m]	BG	N [kN] / N_r [kN]	M_y [kNm] / M_{yr} [kNm]	M_z [kNm] / M_{zr} [kNm]	σ_s [MPa] / $f_{ct,eff}$ [MPa]	$s_{r,max}$ [mm] / $\varepsilon_{sm}-\varepsilon_{cm}$ [1e-4]	w [mm] / w_{lim} [mm]	$Controle_{ber}$ [-] / $Controle_{lim}$ [-]	Controle
B1	0,400	SLS/2	0,00	43,53	0,00	0,0	0	0,000	0,00	OK
			0,00	103,32	0,00	0,00	0,0		1,00	
B1	0,800	SLS/2	0,00	86,28	0,00	0,0	0	0,000	0,00	OK
			0,00	105,08	0,00	0,00	0,0		1,00	
B1	1,200	SLS/2	0,00	128,24	0,00	160,3	300	0,144	0,48	OK
			0,00	105,08	0,00	2,90	4,8	0,300	1,00	
B1	1,600	SLS/2	0,00	169,42	0,00	211,7	300	0,191	0,64	OK
			0,00	105,08	0,00	2,90	6,4	0,300	1,00	
B1	2,000	SLS/2	0,00	209,81	0,00	262,2	300	0,236	0,79	OK
			0,00	105,08	0,00	2,90	7,9	0,300	1,00	
B1	2,400	SLS/2	0,00	169,42	0,00	211,7	300	0,191	0,64	OK
			0,00	105,08	0,00	2,90	6,4	0,300	1,00	
B1	2,800	SLS/2	0,00	128,24	0,00	160,3	300	0,144	0,48	OK
			0,00	105,08	0,00	2,90	4,8	0,300	1,00	
B1	3,200	SLS/2	0,00	86,28	0,00	0,0	0	0,000	0,00	OK
			0,00	105,08	0,00	0,00	0,0		1,00	
B1	3,600	SLS/2	0,00	43,53	0,00	0,0	0	0,000	0,00	OK
			0,00	103,32	0,00	0,00	0,0		1,00	

200 kn Optimized (method 2- Sep by Step Method)





Controle - Scheurvorming EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : SLS

Scheurwijdte berekening voor geselecteerde staven

Staaf	d_x [m]	BG	N [kN] / N_r [kN]	M_y [kNm] / M_{yr} [kNm]	M_z [kNm] / M_{zr} [kNm]	σ_s [MPa] / $f_{ct,eff}$ [MPa]	$s_{r,max}$ [mm] / $\varepsilon_{sm}-\varepsilon_{cm}$ [1e-4]	w [mm] / w_{lim} [mm]	$Controle_{ber}$ [-] / $Controle_{lim}$ [-]	Controle	Info nummer
B1	0,400	SLS2	0,00	43,53	0,00	0,0	0	0,000	0,00	OK	12
			0,00	101,10	0,00	0,00	0,0		1,00		
B1	0,800	SLS2	0,00	86,28	0,00	0,0	0	0,000	0,00	OK	12
			0,00	103,73	0,00	0,00	0,0		1,00		
B1	1,200	SLS2	0,00	128,24	0,00	194,6	292	0,170	0,57	OK	
			0,00	103,73	0,00	2,90	5,8	0,300	1,00		
B1	1,600	SLS2	0,00	169,42	0,00	257,0	292	0,225	0,75	OK	
			0,00	103,73	0,00	2,90	7,7	0,300	1,00		
B1	2,000	SLS2	0,00	209,81	0,00	318,3	292	0,279	0,93	OK	
			0,00	103,73	0,00	2,90	9,5	0,300	1,00		
B1	2,400	SLS2	0,00	169,42	0,00	257,0	292	0,225	0,75	OK	
			0,00	103,73	0,00	2,90	7,7	0,300	1,00		
B1	2,800	SLS2	0,00	128,24	0,00	194,6	292	0,170	0,57	OK	
			0,00	103,73	0,00	2,90	5,8	0,300	1,00		
B1	3,200	SLS2	0,00	86,28	0,00	0,0	0	0,000	0,00	OK	12
			0,00	103,73	0,00	0,00	0,0		1,00		
B1	3,600	SLS2	0,00	43,53	0,00	0,0	0	0,000	0,00	OK	12
			0,00	101,10	0,00	0,00	0,0		1,00		

Verklaring van fouten en waarschuwingen

12	De scheuren traden niet op.

Controle - Wapeningcapaciteit EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : ULS

Methode van bezwijkdiagrammen voor geselecteerde staven

Staaf	d_x [m]	BG	Controleer type	N [kN] $N_{(r)}$ [kN]	M_y [kNm] $M_{y(r)}$ [kNm]	M_z [kNm] $M_{z(r)}$ [kNm]	N_u [kN] N_{u2} [kN]	M_{yu} [kNm] M_{yu2} [kNm]	M_{zu} [kNm] M_{zu2} [kNm]	$Controle_{ber}$ [-] $Controle_{lim}$ [-]	Controle
B1	0,000	ULS/1	Mu	0,00	71,15	0,00	0,00	**181,74**	0,00	0,39	OK
				0,00	71,15	0,00	0,00	**-82,73**	0,00	1,00	
B1	0,400	ULS/1	Mu	0,00	126,04	0,00	0,00	**181,74**	0,00	0,69	OK
				0,00	126,04	0,00	0,00	**-82,73**	0,00	1,00	
B1	0,500	ULS/1	Mu	0,00	139,61	0,00	0,00	**181,74**	0,00	0,77	OK
				0,00	139,61	0,00	0,00	**-82,73**	0,00	1,00	
B1	0,500	ULS/1	Mu	0,00	139,64	0,00	0,00	**264,73**	0,00	0,53	OK
				0,00	139,64	0,00	0,00	**-87,38**	0,00	1,00	
B1	0,700	ULS/1	Mu	0,00	166,78	0,00	0,00	**264,73**	0,00	0,63	OK
				0,00	166,78	0,00	0,00	**-87,38**	0,00	1,00	
B1	0,700	ULS/1	Mu	0,00	166,81	0,00	0,00	**331,08**	0,00	0,50	OK
				0,00	166,81	0,00	0,00	**-105,74**	0,00	1,00	
B1	0,800	ULS/1	Mu	0,00	180,15	0,00	0,00	**331,08**	0,00	0,54	OK
				0,00	180,15	0,00	0,00	**-105,74**	0,00	1,00	
B1	1,200	ULS/1	Mu	0,00	233,31	0,00	0,00	**331,08**	0,00	0,70	OK
				0,00	233,31	0,00	0,00	**-105,74**	0,00	1,00	
B1	1,600	ULS/1	Mu	0,00	271,77	0,00	0,00	**331,08**	0,00	0,82	OK
				0,00	271,77	0,00	0,00	**-105,74**	0,00	1,00	
B1	2,000	ULS/1	Mu	0,00	271,77	0,00	0,00	**331,08**	0,00	0,82	OK
				0,00	271,77	0,00	0,00	**-105,74**	0,00	1,00	

Controle - Wapeningcapaciteit EN 1992-1-1

Lineaire berekening, Extreem : Snede
Selectie : Alle
Combinaties : ULS

Dwarskrachtcontrole voor geselecteerde staven

Staaf	d_x [m]	BG	V_{ED} [kN]	beugel afst [mm] dwarsafst [mm]	diam. [mm]	A_{ss} [mm²/m]	$V_{Rd,c}$ [kN] $V_{Rd,max}$ [kN]	V_{Rd} [kN]	$Controle_{ber}$ [-] $Controle_{lim}$ [-]	Controle	Methode
B1	0,000	ULS/1	141,77	125	10,0	1257	63,95	**522,16**	0,27	OK	
				120			833,97		1,00		formule 6.2a.b) EN1992-1-1
B1	0,400	ULS/1	139,42	277	10,0	567	63,95	**235,70**	0,59	OK	
				120			833,96		1,00		formule 6.2a.b) EN1992-1-1
B1	0,500	ULS/1	138,83	277	10,0	567	63,95	**235,70**	0,59	OK	
				120			833,96		1,00		formule 6.2a.b) EN1992-1-1
B1	0,500	ULS/1	138,83	277	10,0	567	72,64	**236,72**	0,59	OK	
				120			837,58		1,00		formule 6.2a.b) EN1992-1-1
B1	0,700	ULS/1	137,65	277	10,0	567	72,64	**236,72**	0,58	OK	
				120			837,58		1,00		formule 6.2a.b) EN1992-1-1
B1	0,700	ULS/1	137,65	277	10,0	567	78,28	**229,34**	0,60	OK	
				120			811,49		1,00		formule 6.2a.b) EN1992-1-1
B1	0,800	ULS/1	137,06	277	10,0	567	78,28	**229,34**	0,60	OK	
				120			811,49		1,00		formule 6.2a.b) EN1992-1-1
B1	1,200	ULS/1	134,71	277	10,0	567	78,28	**229,34**	0,59	OK	
				120			811,49		1,00		formule 6.2a.b) EN1992-1-1
B1	1,600	ULS/1	132,35	277	10,0	567	78,26	**229,24**	0,58	OK	
				120			811,11		1,00		formule 6.2a.b) EN1992-1-1
B1	2,000	ULS/1	130,00	277	10,0	567	78,26	**229,24**	0,57	OK	
				120			811,11		1,00		formule 6.2a.b) EN1992-1-1

Deep Beams

Naming of the different reinforcement configurations

For deep beam specimens the naming of the specimens is based on the following factors:

- Analysis method
  Deep beams are analyzed by using the following methods
  1. Standard beam method (SBM)
  2. Strut and Tie Method (STM)
  3. Linear finite element method with Scia Engineer (L FEM)
  4. Nonlinear finite element method with Scia Engineer (NL FEM)
- Dimension of specimens
  In the category Deep beams there are three specimens considered in this thesis specimen 1 or D1 and specimen2 or D2 and specimen 3 or D3.

Specimens	Length[mm]	Effective length[mm]	Height [mm]	Width[mm]
D1	3600	3000	4000	250
D2	7600	7000	3000	250
D3	3600	3000	8000	250

- Load
  There are two load cases which as following

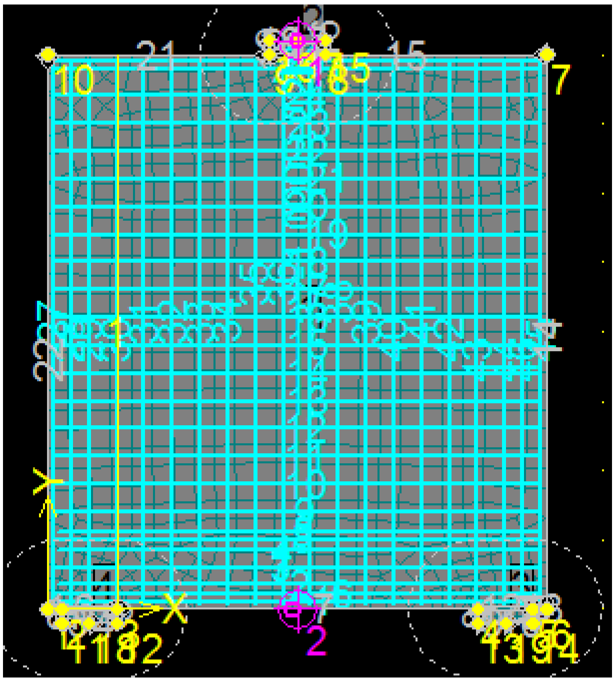
P1	Point load 800 kN applied load (SLS factor 1)
P2	Point load 1500 kN pplied load (SLS factor 1)

- Method of reinforcing
  a) SBM
  b) STM
  c) LE-FEM(Scia)
  d) NL-FEM(Scia)
  e) ATENA

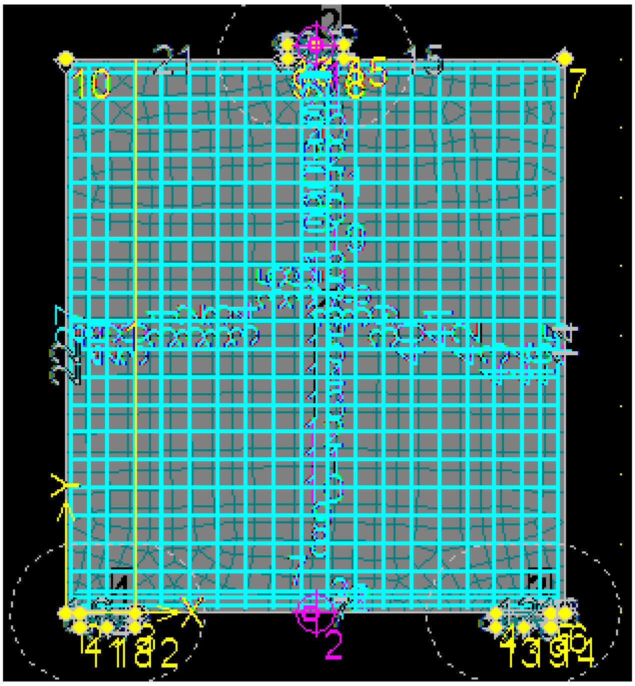
- Naming of the specimens
  The naming of the specimens is as following

	D1P1	D1P2	D2P1
SBM	D1P1SBM	D1P2SBM	D2P1SBM
STM	D1P1STM	D1P2STM	D2P1STM(1) D2P1STM(2) D2P1STM(3)
LE FEM	D1P1LFEM	D1P2LFEM	D2P1LFEM
NL FEM	D1P1NLFEM	D1P2NLFEM	D2P1NLFEM

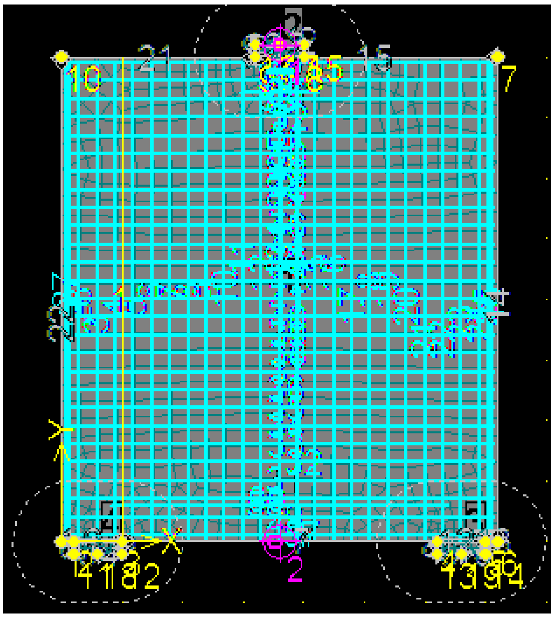
D1P1SBM

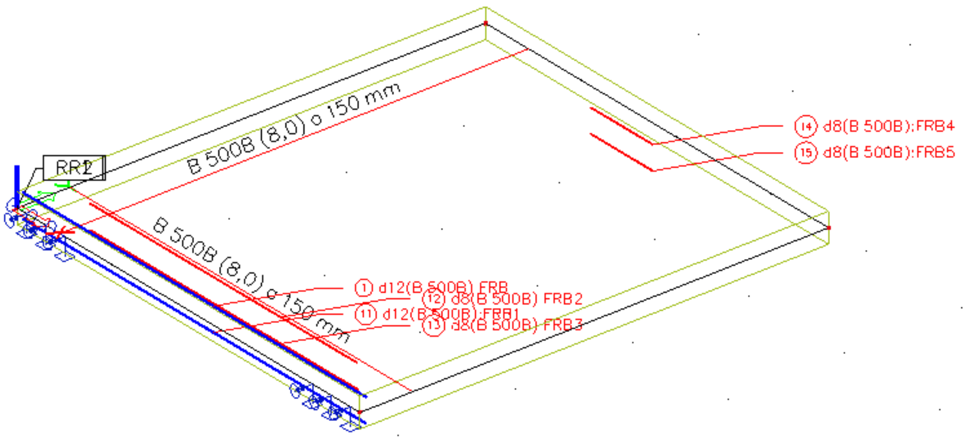


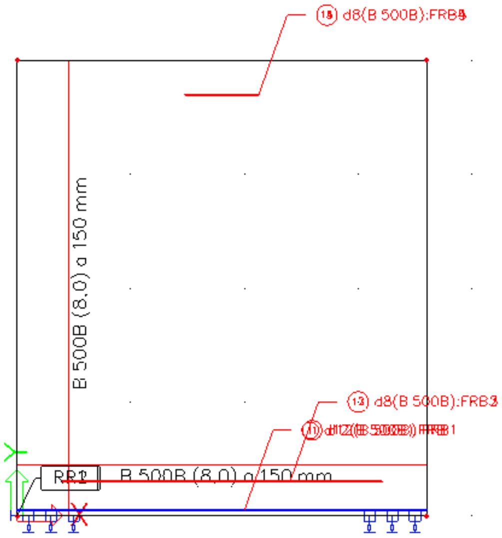
D1P1STM



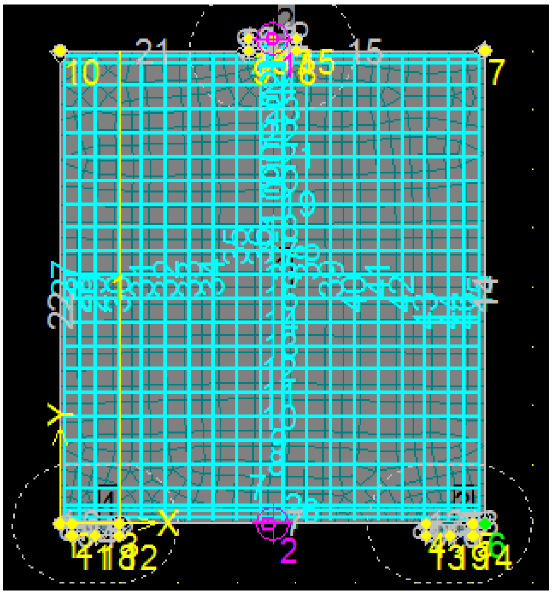
D1P1LEFEM




B 500B (8,0) a 150 mm
B 500B (8,0) a 150 mm
14 d8(B 500B):FRB4
15 d8(B 500B):FRB5
12 d8(B 500B) FRB2
13 d8(B 500B) FRB3

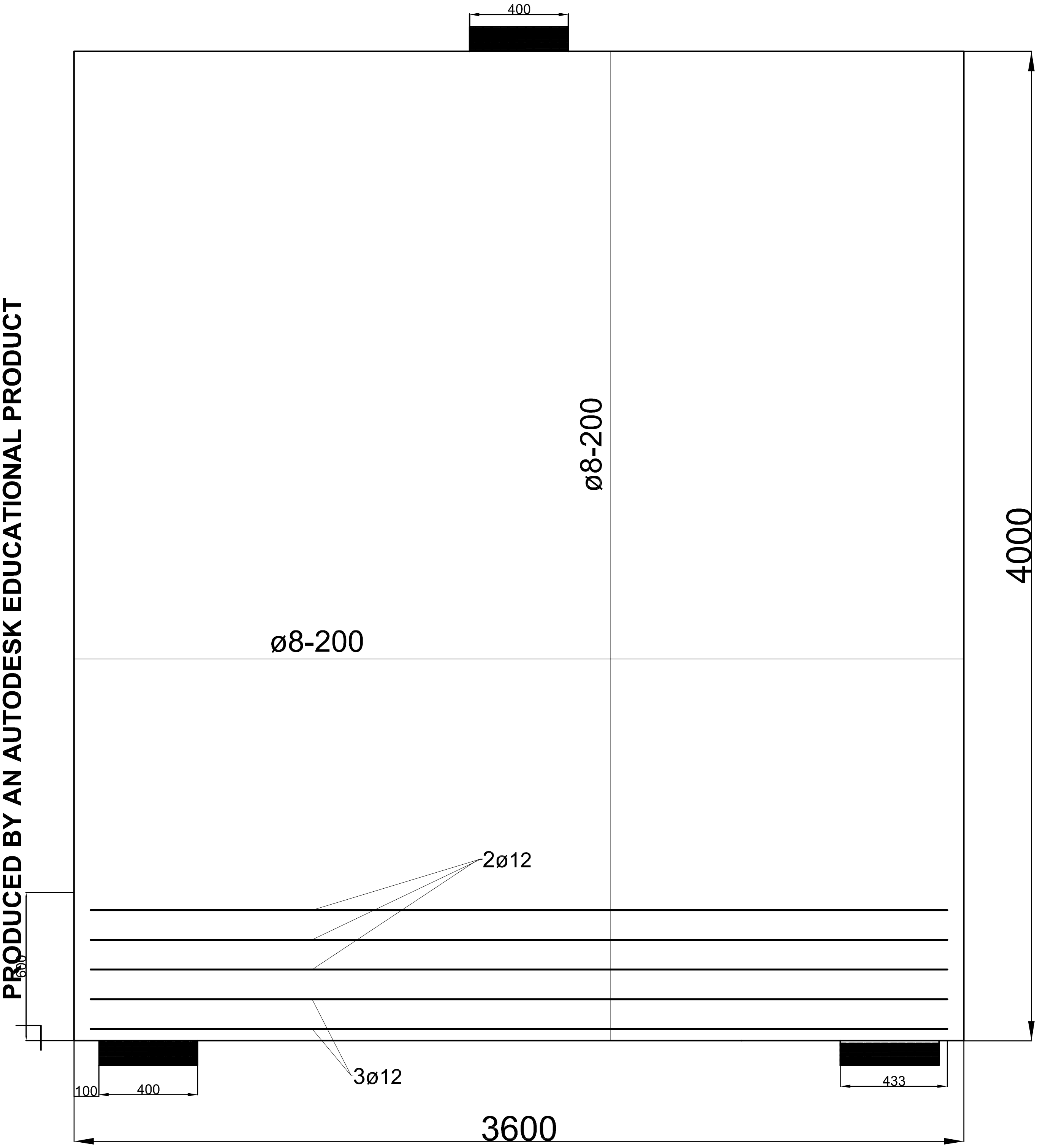

B 500B (8,0) a 150 mm
B 500B (8,0) a 150 mm

D1P1NLFEM



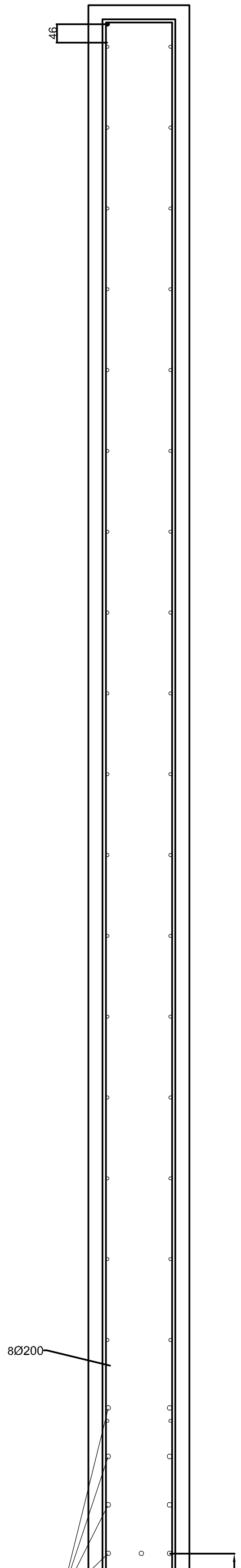
D1P1SBM

Spec 1 – Point load 1(800 kN applied load) – standard beam method-



800 kN SBM

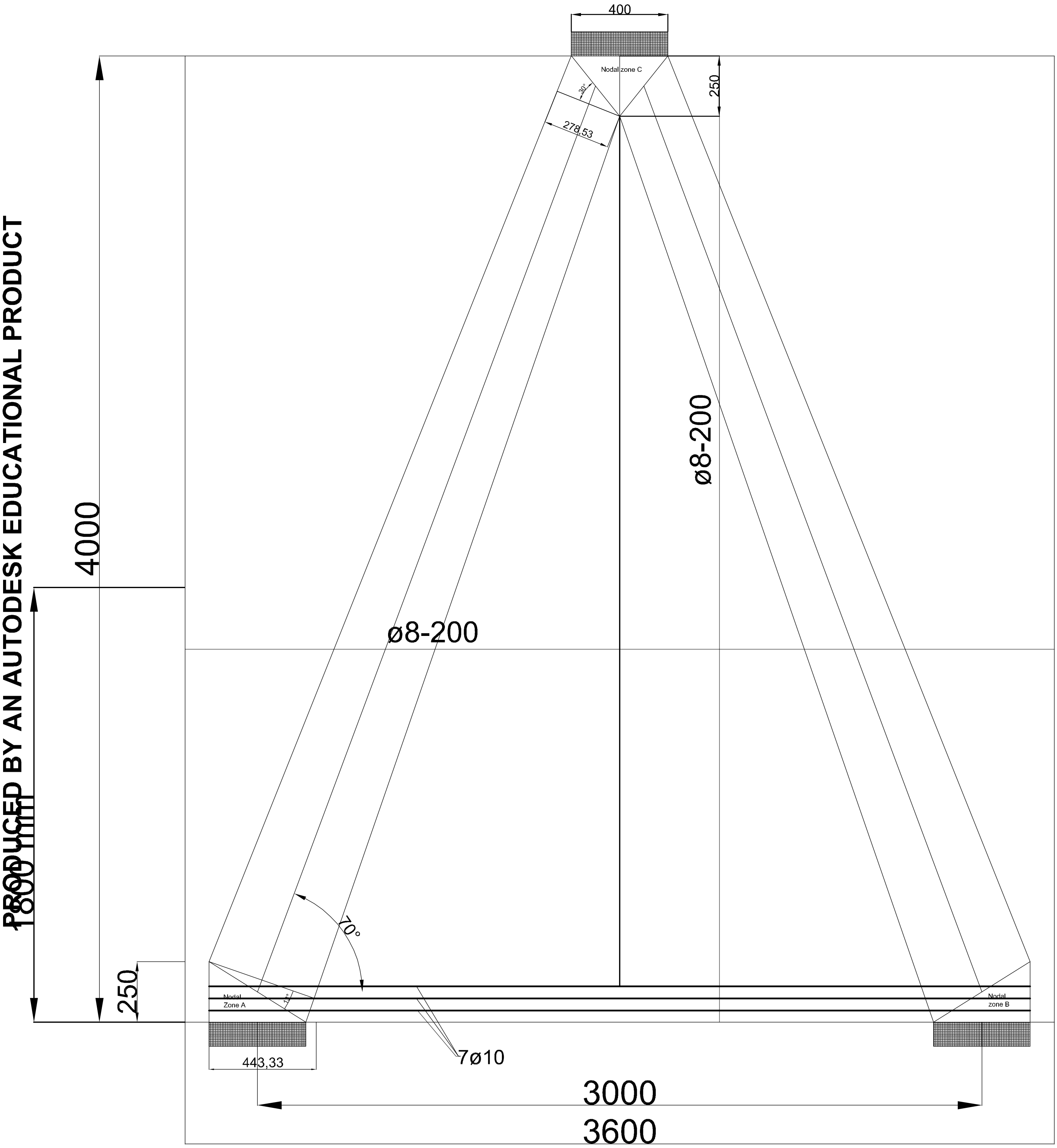
D1P1SBM



Load 800 kN
Method Braam
SBM

D1P1STM

Spec 1 – Point load 1(800 kN applied load) – Strut and Tie Model



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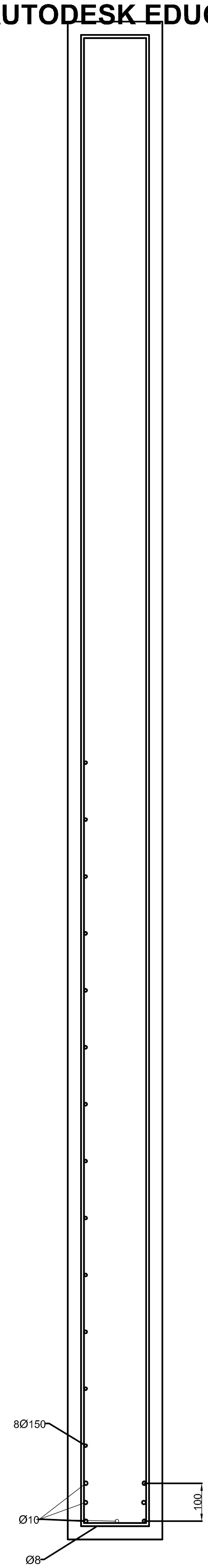
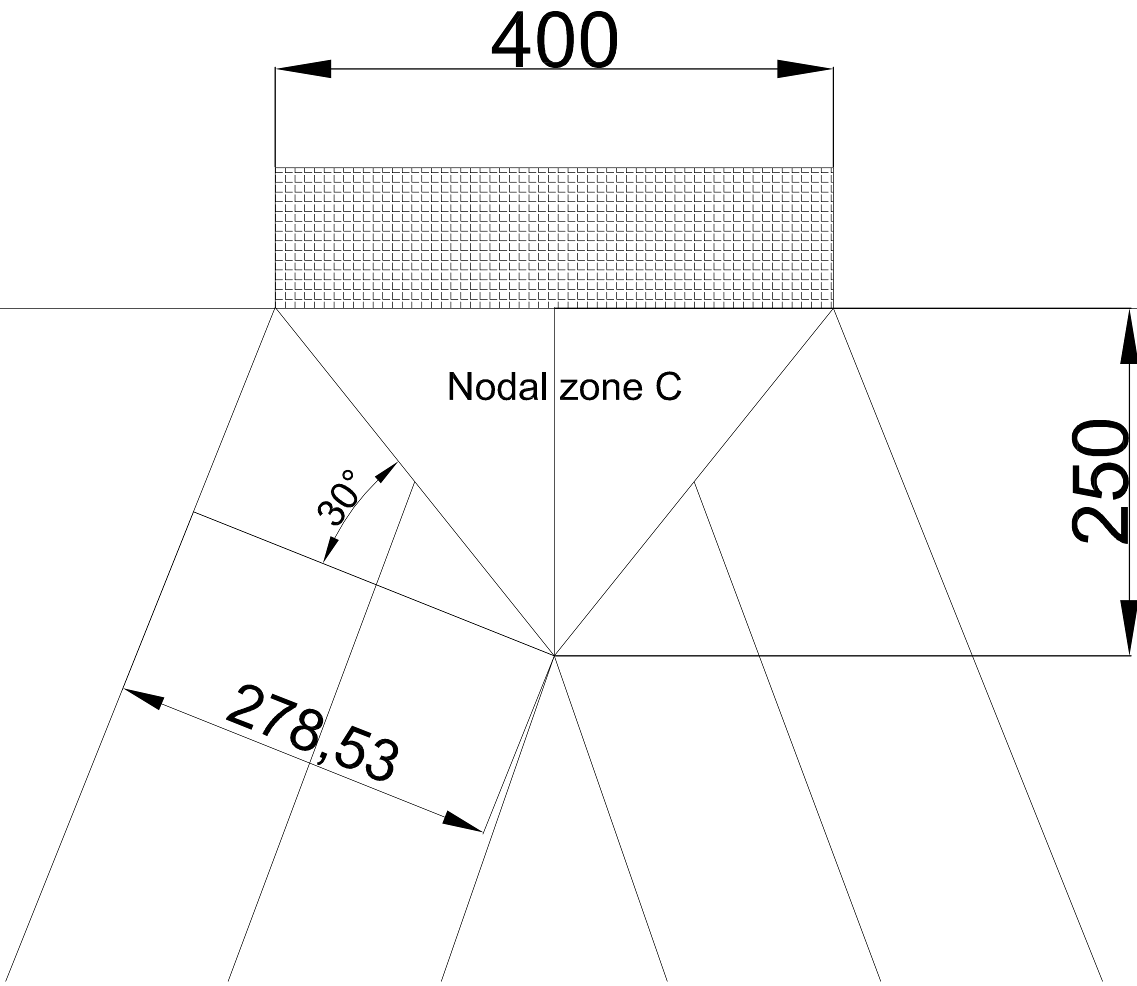
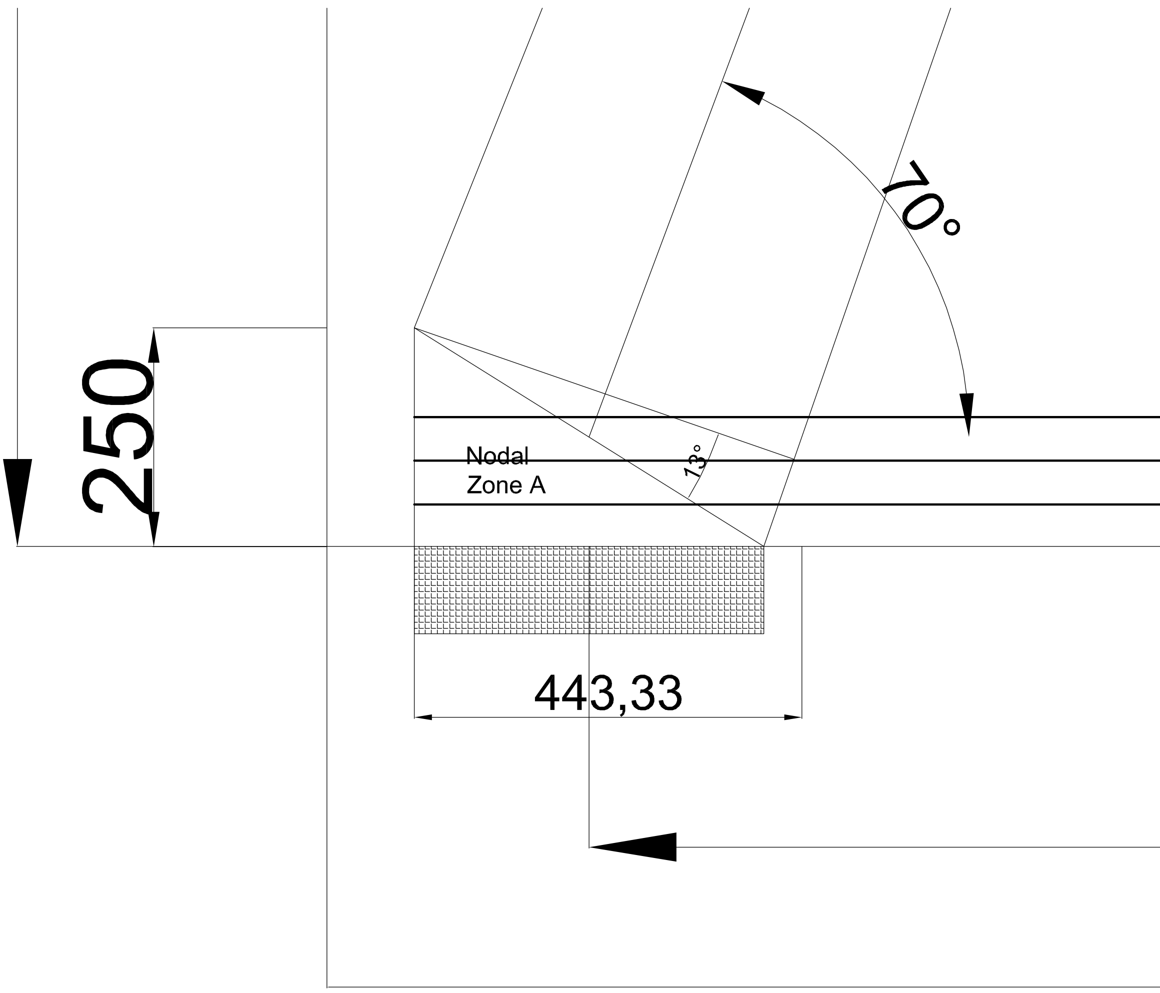


Load 800 kN
STM
S1P1STM


400
Nodal zone C
250
30°
278,53



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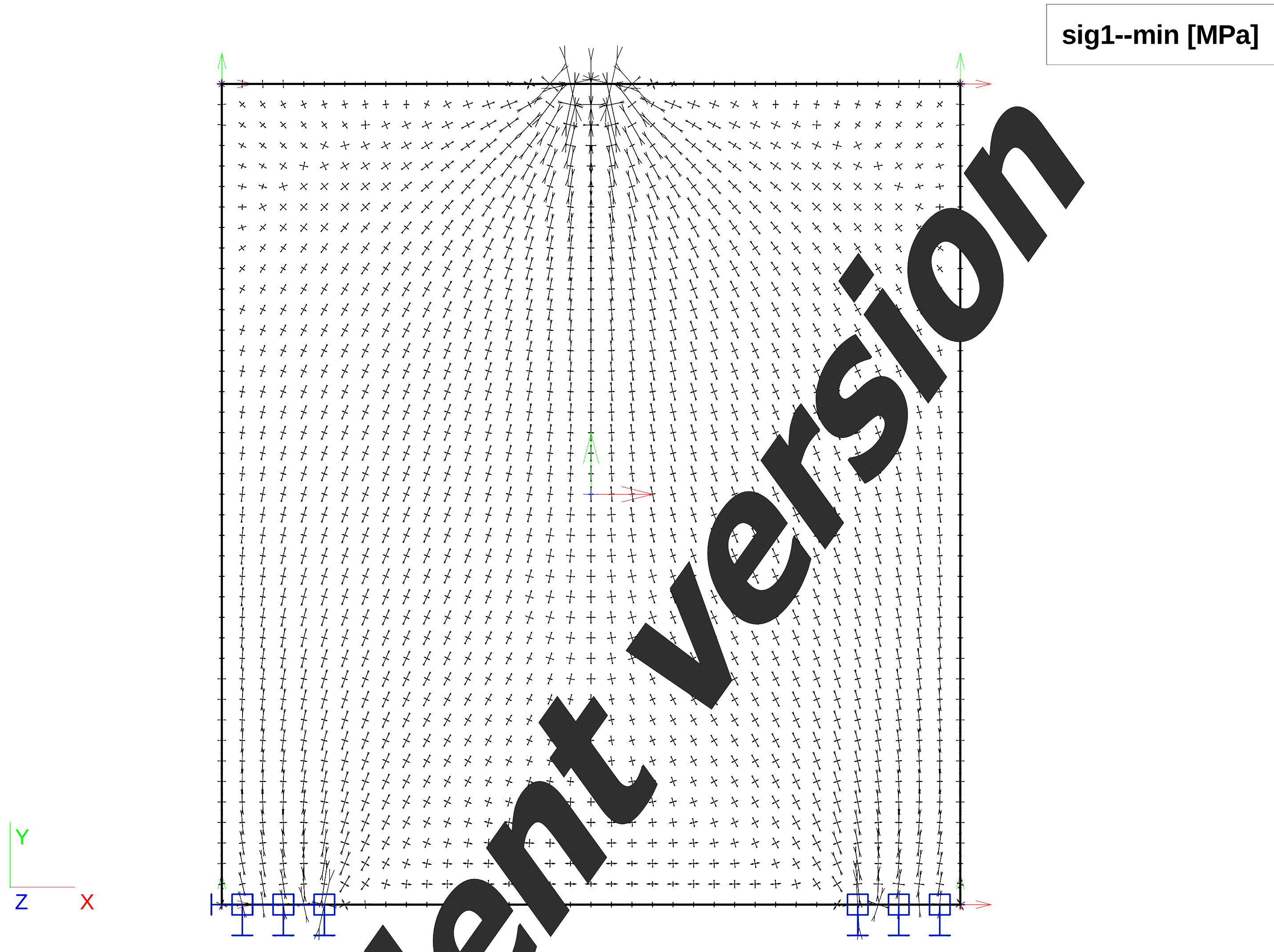
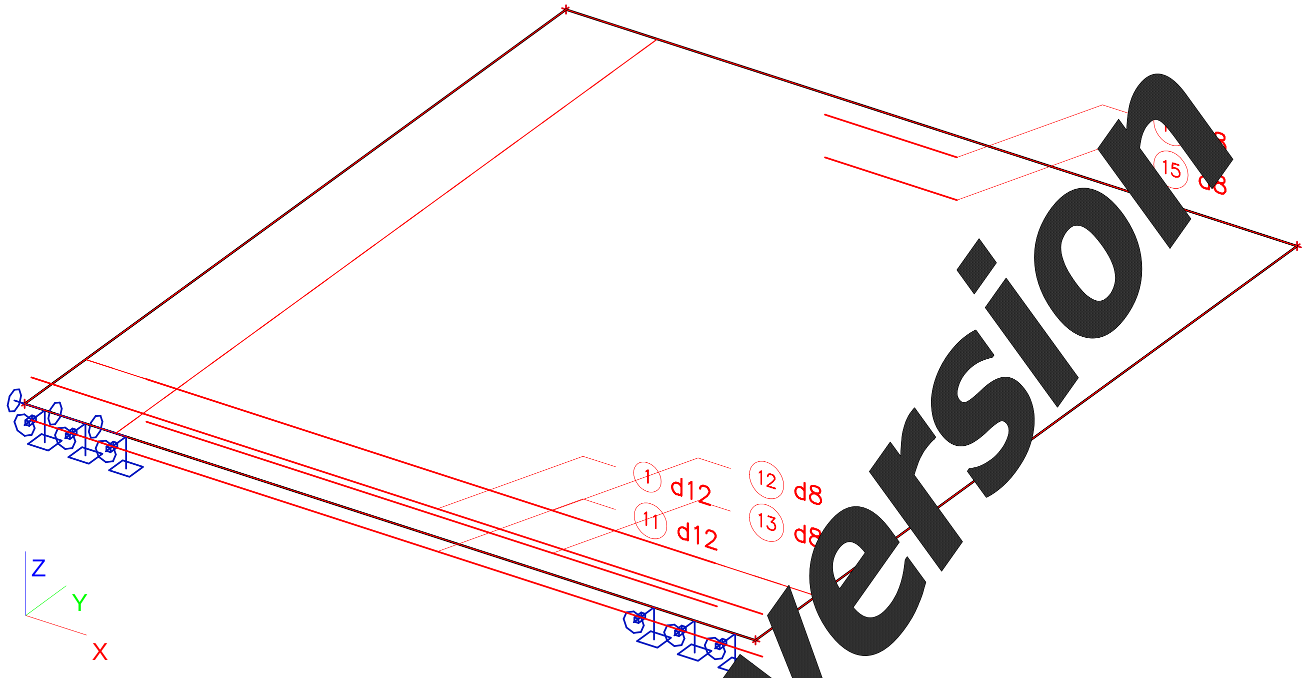
D1P1LFEM

Spec 1 – Point load 1(800 kN applied load) – LE FEM

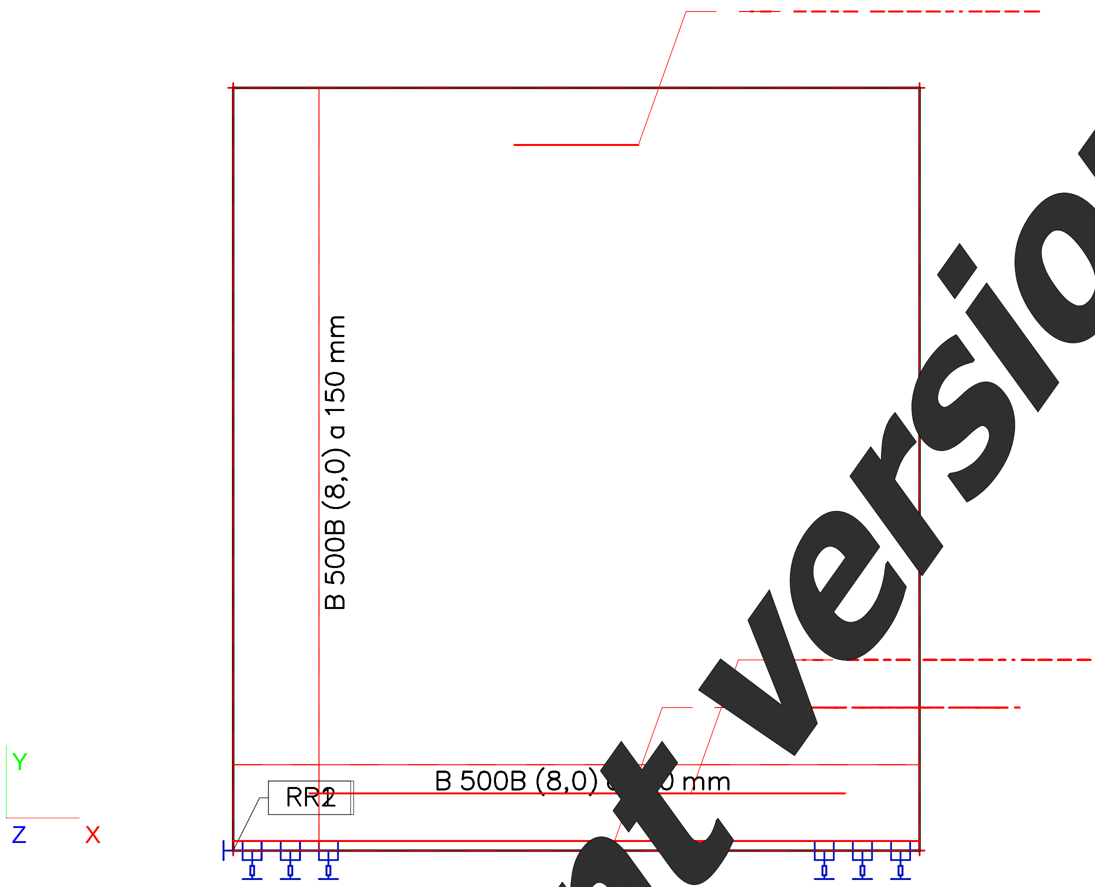
1. 2D member - Stresses; sig1-



2. Analysis model



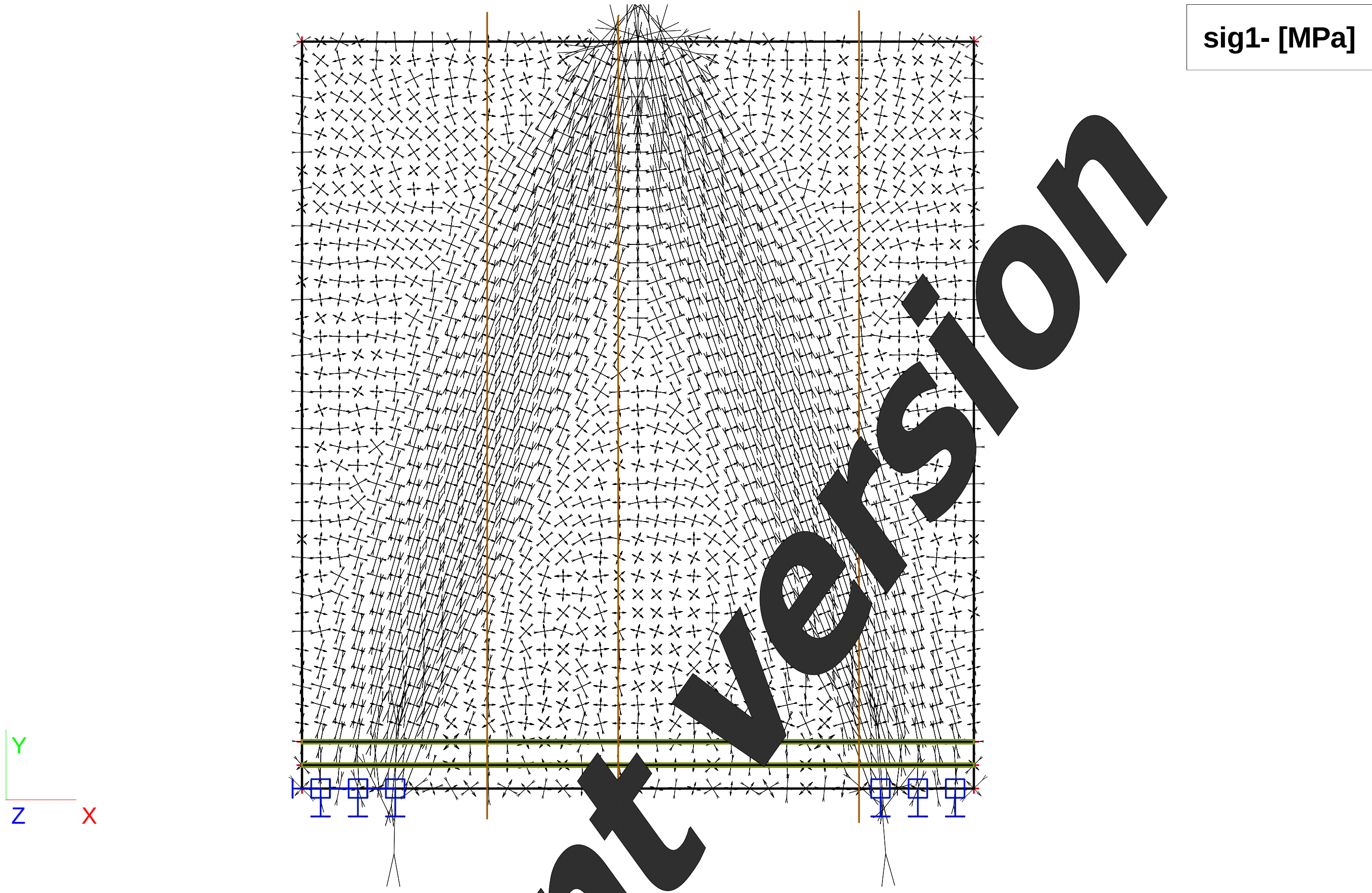
3. Analysis model



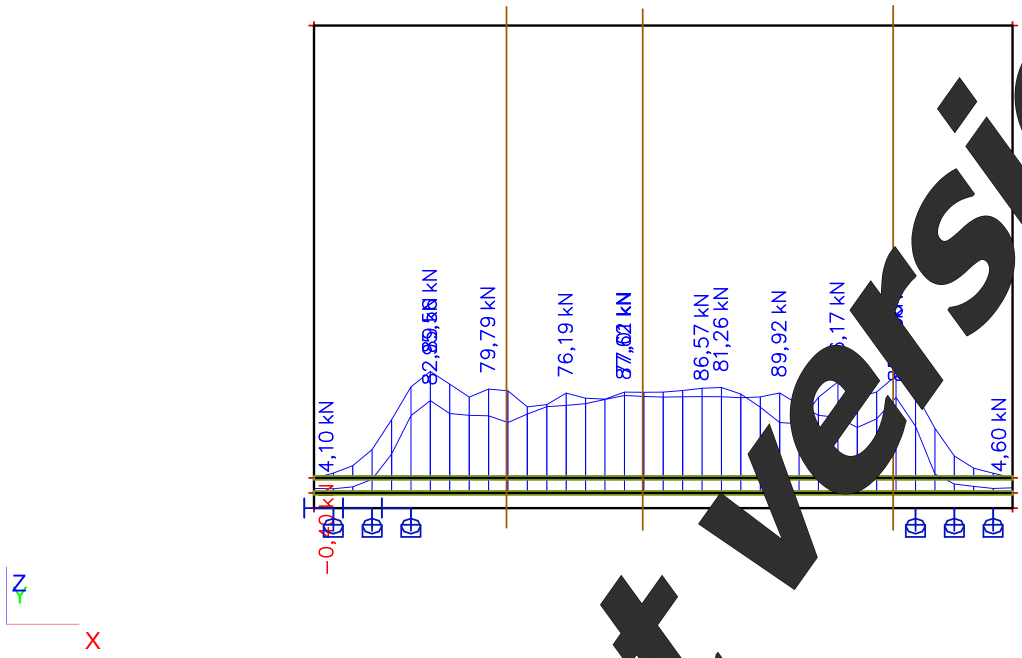
D1P1NLFEM

Spec 1 – Point load 1(800 kN applied load) – NL FEM

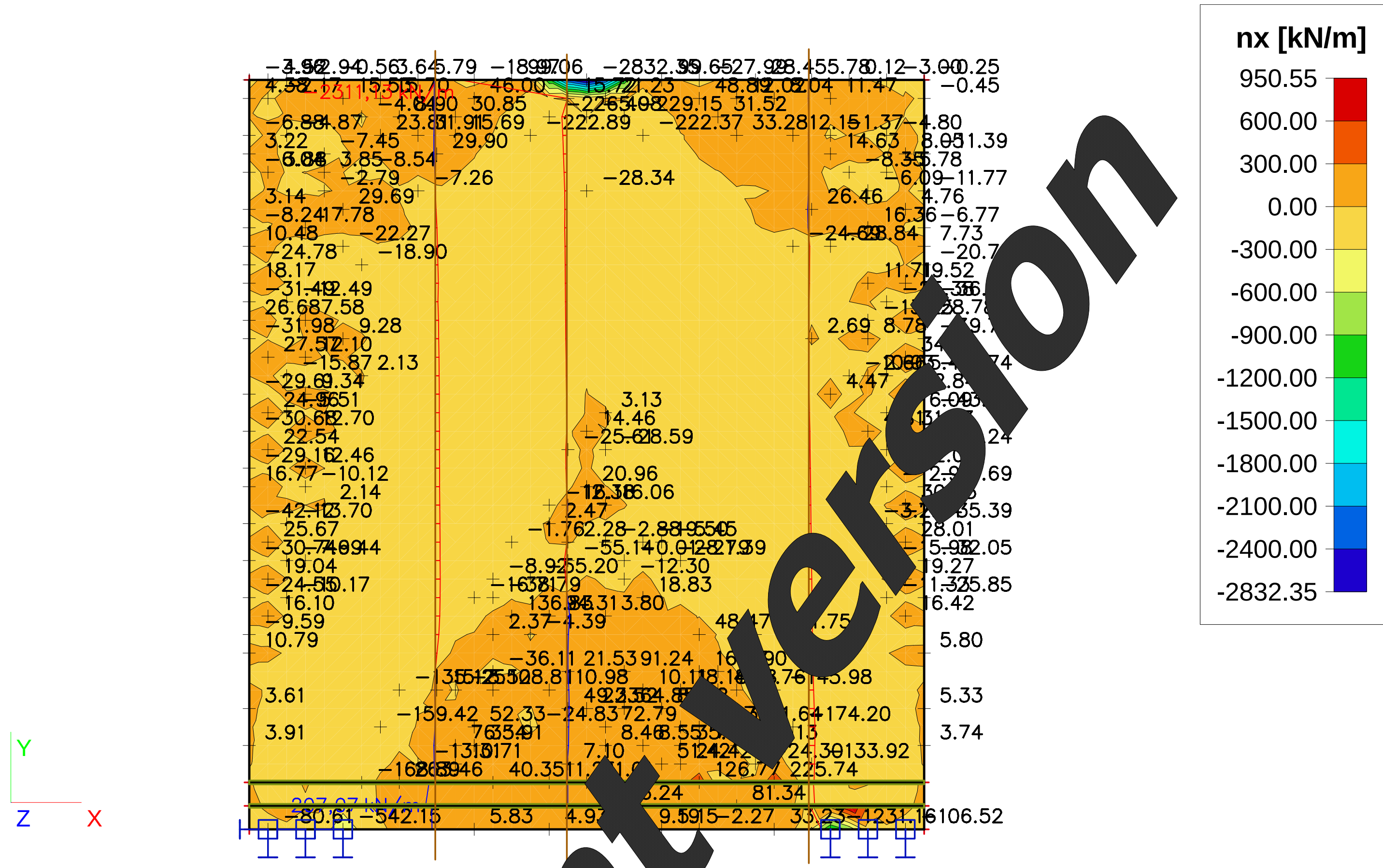
1. 2D member - Stresses; sig1-



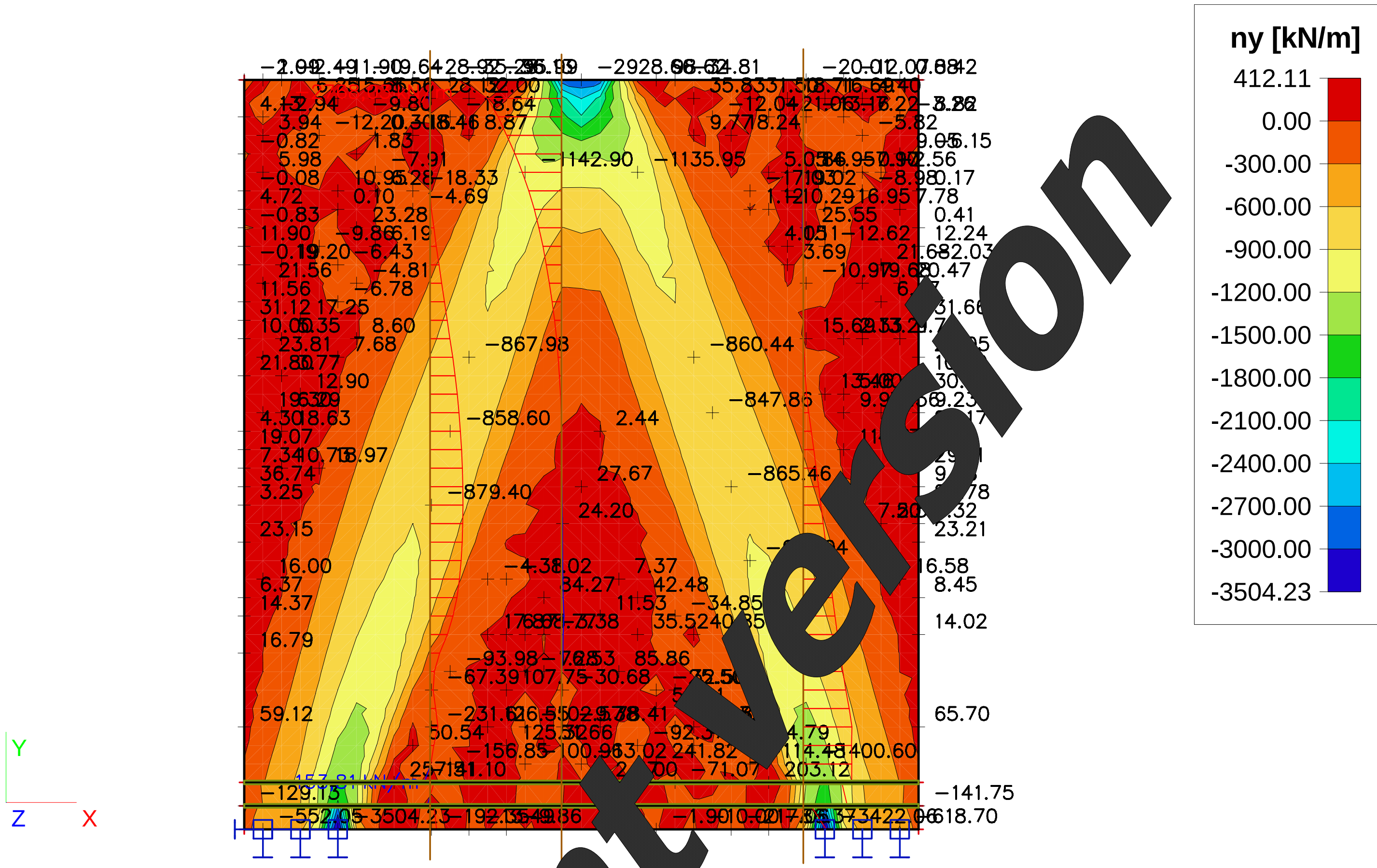
2. Internal forces on member; N



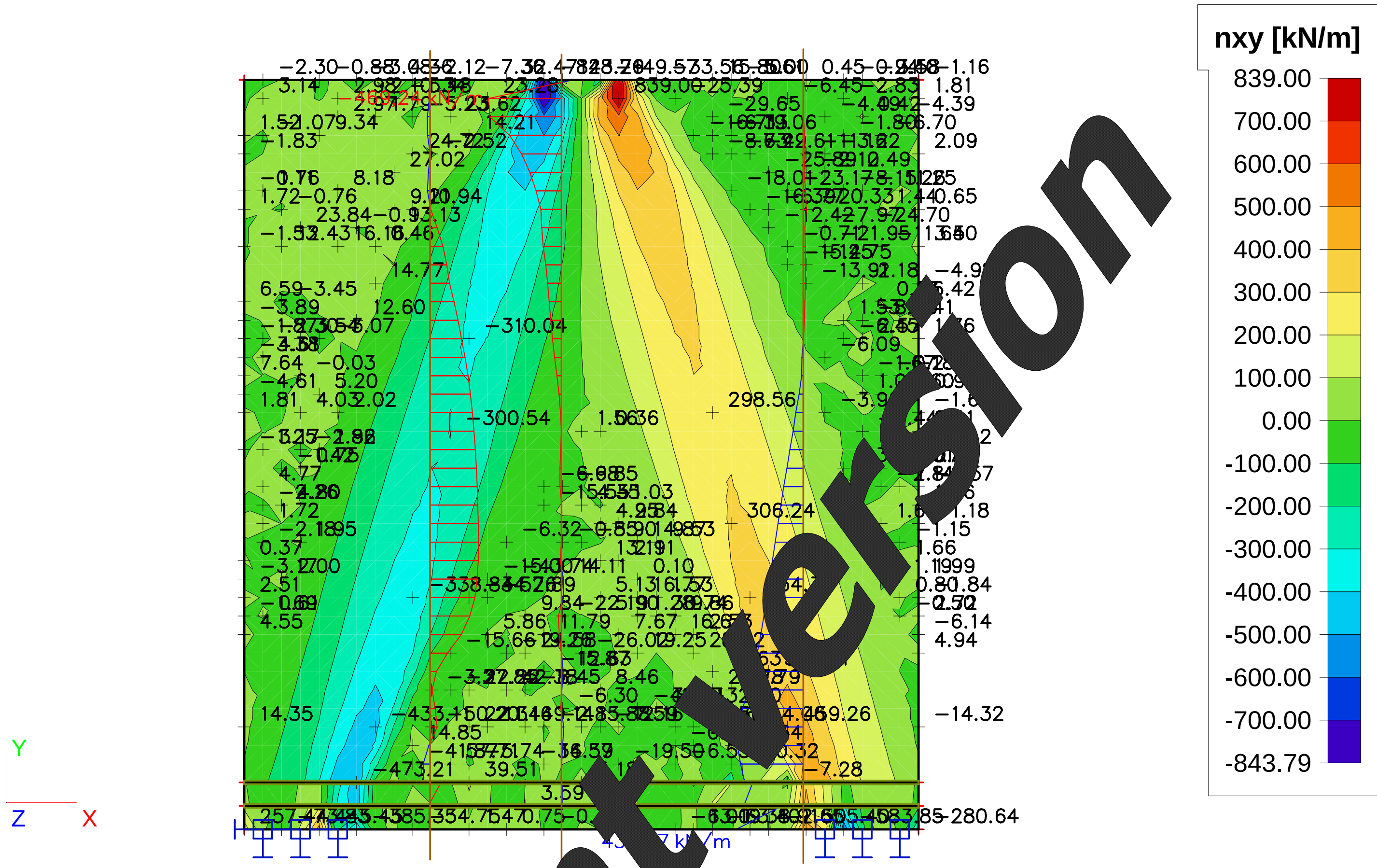
3. 2D member - Internal forces; nx



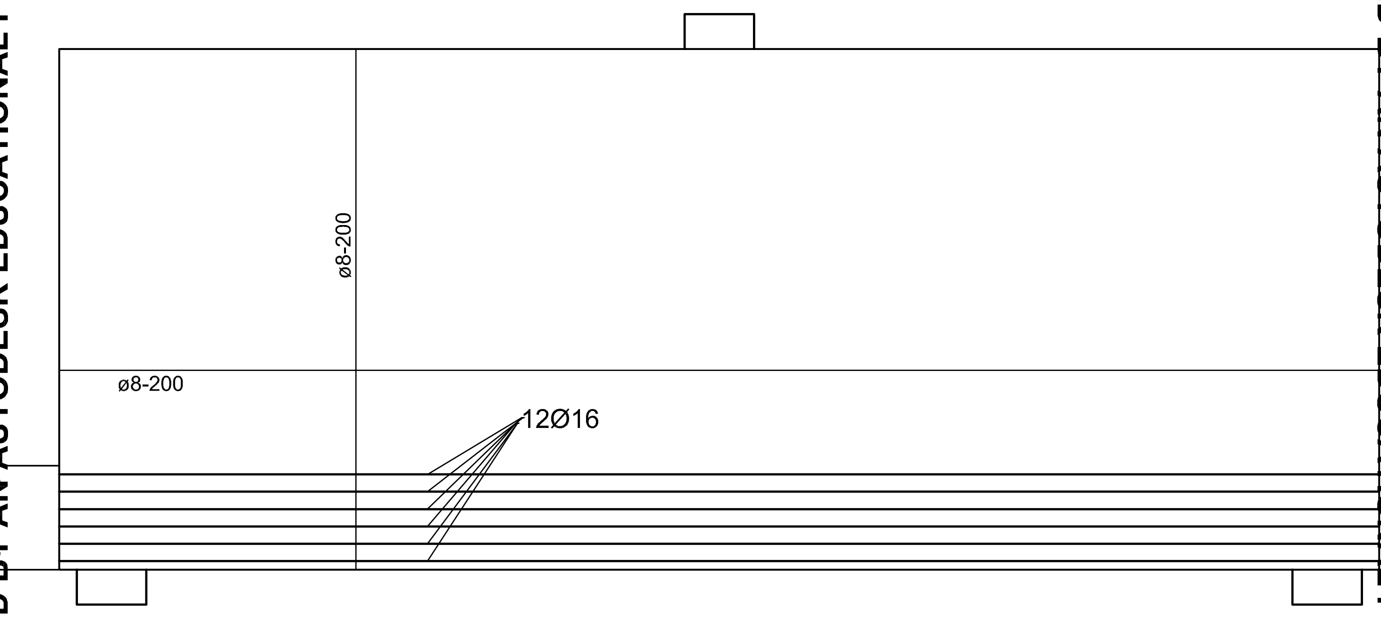
4. 2D member - Internal forces; ny



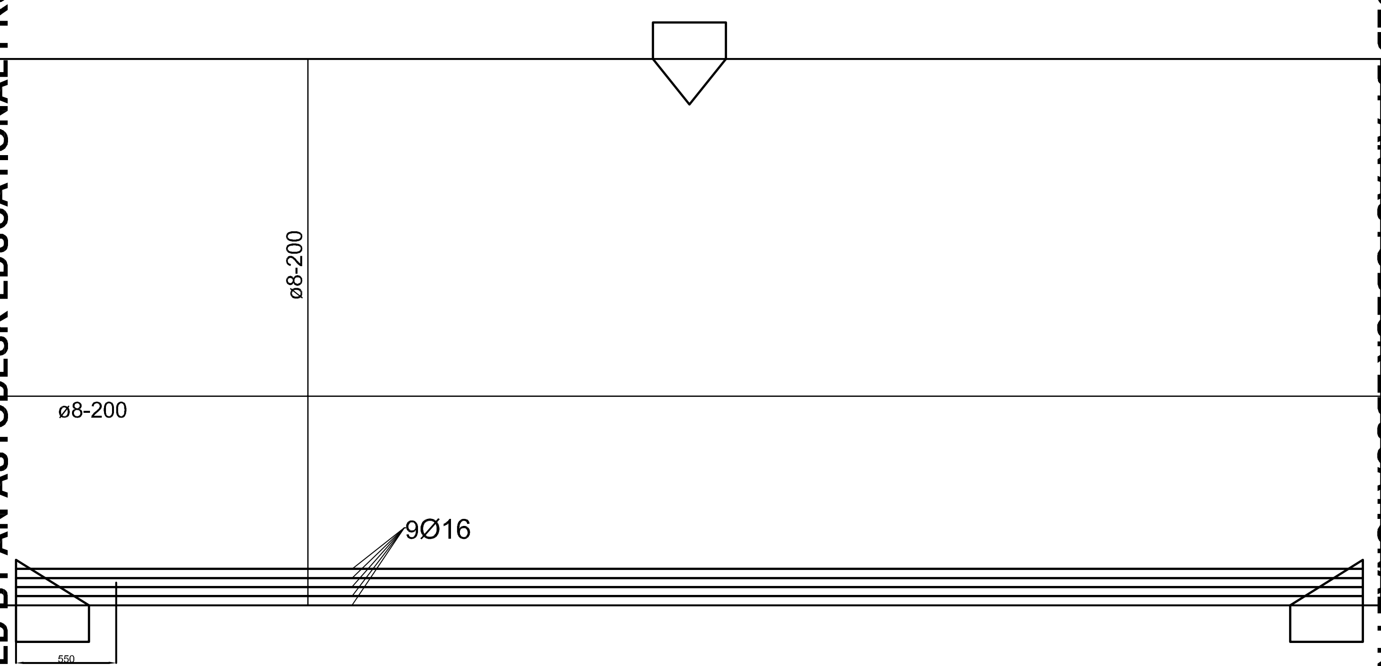
5. 2D member - Internal forces; nxy



D2P1SBM


ø8-200
ø8-200
12Ø16

D2P1STM(1)



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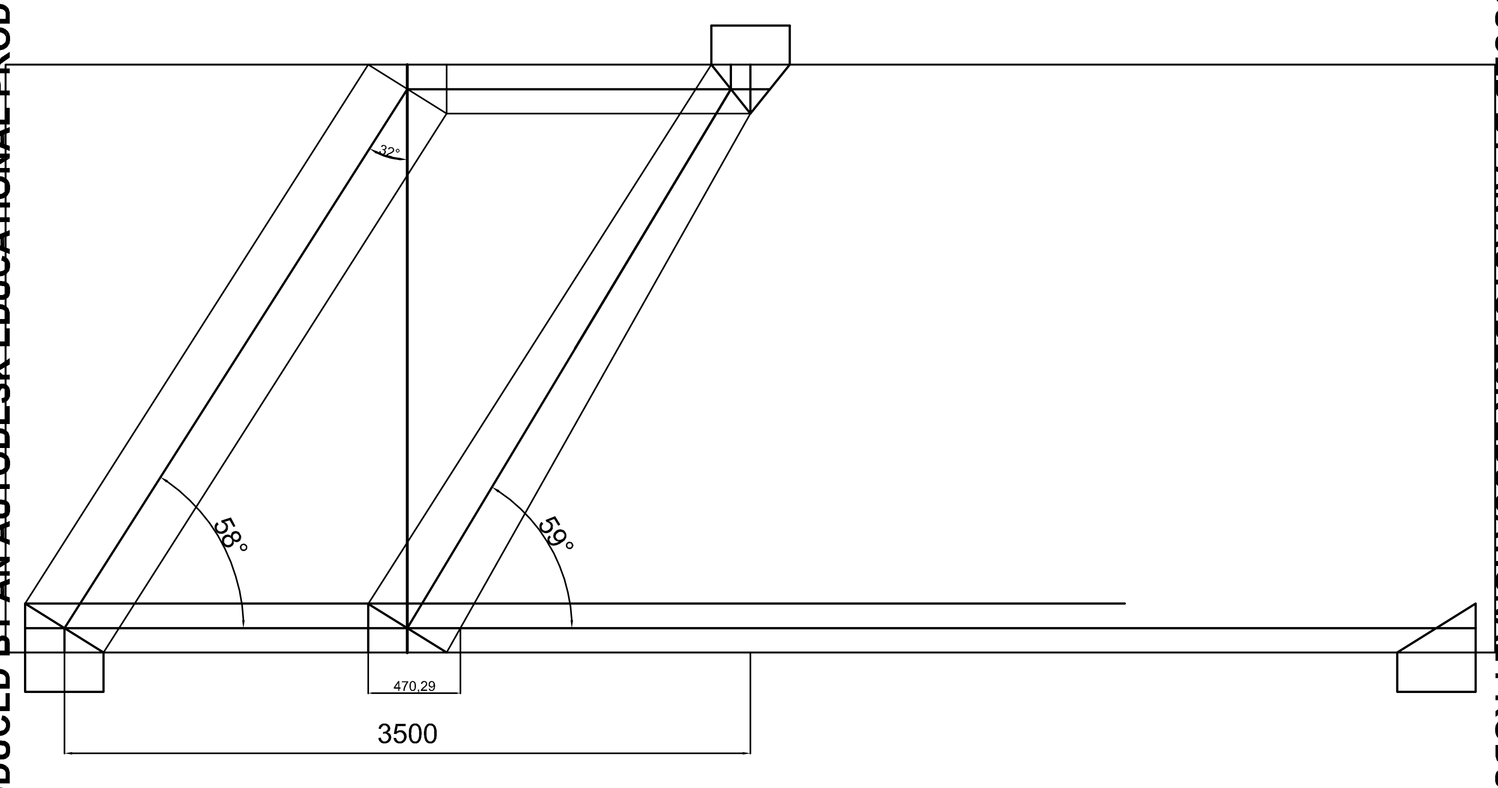
D2P1STM(2)



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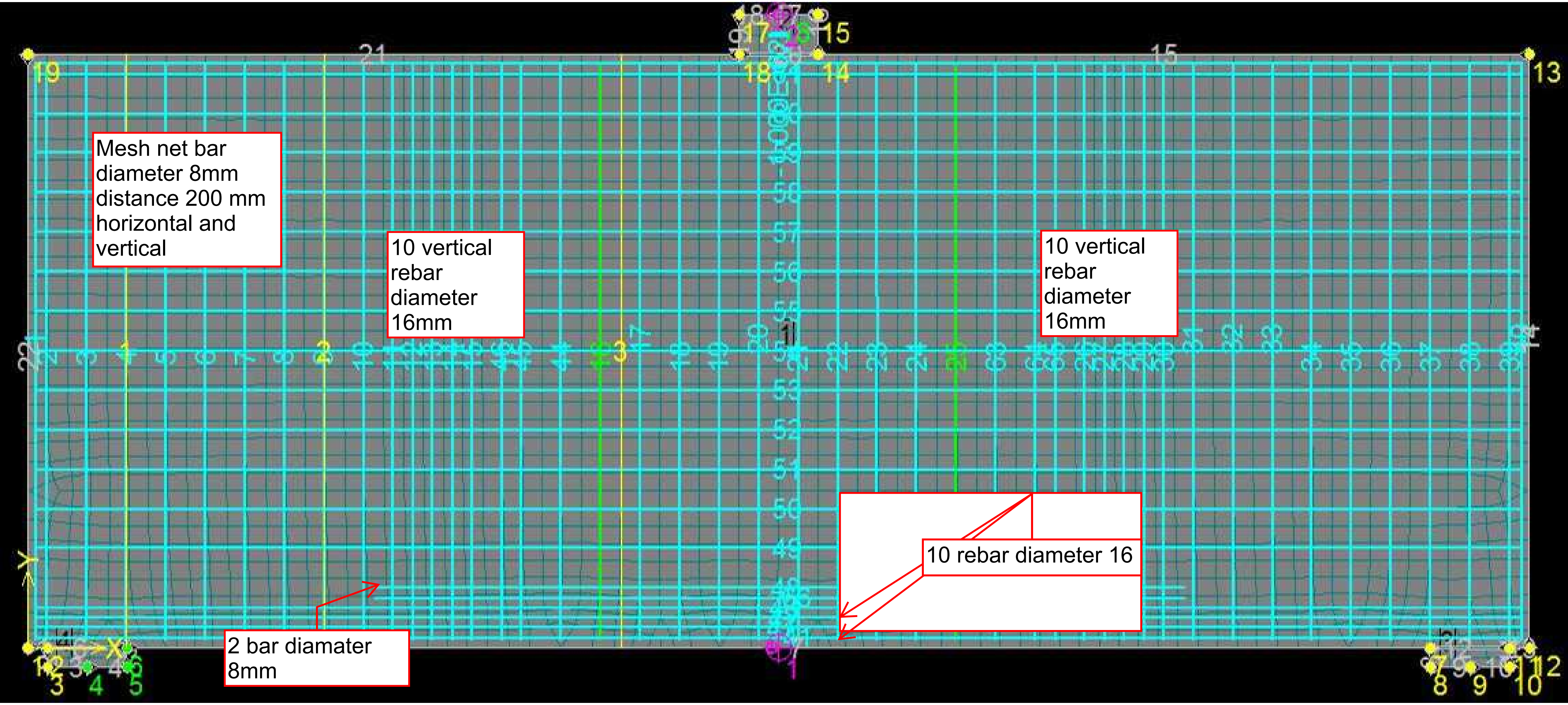
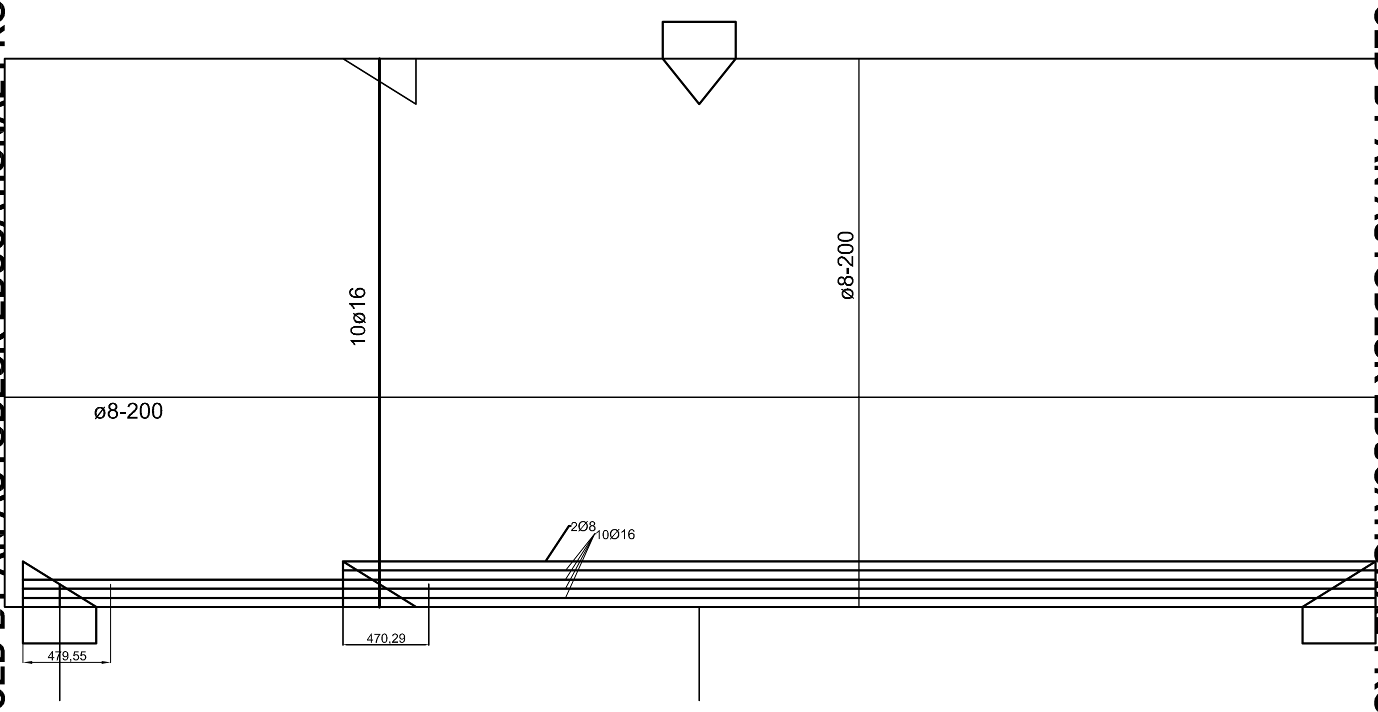
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



Mesh net bar diameter 8mm distance 200 mm horizontal and vertical
10 vertical rebar diameter 16mm
10 vertical rebar diameter 16mm
10 rebar diameter 16
2 bar diamater 8mm



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PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

D2P1STM(3)

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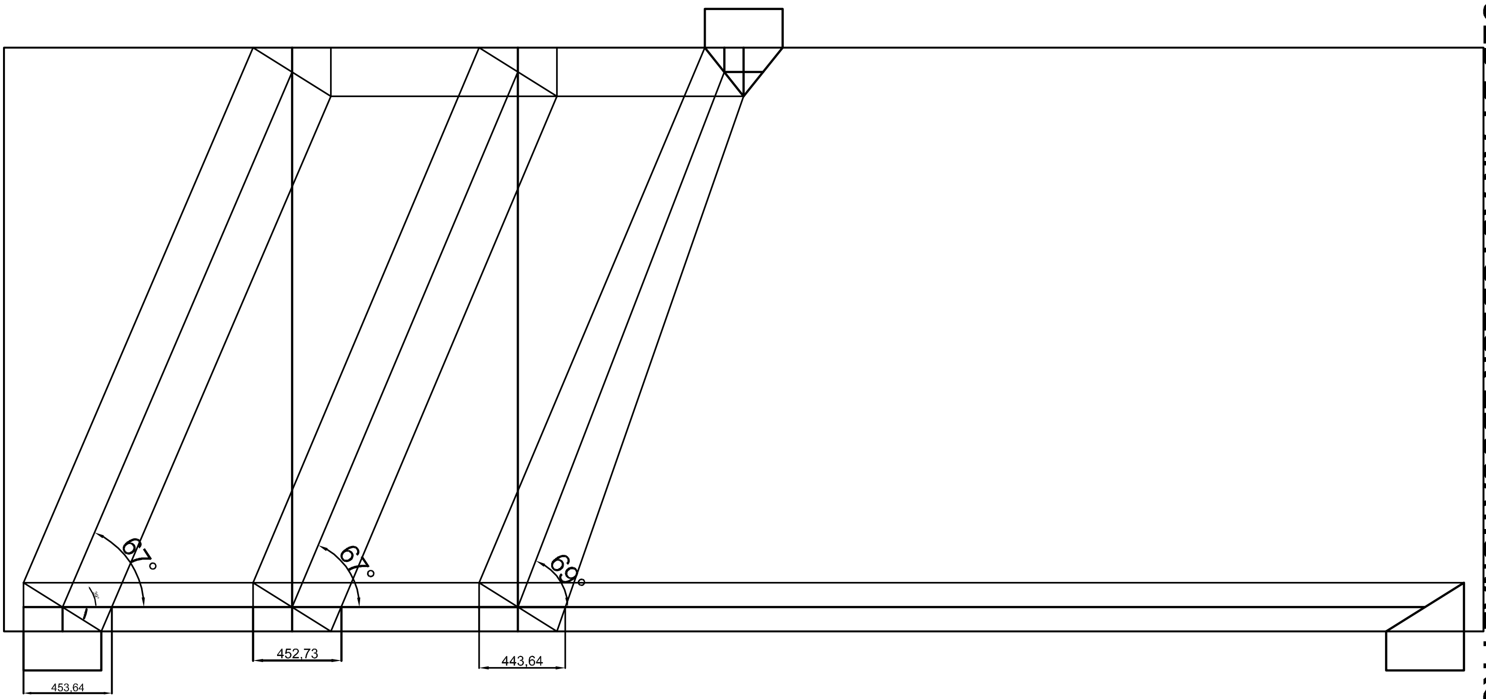

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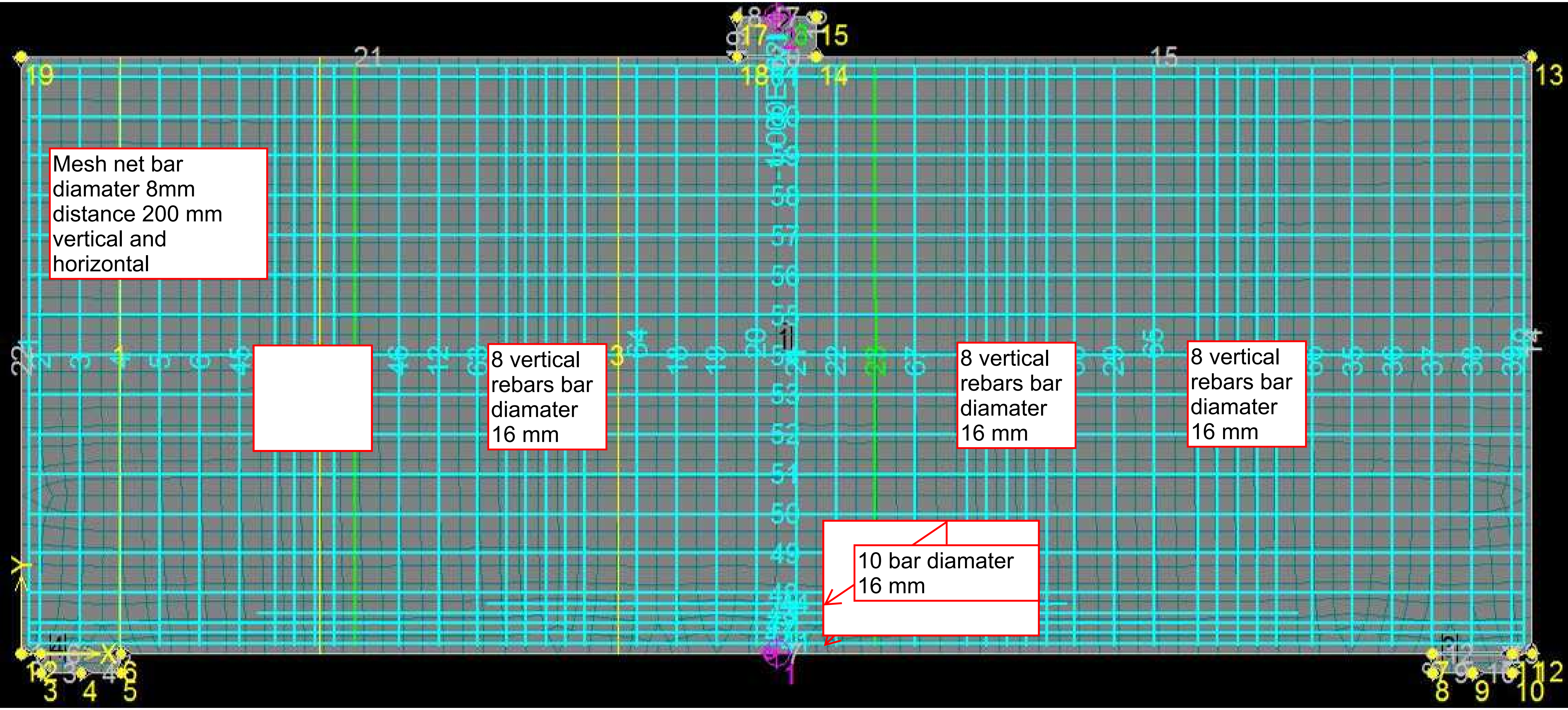
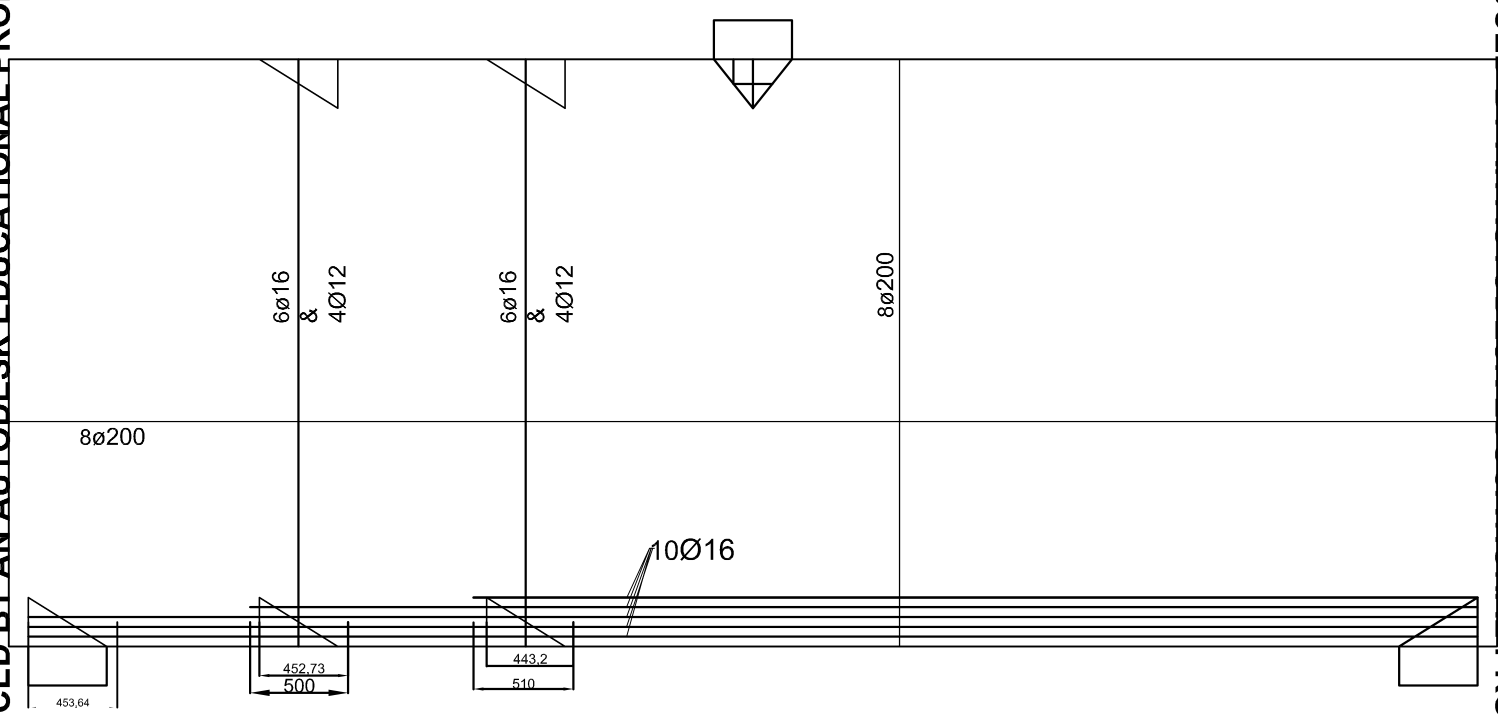
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



Mesh net bar diamater 8mm distance 200 mm vertical and horizontal
8 vertical rebars bar diamater 16 mm
8 vertical rebars bar diamater 16 mm
8 vertical rebars bar diamater 16 mm
10 bar diamater 16 mm

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



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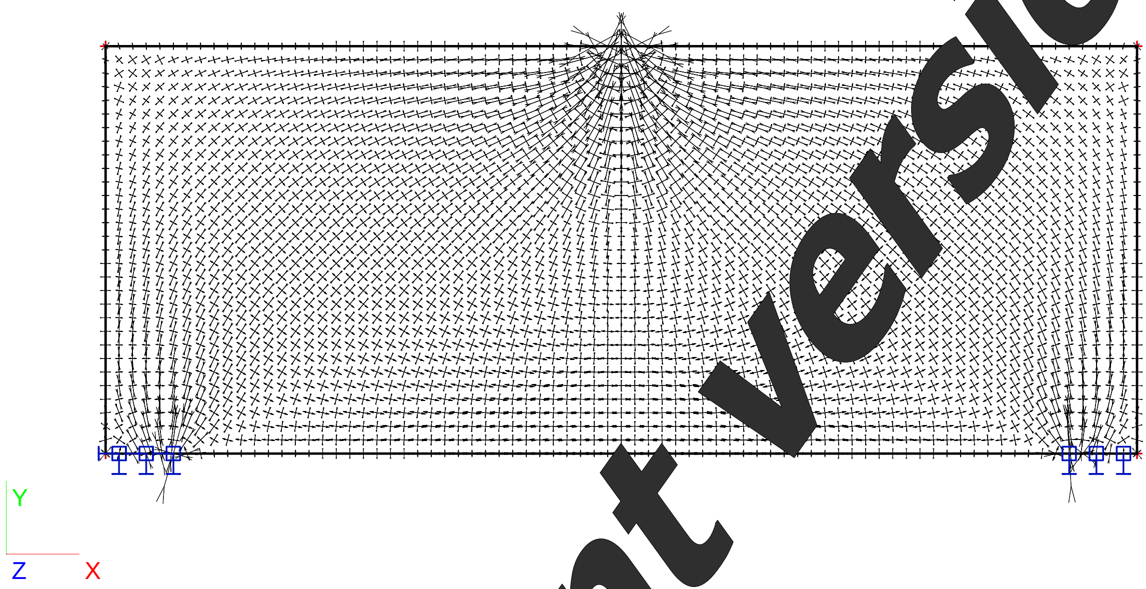
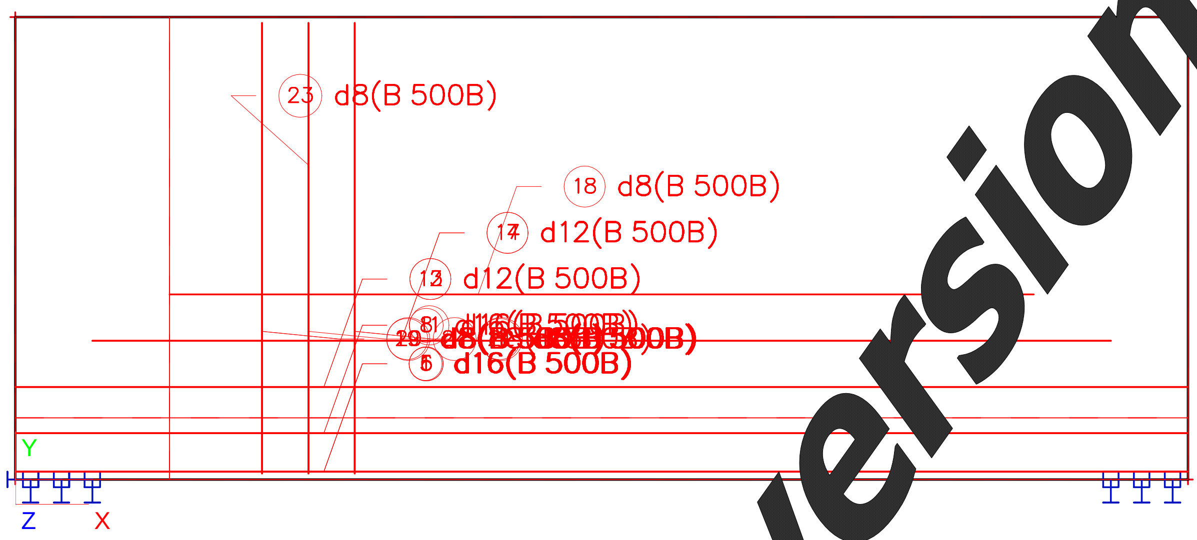
D2P1LEFEM

1. 2D member - Stresses; sig1-

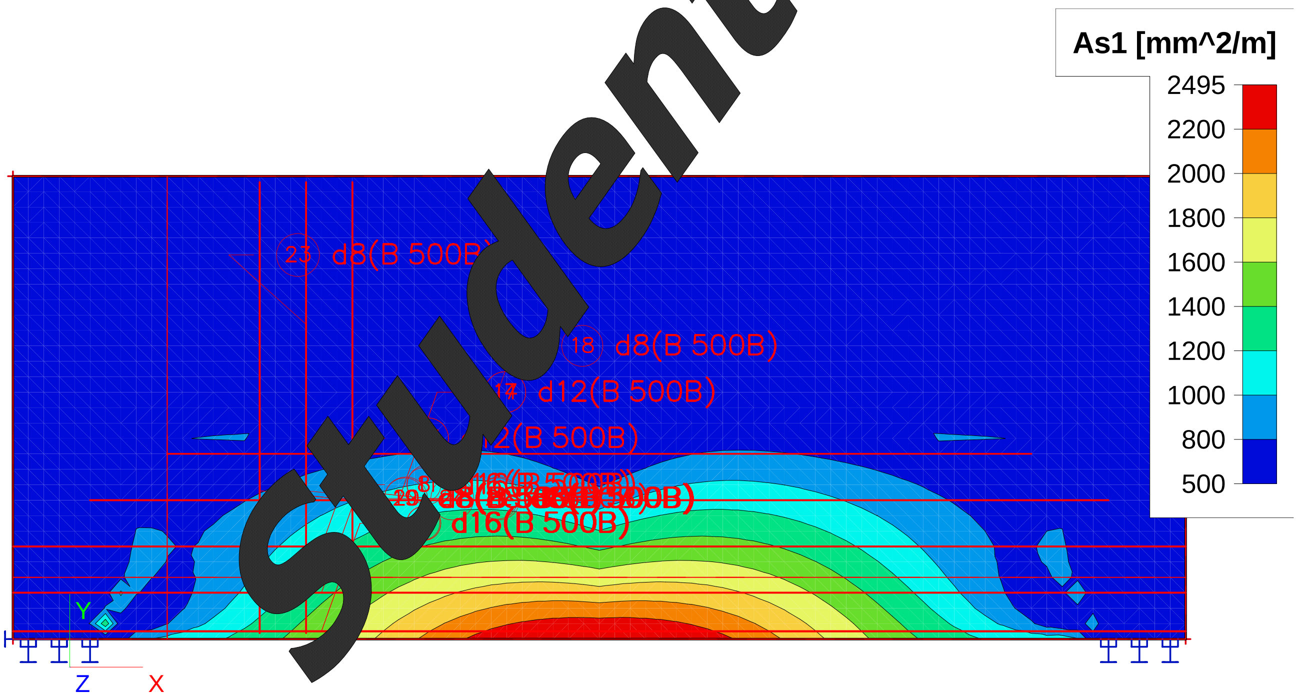
sig1--min [MPa]



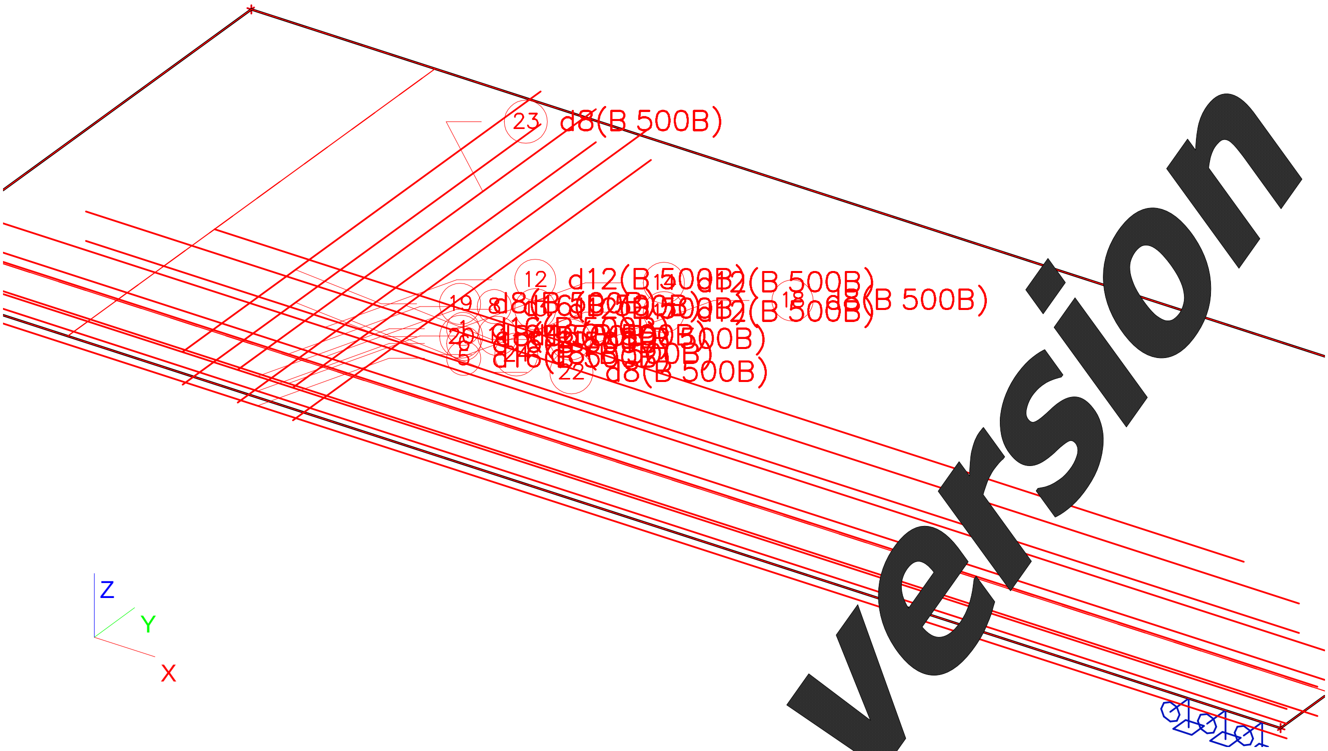
2. Analysis model



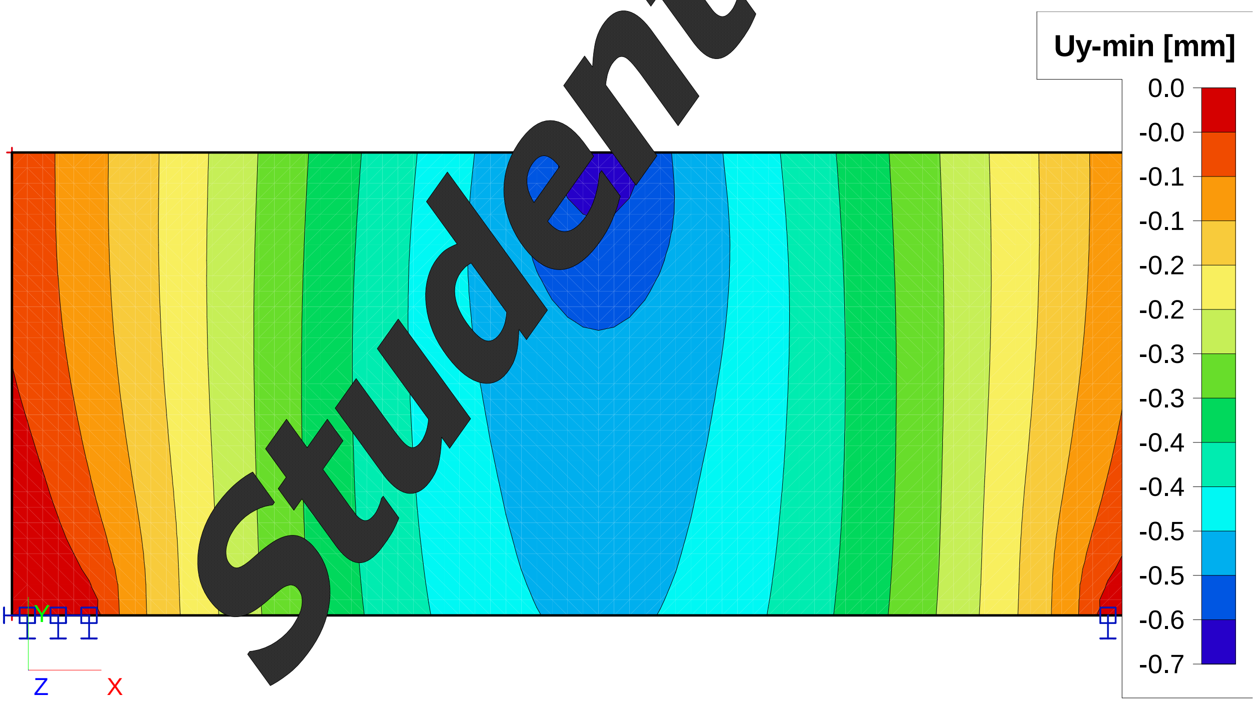
3. Member 2D - design - required areas; As1



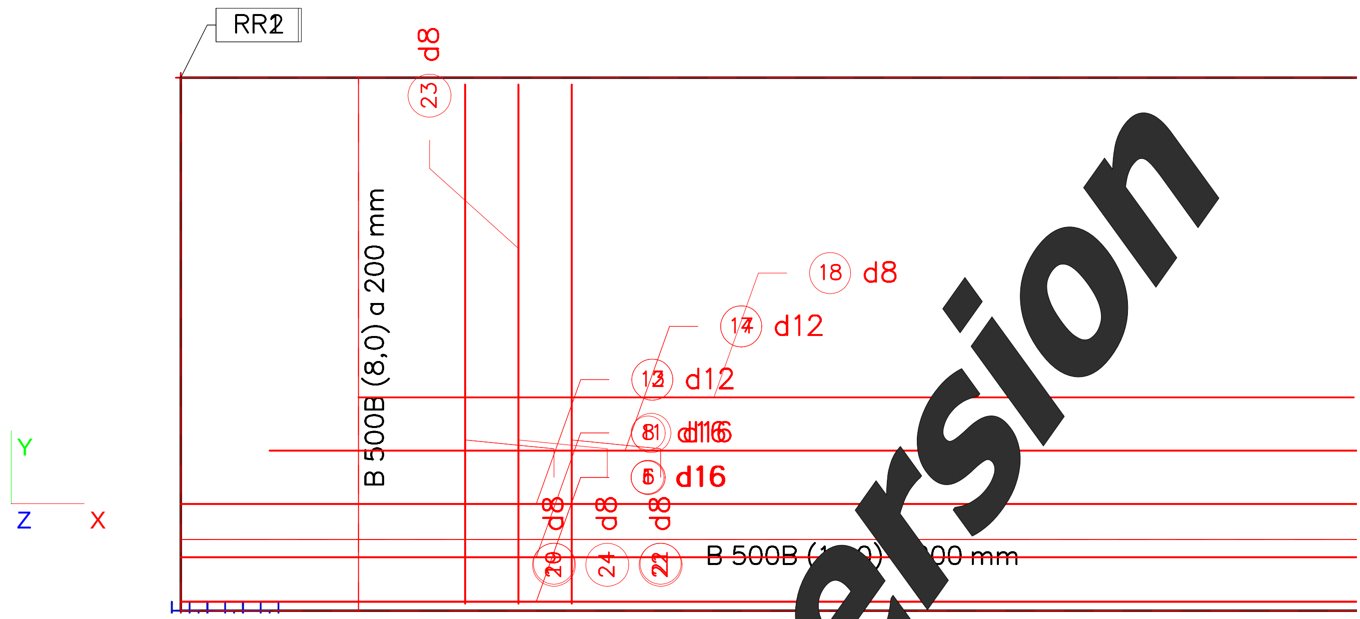
4. Analysis model



5. Displacement of nodes; Uy



6. Analysis model

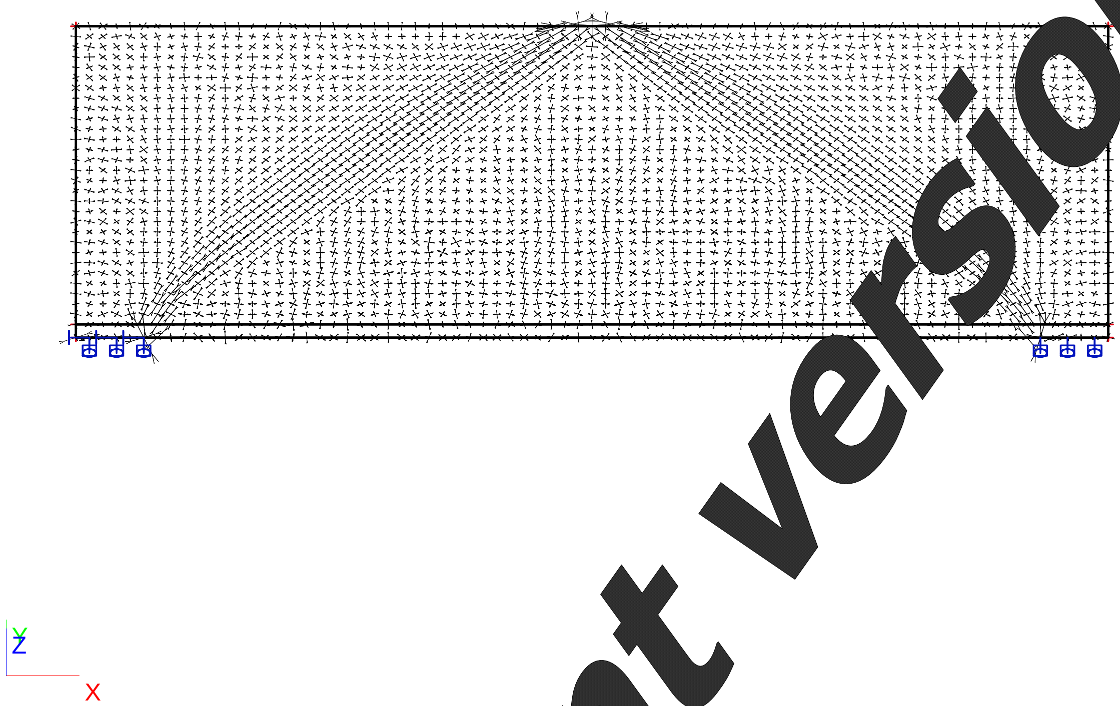


7. Analysis model

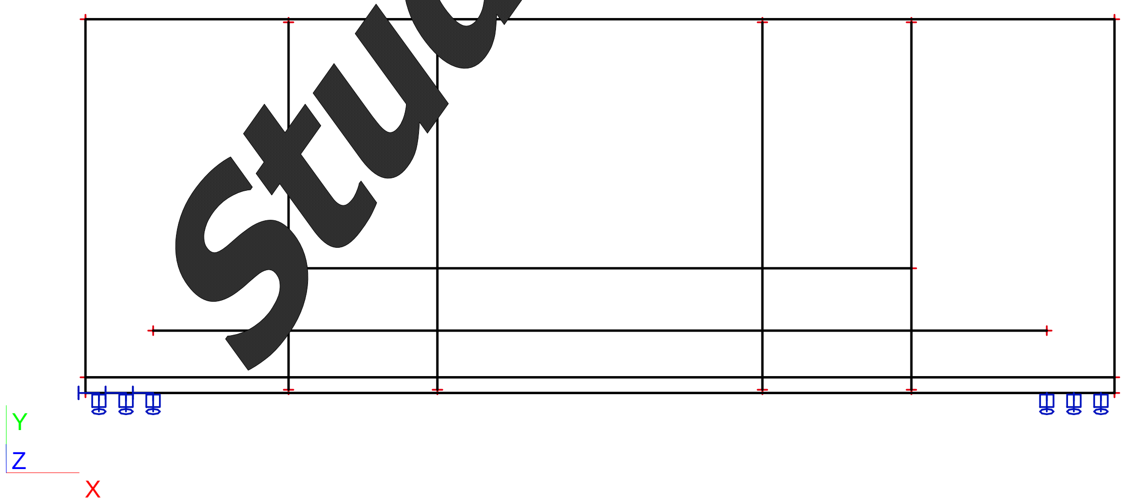
D2P1NLFEM

1. 2D member - Stresses; sig1-

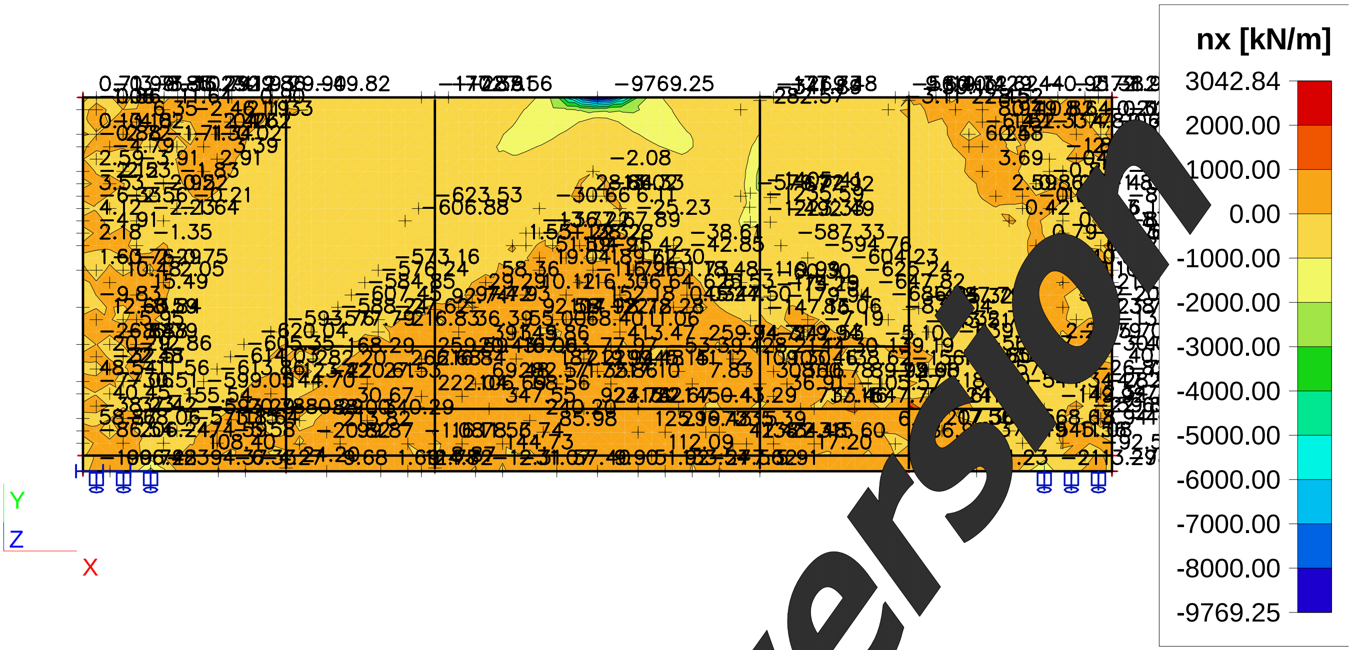
sig1- [MPa]



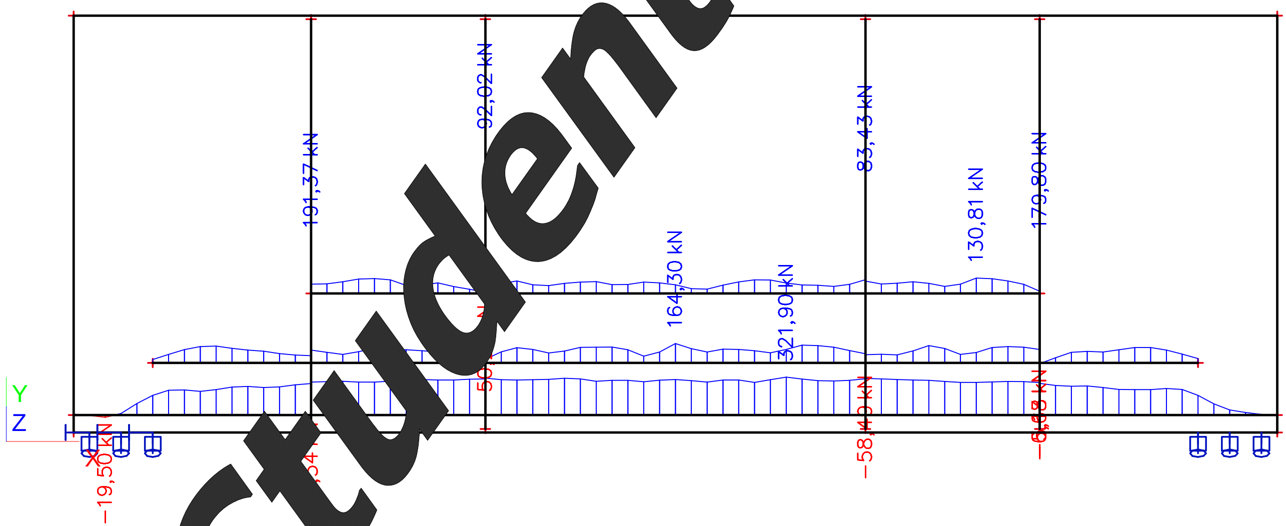
2. Analysis model



3. 2D member - Internal forces; nx



4. Internal forces on member; N



Specimen D3 examples

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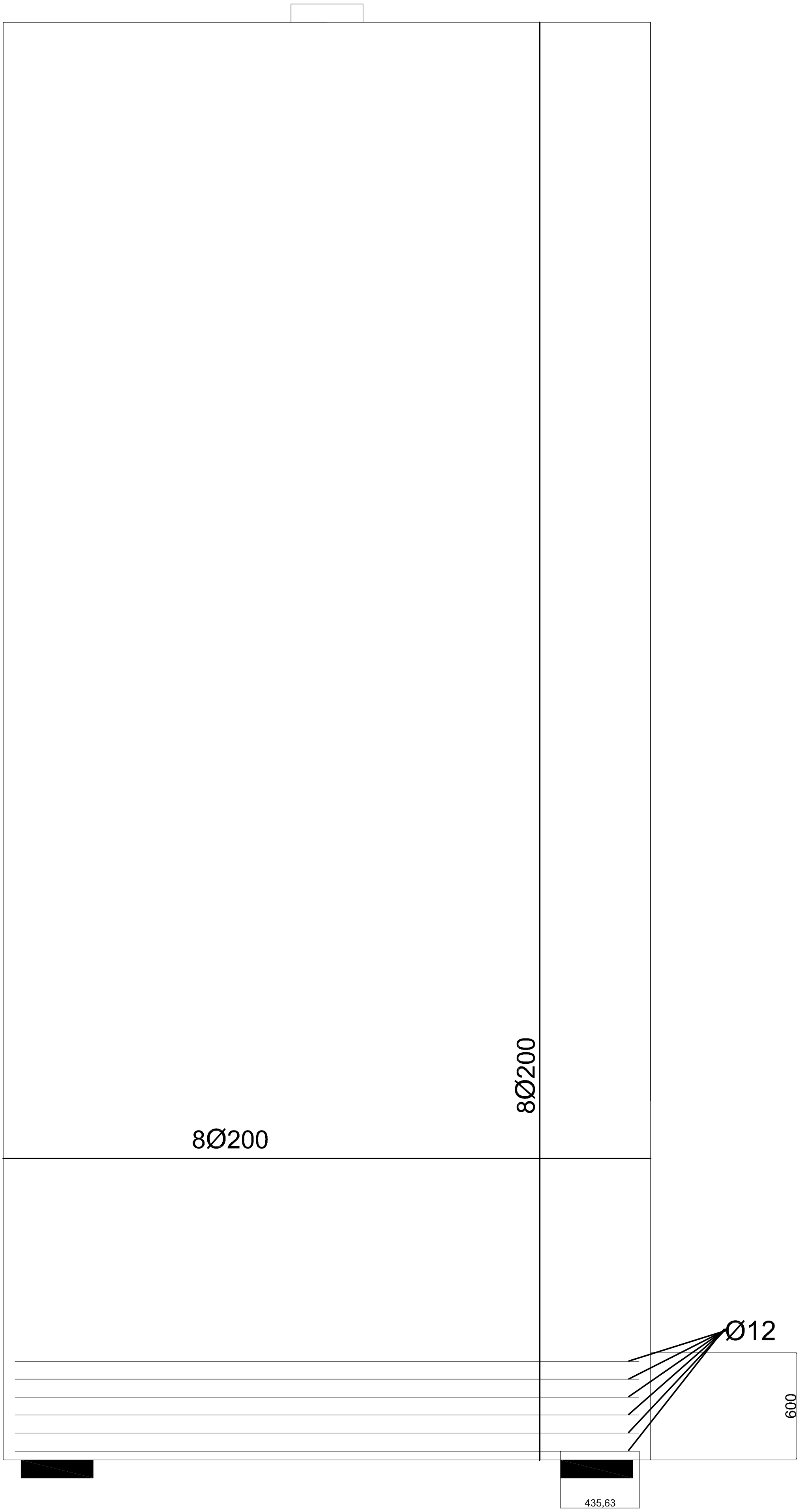

Specimen 2 800 Beam

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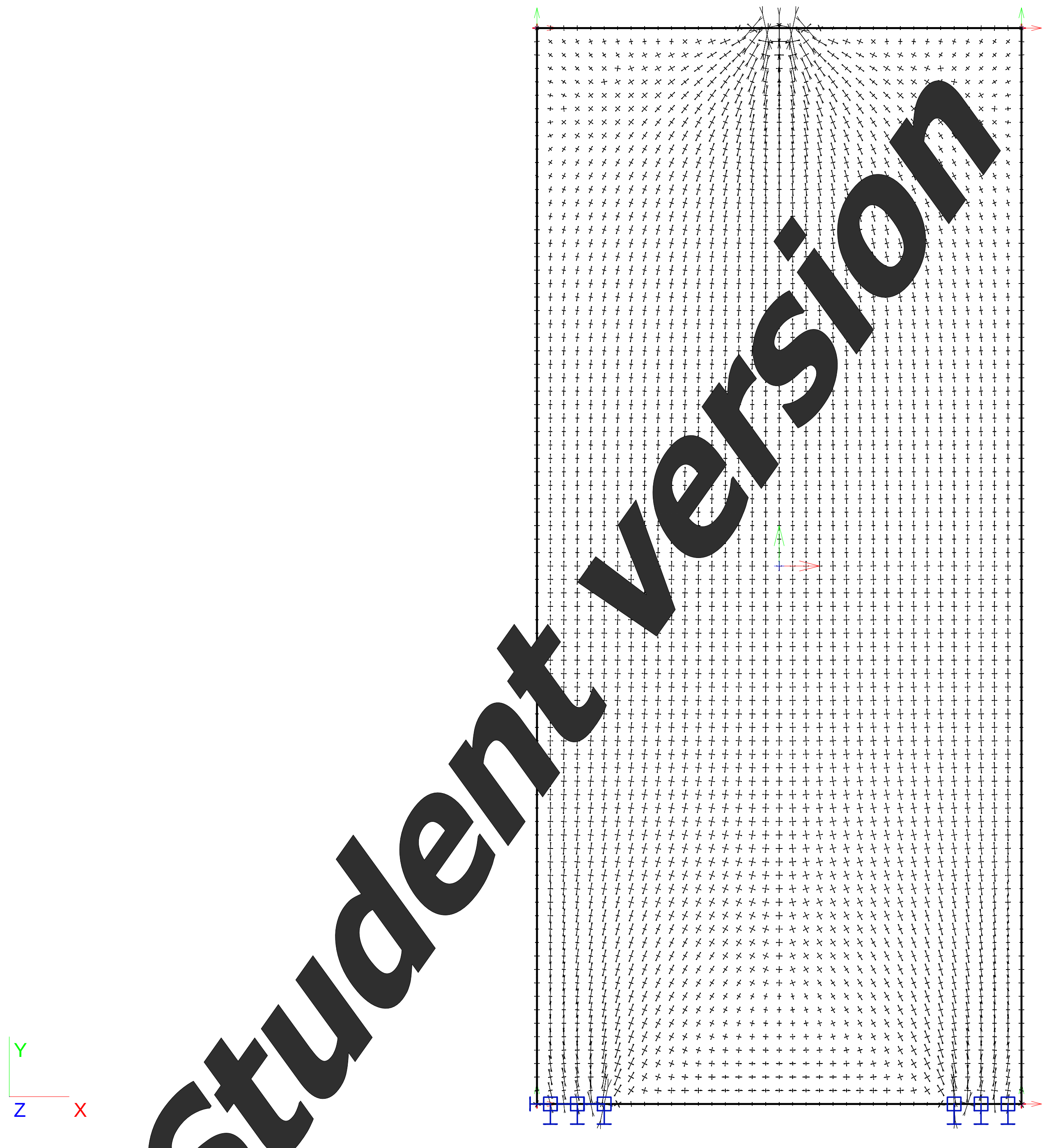
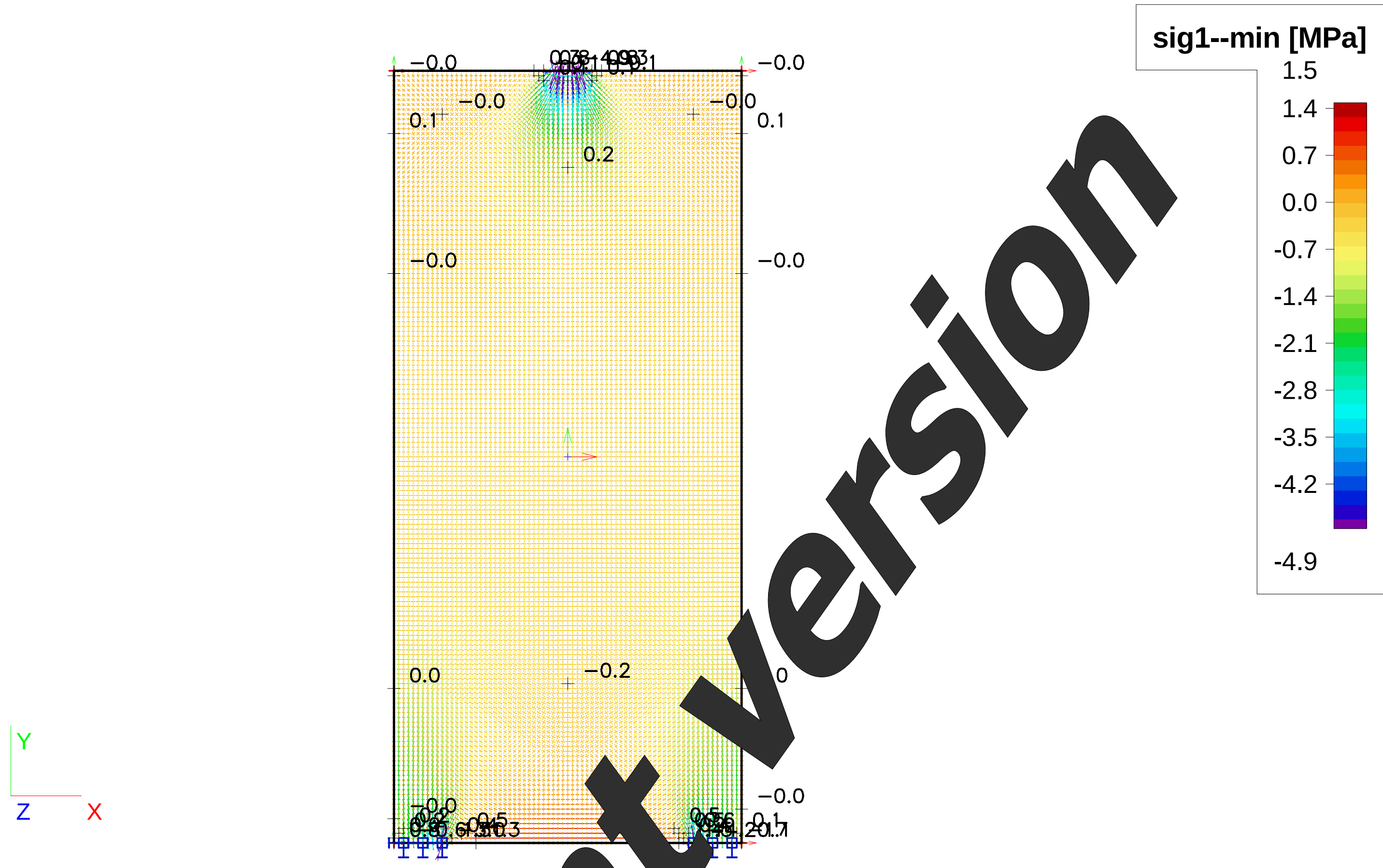
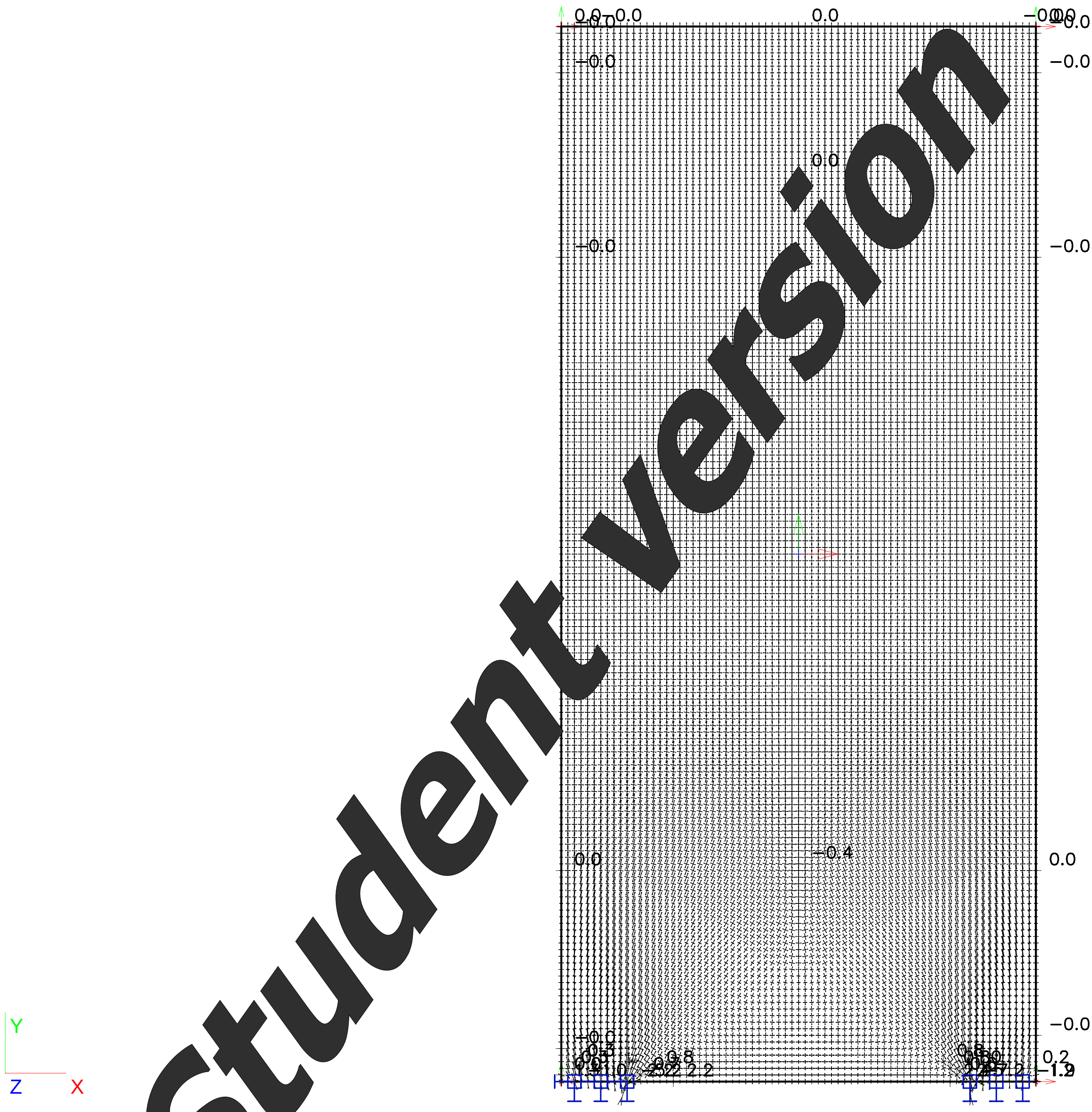

Y
Z
X

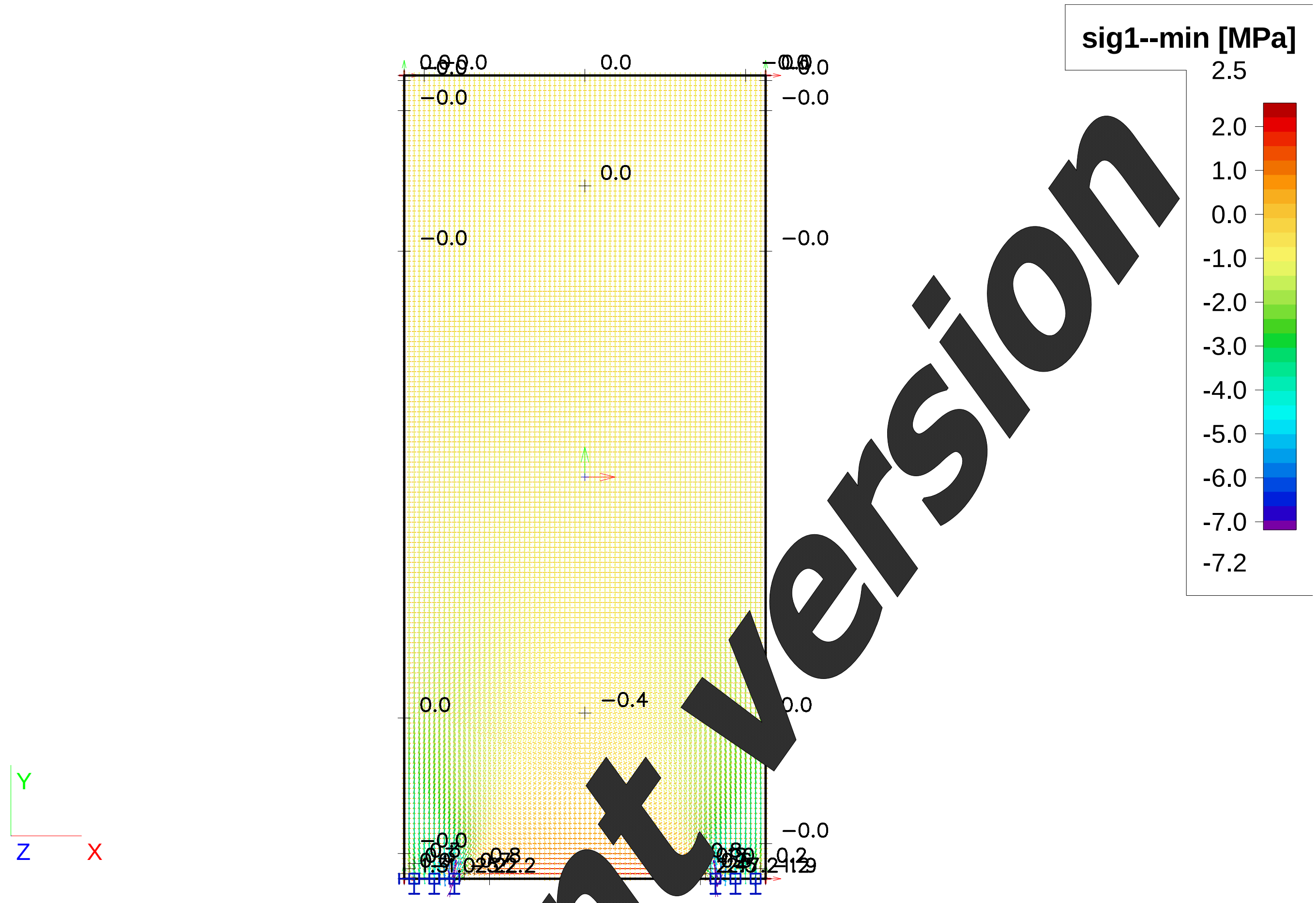
1. 2D member - Stresses; sig1-

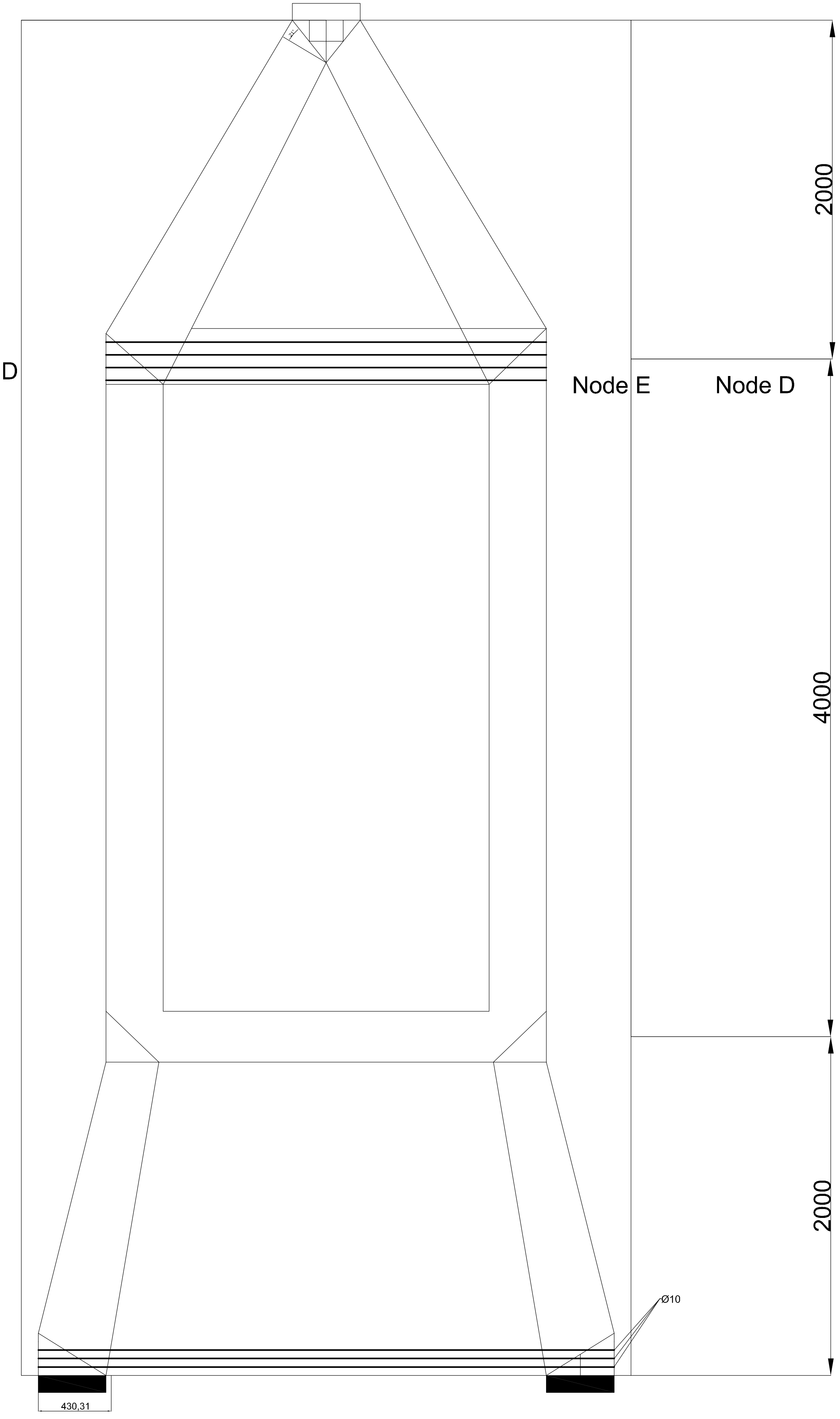


2. 2D member - Stresses; sig1-



3. 2D member - Stresses; sig1-





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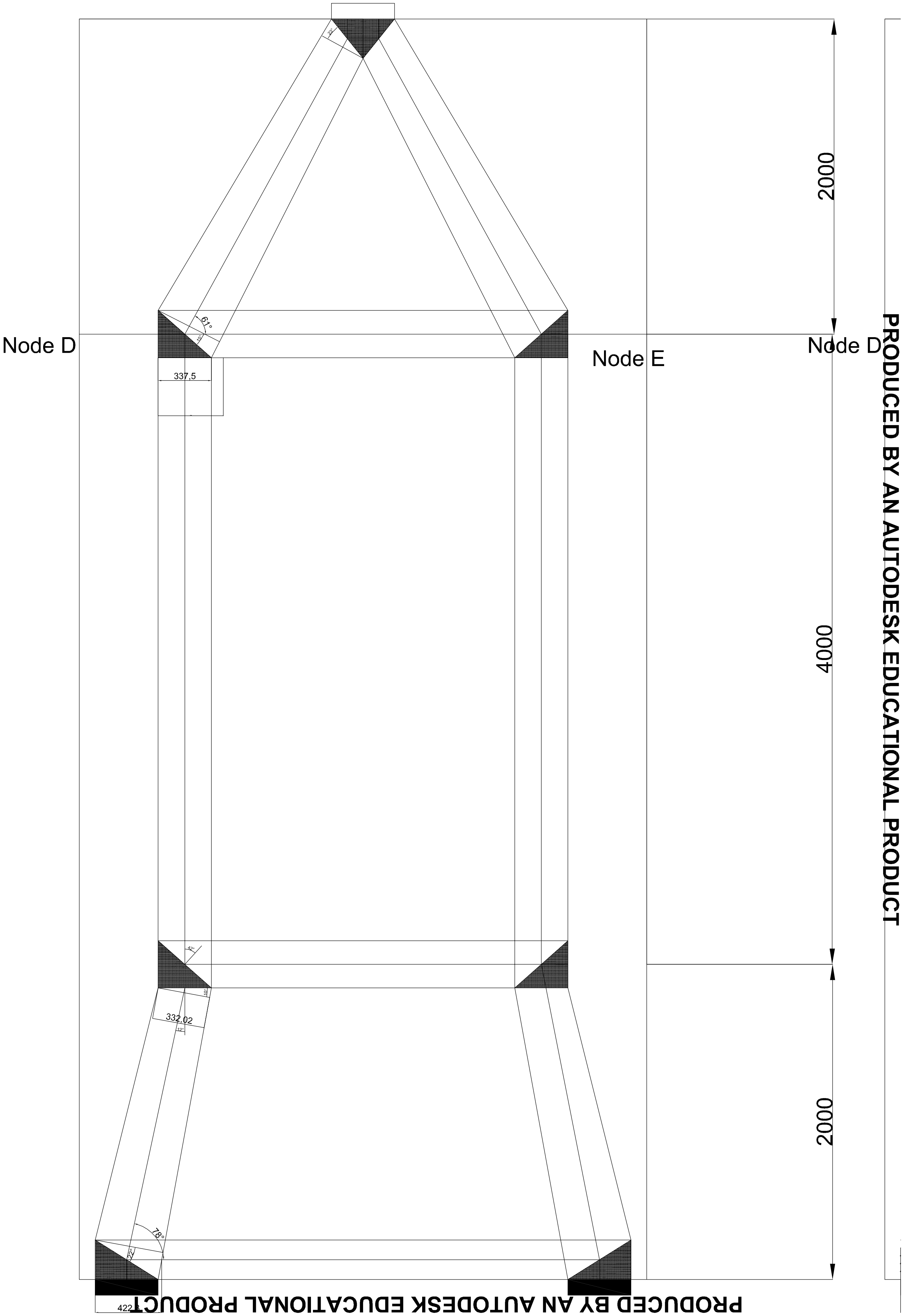
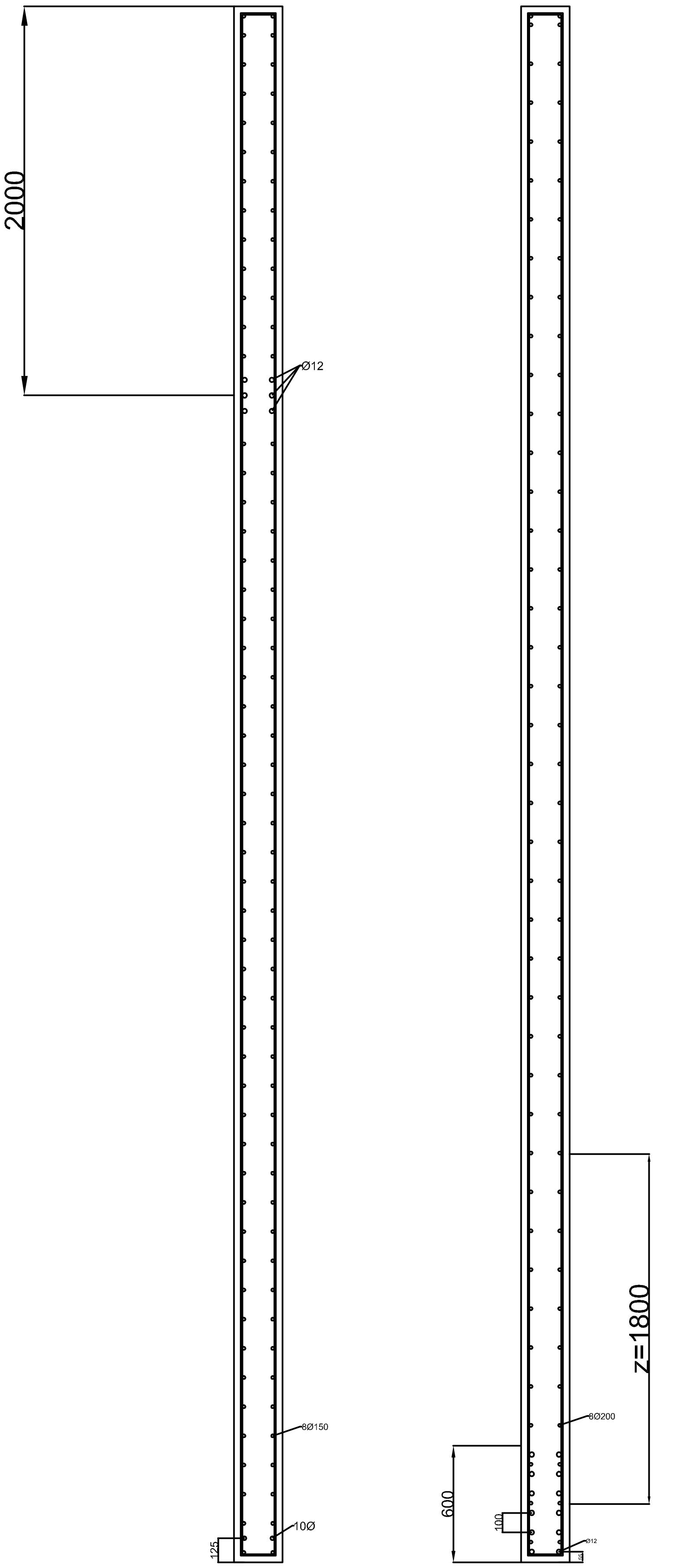
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



Node D
Node E
Node D
61°
337,5
332,02
78°
422
2000
4000
2000



800kN STM

800kN Beam

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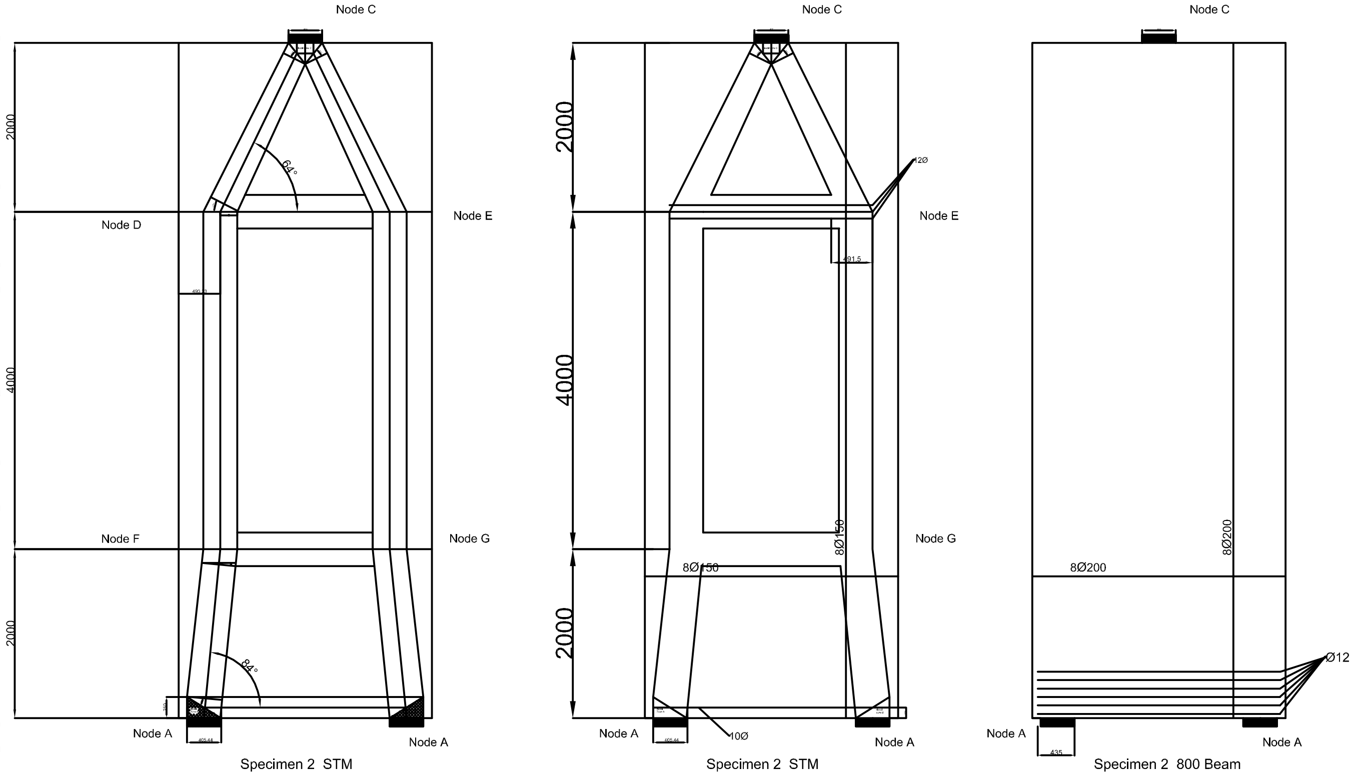

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Annex 1

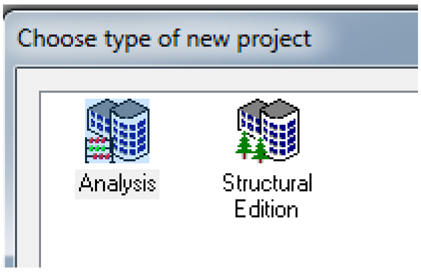
Practical design with

Scia Engineer version 2011

Step by step

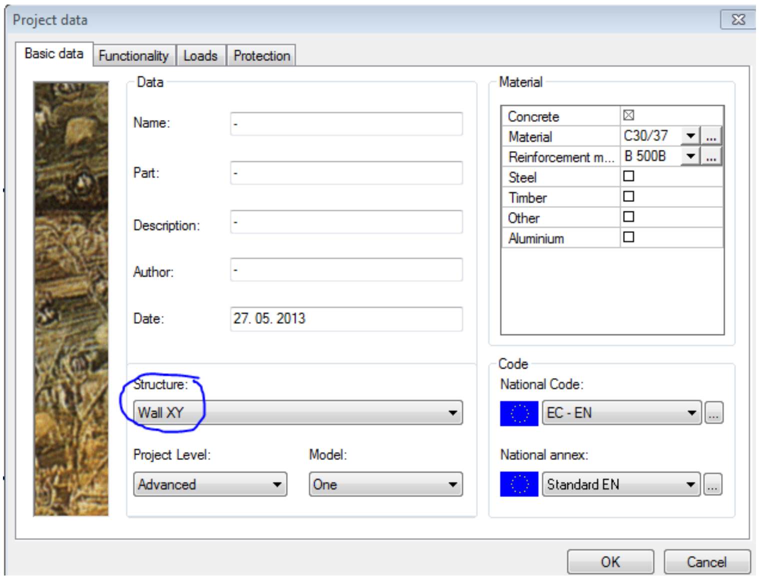
SLENDER BEAM general

1- Type of new project,
After opening the program menu pop up which asks user to define the type of project which is going to be used.(or File→new) Considering that in this thesis the focus is to run analysis about different elements of structure, the type of project is considered as Analysis.



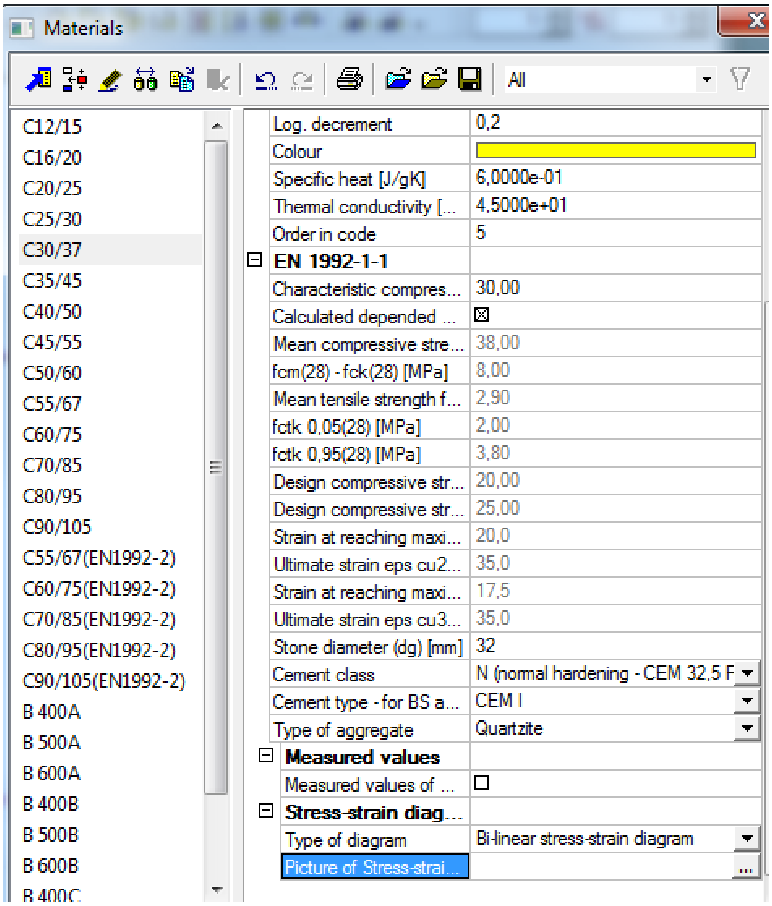
2- After defining type of project, the “project data” menu pops out. Under the tab “basic data” Material properties can be filled according to chapter 3 of this thesis. This can also be done during the modeling phase. For modeling of slender beam the following option is chosen.

- Structure→Wall XY



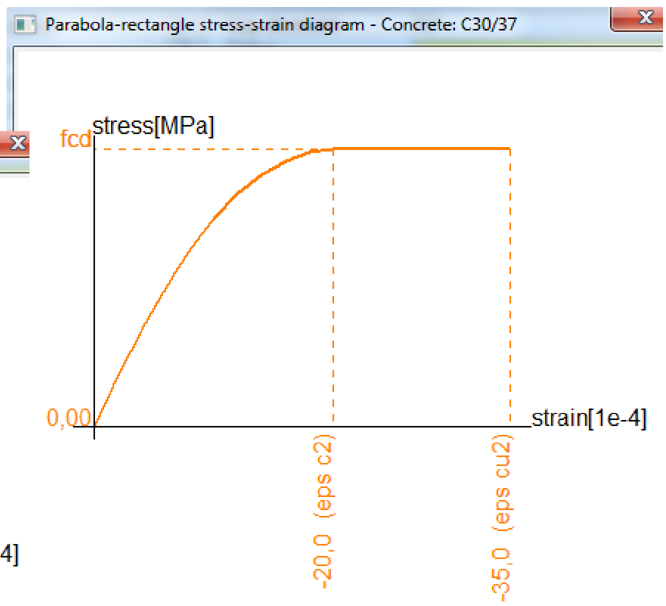
Note: Leave, for now, the rest of the tabs In “project data” menu, as standard values which is given by program.

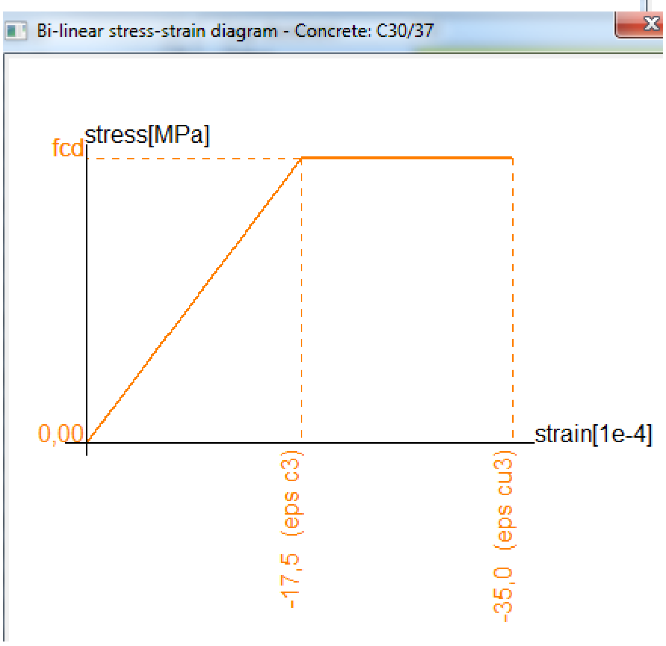
Note: In SCIA engineering (Linear finite element program), in the material properties of C30/37 the concrete quality which is chosen in this thesis, under type of diagram there are 2 possible choices:



Parabola rectangle stress-strain diagram (NEN-EN 1992-1-1 :2011 art. 3.1.7 (1)).

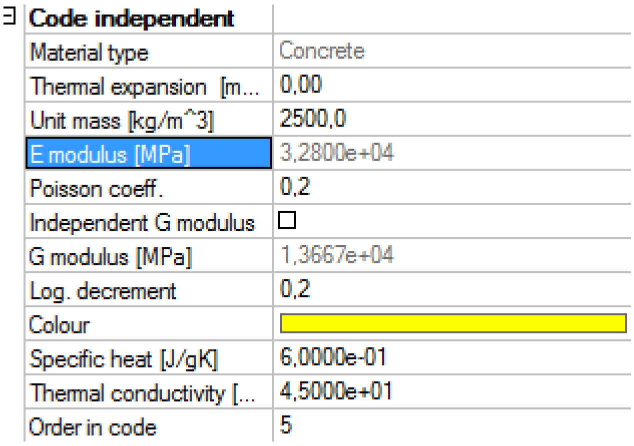
By clicking on the “picture of stress-strain diagram” user can see the diagram itself





1- **Bi- Linear stress strain diagram (this is chosen in this Thesis) (NEN-EN 1992-1-1 :2011 art. 3.1.7 (2)).**

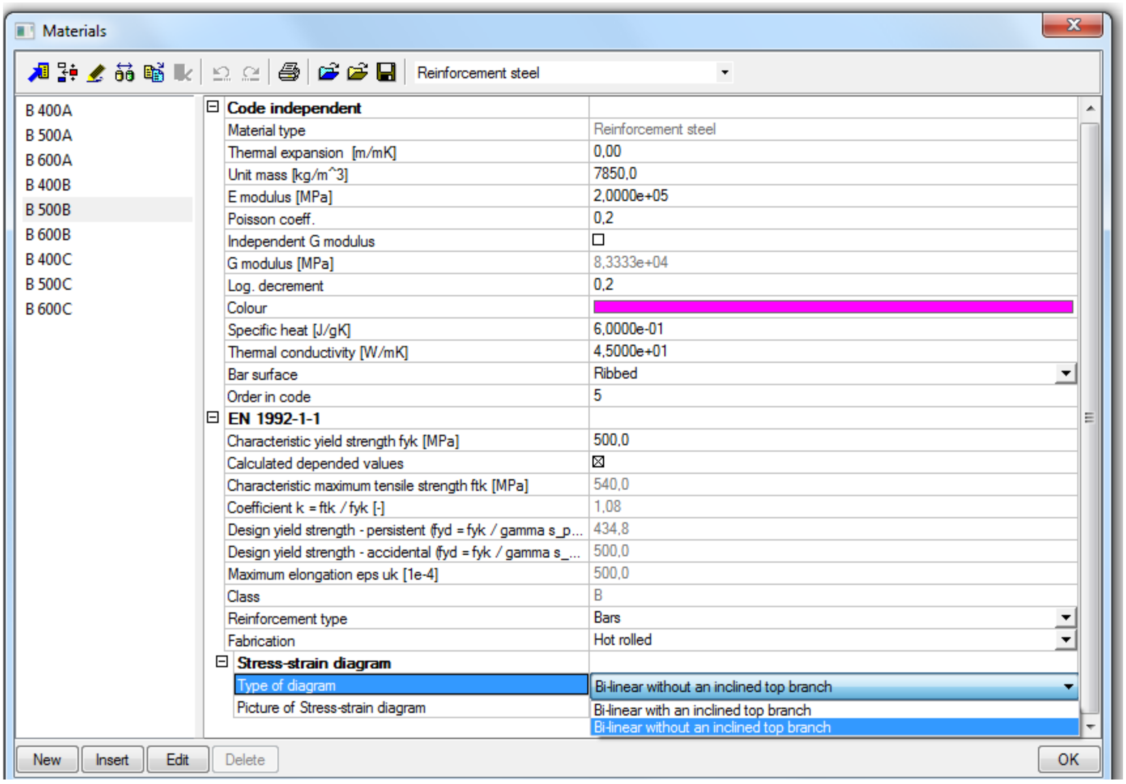
Note 2: concrete properties:



Code independent	
Material type	Concrete
Thermal expansion [m...	0,00
Unit mass [kg/m^3]	2500,0
E modulus [MPa]	3,2800e+04
Poisson coeff.	0,2
Independent G modulus	☐
G modulus [MPa]	1,3667e+04
Log. decrement	0,2
Colour	
Specific heat [J/gK]	6,0000e-01
Thermal conductivity [...	4,5000e+01
Order in code	5

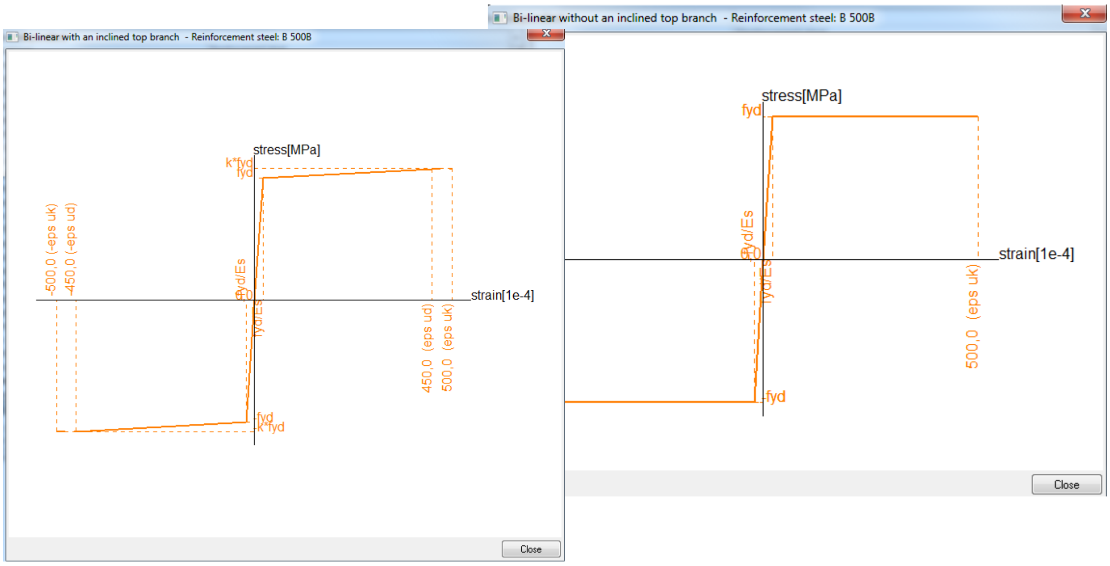
note 3:

Reinforcement properties



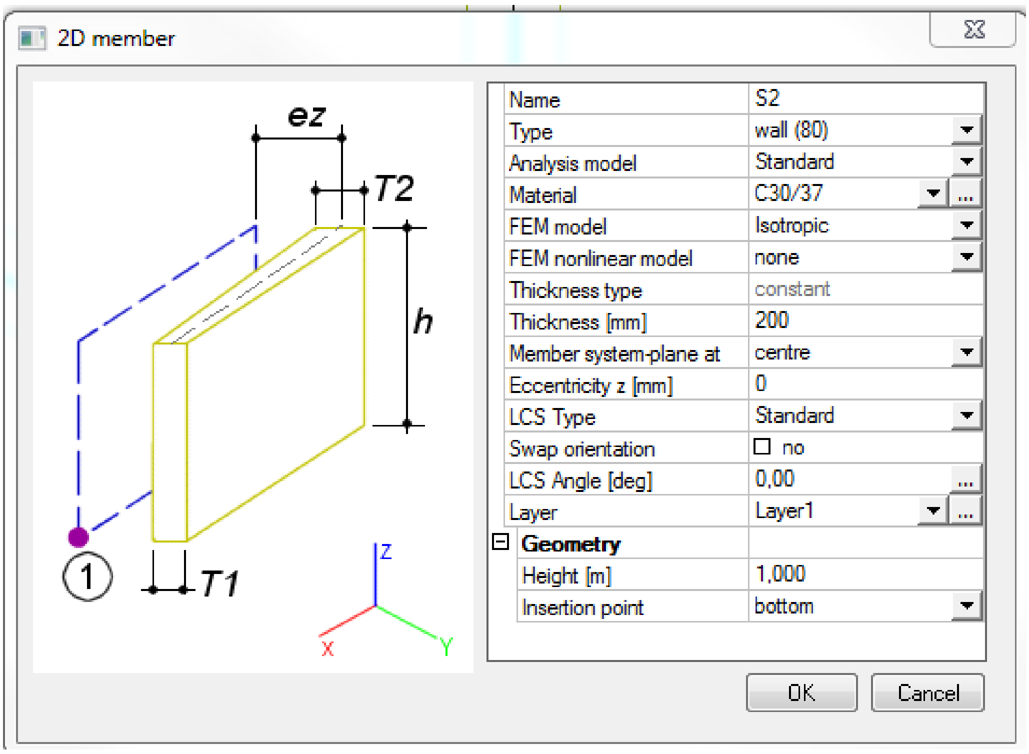
Code independent	
Material type	Reinforcement steel
Thermal expansion [m/mK]	0,00
Unit mass [kg/m^3]	7850,0
E modulus [MPa]	2,0000e+05
Poisson coeff.	0,2
Independent G modulus	☐
G modulus [MPa]	8,3333e+04
Log. decrement	0,2
Colour	
Specific heat [J/gK]	6,0000e-01
Thermal conductivity [W/mK]	4,5000e+01
Bar surface	Ribbed
Order in code	5
EN 1992-1-1	
Characteristic yield strength fyk [MPa]	500,0
Calculated depended values	☒
Characteristic maximum tensile strength ftk [MPa]	540,0
Coefficient k = ftk / fyk [-]	1,08
Design yield strength - persistent (fyd = fyk / gamma s_p...	434,8
Design yield strength - accidental (fyd = fyk / gamma s_...	500,0
Maximum elongation eps uk [1e-4]	500,0
Class	B
Reinforcement type	Bars
Fabrication	Hot rolled
Stress-strain diagram	
Type of diagram	Bi-linear without an inclined top branch
Picture of Stress-strain diagram	Bi-linear with an inclined top branch Bi-linear without an inclined top branch

In the stress-strain diagram there are two choices which according to chapter 3 can be chosen.



3- Specimens Can be modeled in Scia by using 2D wall member (from step 2) or (2D shell element). According to chapter 3 to find reinforcement configurations membrane stress field can be used, which is equally recognized as 2D wall elements (XY) in Scia.

4-after choosing 2D Member wall from left menu, (or from top menu Tree→wall), 2D member menu pops up. The chosen values are as following:



FEM model: In slender normal beams assumption of linear isotropic material is valid.

Thickness: 200 mm is basic assumption for slender beams (it is 250 mm for deep beam specimens)

Eccentricity: Not taken into account in this thesis.

Height: slender specimens have the height of 1m.

5-For ease of drawing the user might turn on the “dot grid” from bottom menu

6- Now by using mouse we can draw a line (wall) with length of 4 m as specimen’s span.

7- supports:

- According to the thesis, a free distance of 100 mm is applied between free edge of the beams and the beginning of the support reaction.
- According to thesis the supports can be flexible or rigid support with springs.

Var1 rigid flexible supports ((structure type from step 2 is Wall XY))

Line support on 2D member edge (1)

Name	Sle1
X	Free
Y	Rigid
Rz	Free
2D member	S1
Geometry	
System	GCS
Edge	1
Position x1 [m]	0,100
Position x2 [m]	0,200
Coord. definition	Abso
Origin	From start

Line support on 2D member edge (1)

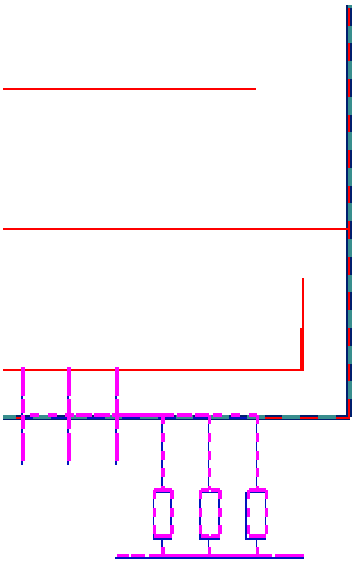
Name	Sle2
X	Rigid
Y	Rigid
Rz	Free
2D member	S1
Geometry	
System	GCS
Edge	1
Position x1 [m]	3,800
Position x2 [m]	3,900
Coord. definition	Abso
Origin	From start

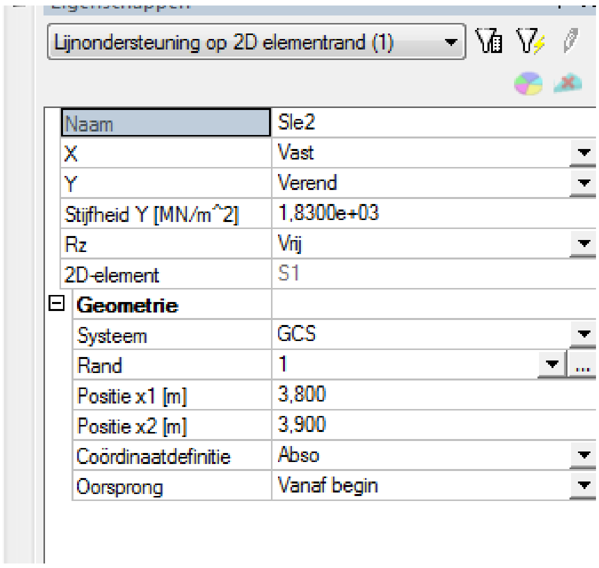
VAR 2 Flexible support (Spring)

In Scia: Main menu in the left hand side→structure→model data→support→line on 2D member edge

As it is already calculated in chapter 3 of thesis the axial stiffness can be filled in the related direction.

To get more realistic results is important to use free movement in the horizontal direction for one of the supports, right or left.

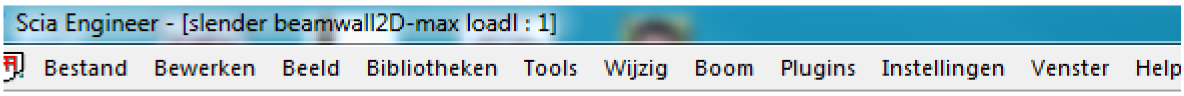


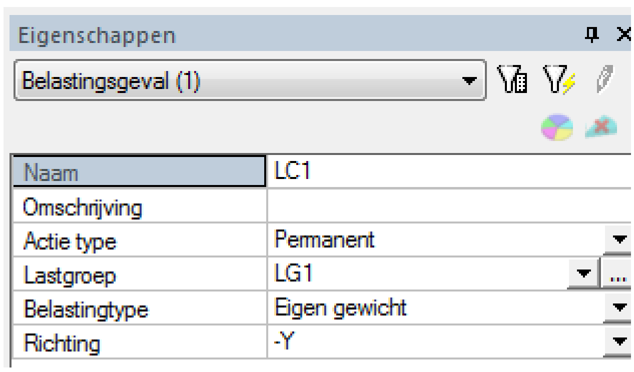


7-Loads:

To define loads in this thesis the following steps is used:

Tree tab in the main tabs top→loads→here the first self-load is defined pay attention to the properties of the self-weight in the right menu.

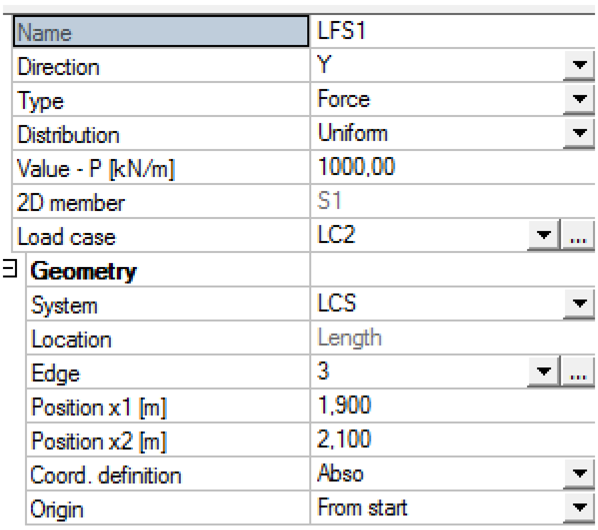


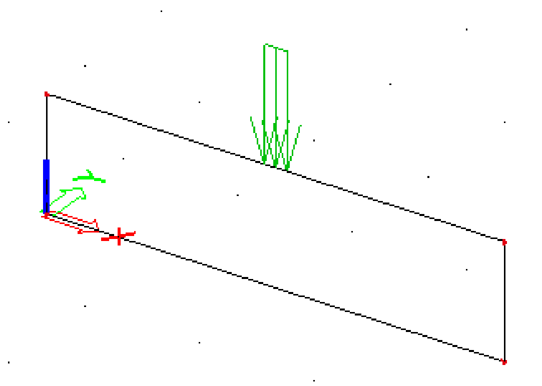


Top menu →Tree→load combinations→load combinations→here choose "new", and then choose a name and type. Note that the type should be "permanent".

Now is the time for introducing the permanent load,

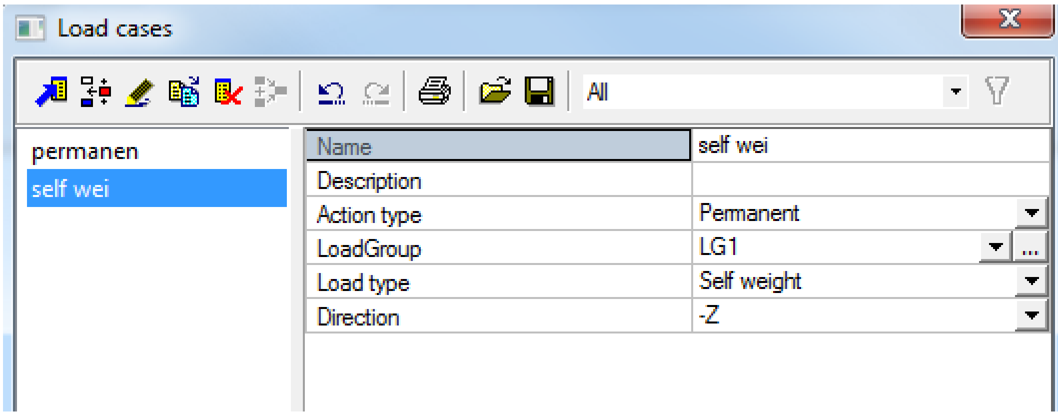
Main menu→Load→on 2D member edge→attention to the properties of the load



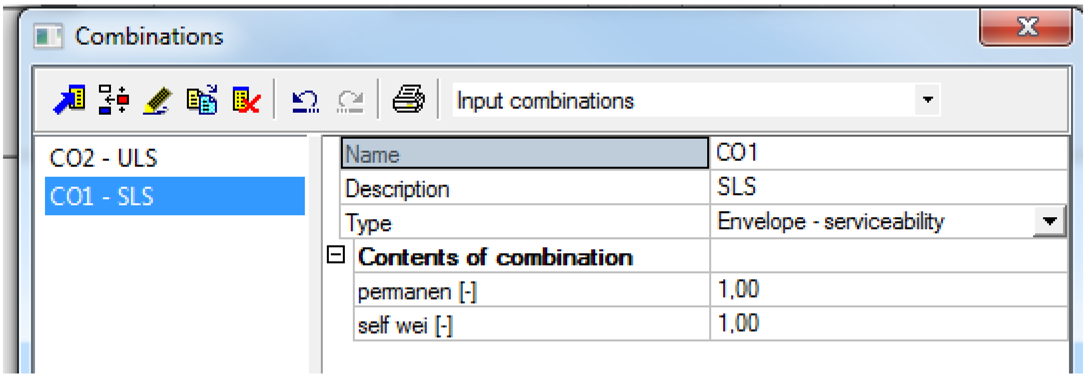


8-Definition of load cases in Scia:

After defining the loads the next step in Scia is to define the load cases. We have only self-weight and permanent load.
Main Menu left side→load cases, combination→load cases



9-definition of load combinations, according to thesis User can fill the combination chart in Scia. Main menu left side→load cases , combinations→combinations



6-Mesh size: from top menu, setup and then mesh. One of the important sources of errors is size of elements. To find the best size for mesh elements, convergence study can be done.

There are different convergence studies which can be done. In the following one convergence study which is used in this thesis will be explained:

Step1- makes the model with supports
Step2- apply the load on the specimen

Step3-assume a size for mesh (let's say 1 m)
Setup menu above→mesh→average size of 2D element/curved element

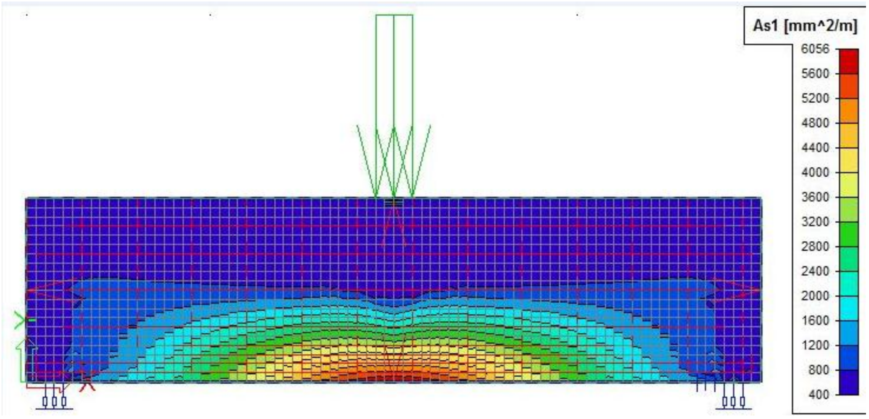
Step4- run the calculation in Scia
Step5- look at the flow stresses or forces in the specimens

Results from left menu→member 2D stresses or member 2D internal forces

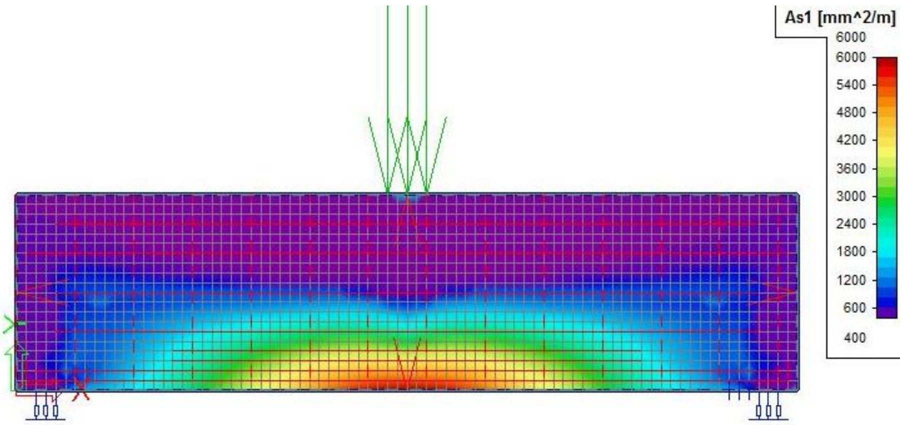
Property menu from right hand side→location (here there are 4 possibilities which 2 of them is needed for determination of best mesh size)
-in nodes, avg (average)
-in nodes, no avg(no average)

Step 6- compare above mentioned possibilities(in nodes ,avg and in nodes, no avg) if they are approximately exact similar to each other the mesh size which is assumed in step 3 is a good mesh size otherwise go to step 2 and choose smaller mesh size and do the steps 2 till 6.

Note-after convergence test in this thesis, the size of mesh is 50 mm is chosen.

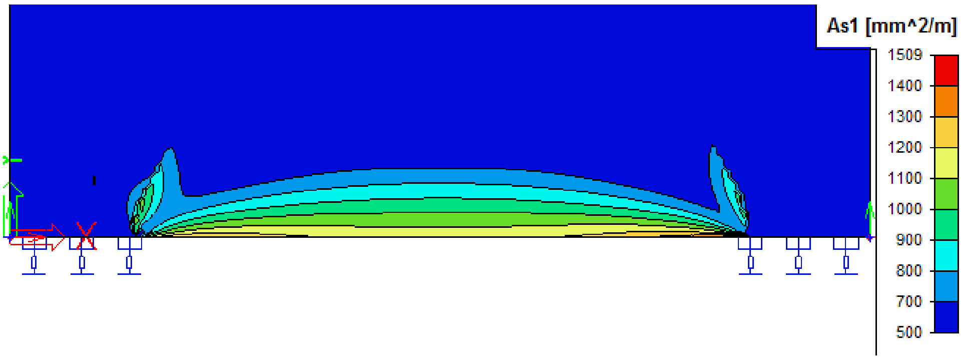


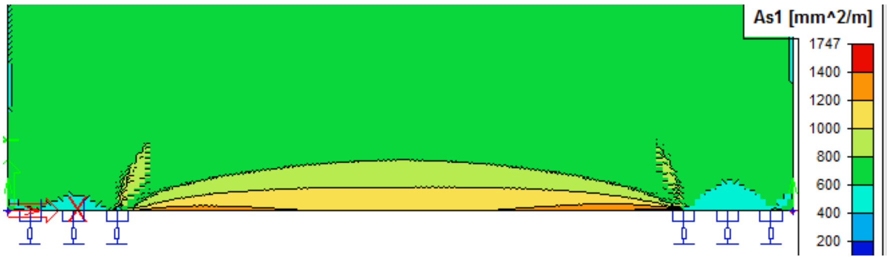
nodes without average



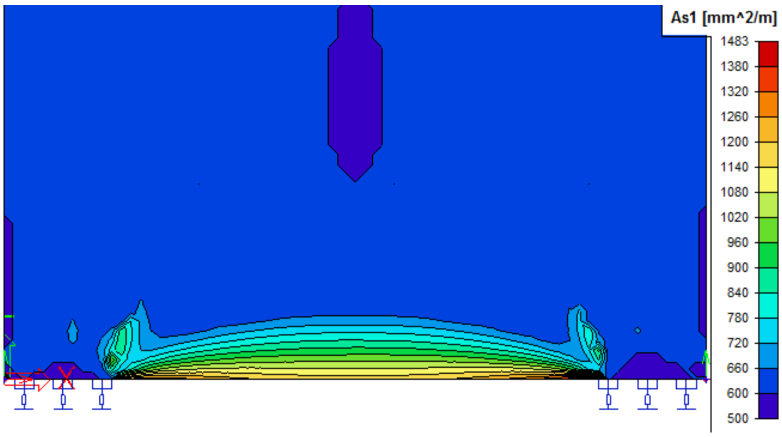
nodes with average

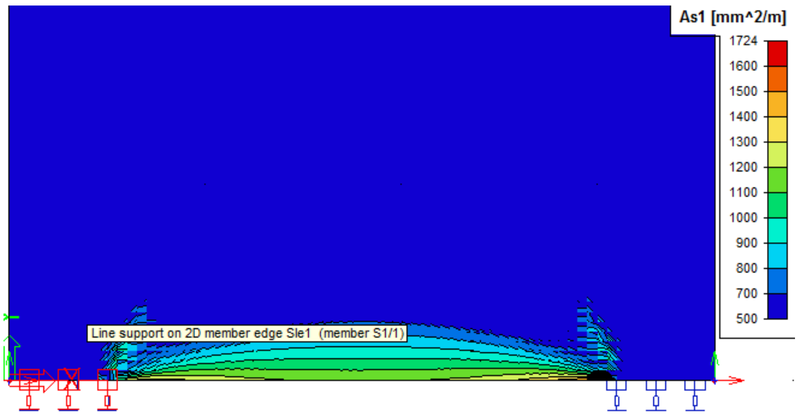
Mesh 25 with avg



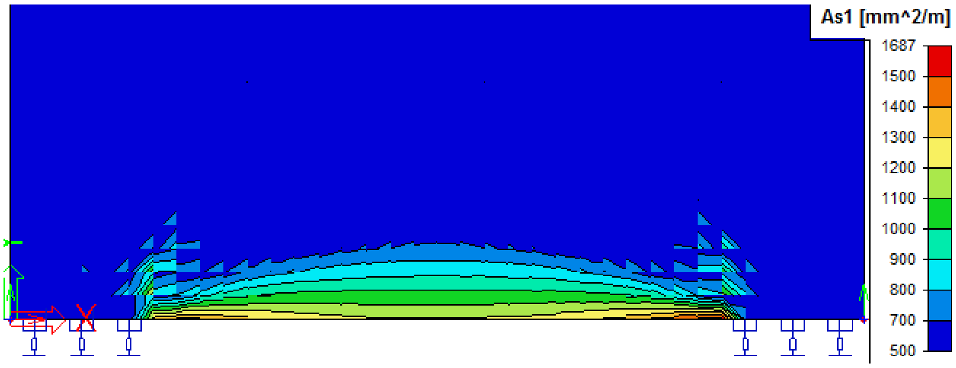


Mesh 50

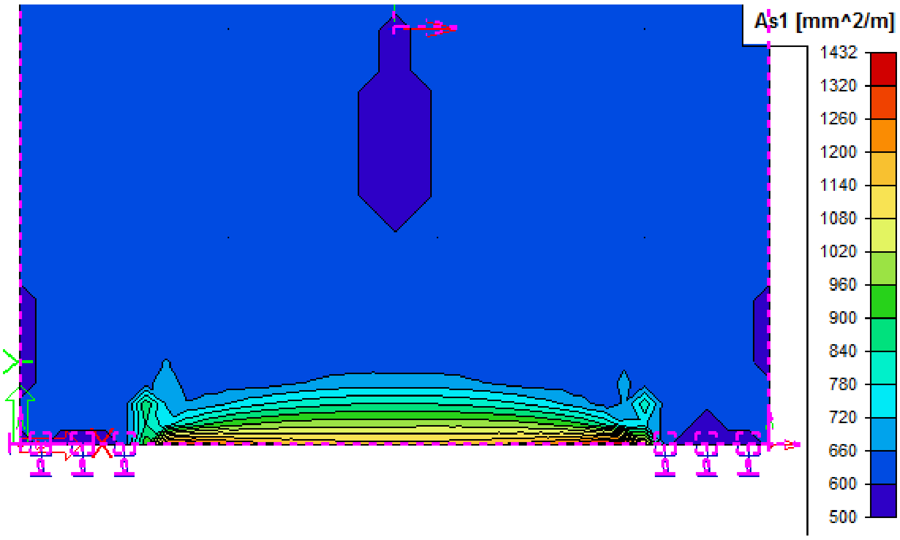




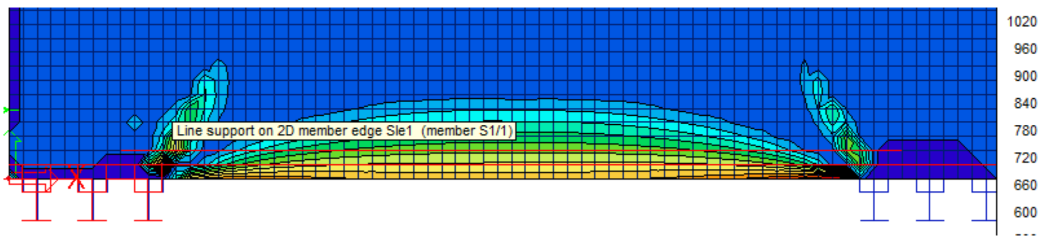
Mesh 100 mm with no avg



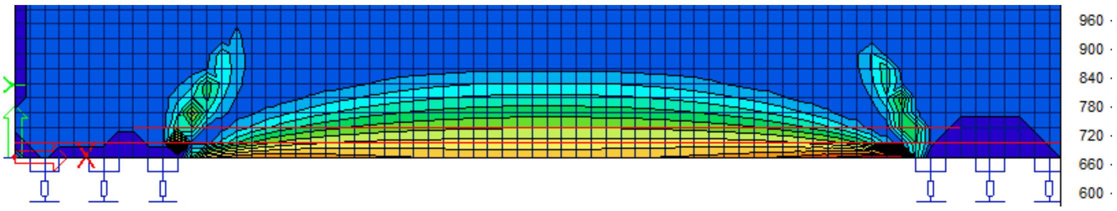
Mesh 100 with avg



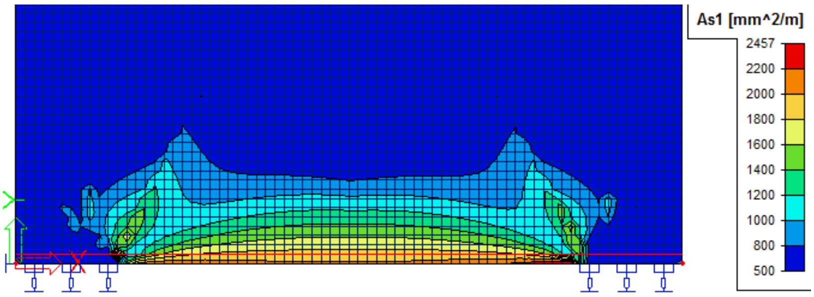
Rigid



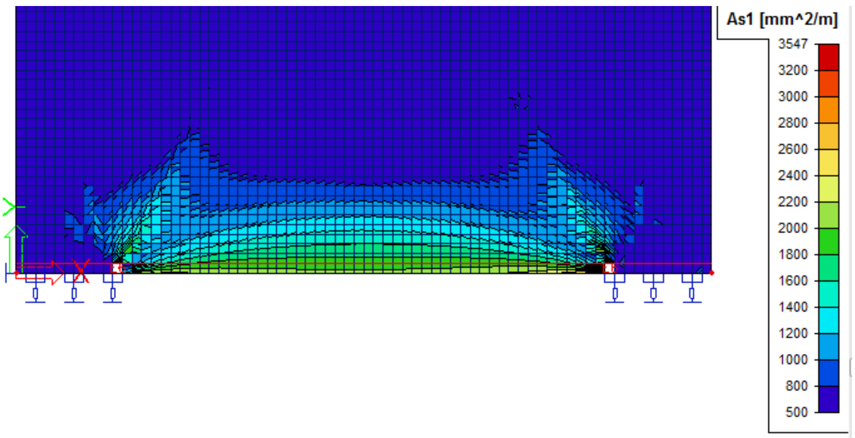
Ver



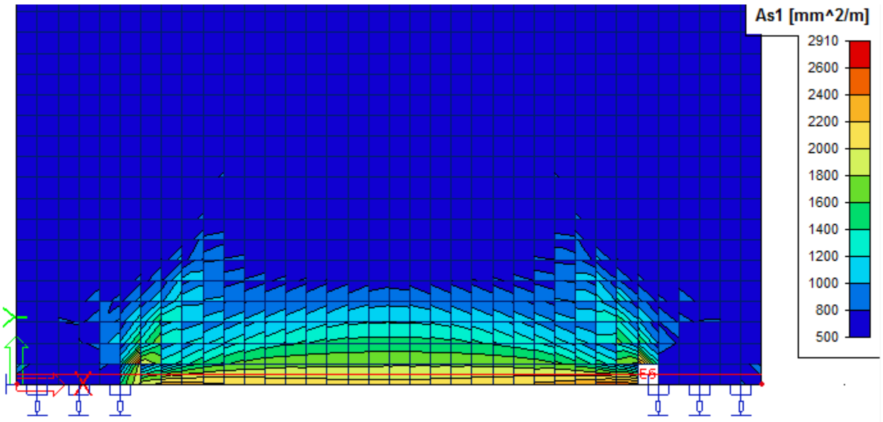
1500 kn

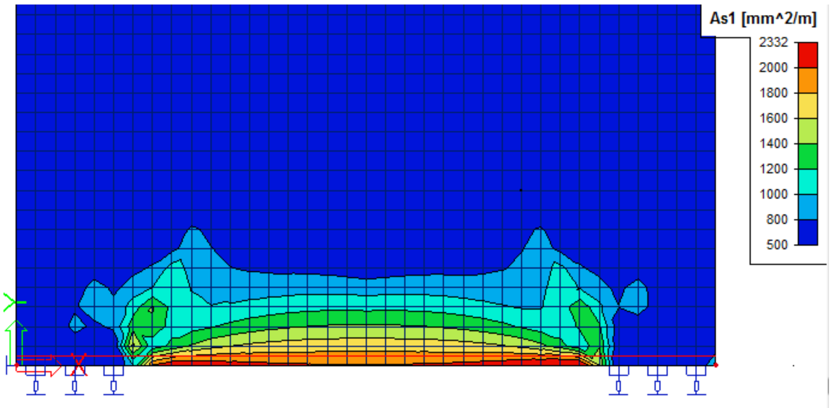


No avg



Mesh 100

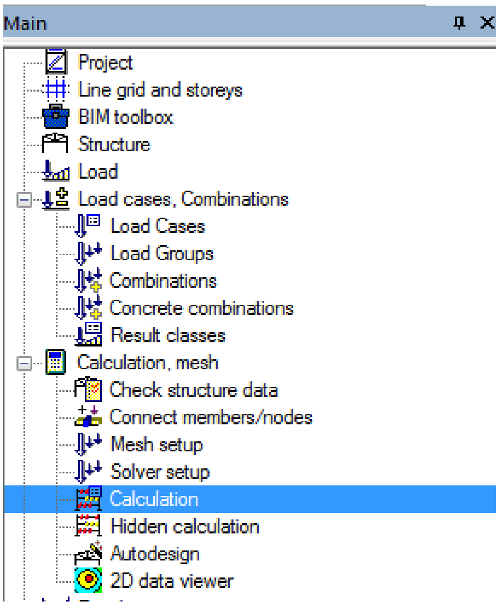




7- Calculations

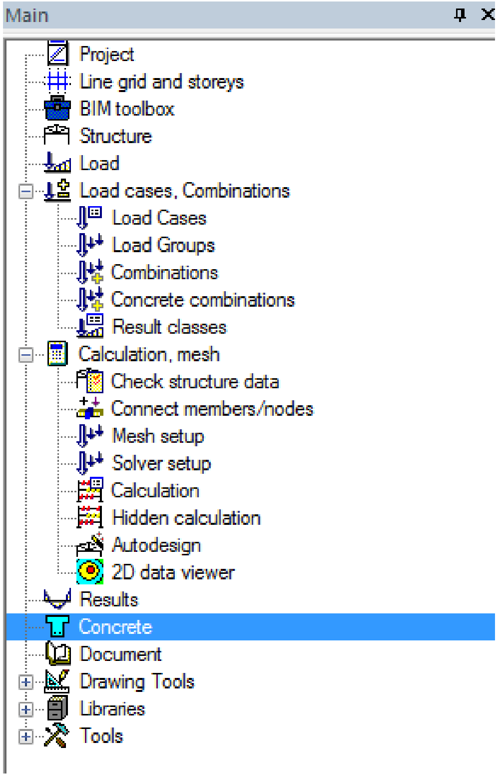
To see the resulting reinforcements:

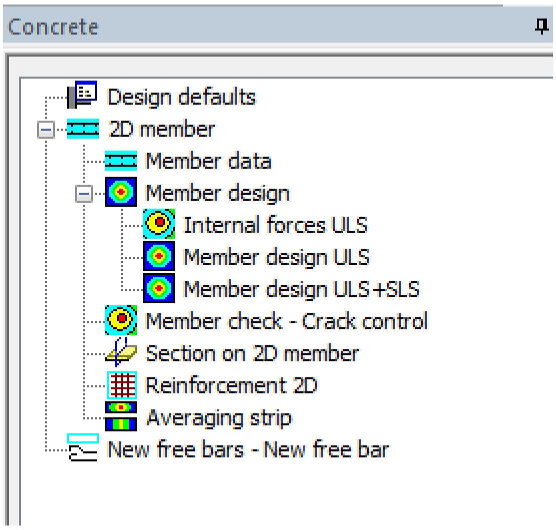
Main menu in the left→calculations, mesh→calculations



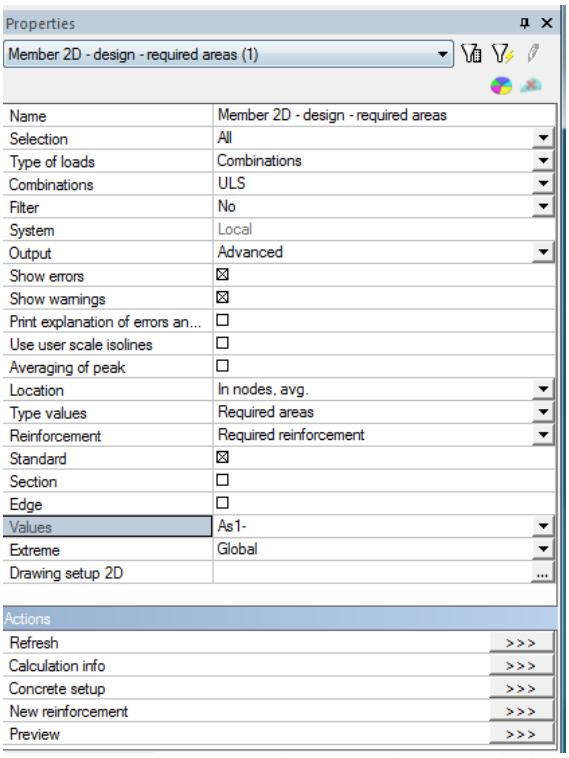
8-reinforcment design by Scia

Main menu on the left side→concrete→Member design in ULS



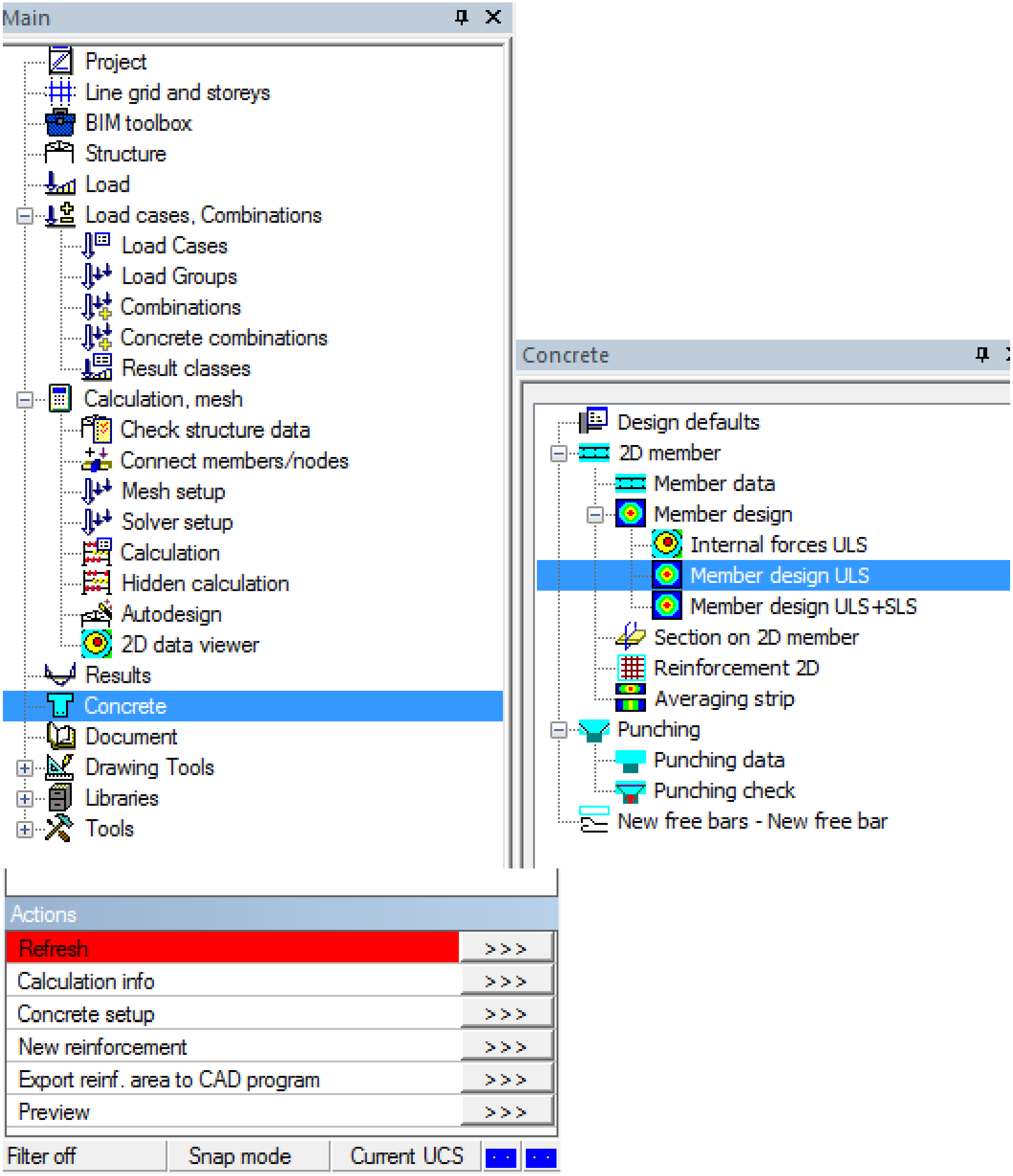


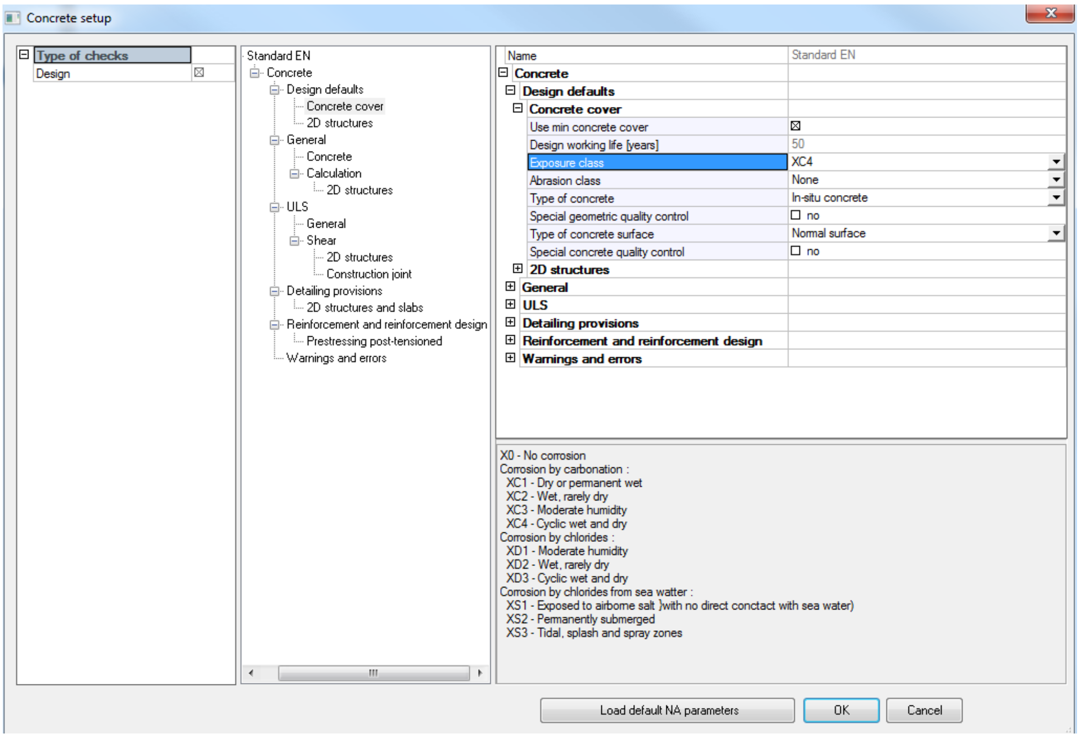
In the properties menu on the right hand side, the user have to choose some properties for the desired reinforcement, pushing Refresh button in the bottom of the properties menu the amount of reinforcements would be calculated by SCIA.



9-

IMPORTANT: After calculation step (running the calculation), user can also go to concrete menu on the left hand side of the Scia interface and then choose member design ULS from the left hand side menu (Actions menu) then on the right bottom of the page concrete setup can be chosen. Here user can change some properties of concrete.



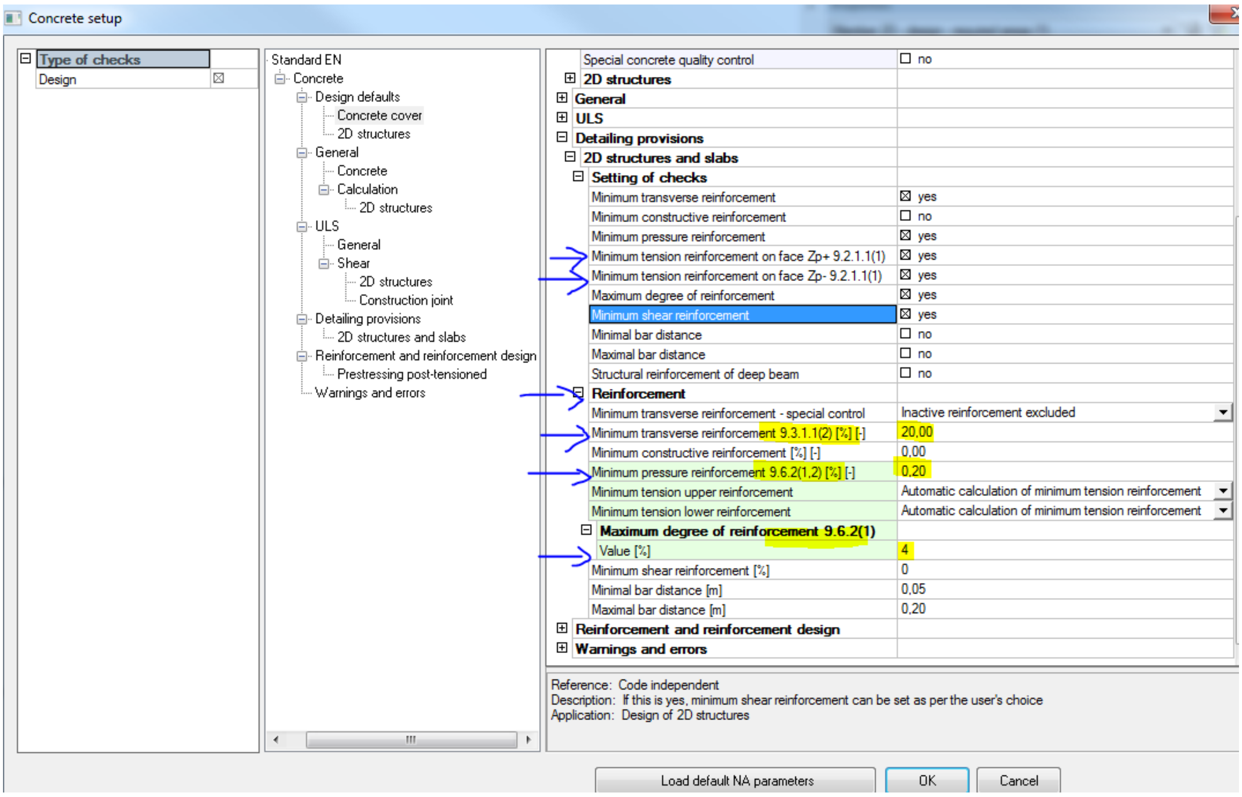


It is assumed for environmental class XC4, is an appropriate choice. The definition also is given by Scia in the above figure.

10-

Default reinforcement in SCIA,

In the same menu of step 9, user can see the default values of Scia engineering which is based on Eurocode art. Concrete setup→detailing provisions→2D structural and slabs→reinforcement

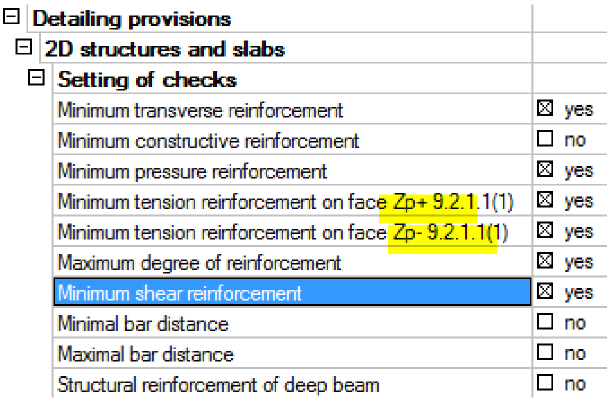


11-

Default reinforcement checks

In the same menu as in step 10.

Detailing provisions→2D structural and slabs→setting of checks

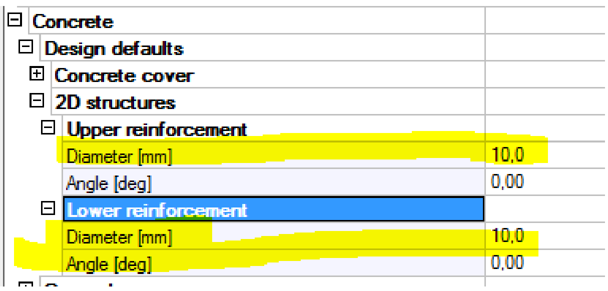


This is important because here the user can see that SCIA does reinforcement checks base on NEN-EN 1992-1-1 9.2.1.1(1) which is actually for Minimum and maximum reinforcement areas for the beam elements.

Note: although Scia in 2D design procedure, for minimum required reinforcements, uses some articles of the Eurocode which is correspond to walls or solid slabs, but it is essential to know for reinforcement checks, SCIA make use of art. 9.2.1.1(1) which is for normal slender beams.

12-

Default reinforcement dimensions



13-

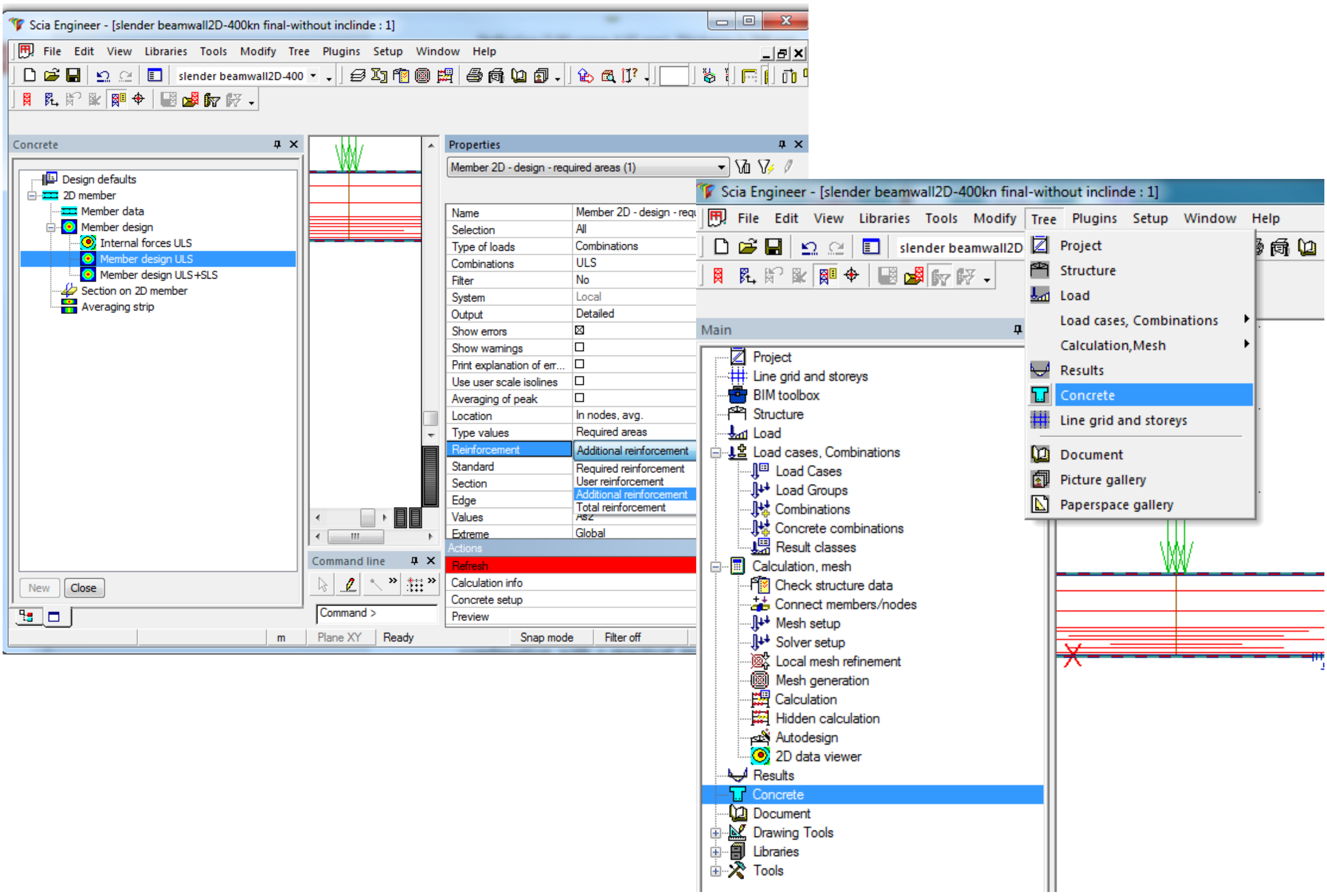
Putting reinforcement As1 into the 2D specimen

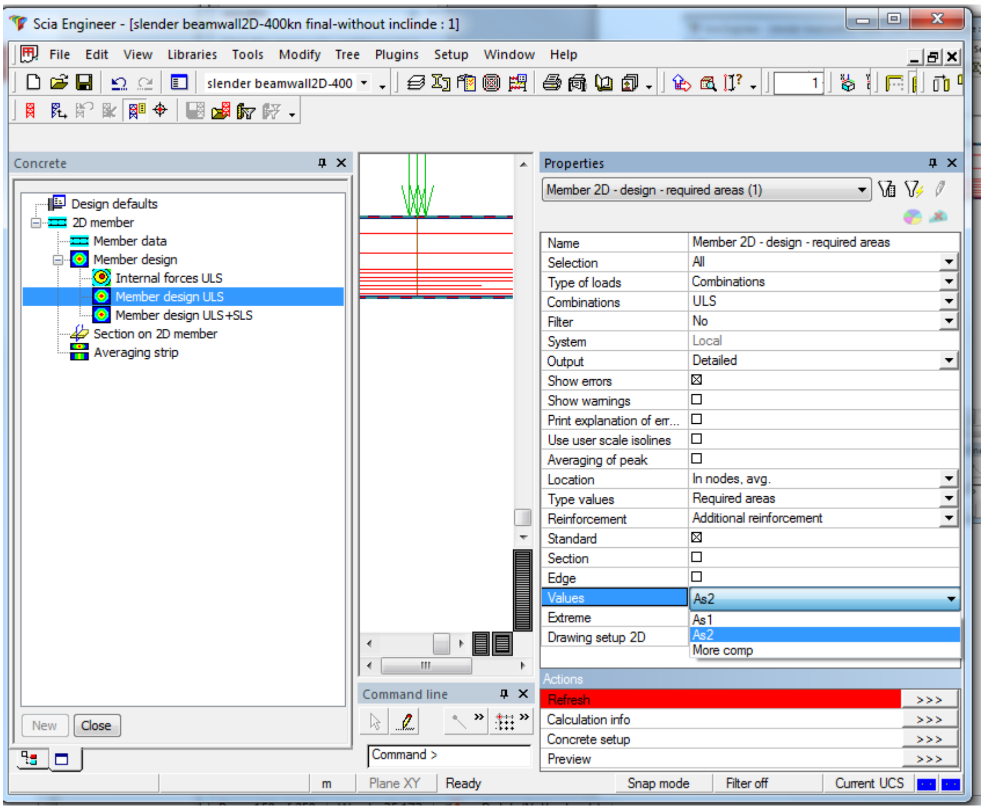
There are two main methods which a user can use the required amount of reinforcement which is calculated by Scia to reinforce the element

- **First method which also is used in Mr. Roman work .The steps are as following:**

Step 1-
After calculation step which is explained before, Scia gives us in the concrete menu the possibilities to see:

Concrete menu→member design ULS→then from property menu user can specify which calculation Scia has to perform.

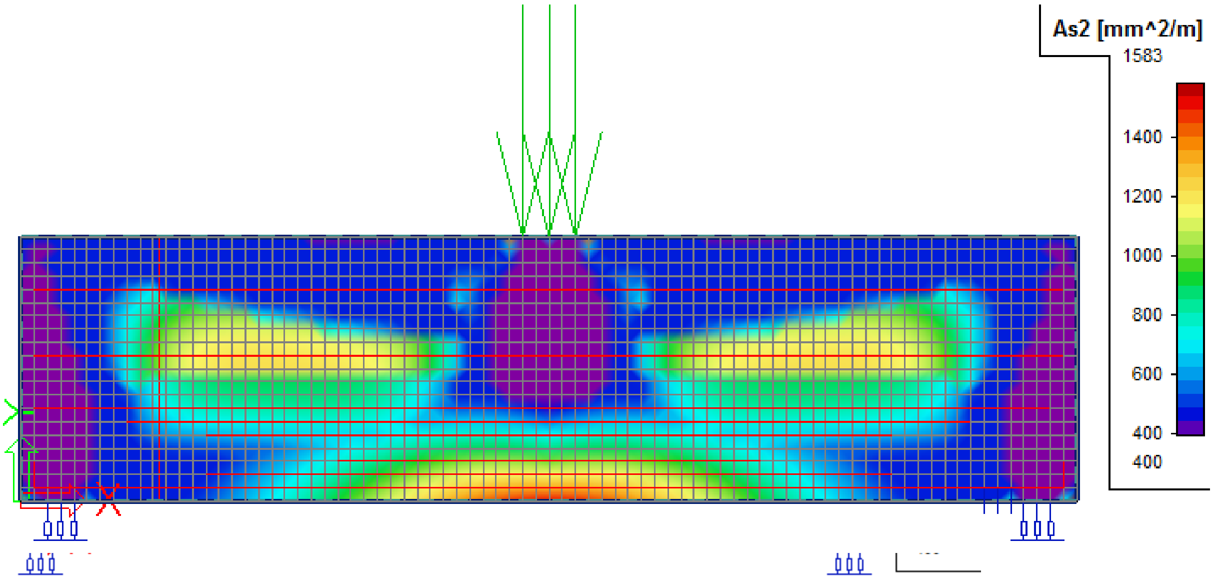




-required amount of reinforcement

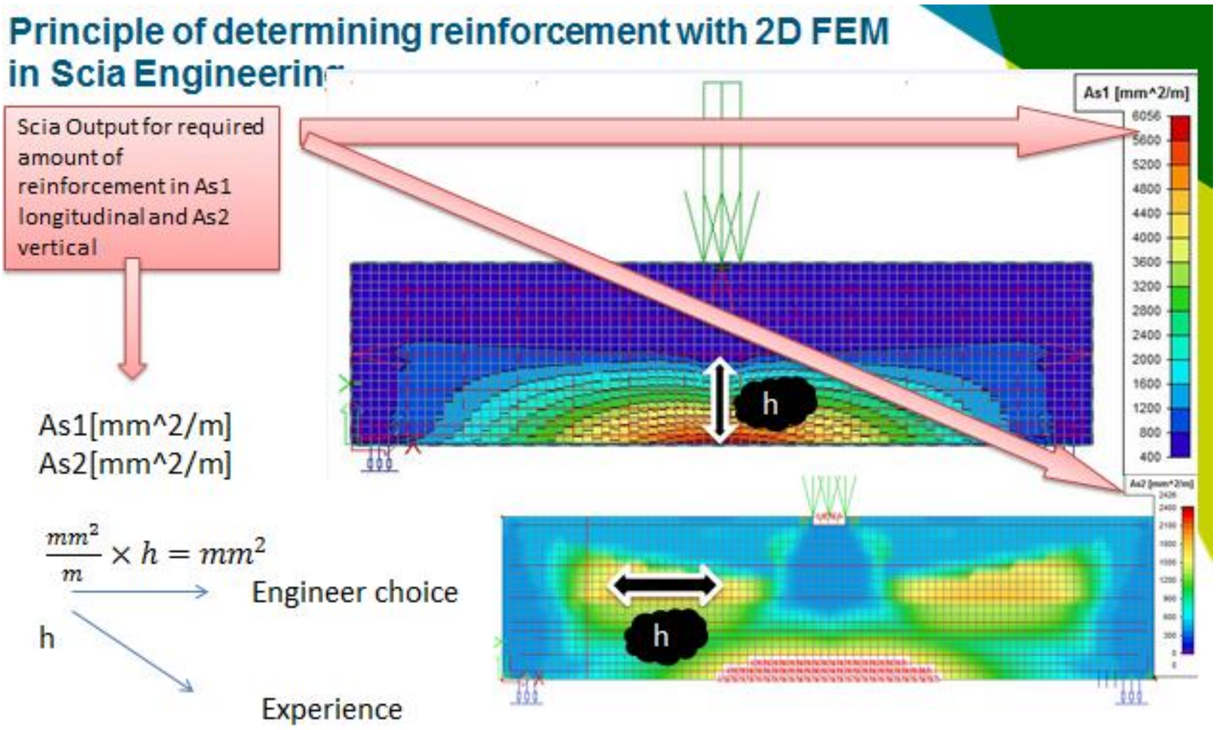
-additional amount of reinforcement (this option is required after putting reinforcement bars)

-Scia calculate above reinforcements in 2 longitudinal As1 and transversal As2 (shear).



Step 2-

With the help of colors one can calculate the amount of reinforcement in mm^2. For As1, the required amount of reinforcement in mm^2/m needs to be multiplied by the height of the considering area. So depend on the mesh size, one should sum the height of the meshes in one color or more colors and using the mean value of them. Example:



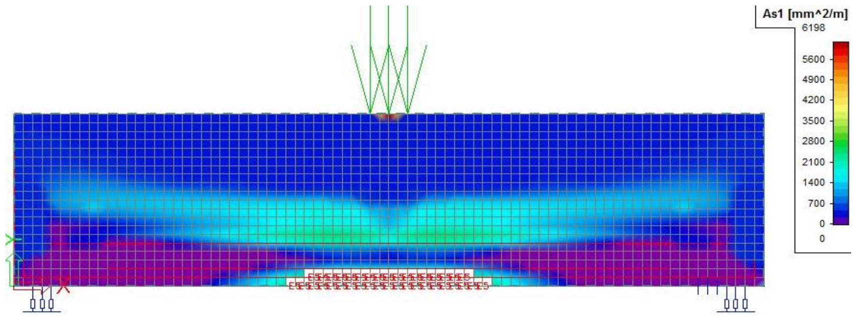
Step 3-

After finding the diameters of the reinforcement bars from previous step , one should follow the following steps to put the longitudinal reinforcement:

- **Concrete menu→longitudinal reinforcement**
- **Note that longitudinal reinforcement does not have to continue till the end , it depend on the colors(required amount of reinforcement)**

Step 4-

By now user has put the reinforcement bars into the specimen, now is the time to use “additional reinforcement” option, to find out if the amount if specimen doesn’t need any extra reinforcing bars



Concrete menu→design in ULS→from right menu choose option "additional reinforcement" from property menu→ click on the refresh button , in the bottom of the property menu, to let Scia calculate and check.

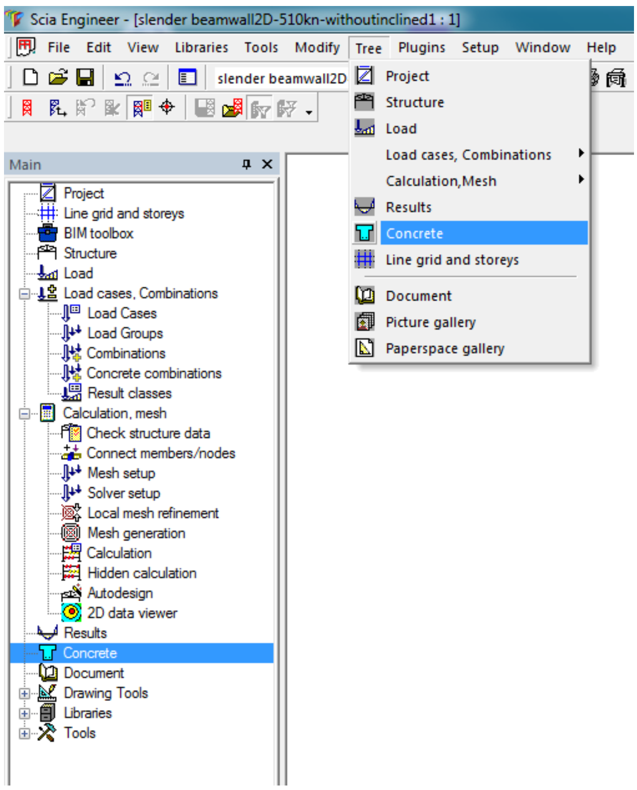
Note: If Scia require more reinforcement (like figure above) in some areas. User has to do the step 2 again, or change the places of reinforcement bars to be able to efficiently reinforcing the elements.

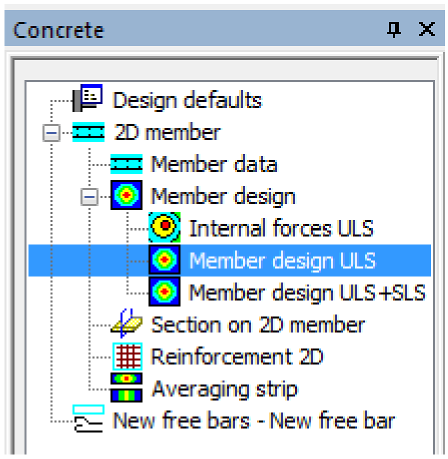
Putting shear reinforcements or As2 in the 2D element

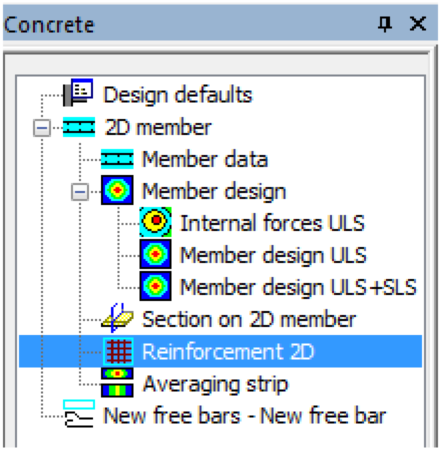
These steps should be followed after putting longitudinal (As1) reinforcements.

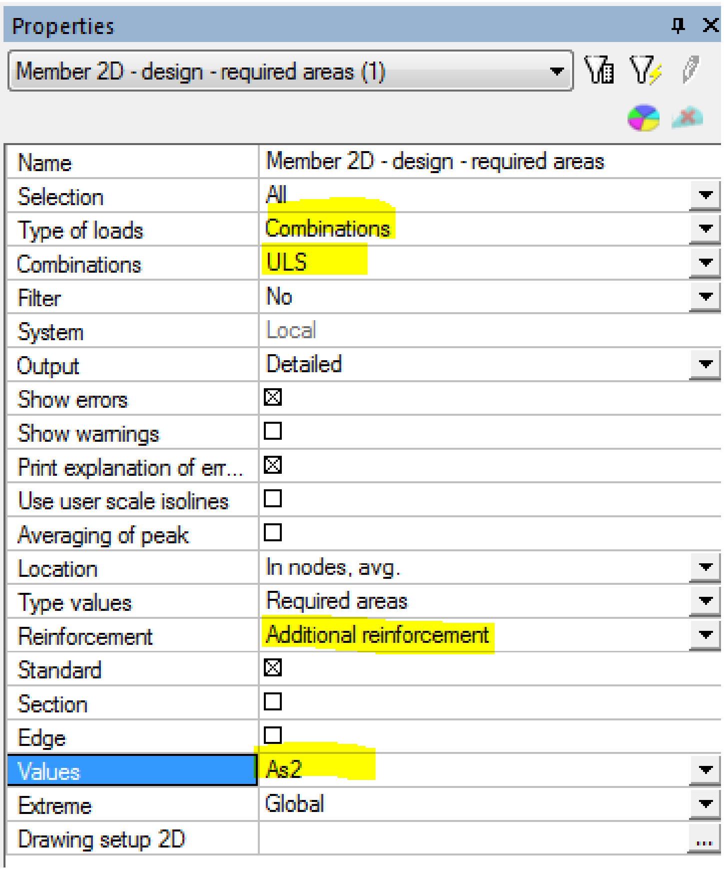
step1

concrete menu→member design ULS→from property menu on the right hand side one can choose the desired, combinations, vertical reinforcements(As2) and for additional reinforcement.

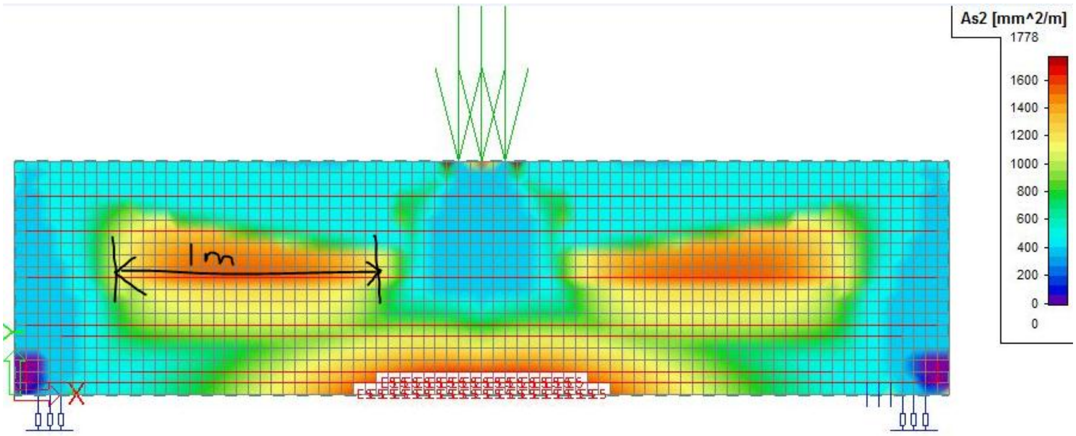






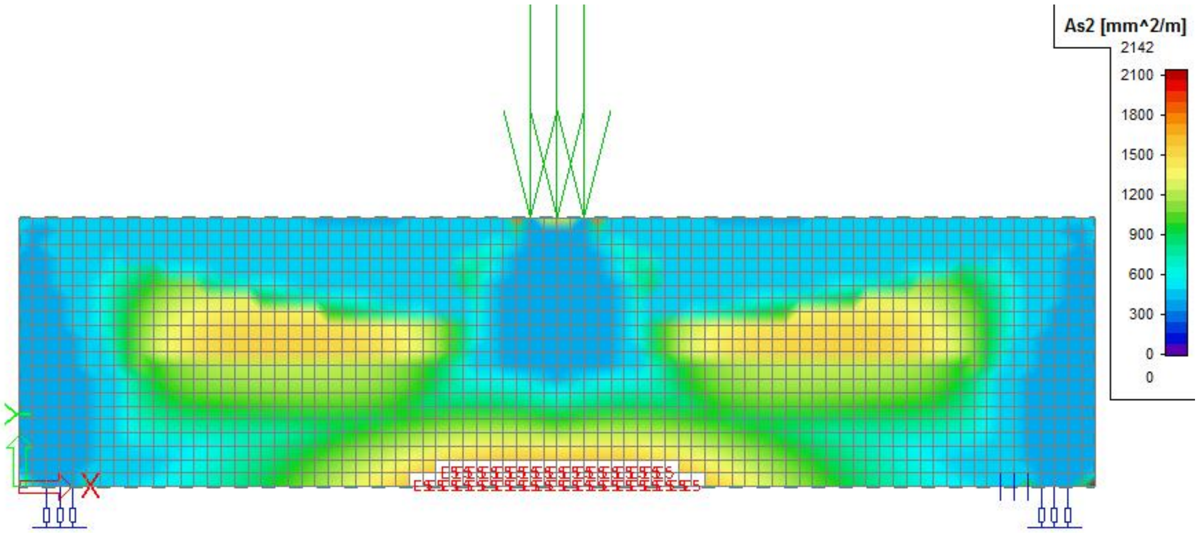


As a result of above mentioned step one can see the additional As2 (vertical, or shear reinforcement) which is needed .



As2, additional, As1 is in element, which is used for calculating shear reinforcement.(As2)

One can see the different between additional required vertical reinforcement (As2) before and after putting longitudinal reinforcements (As1).



As2, additional, As1 is not in the Element, which is not used for calculating As2

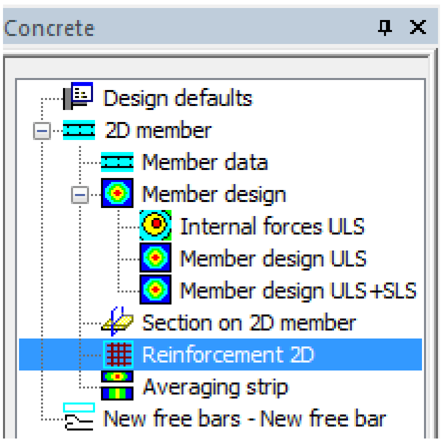
step2

In Scia Engineer 2011, there is no option for 2D elements to put stirrups in them, so it is decided to use mesh reinforcement, to simulate the shear reinforcements in the real slender beam.

for simplicity, an average length of maximum value of As2 in 1 meter can be read from figure , in this example is about 1600 mm2/m. by multiplying this amount needed additional vertical reinforcement with 1 meter length, one can get 1600mm2 needed vertical reinforcement which can be satisfied by using 20 bar 10mm in the horizontal distance of 1,0 meter.

step3

In concrete menu→reinforcement 2D



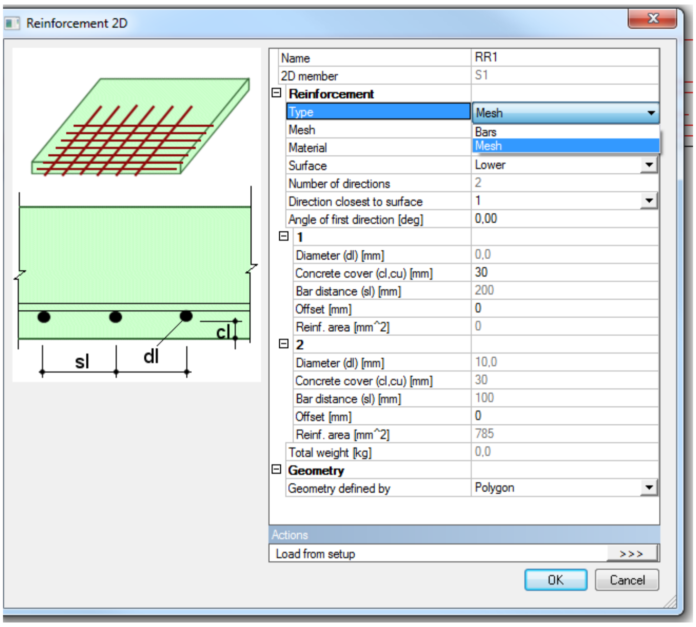
step4

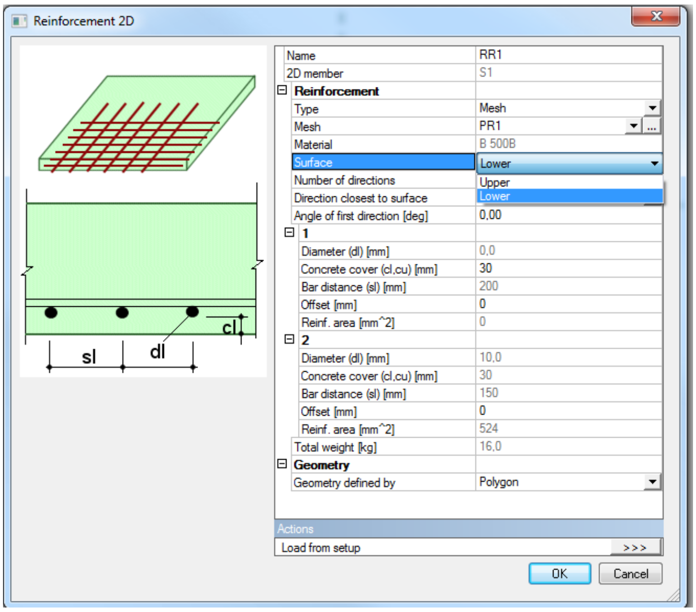
reinfrocment 2D window:

there are options which the user have to adjust them for the desired situation,

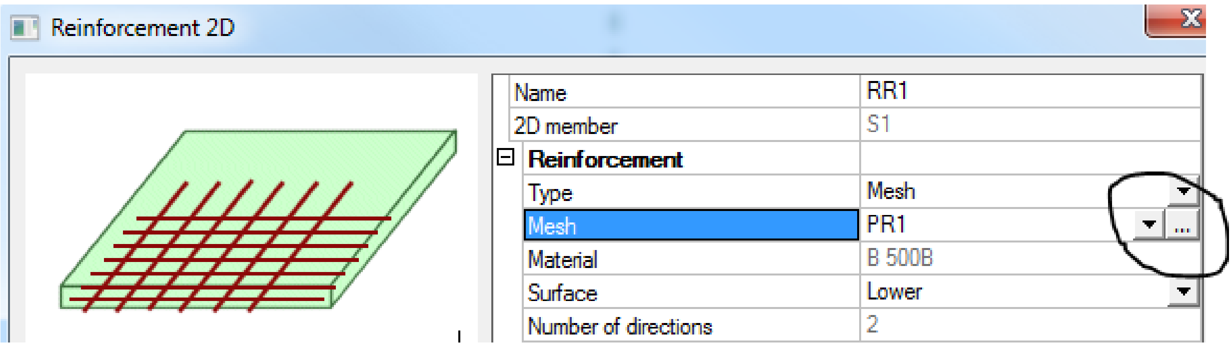
note1: bear in mind that there are lower and upper mesh reinfrocment

note2: mesh reinforcment standard actualy has vertical and horizontal reinfrocment that why is called mesh. here to be able to simulate only vertical shear reinfrocment , it is decided to put zero for the horiozontal bars , so we get only verticaal shear mesh reinfrocment.

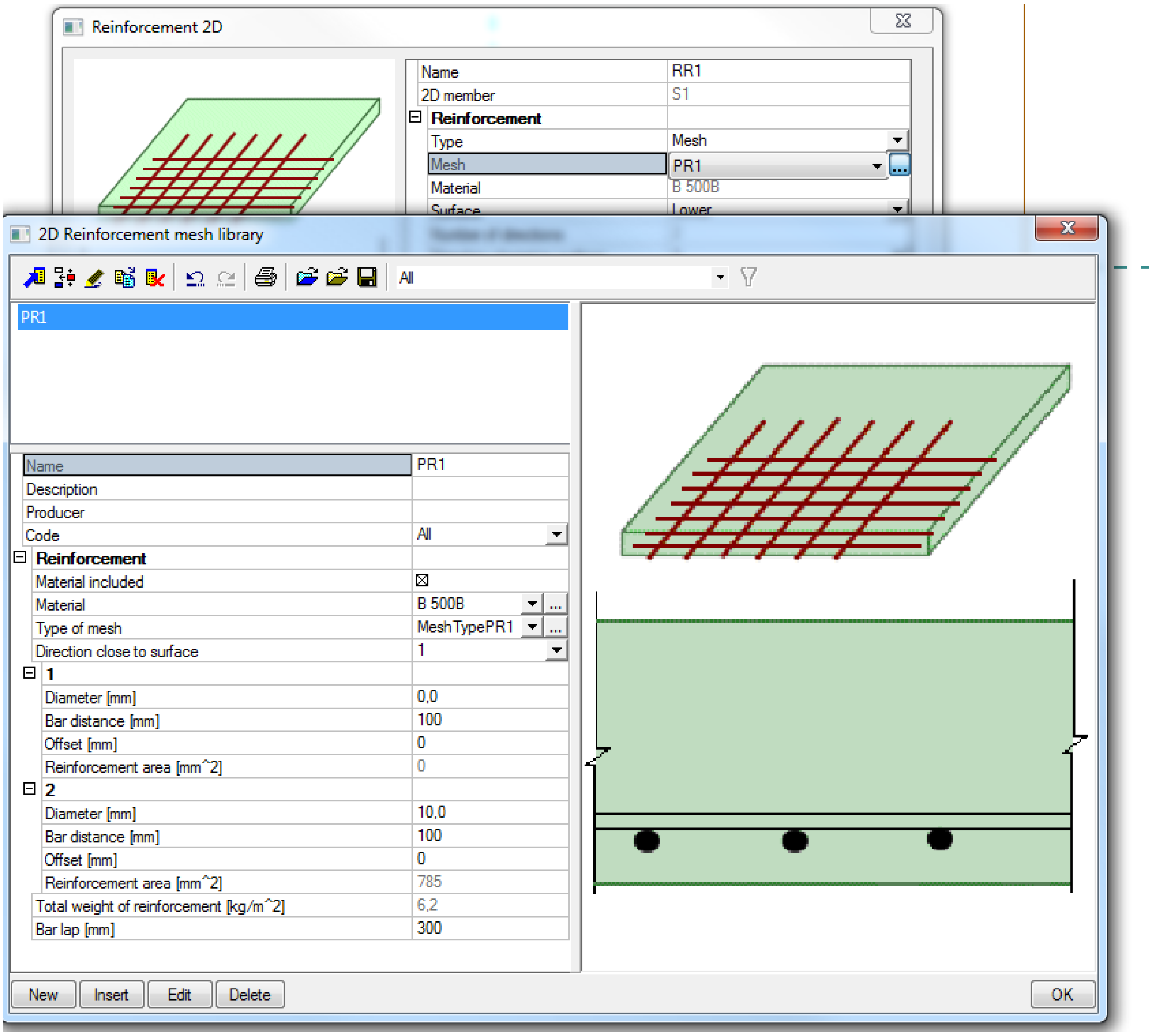




Note3: on the left side of the"mesh" option ,click on ... .the 2Dreinfrocment mesh library window pups up and the user is able to adjust all mesh configurations.



note4: one must bear in mind that there are two layers , upper and lower, which both have to be adjusted by using ... button, and 2D reinfrocment mesh library.

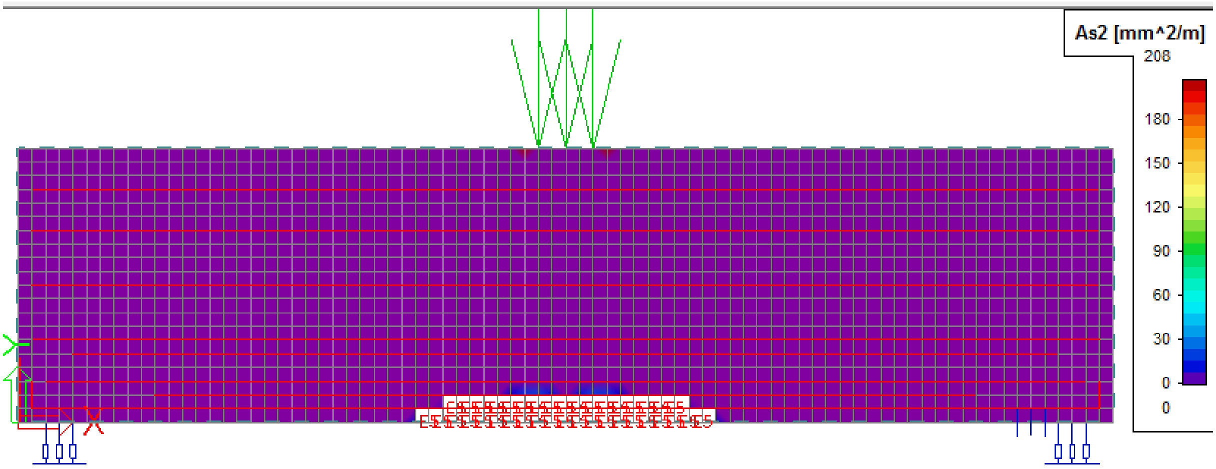


Step5

After step 4, one has to run calculation again and by using concrete menu and member design ULS, check for additional As2 reinforcement. In the bottom figure the results of the example is shown.

Note:

The additional required As2 reinforcement should be overall or almost zero.



Annex 2

Making A 1D Slender Beam model in Scia

This Annex is going to discuss the following subjects:

- **Recollection about plates**
- **Design and model 1D custom slender beam**
- **Reinforcing the element**
- **Running the all Eurocode checks**
- **Making 2D pressure only model for Nonlinear FEM in Scia Engineer**
- **Making 1D PNL Nonlinear FEM in Scia Engineer**

Recollection about Plates

"The word plate is a collective term for systems in which transfer of forces occurs in two directions; walls, deep beams, floors and bridge slabs are al plates".

Plates can be loaded in their plane or perpendicular to their plane. A plate loaded in its midplane is said to be in a state of plane stress, or a membrane state, if the following assumptions hold:

1. All loads applied to the plate act in the midplane direction, and are symmetric with respect to the midplane.
2. All support conditions are symmetric about the midplane.
3. In-plane displacements, strains and stresses can be taken to be uniform through the thickness.
4. The normal and shear stress components in the z direction are zero or negligible.

   The last two assumptions are not necessarily consequences of the first two. For the latter to hold, the thickness h should be small, typically 10% or less, than the shortest in-plane dimension.

5. The plate is fabricated of the same material through the thickness.

   In the first phase of this thesis which is about slender beams loaded by bending moment sand shear forces (figure 1) bending and shear stresses can be easily calculated by using Euler Bernoulli beam theory.

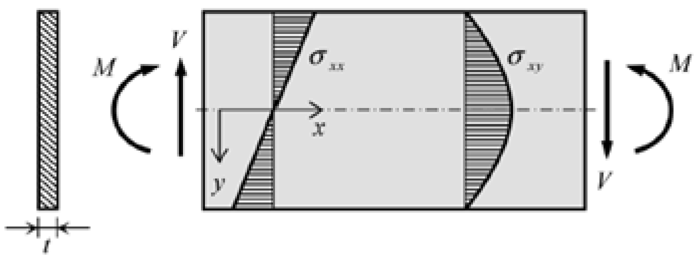


Figure 1, stress in prismatic beam in classical beam theory [1]

In a deep beam or high walls which is in the second phase of this project will be analyzed, the stress distribution differs from what the classical beam theory predicts. The bending stress is no longer linear and beam theory does not give any information about vertical normal stresses but they do of course occur. The shear stress in a deep beam does not have a parabolic distribution as in the classic beam theory.

Plate theory in Scia Engineer

In Scia Engineer software ,in Solver setup there are two choices for” bending theory of plates and shell analysis” from which one of them should be chosen. This chapter explains why and when the user might choose different bending theory .

Thick plates

The theory for thick plates was derived independently by E. Reissner (1945) [5] and R.D. Mindlin (1951) [6], with small differences in their theories. If a plate is loaded perpendicular to its plane, it is in the state of bending and transverse shear.

This is called “slab”, which is not considered in this thesis. Thick plates are generalization of beams, beams spans one direction but plates is able to carry the load in two directions. In thick plates three independent degrees of freedom is used, vertical displacement and 2 rotations. There are 5 deformations in thick plates , three plate curvatures and 2 transverse shear angles.3 plate moments and 2 shear forces are associated with these deformations.

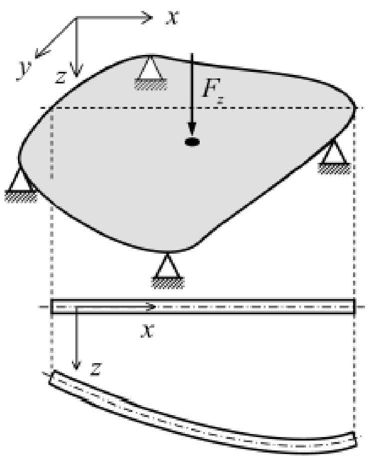


Figure 2 Plate with transverse load

Thin Plates

Theory of thin plates is based on that shear deformation is negligible. The theory for thin plates is a limiting case of the theory of thick plates in which shear deformation tends to zero. Rotations depend on the vertical displacements. Curvatures become second derivatives of the displacement. In thin plate analysis we must use Kirchhoff. The Mindlin analysis requires a senseless fine mesh to produce partially the same results. Choosing Kirchhoff we need to never use element size smaller than plate thickness.

Kirchoff-Love theory for thin plates

The Kirchhoff–Love theory is an extension of Euler–Bernoulli beam theory to thin plates. The theory was developed in 1888 by Love using assumptions proposed by Kirchhoff. It is assumed that a mid-surface plane can be used to represent the three-dimensional plate in two-dimensional form.

The following kinematic assumptions that are made in this theory:

- straight lines normal to the mid-surface remain straight after deformation
- straight lines normal to the mid-surface remain normal to the mid-surface after deformation
- the thickness of the plate does not change during a deformation

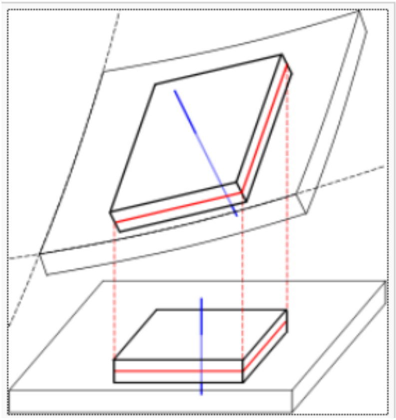


Figure 3 deformation of thin plate highlighting the displacement, the mid-surface (red) and the normal to the mid-surface (blue)

Different between Mindlin and Kirchhoff theories

Classically, plates have been analyzed by the Kirchhoff theory for thin plates. The user of finite element software expected to choose between two theories, but often one of them is a default option without the user being aware of that. Kirchhoff theory holds for plates in which the deformation by shear forces can be neglected, which is the case for a sufficient large span-thickness ratio l/t. The slenderness l/t >10 is sufficient, and most slabs will satisfy l/t≥20.

In Mindlin theory there are 3 independent degrees of freedom (DOF), the displacement w, the rotation φ_n normal to the edge and φ_s in the plane of the edge.In Krichhoff theory there are only two DOFs at the free edge: the displacement w and the rotation φ_n normal to the edge.the rotation φ_s in the plane of the edge is a slabe of the displacement w because of the relation

$$\varphi_s = \frac{\partial_w}{\partial_s}$$

Now only two edges loads can be applied, f in the direction of w and t_n in the direction of φ_n.Yet , in general all three57 plate quantities v_n, m_{nn} and m_{ns} can occur at the edge and may be non-zero.

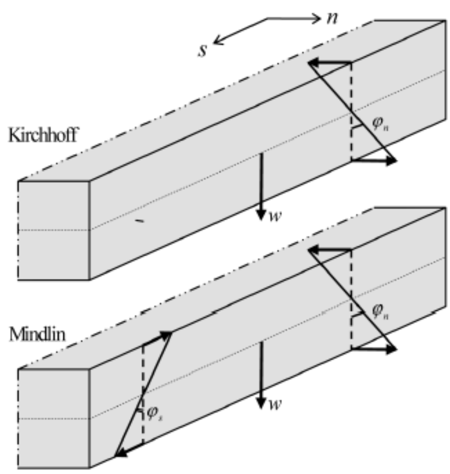


Figure 4 different boundary conditions for Kirchhoff and Mindlin

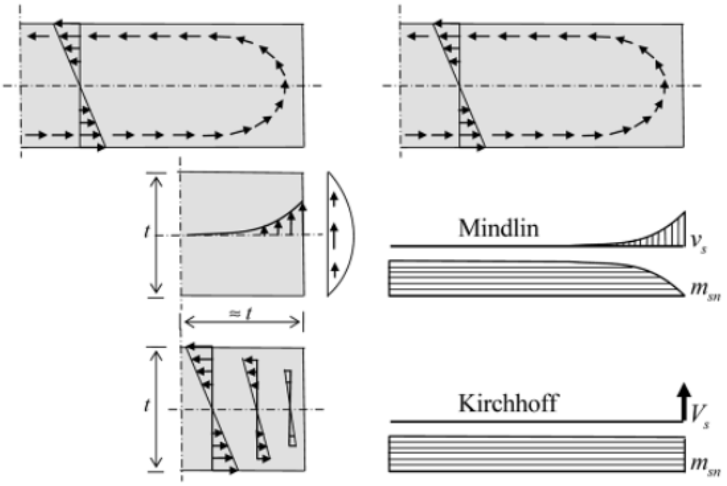


Figure 5 close look at stress state near free edge

Mindlin is able to describe the discussed distribution of the shear forces and twisting moment and Kirchhoff is not. In Mindlin theory one can handle the boundary condition$m_{ns} = 0$, whereas it is not possible with Kirchhoff theory. Kirchhoff determines the integral of all the local vertical stress components and concentrates then into one shear force V_s located at the very edge.At the same time Krichhoff is not able to have twisting moment diminish to zero and instead keeps it contact up to the edge .

Plate theory in Scia Engineer

As it is shown in figure 7 and 8, in Scia Engineer one of these plate theories should be chosen in the solver setup menu for the 1D and 2D modeling. The applicability of the plate theories which is mentioned above in Scia Engineer is when Plate material is chosen for the modeling of the specimens. **By having wall 2D models in Scia Engineer, which plate theory is chosen is not important at all**. In principle wall elements in definition are also plate elements but they are Plates which are loaded in their plane, and have 2 DOFs u_x(x,y) in the direction of x-axis and u_y(x,y) in the direction of y axis. The displacement field is fixed with two degrees of freedom. If plates are loaded perpendicular to the plane then one can talk about plate theories Mindlin and Kirchhoff.

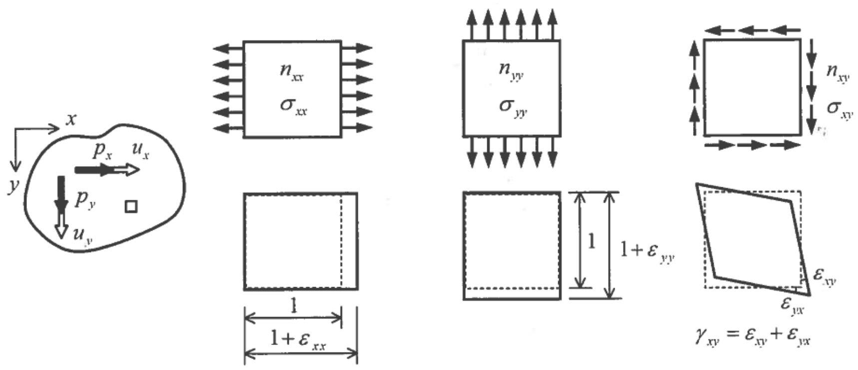


Figure 6 quantities which play a role in a plate loaded in-plane [8]

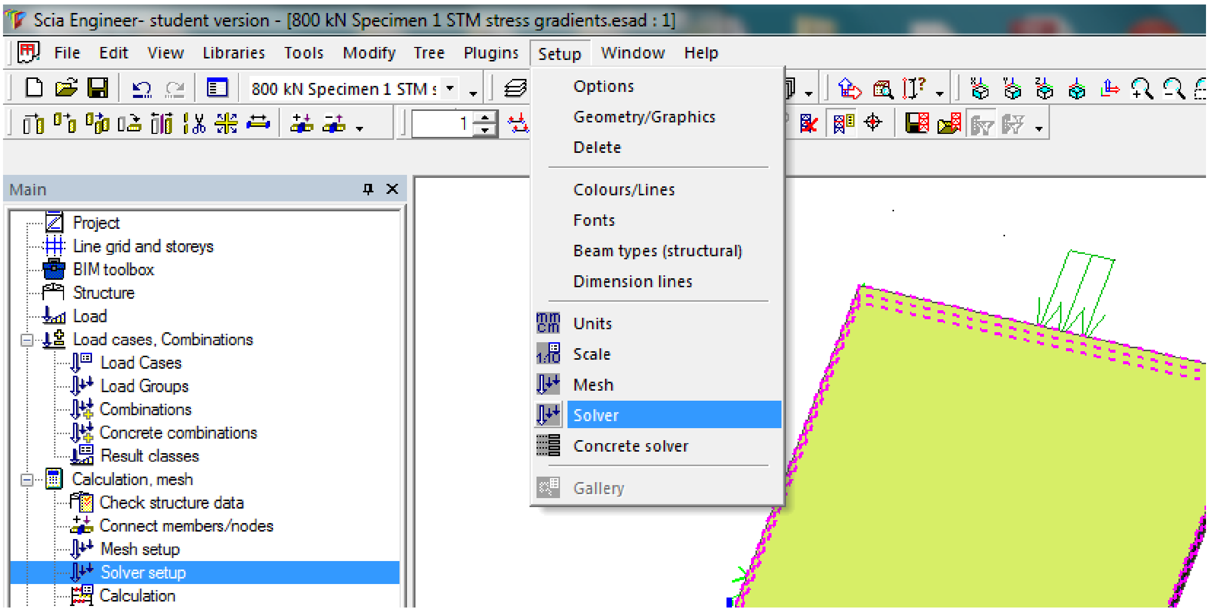


Figure 7 reaching solver setup menu a) by the main menu from left b) from tree menu setup at top

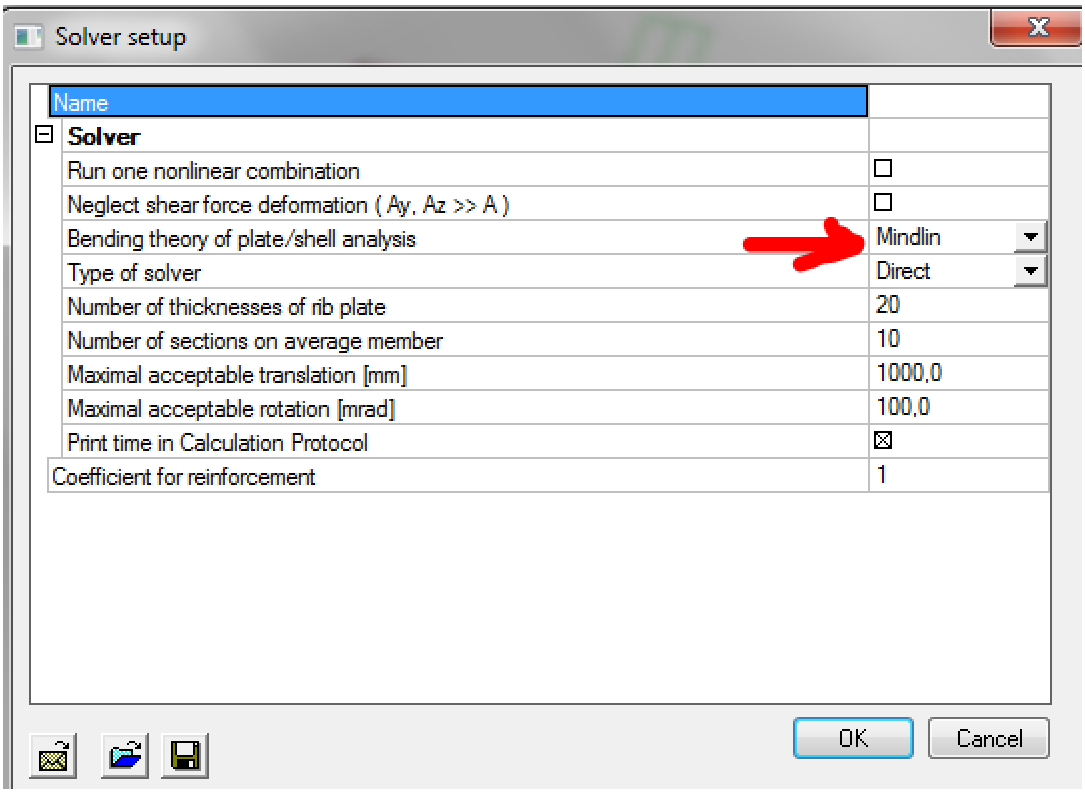
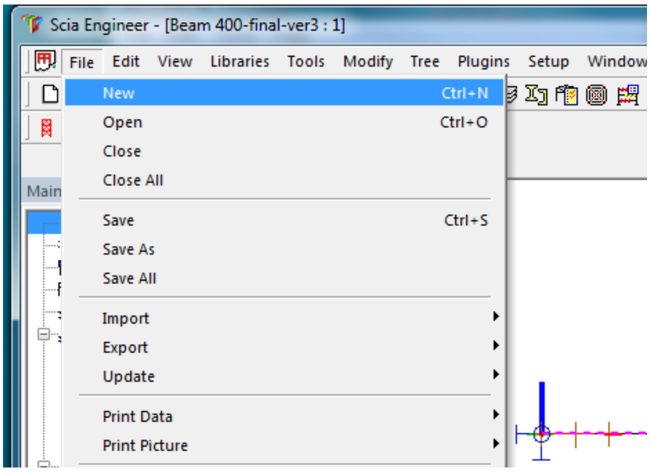


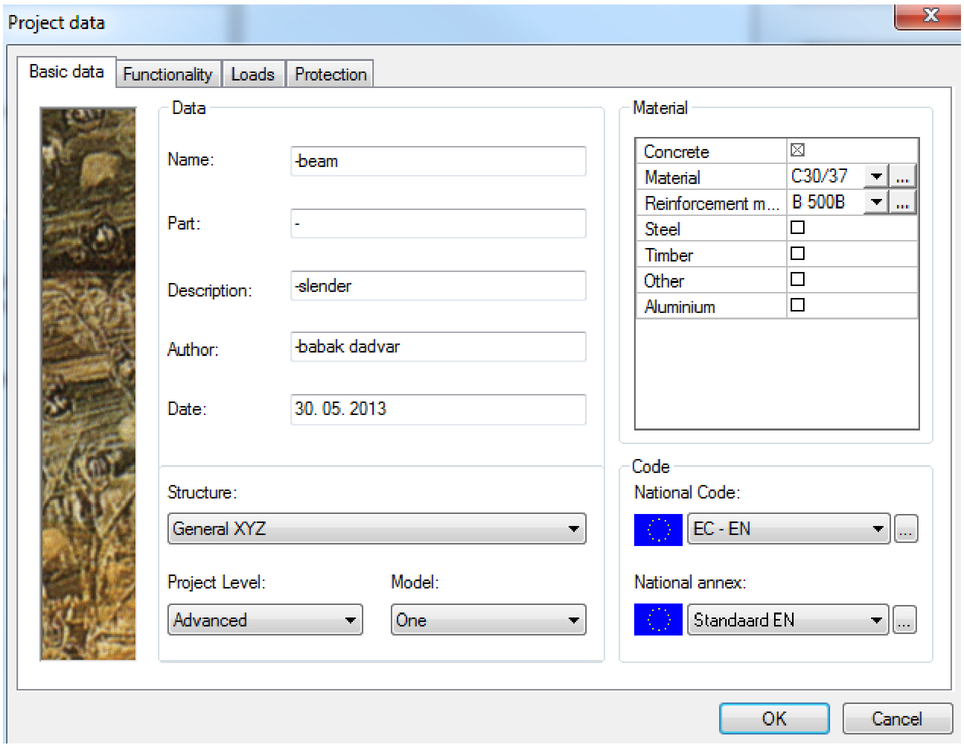
Figure 8 In solver menu always one of the plate theories should be chosen

Design and modeling of 1D model beam in Scia Engineer (step by step)

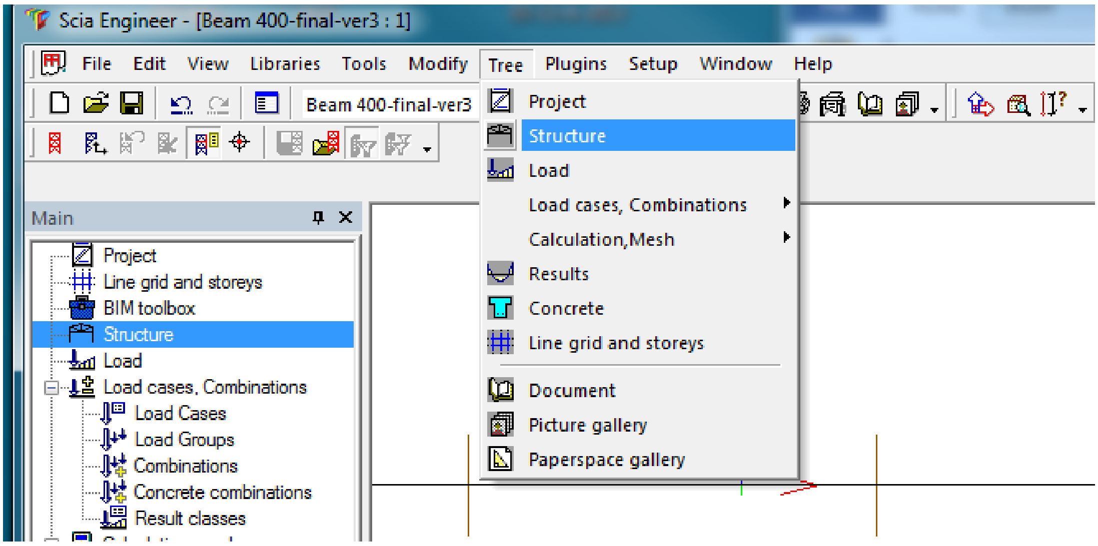
1. Oppeing the new project



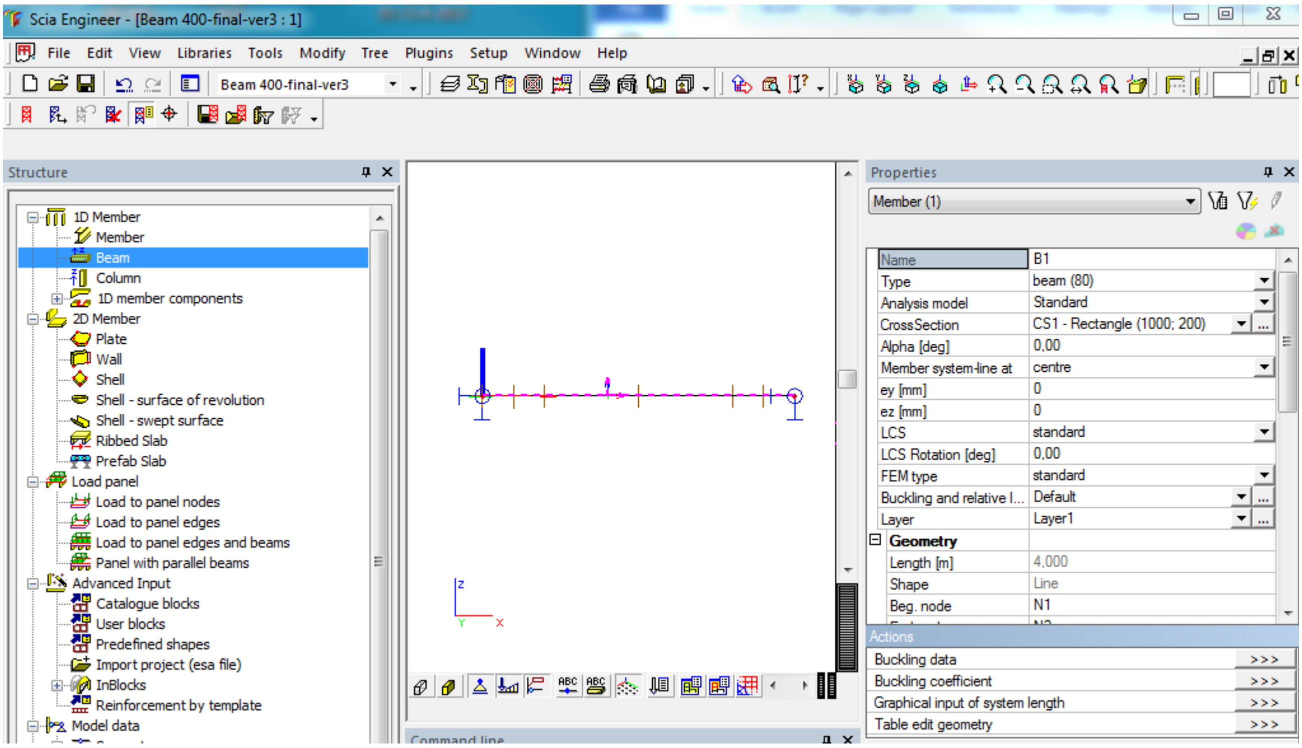
2. Choosinfg the properties of the concrete and reinfrocment also Nationale code should be accordin to EC-EN(eurocode). The structure is chosen to be General XYZ.



3. Choose structure from “tree ” tab above or from main menu in the left side of the main window of the program.



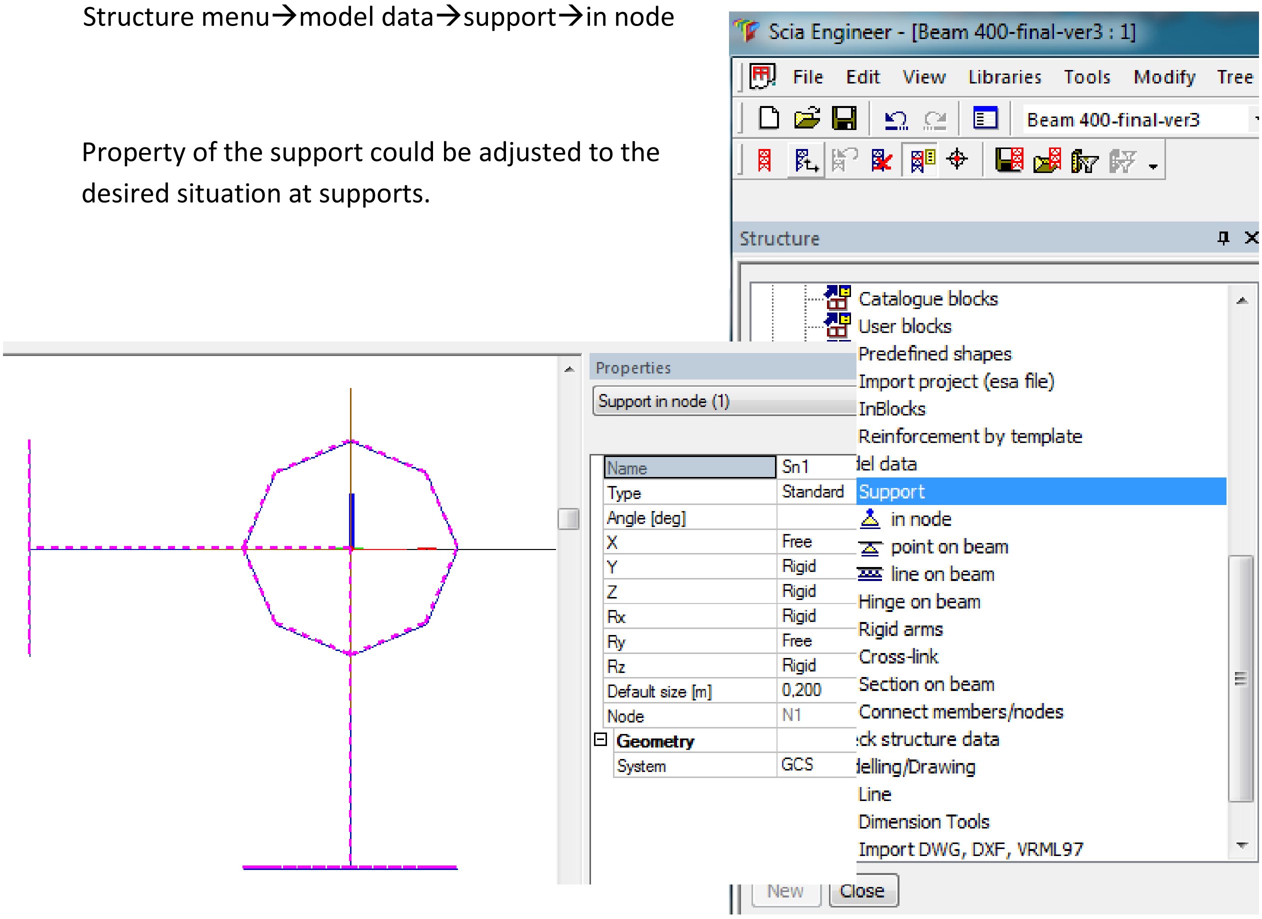
4. Choosing Beam from structure menu and define the properties and dimension from the property menu.



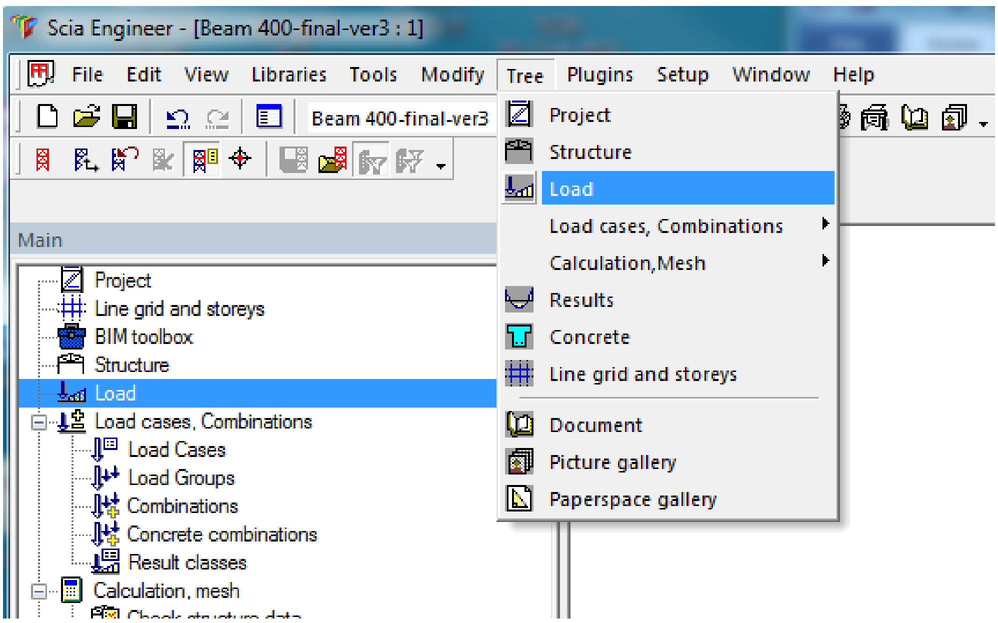
5. After drawing the beam in the area. It is time for supports. Choose the degree of freedom carefully. Below example of slender beam on 2 supports.

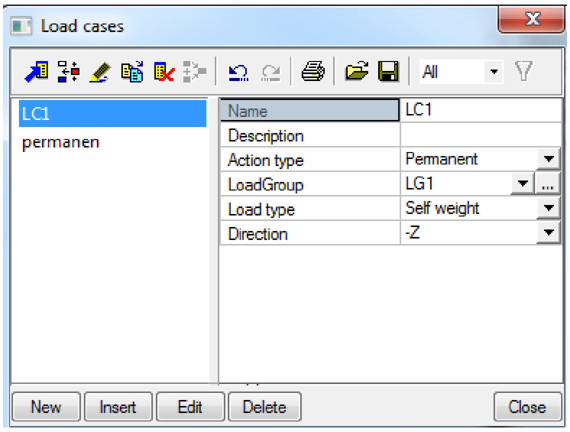
   Structure menu→model data→support→in node

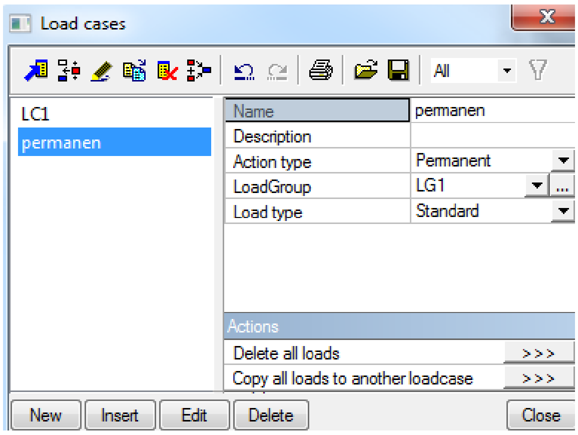
   Property of the support could be adjusted to the desired situation at supports.

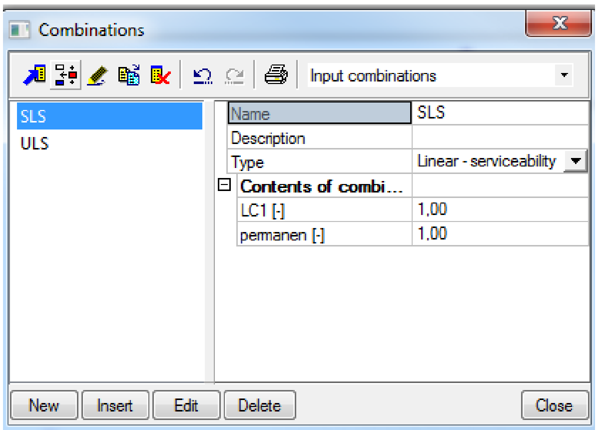


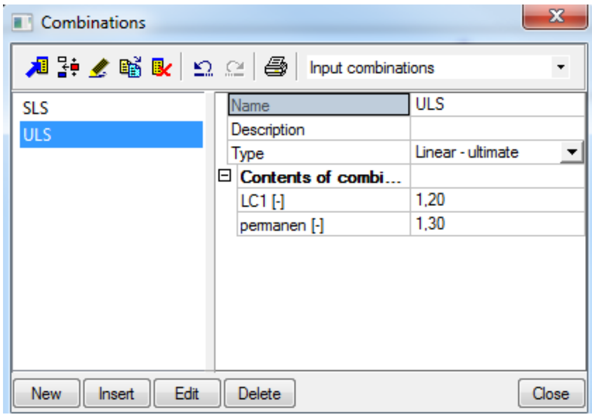
6. **Load should be applied, attention should be on the different type of loads, load cases and Combinations, which are different for different situations.(example below)**



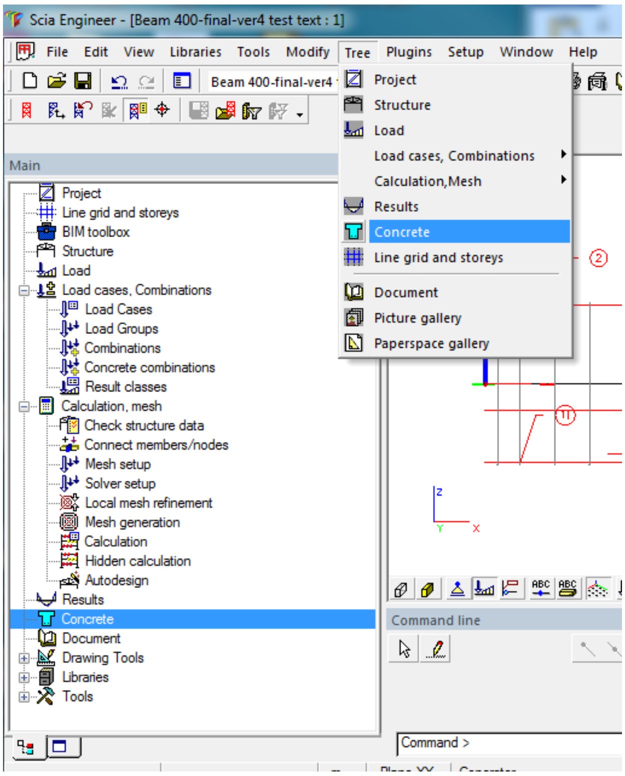








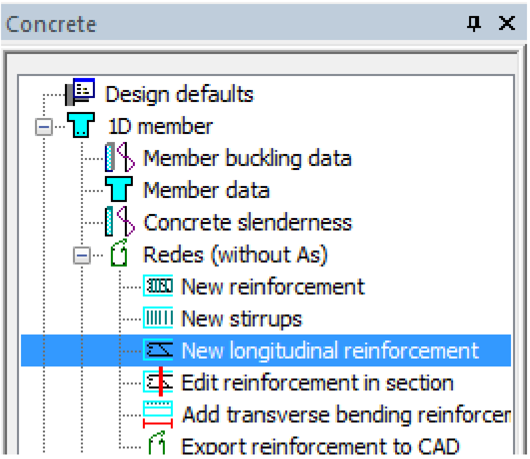
7. Putting reinforcement which is determined from 2D FEM into the 1D beam



Concrete menu→

8. **(**important step, because of some Bugs in Scia Engineer version 2011),

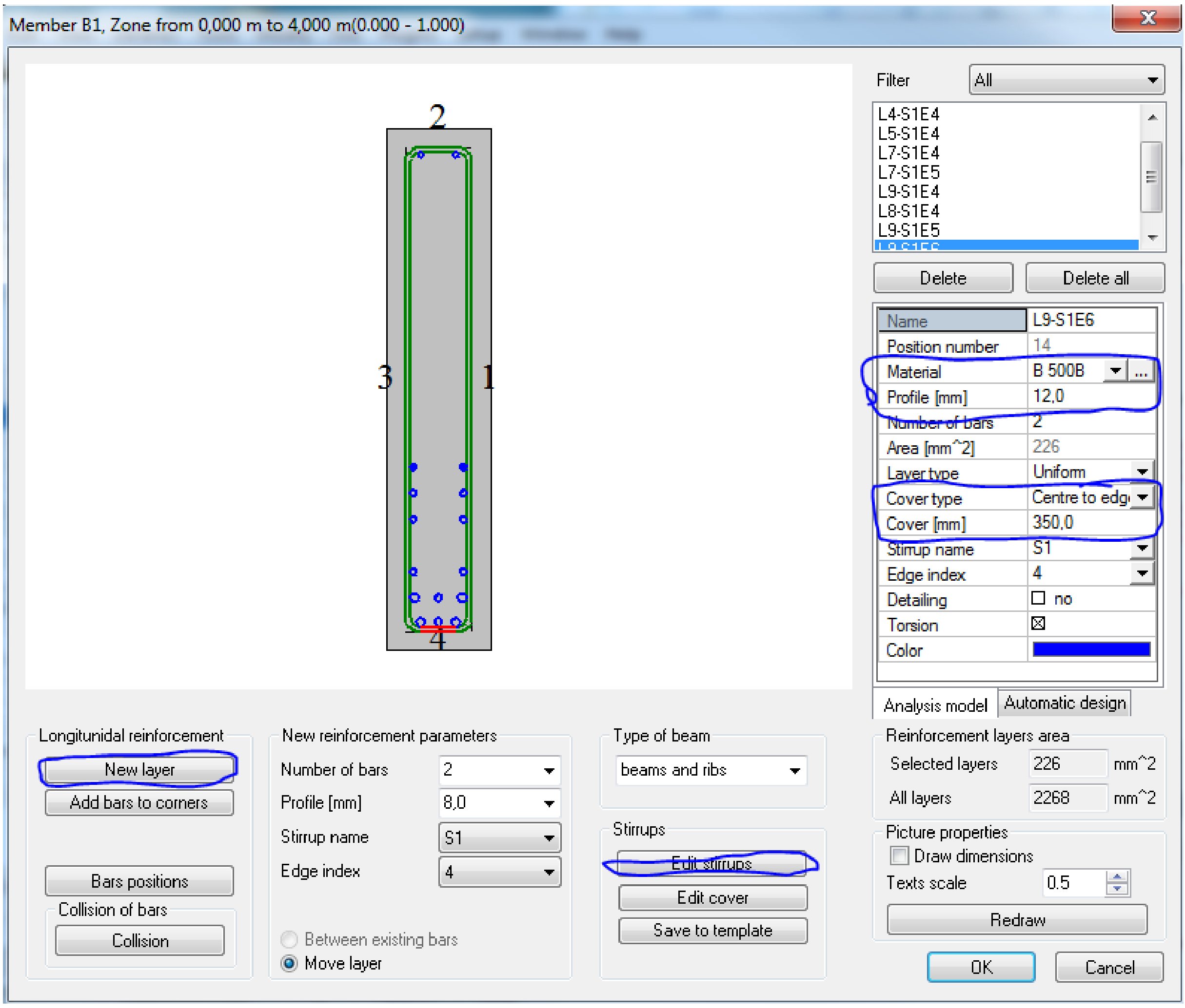
From concrete menu→double click on “new longitudinal reinforcement”→choose with mouse from the beginning of the member till the end of the member (in this case slender beam)



9. after doublclicking on new longitudunal reinfrocment a new menu pops up, here user can add and adjust the reinfrocemtn bars , which is determined in 2D finite element model.

Note:for ease of putting the reinfrocment in the desired places , cover type , and cover should be changed into the desiered option like center to center or center to edge.

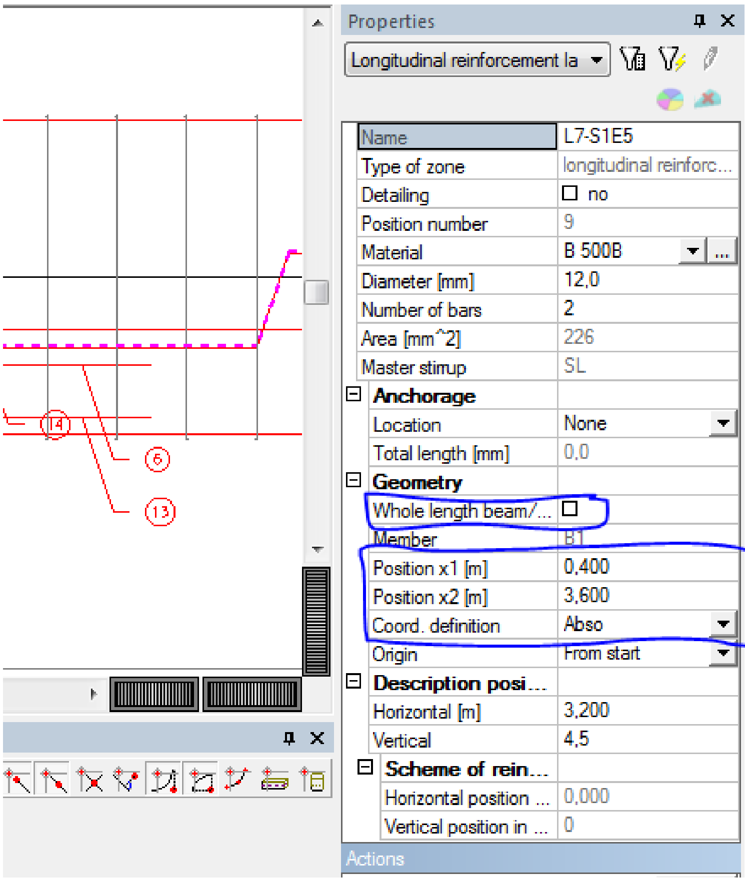
New layer	To add another reinfrcing bar
Number of bars	Can be changed in the new layer
profile	Diameter of the new layer reinfrocmentbars
material	Reinfrocment type , quality
Cover type	Center to edge or senter to center(easier one can be chosen)
cover	mm distance depends on what is chosen in the cover type
Edite cover	Concrete cover
Edite stirrups	Striups diameter



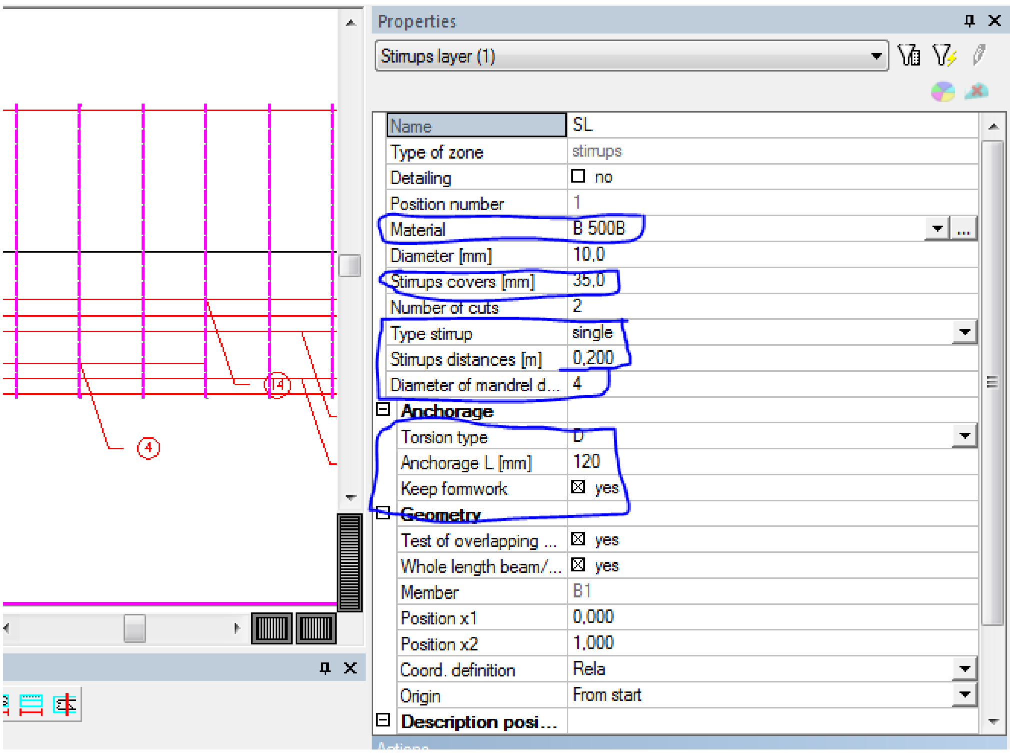
10. Adjusting the length of the bars, by choosing a reinforcement bar from main window of the program. User can change the lengths of the bar in the properties menu.

Note: if reinforcement is not completely from start to the end of the beam, the “whole length beam” option should not be check otherwise user cannot change the length of the reinforcements.

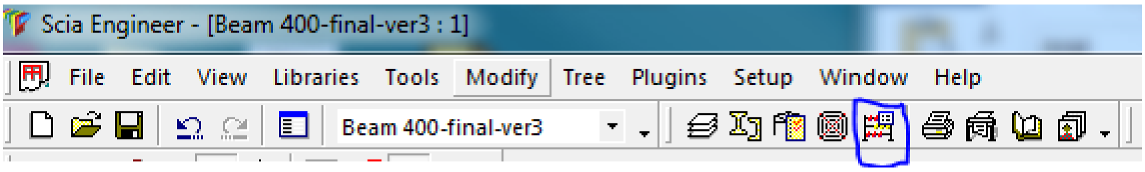
Note: coordination definition is set to be “absolute” for ease of giving coordination of the start and end of the reinforcing bars(optional).

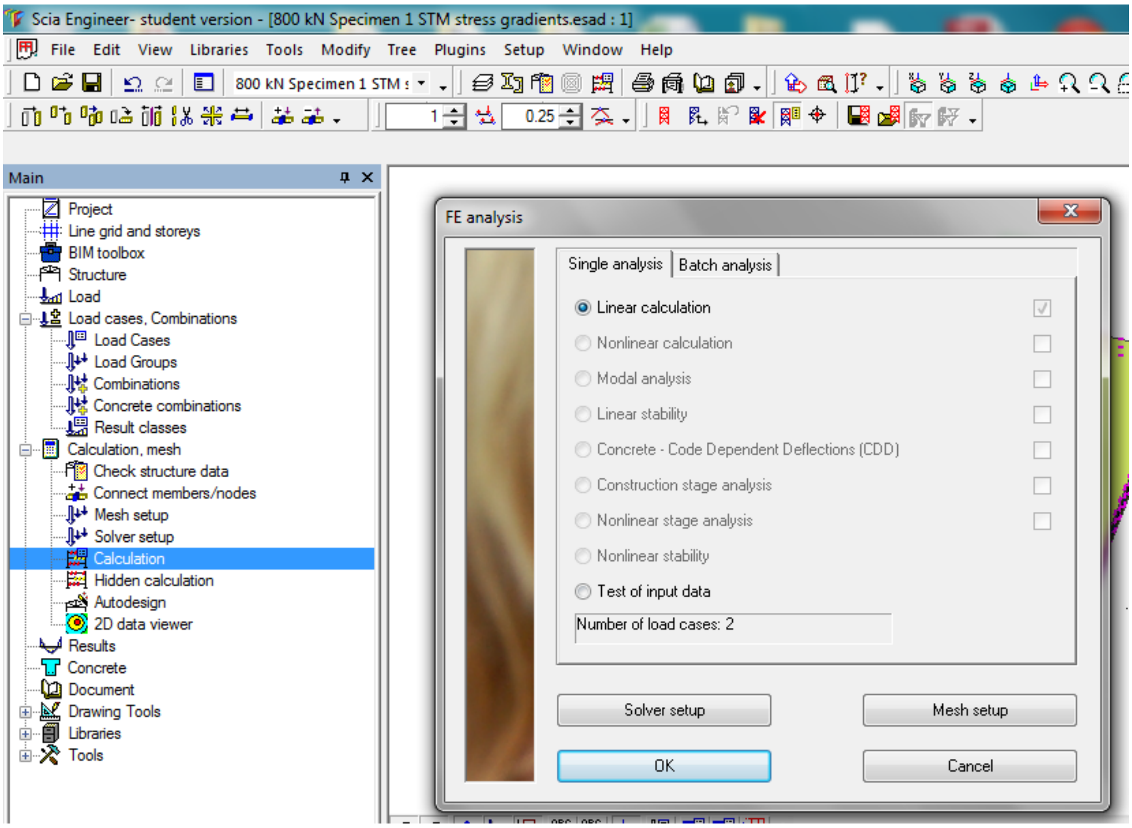


11. Adjusting the shear stirrups, here by choosing the stirrups with mouse the properties of the stirrups reinforcement can be adjusted.



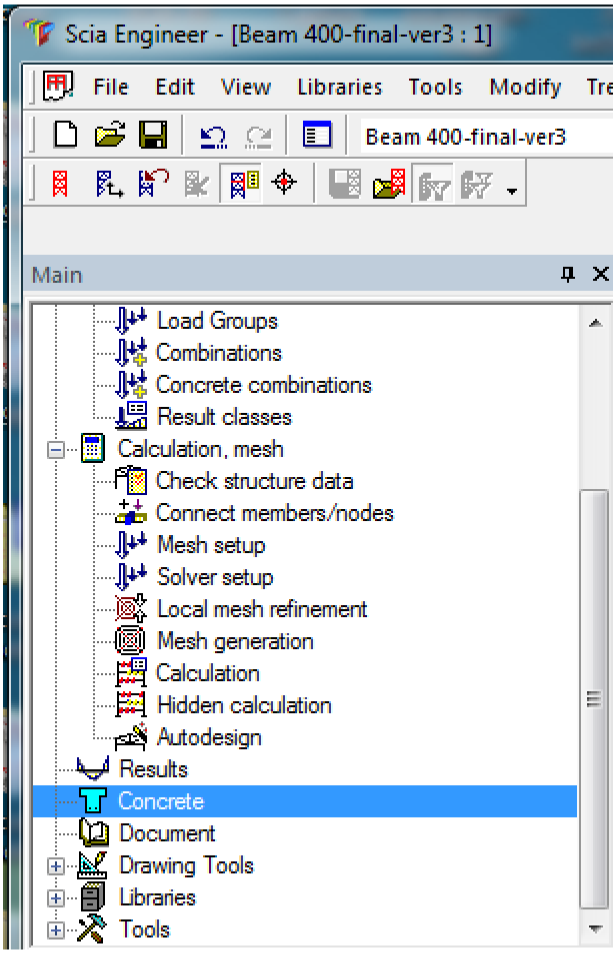
12. Running the calculation. One can run the calculation by using calculation tab from top or from the tree menu left of the Scia Engineer interface,

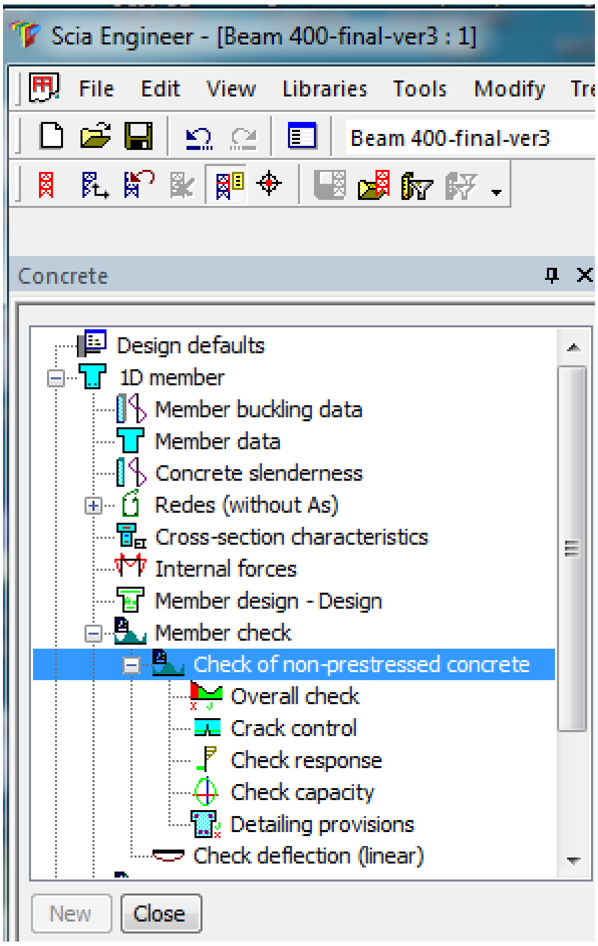




13. Checking the capacity of the beam in SLS and ULS which Scia software, and comparing with hand calculation, both are based on Eurocode.

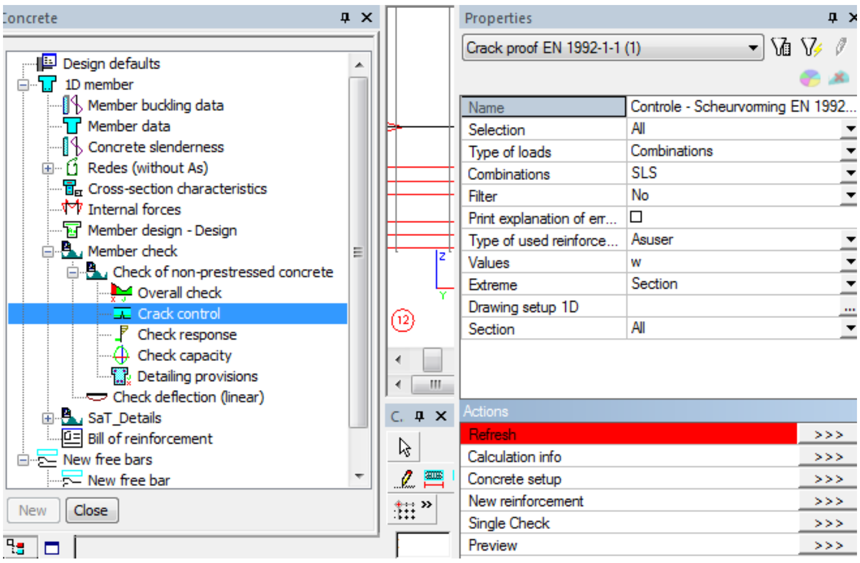
Concrete menu→member check→ for non-pre-stressed concrete





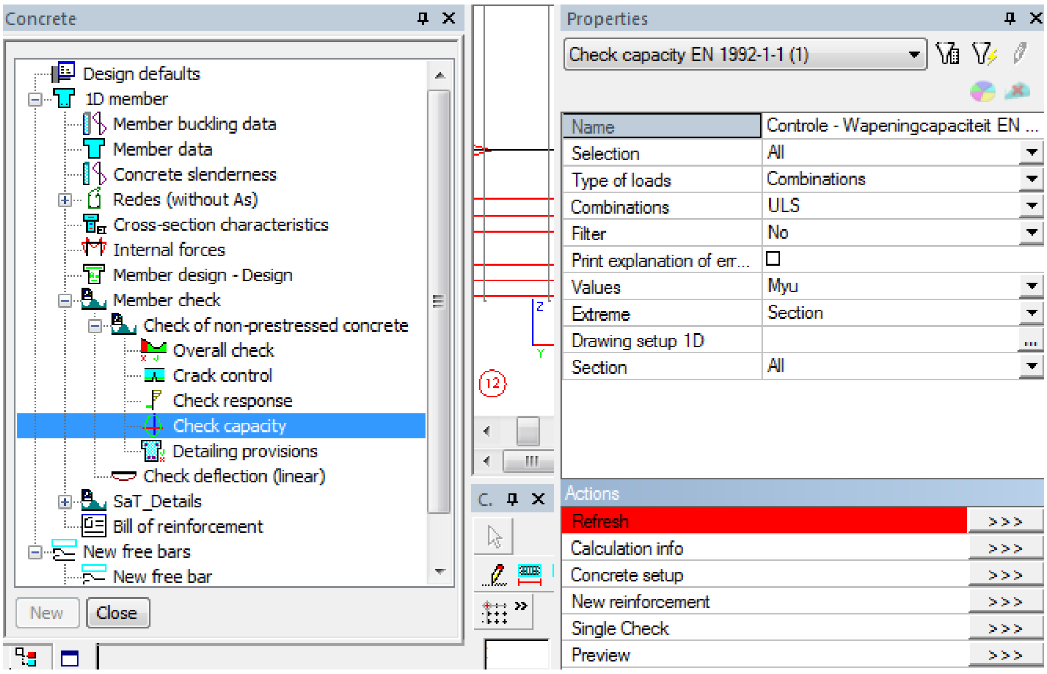
Here all sorts of the checks can be done:

- **Crack control**
  Note: one can choose the desired checks from property window



- **Check capacity**

  Note: one can choose the desired checks from property window



Making a 1D PNL nonlinear analysis model in Scia Engineer (Step by Step)

- **This model is aimed to predict the SLS behavior of the slender beam with the help of 1D model**

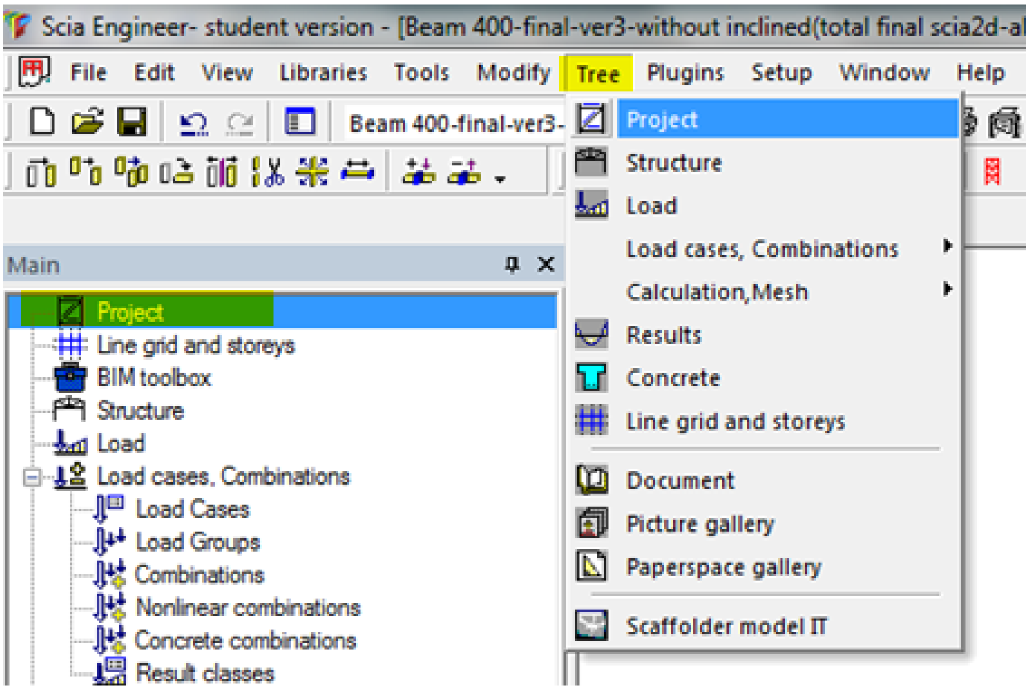
PNL analysis is done only to predict the SLS behavior of the 1D model for slender beams. The procedure of making 1D model is precise the same as it is already mentioned in the previous section. The only different for PNL nonlinear analysis is the following steps:

Step 1:

One can use the same 1D slender beam model which is already made in the previous section. So there is no need to make a new model. It is possible to adjust some parameters in the existing model to be able to do PNL analysis.

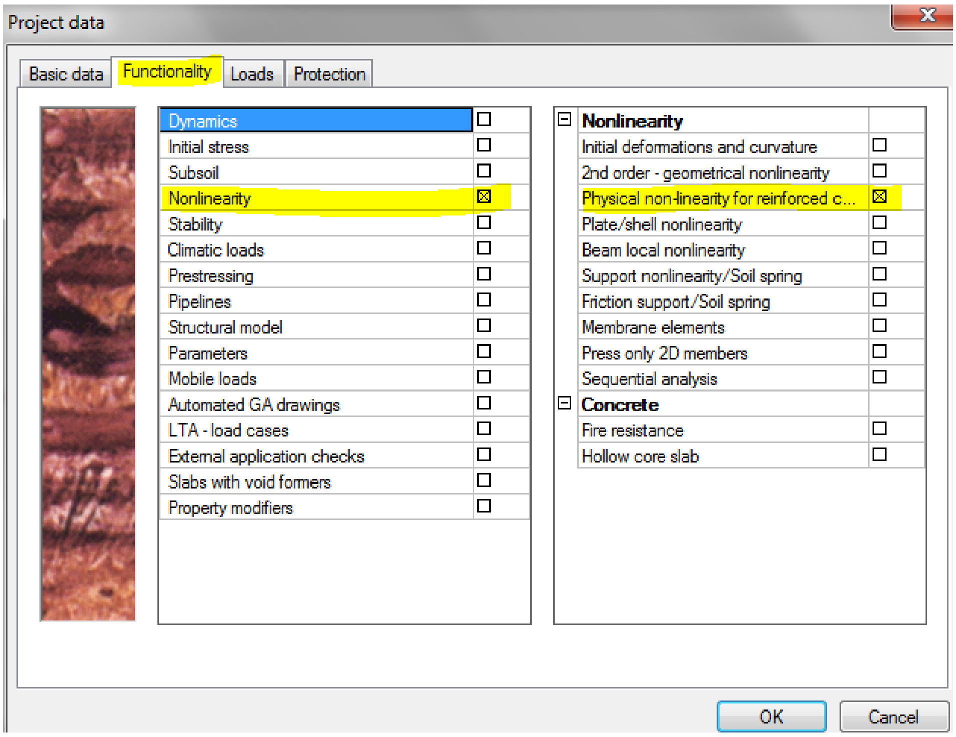
Step 2:

From project tree menu left or using the "tree" tab from the top tabs of the interface go to the project data menu.



Step 3

From project data menu, choose the functionality. Here Nonlinearity should be turned on and then turn on the Physical non-linearity for reinforced concrete. Now Scia Engineer can do also PNL analysis.



Step 4

Now nonlinear load combination should be defined. From left tree menu

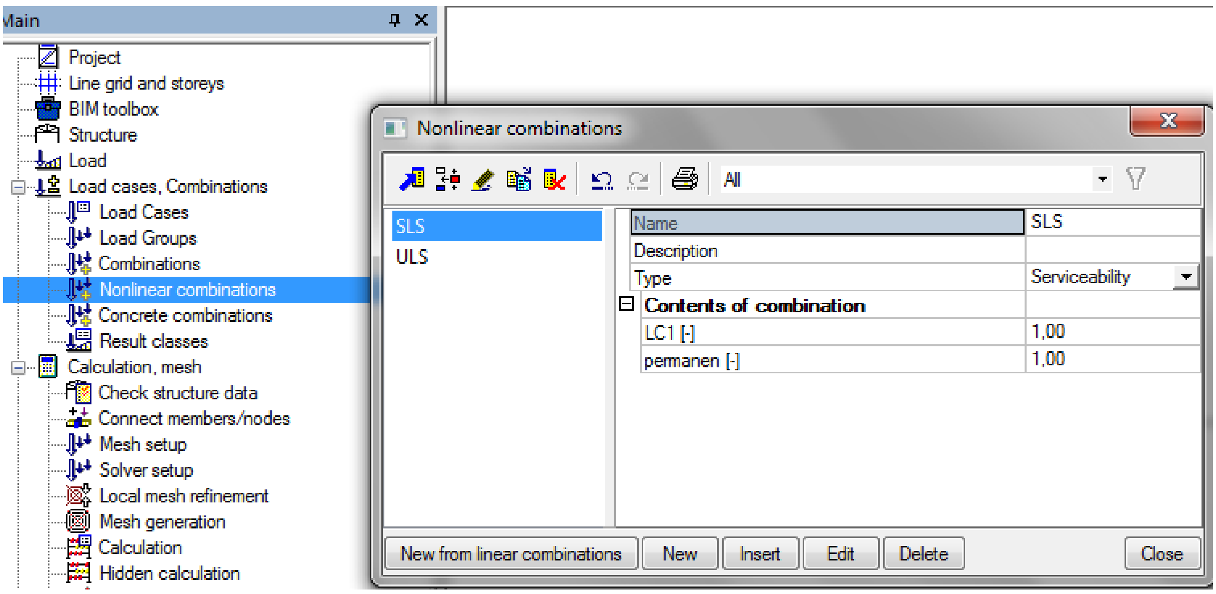
Load cases, combinations→Nonlinear combinations

Here there are two possibilities

Option 1) to define SLS and ULS just like linear analysis

Option 2) choose "New from linear combinations"

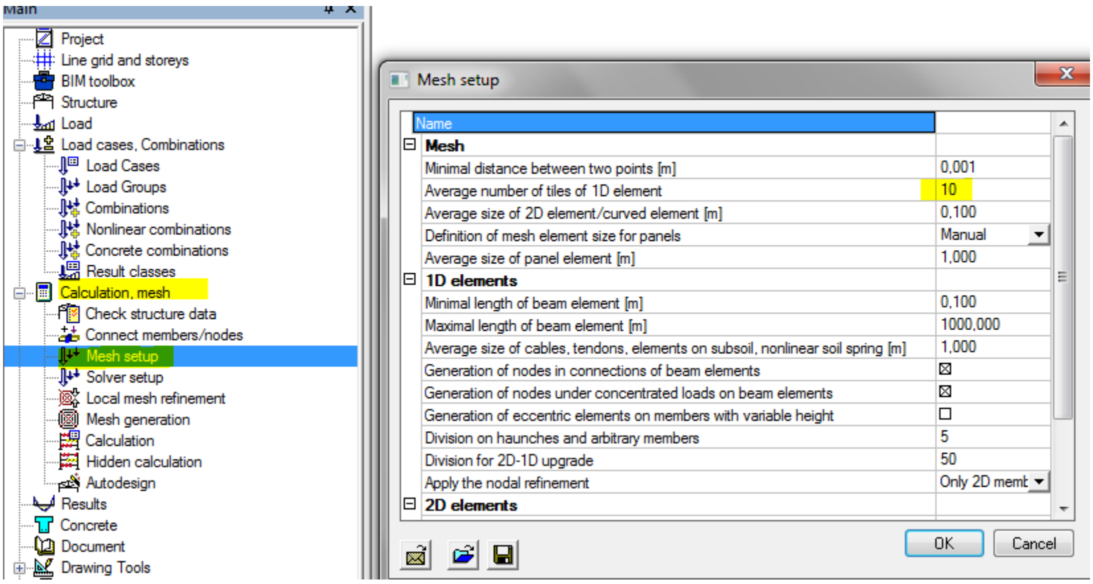
Both gives the same results, but option 2 is faster.



Step 5

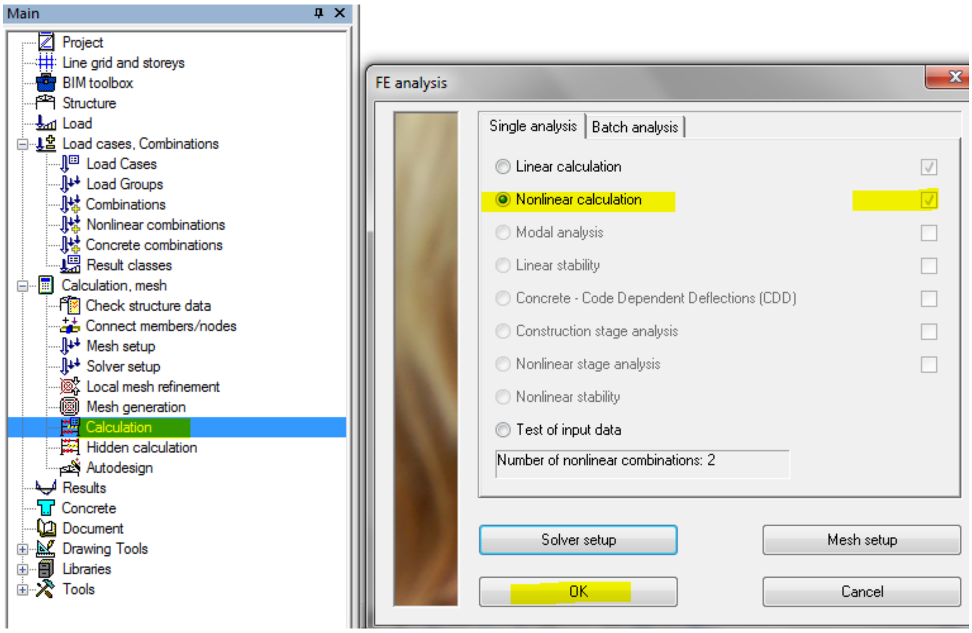
Mesh setup

Go to mesh setup and then to be able to get accurate results change the average number of the tiles of 1D element into a bigger value 20, 30. This is dependent on the size of the beam.



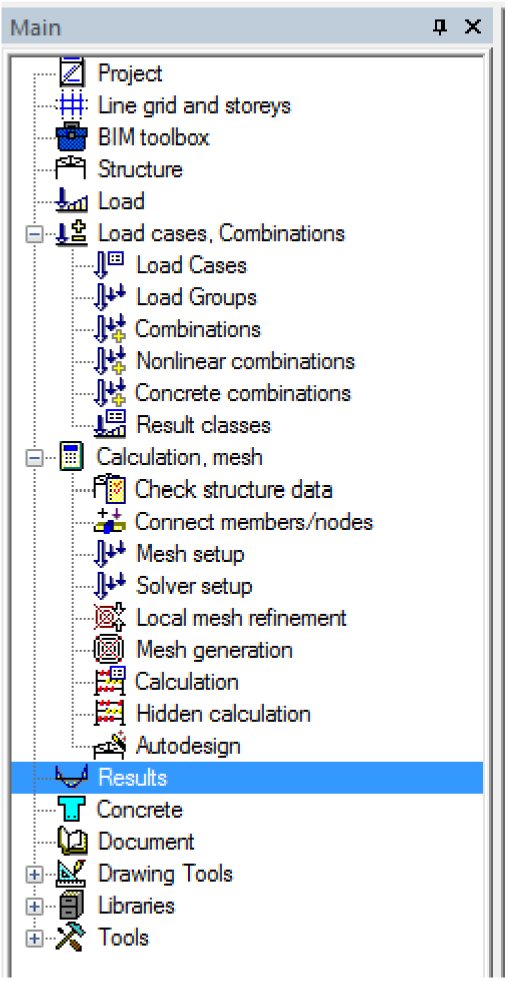
Step 6

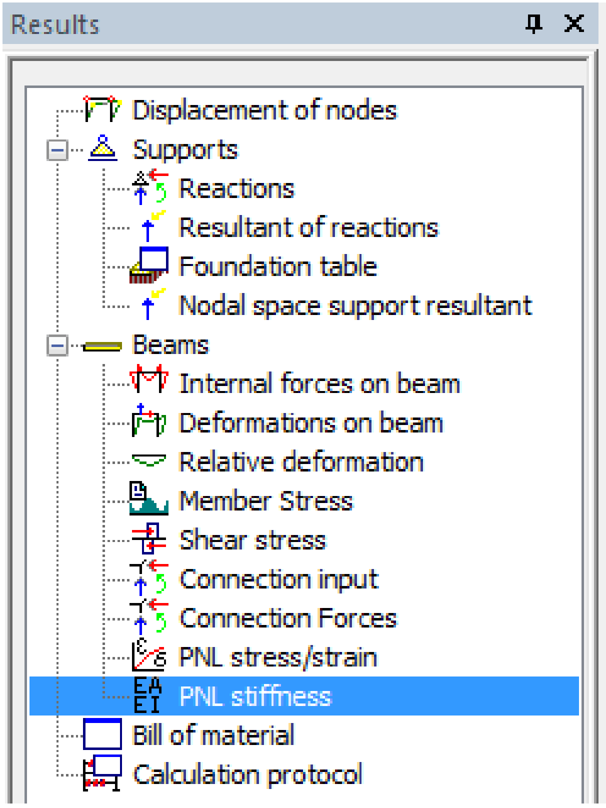
Run the nonlinear analysis



Step 7:

By going to the results and PNL Stiffness, Scia prediction about stiffness reduction due to cracking can be shown. Also deformation of the specimens can be shown.

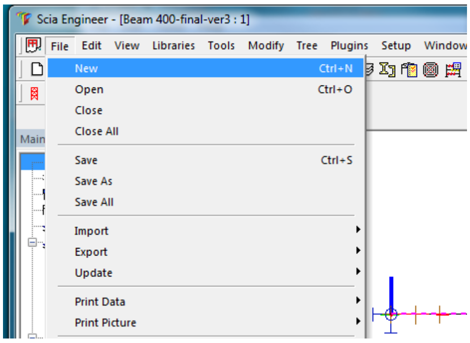




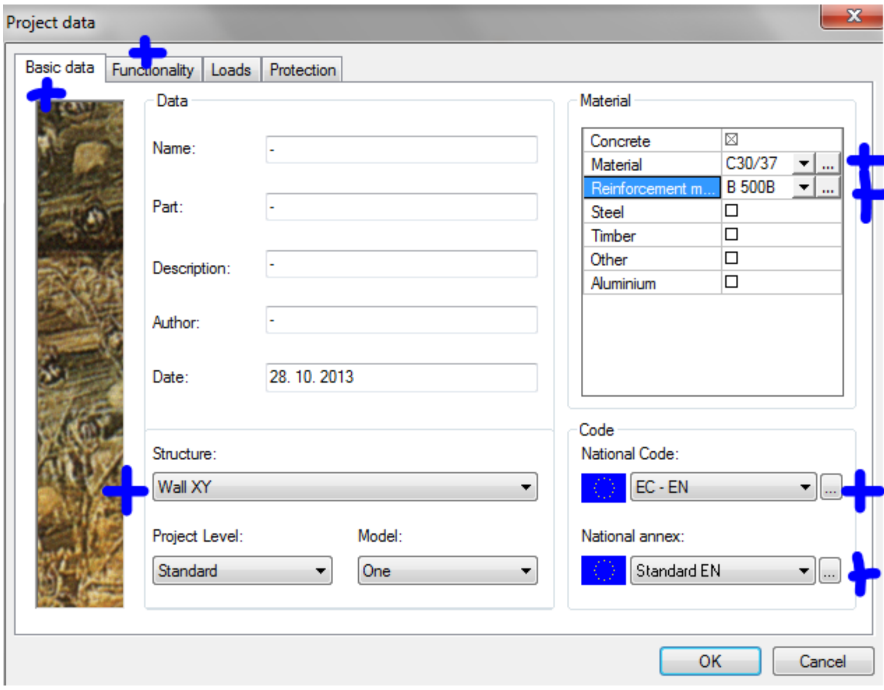
Making a 2D Pressure only Member model in Scia Engineer(Step by Step)

- **This model is aimed to calculate the amount of reinforcement for nonlinear calculation**

Step 1: Oppeing the new project

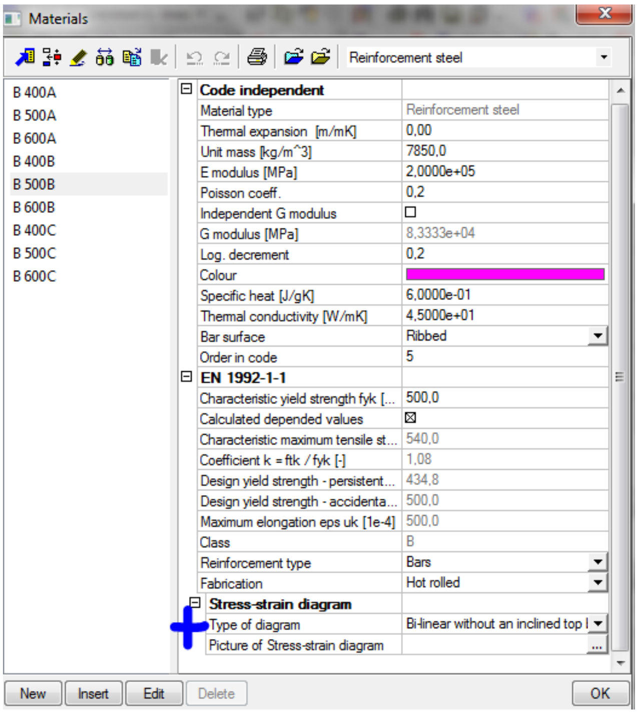


Step 2: Choosinfg the properties of the concrete and reinfrocment also Nationale code should be accordin to EC-EN(eurocode). The structure is chosen to be General XYZ.Note that structre is wall XY should be chosen if 2D wall or deep beam member is goingn to be modeld.

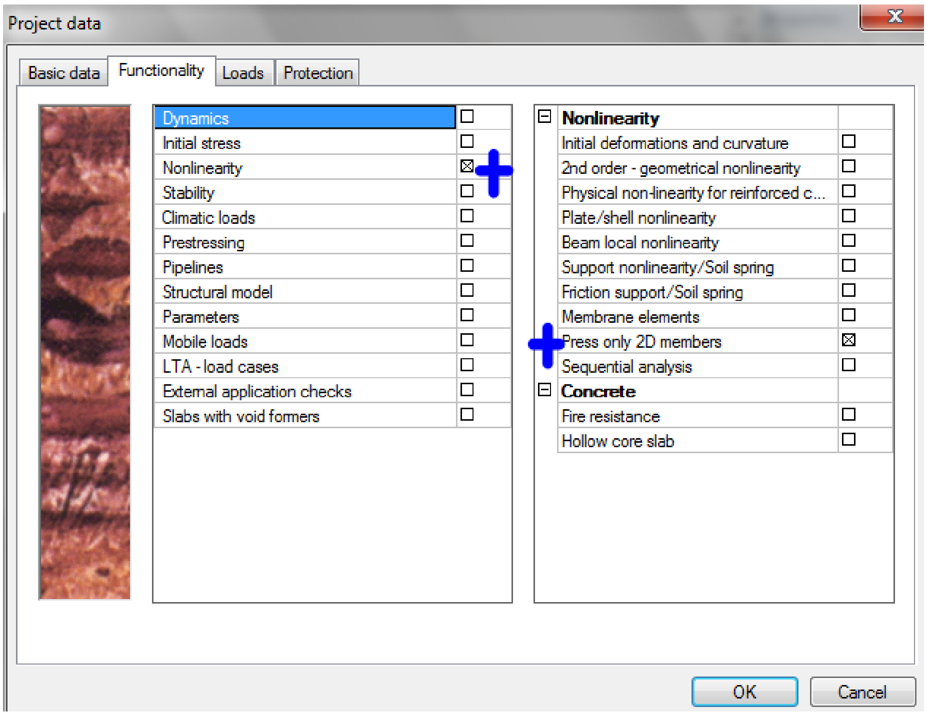


Step 3:

Control if the materiaal properties are chosens properly

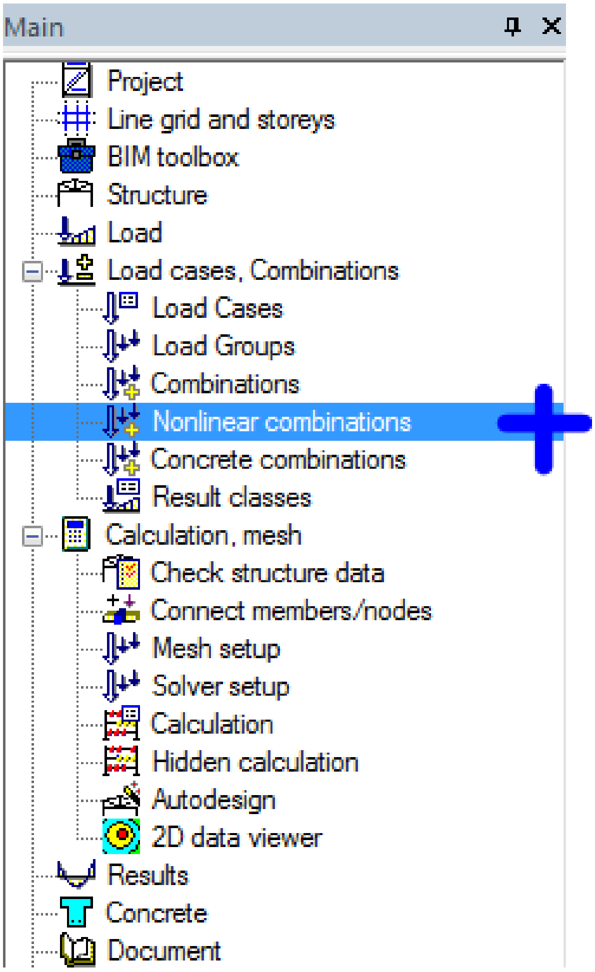


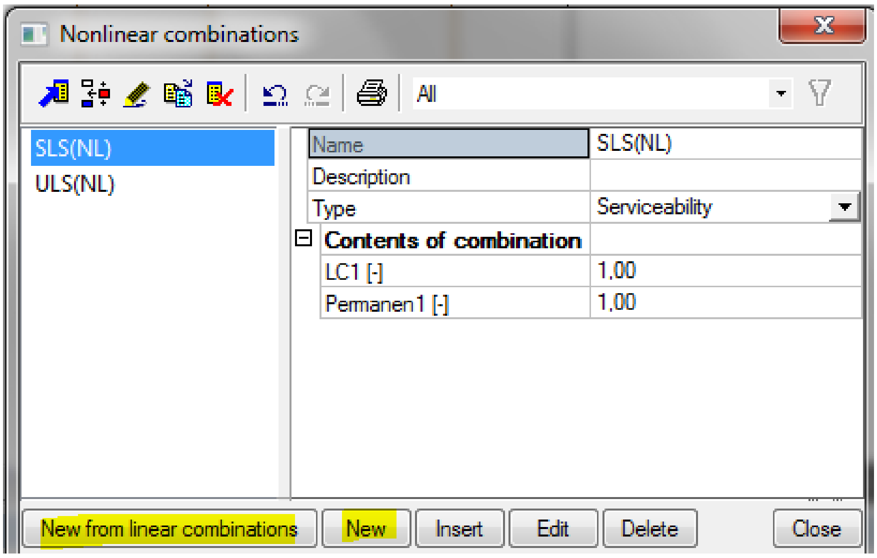
Step 4. In funtionality tab , Nonlinearity and then press only 2D members should be chosen.



Step 5 Defining the geometry and support conditions of specimen is precise the same as it is already explained.

Step 5 defining the load combinations. After defining the general load cases (SLS and ULS) , a nonlinear load combination has to be defined as well. Nonlinear combination can be defined just like linear combination by using tab “New” or it can be imported from linear combination by using tab ”New from linear combination” .





Step 6 Putting reinforcement bars into the 2D pressure only member

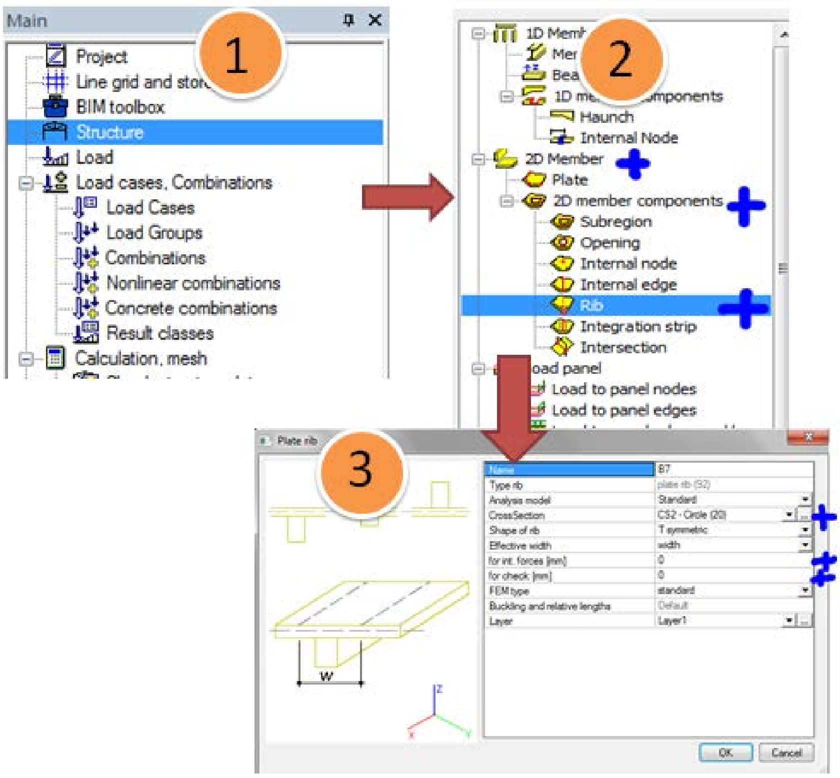
Note: the big difference here with linear calculations is that, here it is not possible to run the calculations before putting reinforcement in the specimen. This is due to the fact that 2D pressure only members can take a little tension so without reinforcement in the model , the model is already failing due to large cracks.

Note: In nonlinear calculation only steel ribs can be used as reinforcements.

The procedure is as following

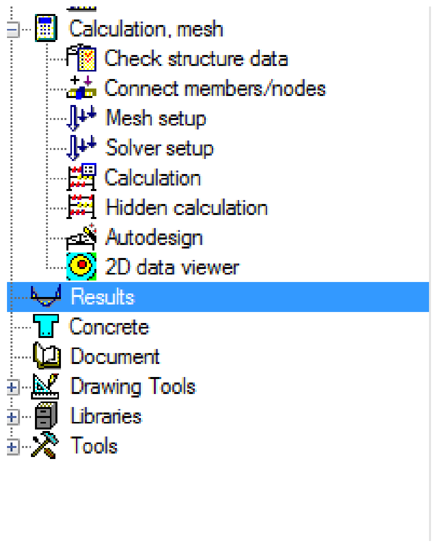
Structure→2D member →2D member components→Rib

It is important that the property of the rib is chosen in a proper manner.



Step 7 Putting Ribs into the specimen

Ribs should be places in the specimens in a way that following the flows of tension forces in the specimen. It is important that the user has the complete knowledge of flow of forces in specimen. (STM)

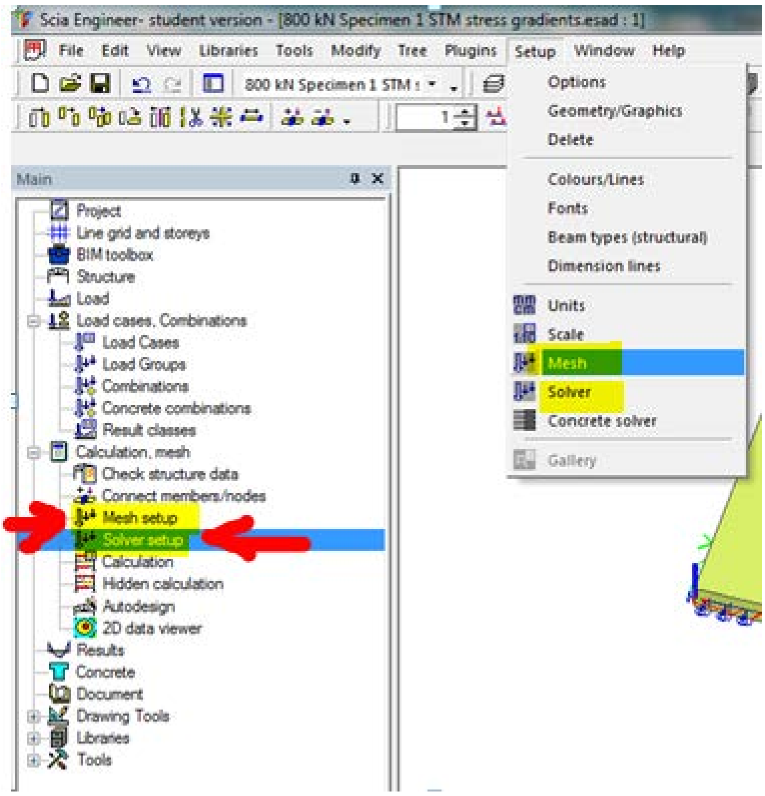


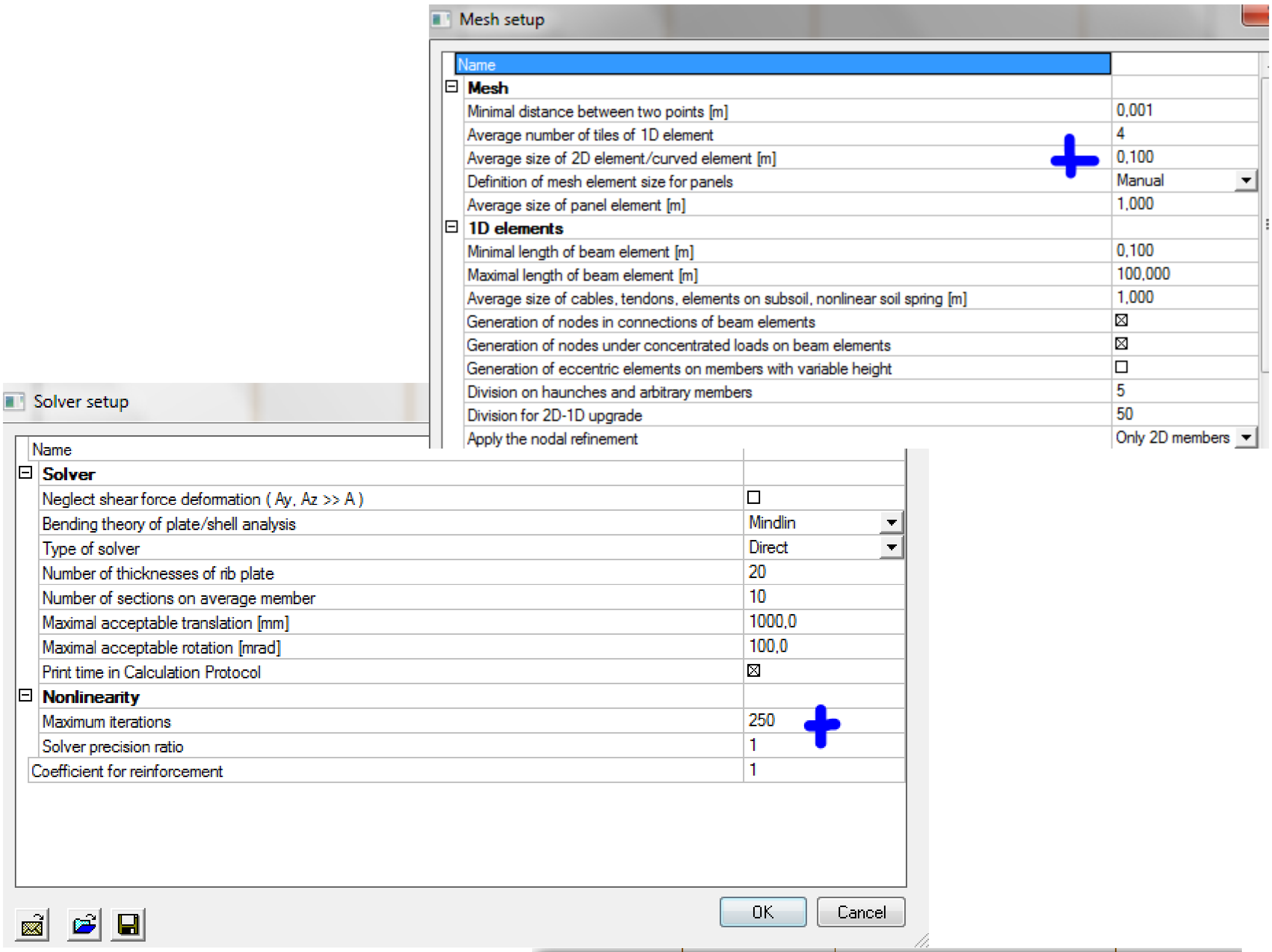
Suggestion: beforehand it is handy to do linear analysis and check the trajectory of stress flow in the specimen.

Putting Ribs in to the specimen is done by using STEP by STEP Method (SSM) which is illustrated in annex 3 also in chapter 4.4.3 of the thesis.

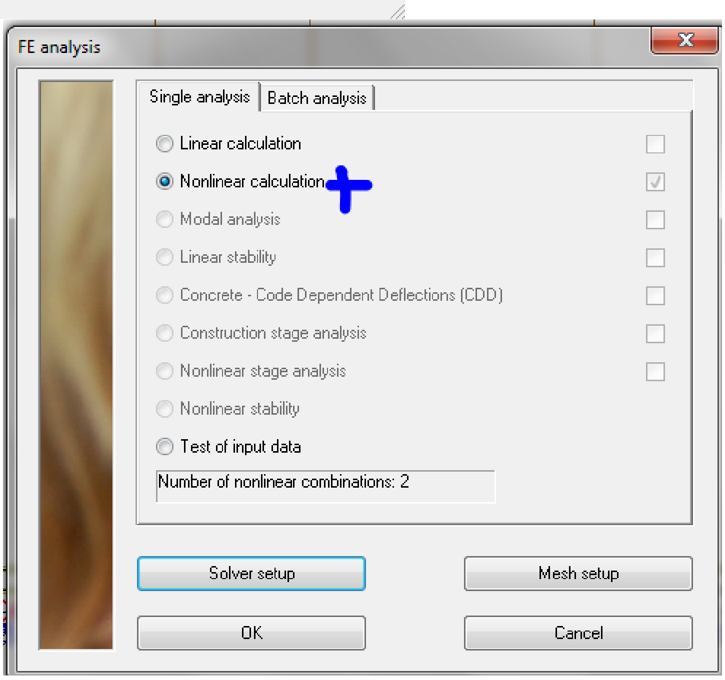
Step 8

After putting initial rib in to the specimen, solver setup and mesh setup should be checked. Maximum iteration in solver setup is set to be 250.





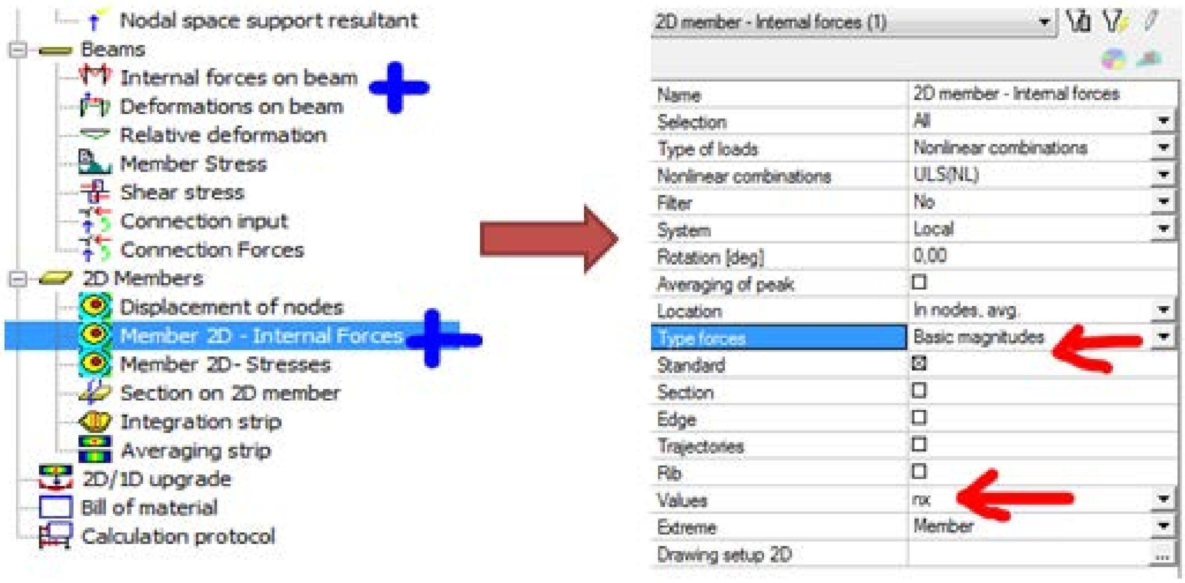
Step 9 Running the calculation



Step 10

Check in the result menu if in Nx and Ny direction there is enough Ribs in the specimen. For both vertical and horizontal reinforcements it is assumed that basic mesh net is already applied (NEN EN1992-1-1 cl 9.7.

It is not necessary and possible to put mesh net in to the model. Only main horizontal of vertical reinforcement (Ribs) should be applied.



Example:

Available mesh net is $\emptyset 8 - 200$. This means that in every 200 mm (0,2m) height of the beam there is $100\ mm^2$ ($2\emptyset 8$) is available. The max Nx is around 243 kN/m (figure below). The same procedure also for shear reinforcing(ribs-Ny).

$$N_x \cdot 0{,}2m = 243 \cdot 0{,}2 = 48{,}6\ kN$$

$$A_{s,needed} = \frac{48{,}6 \cdot 1000}{\sigma_{yd}(\frac{N}{mm^2})} = \frac{48{,}6 \cdot 1000}{435} = 111{,}7mm^2$$

Amount of $111{,}7mm^2$ reinforcement is needed which is bigger than amount of available mesh net which is $100mm^2$. Here it means another Rib should be added. Again this procedure of control should be carried out, till there is no need for extra steel ribs. This procedure is actually based on SSM or step by step method which is illustrated in Annex 3.

- Adding rib
- Control
- If needed adding another rib
- Control

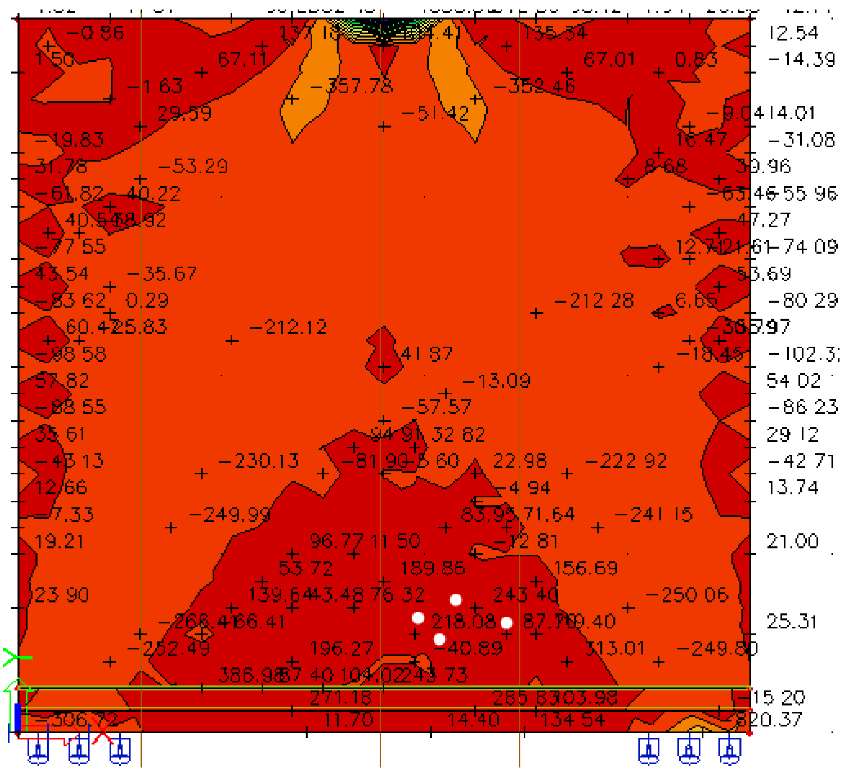
- If needed adding another rib
- Control

.

.

.

.



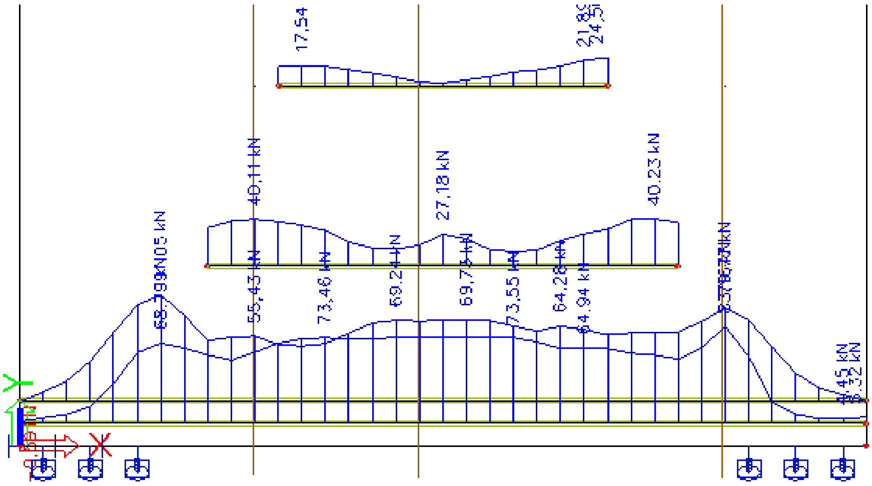
Step 11

Calculating the amount of reinforcement

After putting enough ribs into the specimen, so Nx and Ny in no other places exceeds the amount of reinforcements. By using the forces in the ribs the amount of reinforcements can be calculated.

$$A_{s,needed} = \frac{F_{rib}(N)}{\sigma_{yd}(\frac{N}{mm^2})}$$

$$\sigma_{yd} = 435N/mm^2$$



17,54
40,11 kN
27,18 kN
40,23 kN
55,43 kN
73,46 kN
73,55 kN
64,28 kN

Annex 3

Introduction:

In Annex 3 the following subjects are going to be discussed:

- **Step by Step Method or SSM for 2D LE-FEM**
- **Step by Step Method or SSM for 2D NL-FEM**
- **Mesh Dependencies in Scia Engineer**
- **Scia Engineer 2011 Errors**

Step By Step Method or SSM

Second method which is introduced in this thesis is going to be called as "SSM". This method is based on the redistribution of the forces in the concrete element after any however small reinforcing.

This method can be formulated as following:

1- **One have to use annex 1 to make a 2D model**

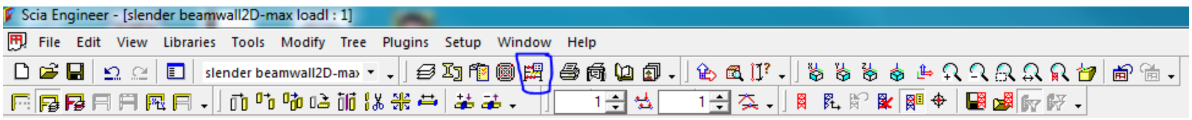
2- **As a result of running the calculation by Scia Engineer, from concrete menu and then member design ULS, and then choosing required reinforcement. Amount of reinforcement which is needed in the model is the result of Scia Engineer calculations.**

3- **In this step, depend on the mesh size and colors, the concrete element is going to be divided in height by reasonable pieces. Reasonable peace means the different between required reinforcement should not be so high. (round 500 mm^2/m)**

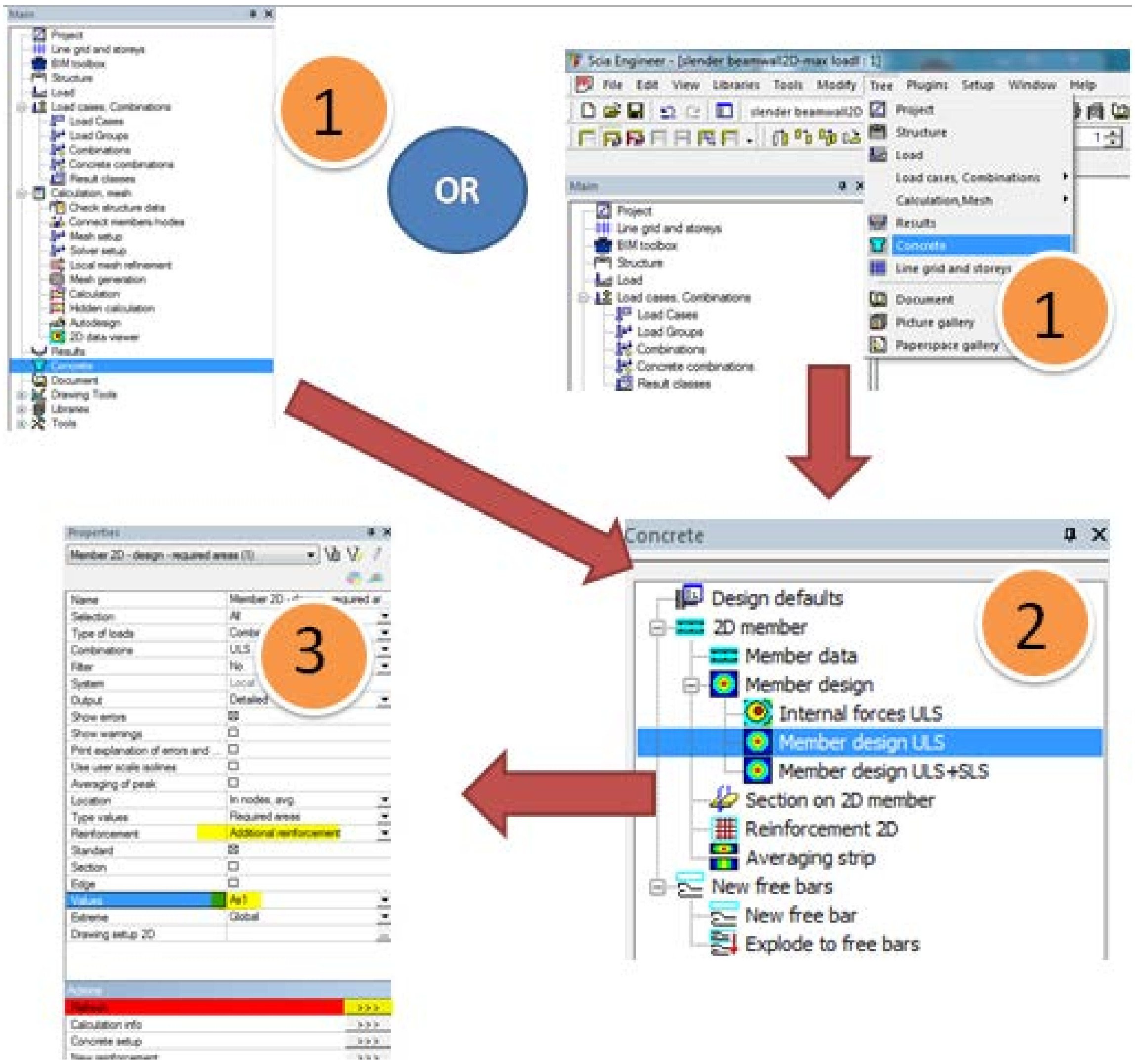
   Note: during reinforcing the elements in each step always begin reinforcement in places in which Scia gives higher required amount of reinforcements, this gives engineer the feeling of the element behavior in each step.

4- **Now for the first layer from bottom which is defined in the previous step, one can calculated needed amount of rebar's in this area of concrete element.**

5- **After calculating the required rebars in the first bottom layer of the concrete element. User should run the calculation again.**



6- **Concrete menu→design ULS→then from property menu from right →additional reinforcement (As1)→refresh**



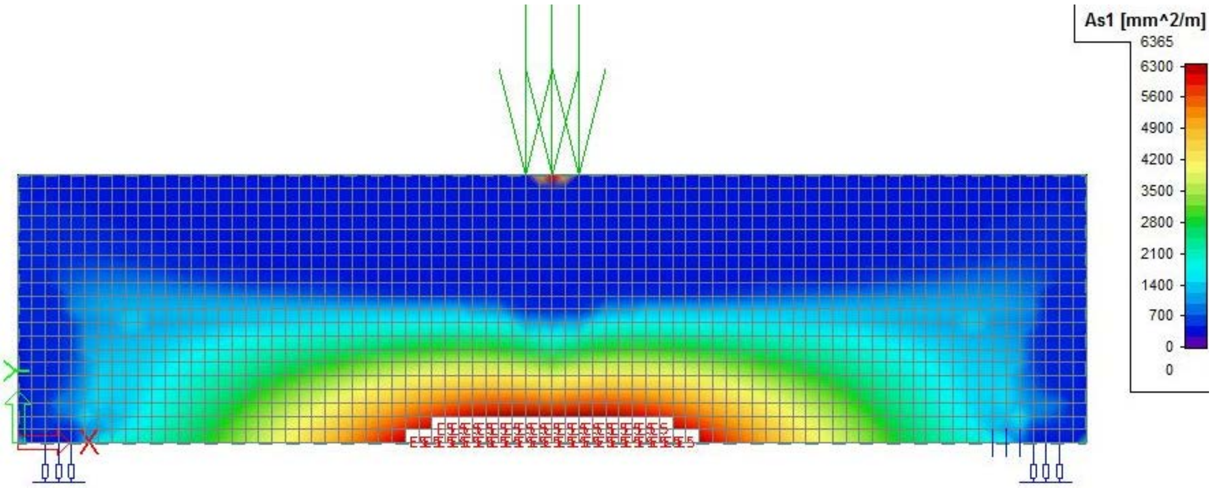
7- One can see the effect of one layer of reinforcement, and additional required reinforcement.

8- Now step 3 through step 7 should be repeated for other divided layers from step 2.

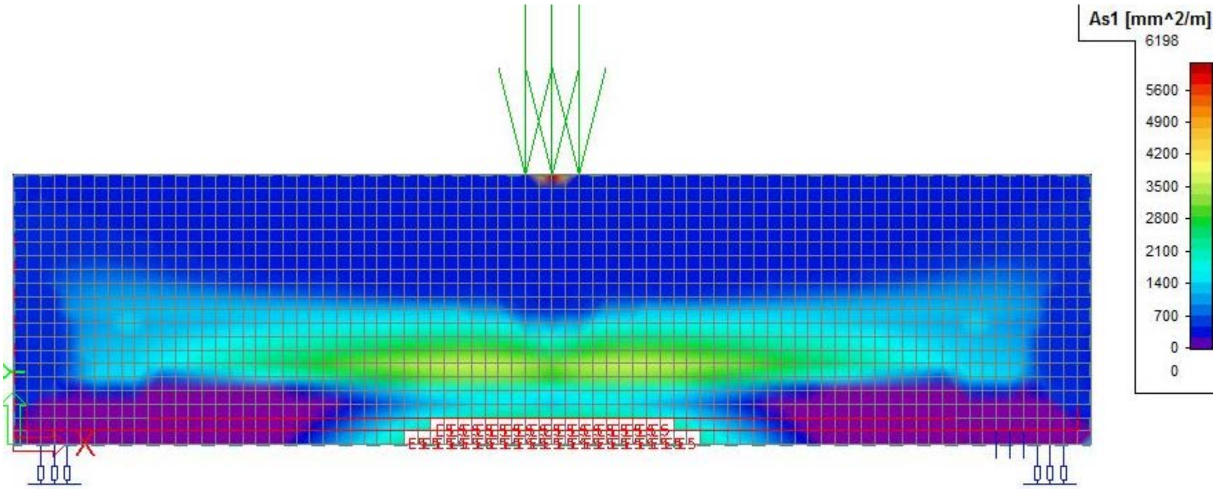
Note: one should perfectly take care about bottom reinforcement at higher loads. At higher loads Scia may give Error 5 at the bottom part of the beam, so user partially cannot see the whole bottom part, but right after the Error part the additional required reinforcement should be perfectly zero.(E5 error might be wisely ignored).

Figures step by step method (example)

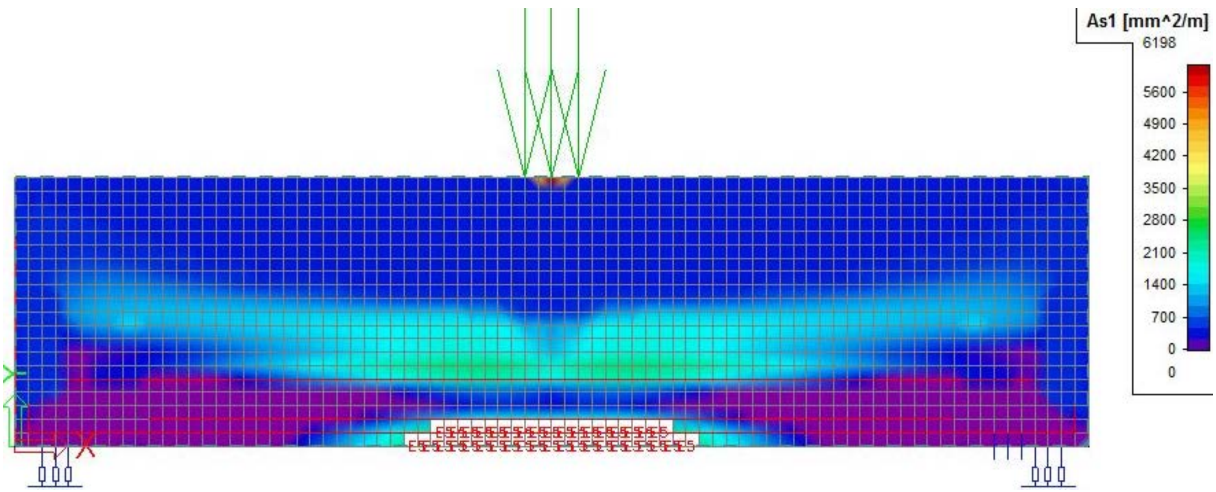
step1



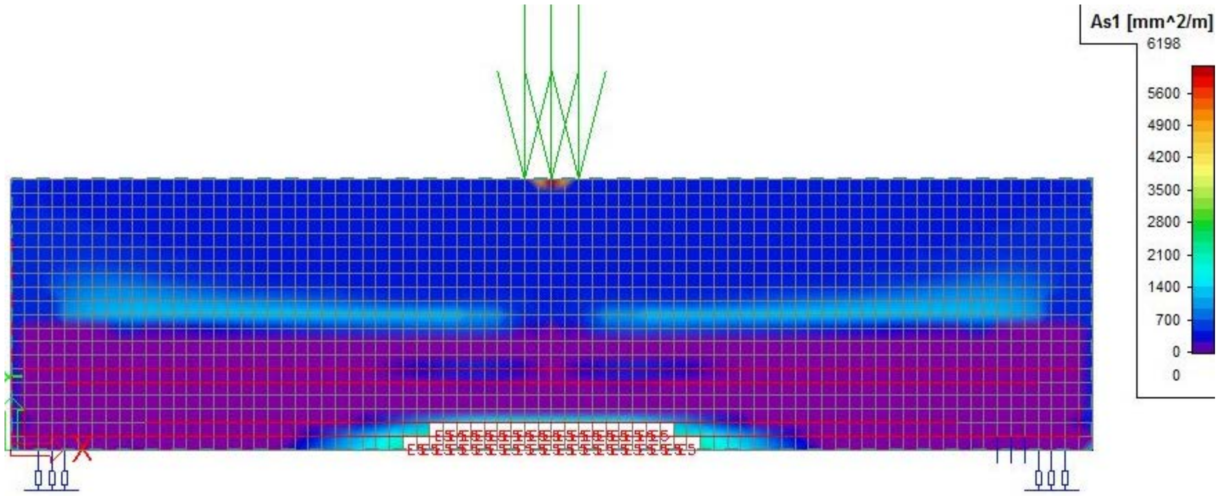
step2



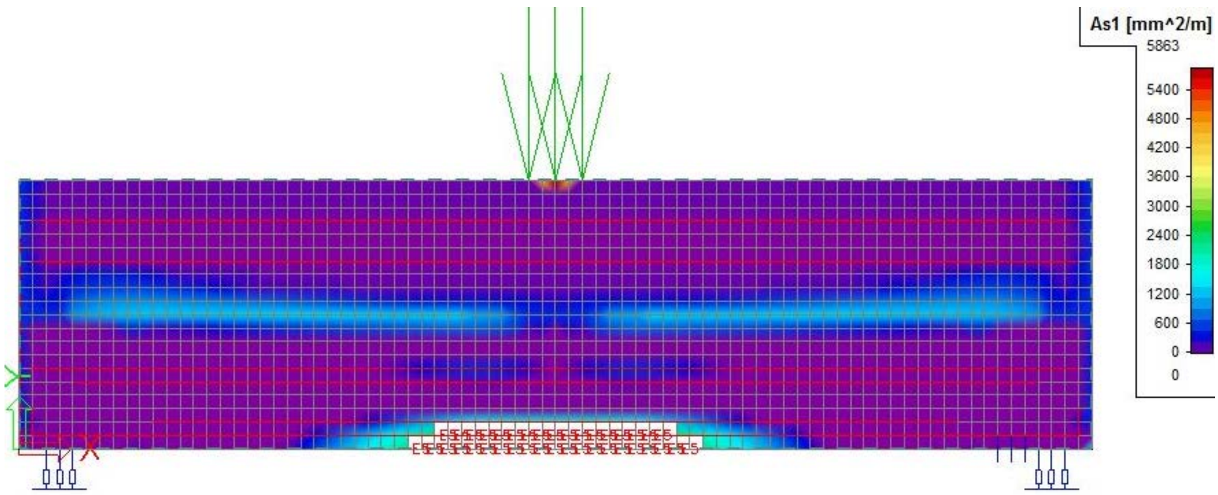
step3

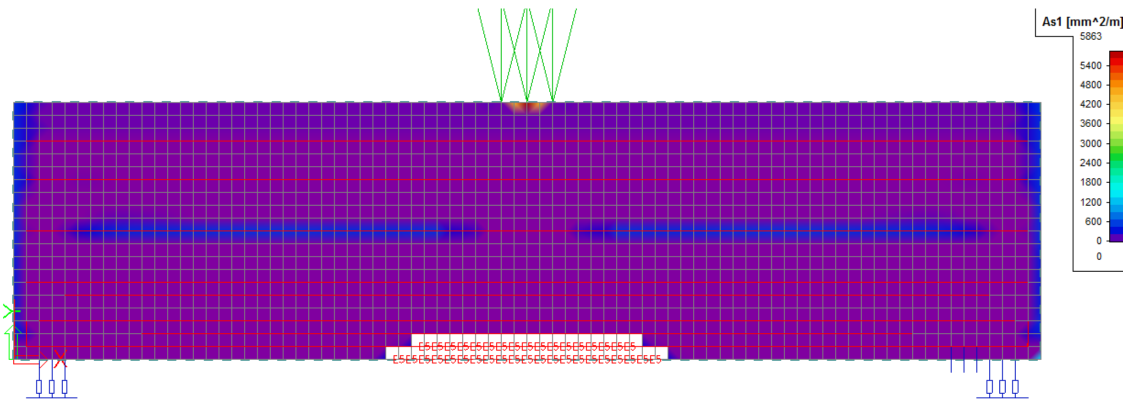


step4


As1 [mm^2/m]
6198
5600
4900
4200
3500
2800
2100
1400
700
0
0

step5


As1 [mm^2/m]
5863
5400
4800
4200
3600
3000
2400
1800
1200
600
0
0


As1 [mm^2/m]
5863
5400
4800
4200
3600
3000
2400
1800
1200
600
0
0

Appling STEP by STEP Method (SSM) in to the nonlinear 2D pressure only members

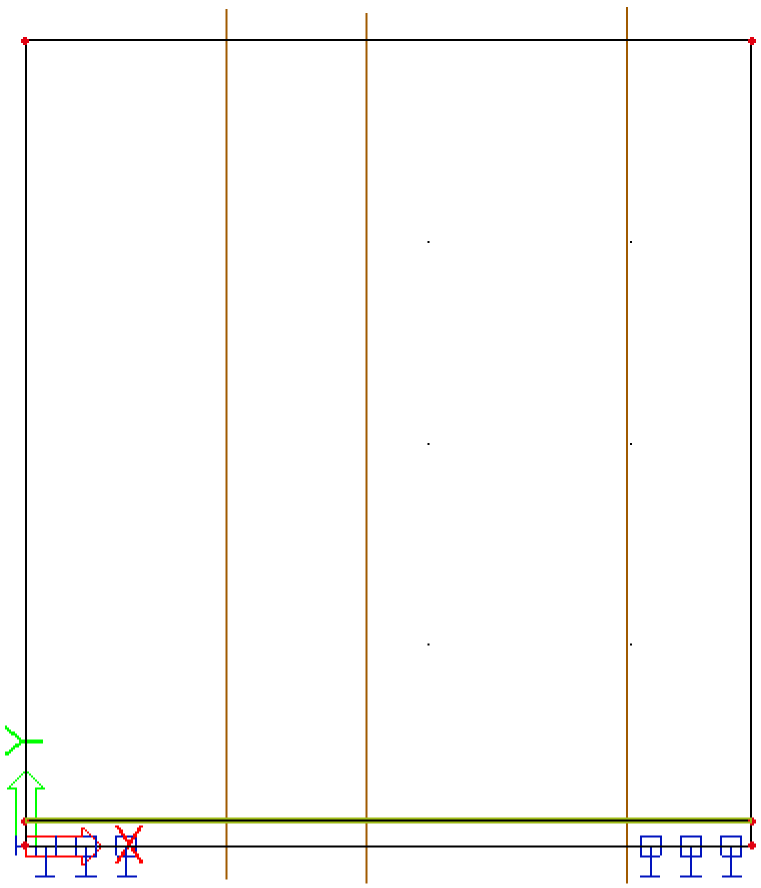
- **The principle is the same as in previous case**

  This method can be formulated as following:

Step 1: Model the specimen

Step 2: By using LE FEM, put an initial rib into the model

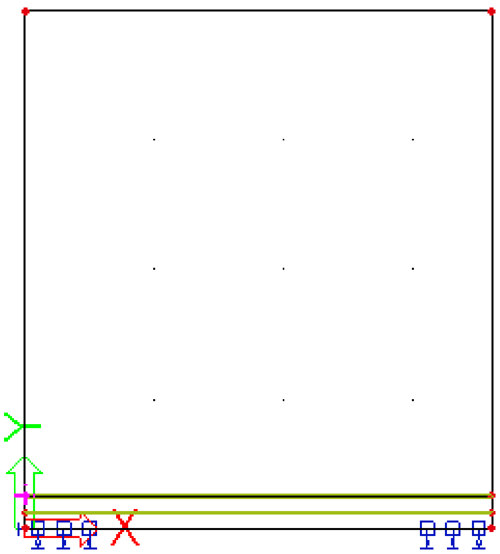
Step3: after choosing proper mesh net and mesh solver setup, run the nonlinear analysis(mesh of 100 mm and number of iteration of 250 is recommended)

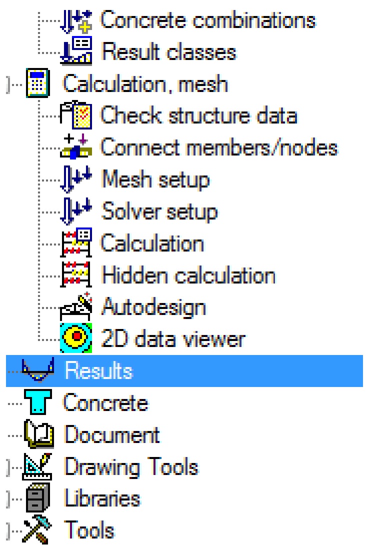


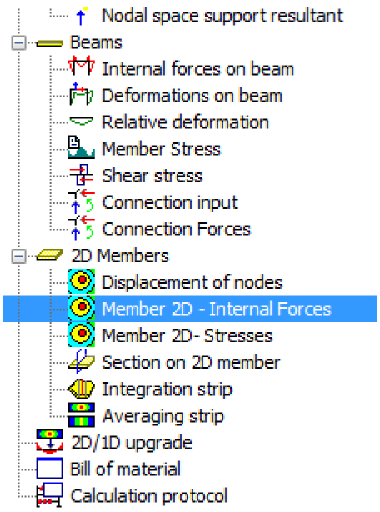
Step 4: If Scia Engineer is capable to do analysis without any error go to step 5,

Check the section ERRORS and TROUBLESHOOTING, at the end of this annex.

Step 5: In the result menu (CONCRETE MENU DOENST WORK IN NLFEM), choose Member 2D internal forces.

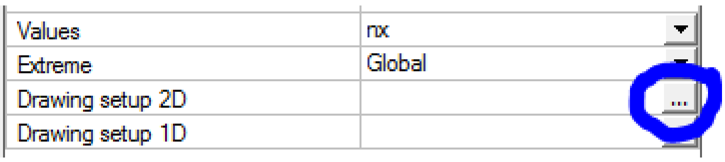


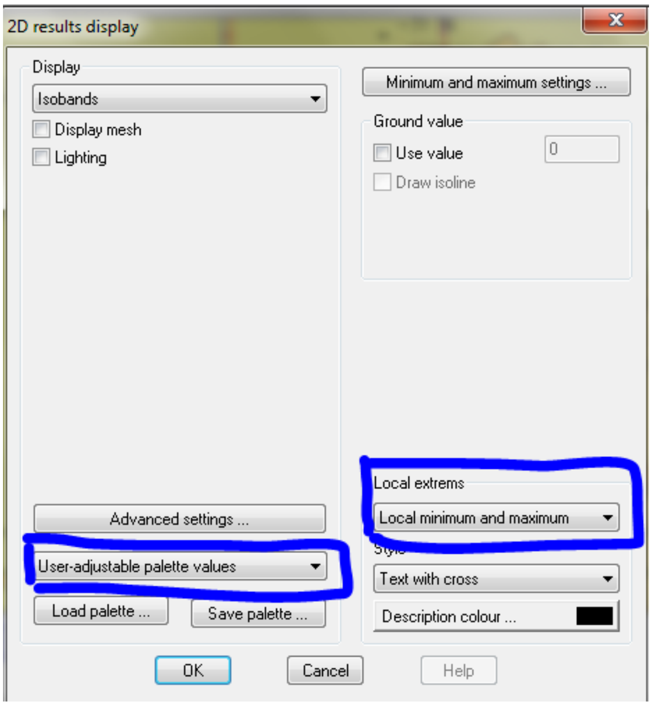




Step 5: by choosing Nx and Ny in the right menu, one can see the amount of forces in x and y direction.

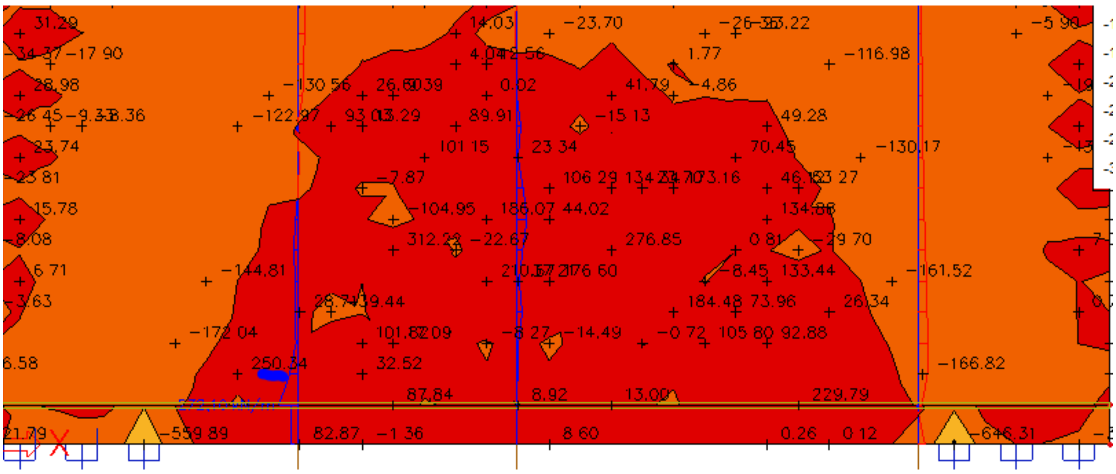
Note: It is important to choose in the “Drawing setup 2D” that Scia Engineer shows the local minimum and maximum.





Step 6: evaluation and decision making,

By looking at the Nx forces (kN/m) one can decide easily whether, more ribs (reinforcement) are needed or not. Important consideration here is that one, already knows that minimum mesh net (In this example $A_s = \emptyset 8 - 200 = 100,5\ mm^2/200mm$) is available.



Example: By looking at figure above one should find the highest values of Nx and to determine whether the mesh reinforcement of $\emptyset 8 - 200 = 100mm^2$ is enough or not. The following simple calculation can be carried out. The highest amount of Nx which can be found in figure above is $250\frac{kN}{m}$.

$$250\frac{kN}{m} \cdot 0,2m = 50\ kN$$

$$A_s = \frac{F}{\sigma_{yd}}$$

$$A_s = \frac{50000\ N}{435\ N/mm^2}$$

$$A_s = 115\ mm^2$$

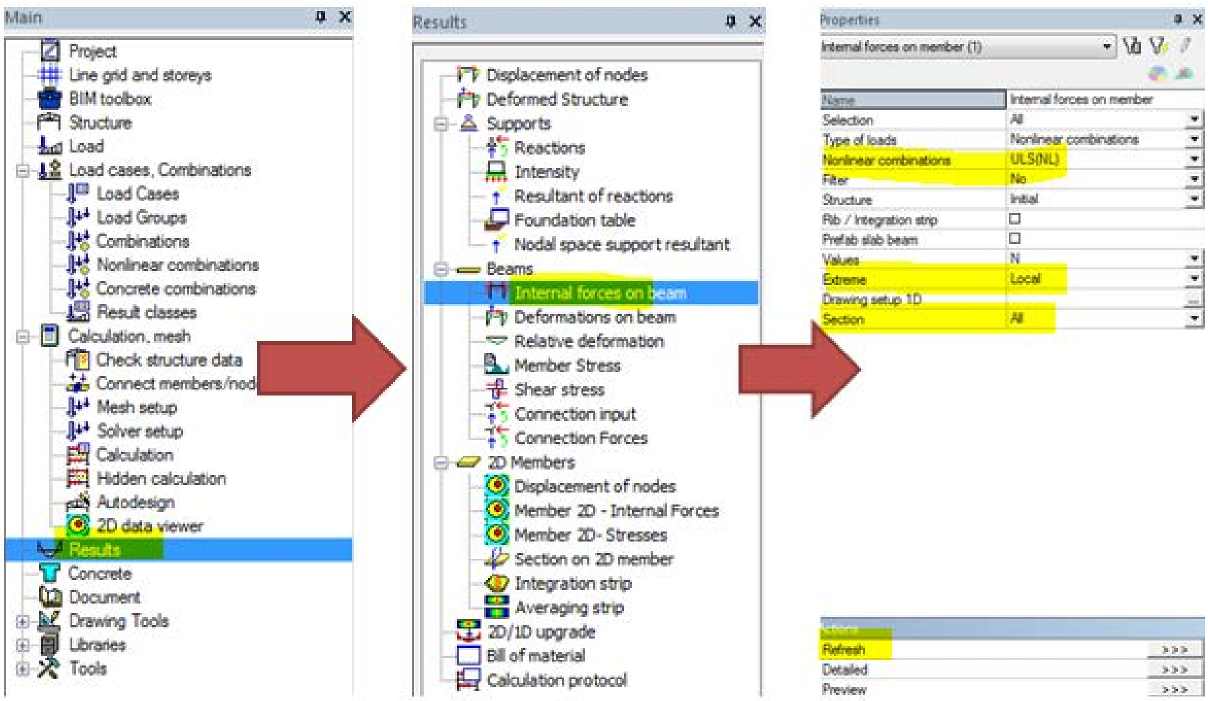
Step 8: compare A_s with amount of 2 $\emptyset 8 = 100mm^2$.

Step 9: IF $A_s > 100mm^2$ this means that Ribs should be added to those places where the highest amount of tensile forces are happening

Go again to step 2 and this procedure repeat itself till condition at step 10 is reached.

Step 10: If $A_s < 100mm^2$ this means there is no reinforcement needed any more. The reinforcement design is complete.

Step 11: Now from the result menu, under the tab beams and then internal forces on beams(figure below), Scia engineer determine amount of forces in each Rib. By knowing the amount of forces in each beam by simply dividing the amount of force by yield strength of the rebars which in this case is $435\ N/mm^2$, one can determine the amount of reinforcement needed .

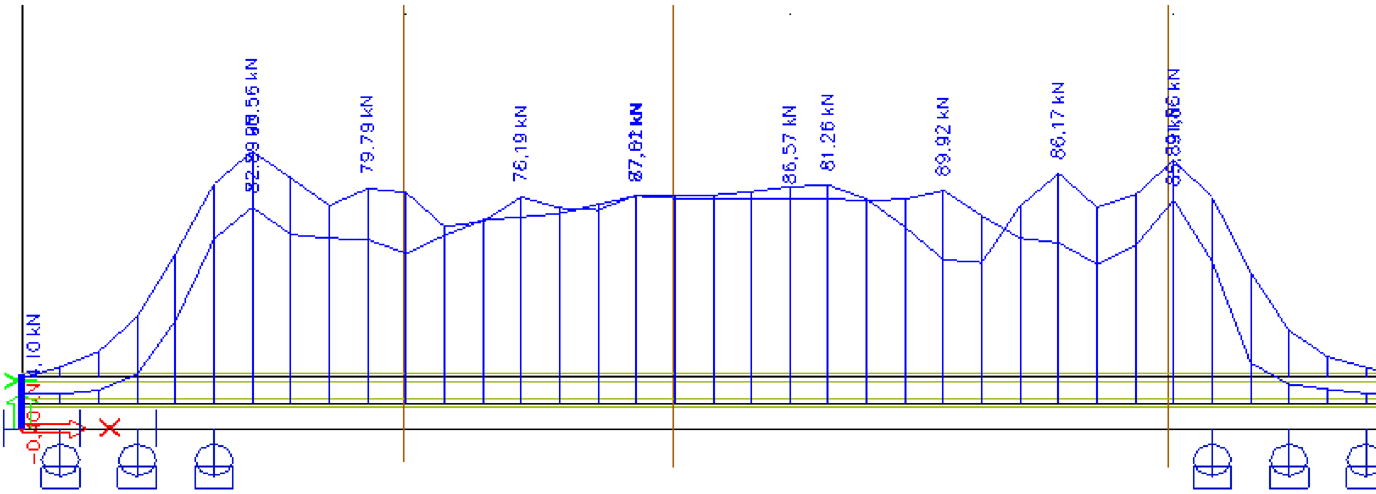


$$A_s = \frac{F_{Rib}}{\sigma_{yd}}$$

Example:

$$A_s = \frac{90000\ N}{435\ N/mm^2} = 206mm^2$$

$$2\emptyset 12 = 226\ mm^2\ \ OK$$



Important Note:

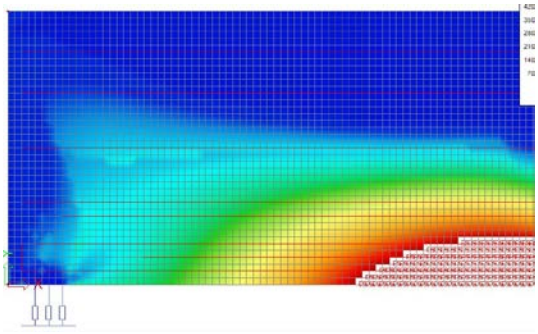
The procedure should also carried out for XY direction (Nxy) , to determine the amount of shear reinforcements. Bear in mind that before calculating amount of shear reinforcement from the Nxy the following two points should be considered:

1. **Consider NEN EN 1992-1-1 cl6.2.2 (6) – So multiply the amount of Nxy by the reduction factor from euro code.**
2. **Take into account imaginary mesh net which is available in the design(just like for Nx part)**

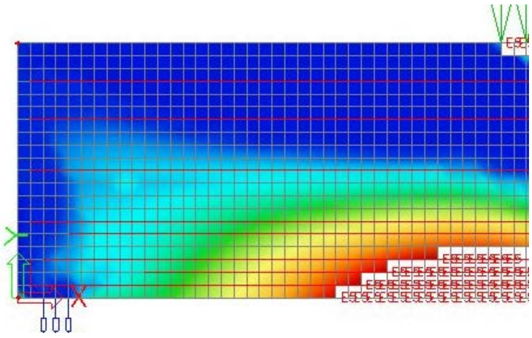
Mesh Dependencies in Scia Engineer

Applied load 600 kN mesh 10

Mesh 25



Mesh 50



Discussion about Scia

As it is shown in above figures, one can recognize that at the same load but with different mesh sizes the E6 error (at the applied load area) is appearing in the right figure while at the left figure it is absent.

Scia in different load steps which is dependent on mesh size, gives also some error codes in the mesh elements .In this Thesis Error E5 and Error E 6 is observed. The reason of these errors are also can be categorized as disadvantage of Scia Engineer. The reason of these errors which are highly dependent of mesh sizes can be illustrated as the following:

- **detailing provisions,**

It is reported that Scia Engineer consider all Eurocode and also non Eurocode detailing provisions, which some of them should be wisely ignored, otherwise Scia results are going to be conservative.

- **singularities**

However to avoid singularities at places like supports , it was decided to use spring supports ,but still dependent on the mesh size and the load E5 and E6 errors can be observed which makes it impossible to safely explaining the reason of these Errors and the results of them.

Environmental conditions for beams and walls

Eurocode EN1992-1-1 cl.4.2 Table 4.1 which is based on EN 206-1 classifies the influence of environmental conditions into exposure classes. Exposure conditions are chemical and physical conditions to which the structure is exposed in addition to the mechanical actions. In addition to Table 4.1 from Eurocode, Particular form of aggressive or indirect action also should be considered including chemical and physical attack as following:

1- Chemical attack
    - The use of building or structure(storage of liquids)
    - Solution of acids or sulfate salts
    - Chlorides contained in concrete
    - Alkali-aggregate reactions

2- Physical attack
  - Temperature change
  - Abrasion
  - Water penetration

It is assumed that none of the above mentioned particular form of aggression is occurring in the specimen's environment. All specimens are in class designation 2 in which the corrosion is induced by carbonation and the environmental condition is cyclic wet and dry, these conditions leads to exposure class of XC4.

Minimum concrete cover

Based on NEN-EN 1992-1-12011 cl. 4.4.1.2, table 4.4N, minimum concrete cover should be providing in order to ensure the following conditions,

- Bond reinforcement to the concrete is so that the two elements act together. The efficiency of the bond increases if the cover increases.
- Protection of the steel against corrosion (depend on the environment and type of member)
- Adequate fire safety(to protect the reinforcement from strength loss due to fire)

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

$c_{min,b}$	Minimum cover to bond requirements
$c_{min,dur}$	Minimum cover due to environmental conditions
$\Delta c_{dur,\gamma}$	Additive safety element
$\Delta c_{dur,st}$	Reduction of minimum cover for use of stainless steel
$\Delta c_{dur,add}$	Reduction of minimum cover for use of additional protection

The recommended structural class (design working of 50 years) is S4 .Also for indicative minimum strength class of concrete for carbonation induced corrosion, EN-1992-1-1 Annex E, suggests the strength class of C30/37.

Ontwerplevensduur-klasse	Richtwaarden ontwerplevensduur (jaren)	Voorbeelden
1	10	Tijdelijke constructies (1)
2	10 tot 25	Vervangbare constructieve onderdelen, bijv. kraanbaanliggers, opleggingen
3	15 tot 30	Landbouwkundige en soortgelijke constructies
4	50	Gebouwen en andere gewone constructies
5	100	Monumentale gebouwen, bruggen en andere civieltechnische werken
(1) Constructies of delen van constructies die kunnen worden ontmanteld met de bedoeling om te worden hergebruikt behoren niet als tijdelijk te zijn aangemerkt.		

Table 3.2, indicative design working life,[EN-1990:2002+A1:2005]

As a guideline for determining concrete cover, one can also use flow diagram in GTB 2010-5.3.

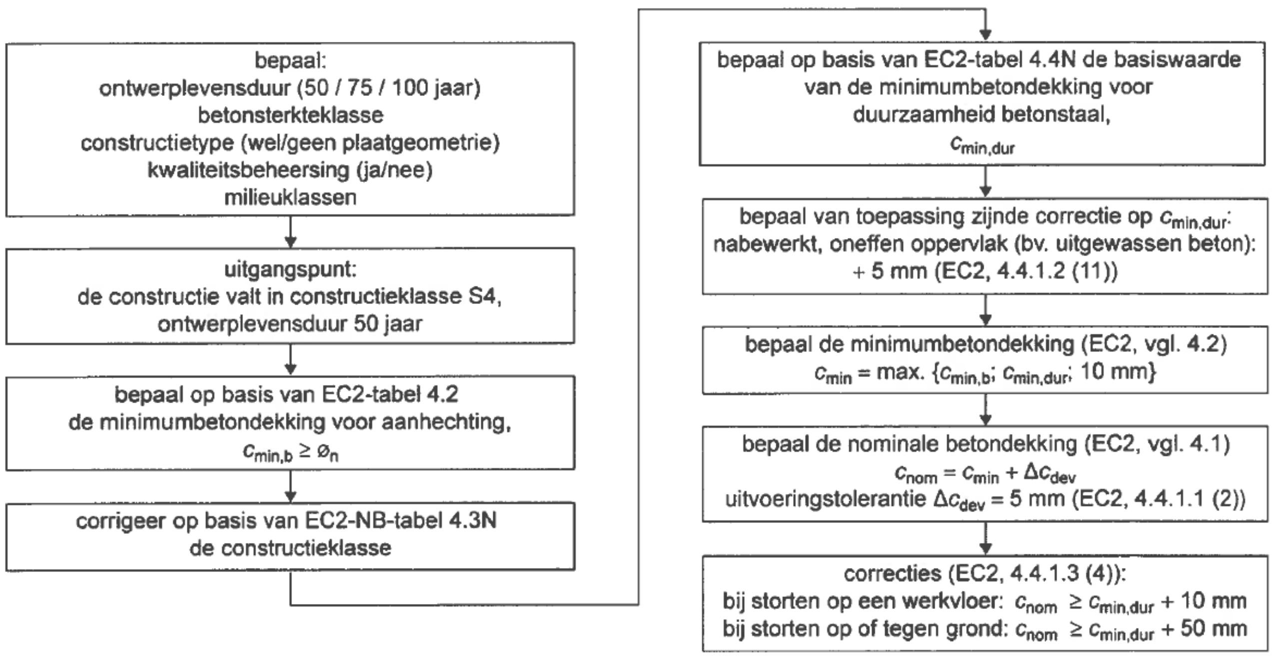


Table 3.3 Flow diagram GTB2010- 5.3

SCIA Errors

Slender Beams

During the loading phase of the 2D Scia finite element Model, one can recognize happening of the E5 and E6 errors in the different mesh elements in the model.

E5
When this error happens, Scia explain that “a higher cross section can no more be achieved by further raising the reinforcement amount”. The reasons for this error is too many detailing provisions that Scia takes into account.

Error E5

5	Error	Upper reinforcement limit exceeded. A higher cross-section resistance can no more be achieved by further raising the reinforcement amount. Enable for a higher percentage limit (if acceptable or based on constructive measures, respectively) or choose a higher cross-section height. Using higher concrete class may be efficient in prevailingly compressed members only. In certain situations also other reinforcement geometry can help.

Error E6

When this error happens means that, at that point failure of the compression struts is happening. This error is highly mesh dependent, and based on this error no reliable explanation about behavior of the specimens can be derived.

S1	6	Error	Allowable concrete strut pressure exceeded. The error message concerns the virtual concrete strut, which symbolises the stiffening function of the concrete continuum, failing due to the actual load impact ?? Try a higher cross-section or a higher concrete class. Choosing another reinforcement geometry may be the optimum solution ("trajectory reinforcement"). Purely increasing the reinforcement amount is, however, inefficient.

ERRORS in the results

For 1D analysis in slender beams in the results, which is done according to Eurocode, sometimes one may get some errors in the check column of the analysis. It is important to know the background of these errors. For example in the below figure , Scia does check the maximum bar diameter based on NEN-EN 1992-1-1 cl.7.3.3, but bear in mind that only one of the two tables in Eurocode (7.2N or 7.3N) should be satisfied and not both of them. As a result of this knowledge about te background of control checks in Scia Engineering, one can simply ignore such these errors.

7.3.3 Control of cracking without direct calculation (Max. profile diameter)

elem	x.loc [m]	N [kN]	My [kNm]	h [mm]	d [mm]	hcr [mm]	sigma [MPa]	phi s* [mm]	phi prov. [mm]	phi s [mm]	check calc	check lim	check	Errors Warnings
B1	2.00	0	210	1000.0	836.4	500.0	343.9	8.8	10.0	5.4(P)	1.8	1.0	NOT OK	669

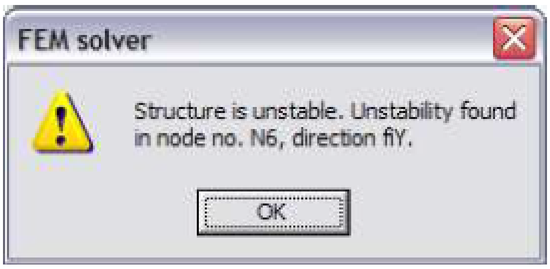
Explanation of calculation info

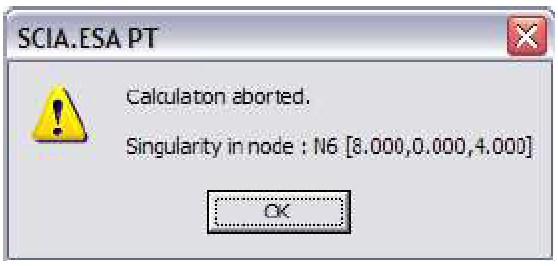
Warning Error	Explanation
669	the bar diameter calculated by crack control is lesser than the input bar diameter.

SCIA Errors for NLFEM Deep Beams

Singularity[1]

In nonlinear analysis singularities can happen frequently. The following messages can be showed during analysis.





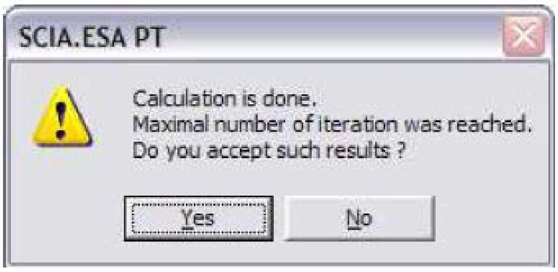
The following reasons and solution are related to singularity errors

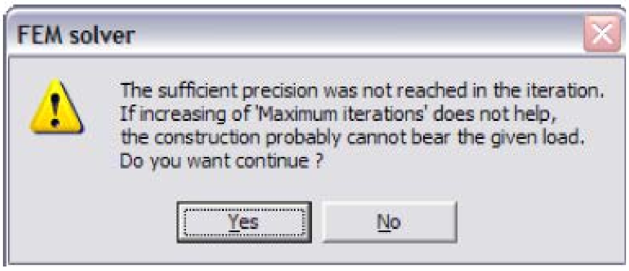
- The structure is instable and is mechanism. Check supports, hinges, un-connected members.

- The structure is unstable due to the plastic hinges.
- Instability can be caused due to the small section properties of manually inputted cross section,(the torsional resistance is too small).
- The Timoshenko method is not suitable when normal force in a member is larger than its critical buckling load. Newton Raphson is the better solution for these conditions. To be able to find which cross section cause this problem , the sections can be adjusted and modified alternately until the second order calculation passes.

Convergence [1]

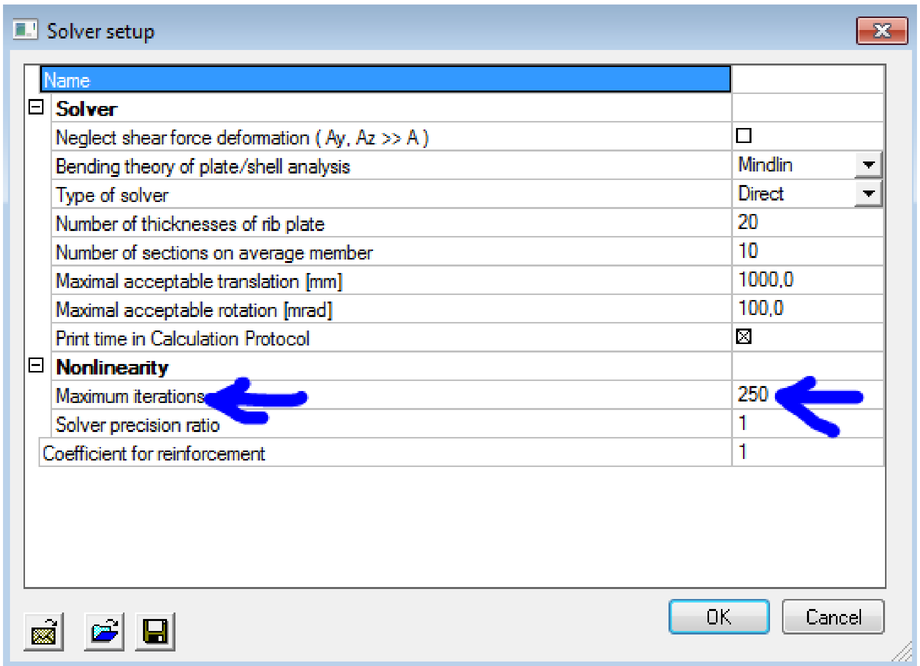
It is possible that during SSM or step by step method, the criterion of convergence is not met. The following messages are typical error messages in this case





The following reasons and solution are related to Convergence errors

- There are just few iterations have been specified in the solver setup. One can simply choose for higher amount of iterations.(figure below)



- The structure is close to instability. The reasons which are mentioned in the singularity part can also be related to this part. Moreover, this might also be caused by too big cracks in the specimen. To be able to solve this problem one may add extra Ribs in to the specimen in sensitive areas where probably high tensile stresses happens.

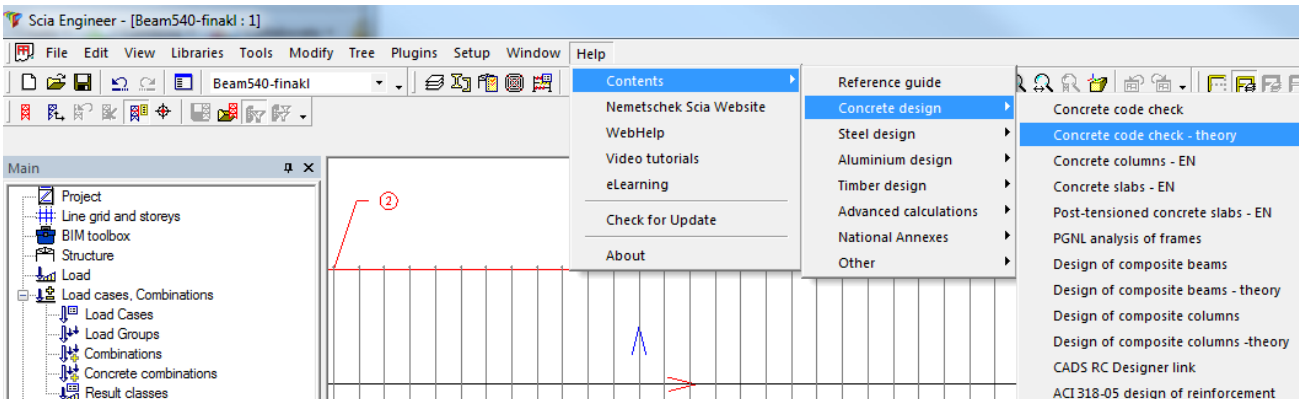
- Cyclic elimination of members or supports.
- If nonlinear stability calculation does not converge, make sure second order is activated as functionality.

[1] Advanced concept training "Non Linear and Stability" 2013 – Scia Engineer manual

Annex 4

Minimum requirements which is used in SCIA:

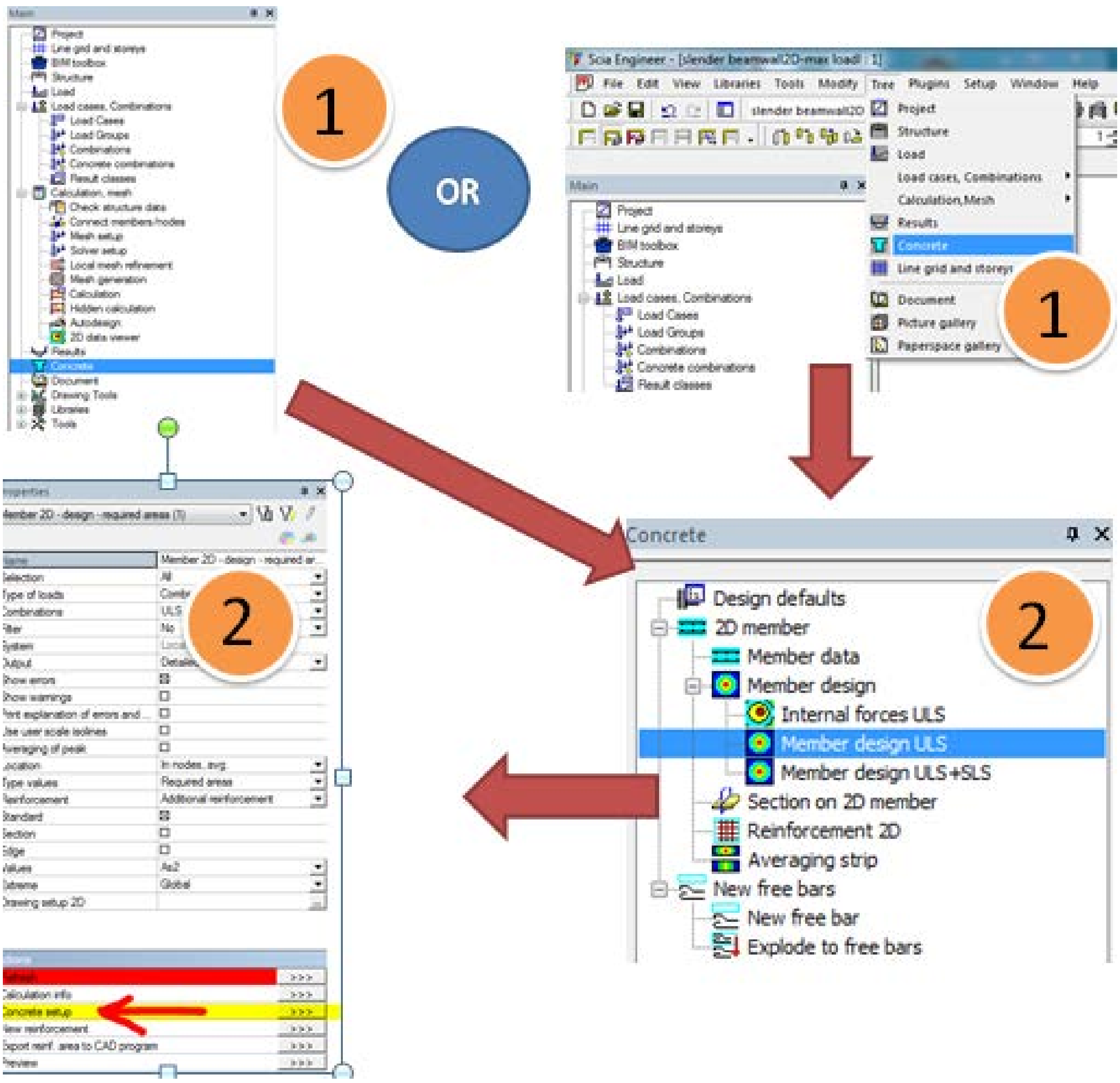
- This annex contains the most important Eurocode requirements in Scia Engineer 2011
- The aim of this annex is to clarify , the background work and calculations of Scia engineer in terms of Eurocode for daily engineering practice
- For all Extra details over Scia Engineer 2011 refer to the help contents in the Help menu of the program. Scia engineering→help→contents→concrete design



Requirements for 2D FEM in Scia Engineer 2011

Making the 2D FEM model in Scia Engineer is already extensively in the previous annexes illustrated. One by following the following guideline can reach the setup menu related to the Eurocode in the program.

After calculation step→concrete→member design ULS(left menu)→concrete setup (bottom right menu) Or (Setup menu > Concrete solver)



1. **Standard EN→concrete→design defaults→concrete cover**

-Here exposure class can be chosen which is defined in the Eurocode

2. **standard EN→concrete→design defaults→2D structures**

Here upper and lower reinforcement can be chosen. Upper and lower reinforcement in this thesis is actually the longitudinal reinforcement in the beam specimens.

3. standard EN→concrete→ULS→shear→2D structures

Here shear strut inclination and shear effect control according to NEN-EN 1992-1-1 cl. 6.2.3
Shear effect control cl.. 6.2.3 (7)

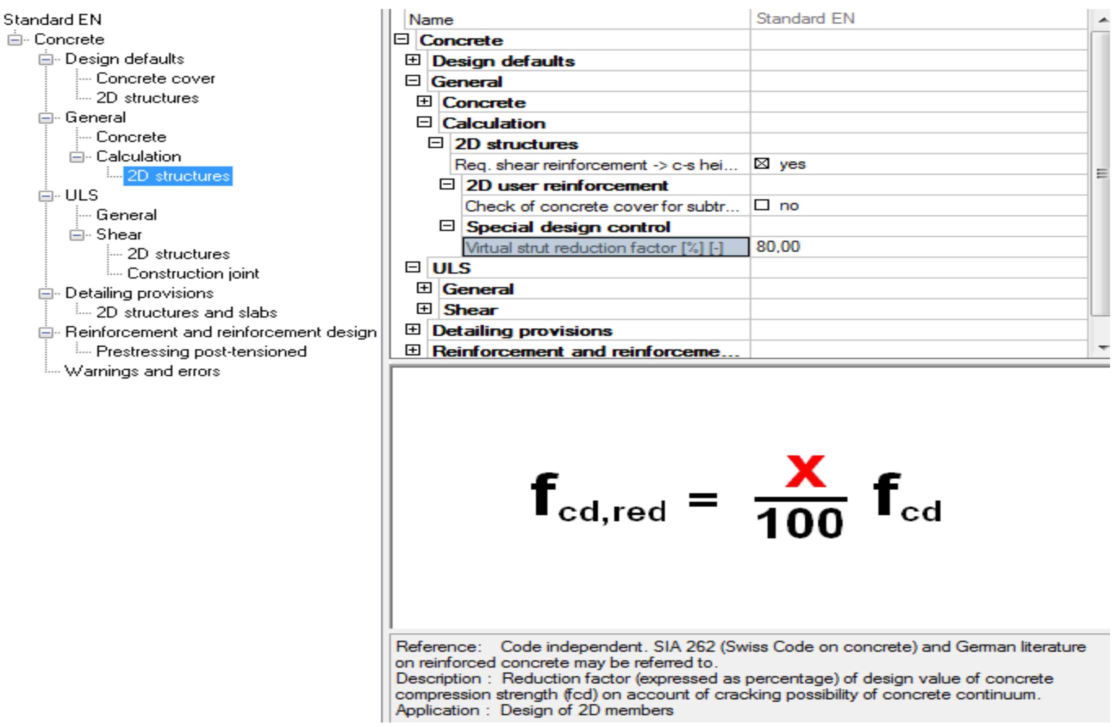
4. standard EN→concrete→detailing provision→2D structures and slabs→reinforcement

Here minimum transverse reinforcement according to NEN-EN 1992-1-1 9.3.1.1 (2). Cl..9.3.1.1 (2) is about secondary transverse reinforcement in the solid slabs. This minimum transverse reinforcement is referred as vertical reinforcement. NEN-EN 1992-1-1 cl.. 9.6.2(1,2) is about Minimum and maximum reinforcement in walls. Here is also referred to the Eurocode, which is about vertical reinforcement in the walls. But in Scia it is about longitudinal reinforcement which is in connection with upper and lower reinforcement from 2.

- **Minimum degree of reinforcement NEN-EN 1992 cl..9.6.2(1)**
- **Minimum tension lower reinforcement, which is calculated automatically by Scia with equation 9.1N from NEN-En 1992-1-1 cl., 9.2.1.1 (1).**
- **Minimum bar distances**
- **maximum bar distances**

Scia Engineer uses also code independent, SIA 262 from Swiss code. In figure below one can see that Scia uses a reduction factor for compression struts to take into account the effect of cracks in 2D FEM model. This factor is implicitly also presented in NEN-EN 1992-1-1 cl.6.5.2, for calculation of the strength of the struts in the strut and tie model.

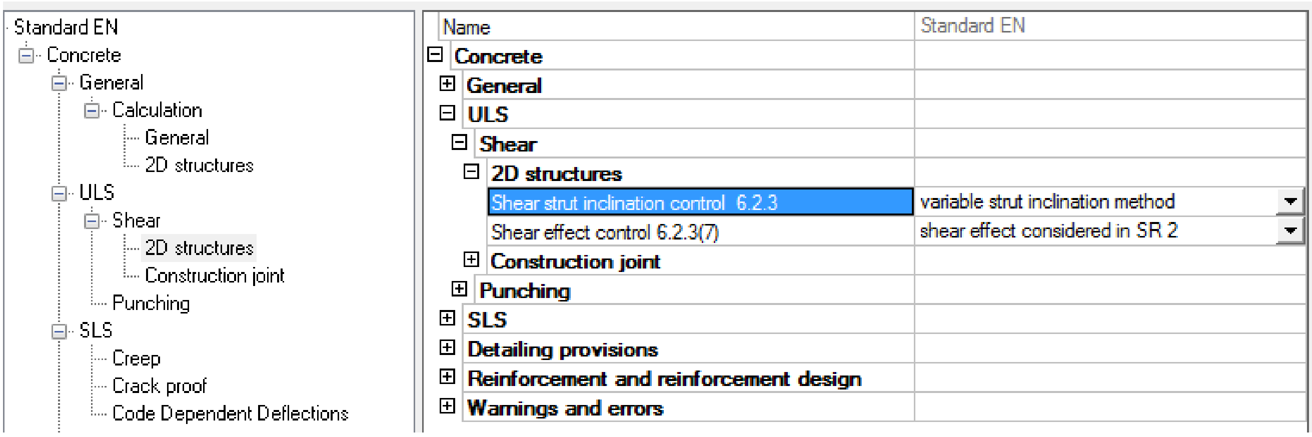
Standard EN→General→2D Structures→special design control



The Swiss structural codes comprise the following:
– SIA 260 Basis of structural design
– SIA 261 Actions on structures
– SIA 262 Concrete structures
– SIA 263 Steel structures
– SIA 264 Composite steel and concrete structures
– SIA 265 Timber structures
– SIA 266 Masonry
– SIA 267 Geotechnical design.

This reduction factor in Scia Engineer which is based on other codes than Eurocode, can also be compared to the reduction factor in strut and tie model in Eurocode. In NEN-EN 1992-1-1 cl.6.5.2, for calculation of the strength of the struts, depends on the situation, a reduction factor is introduced.

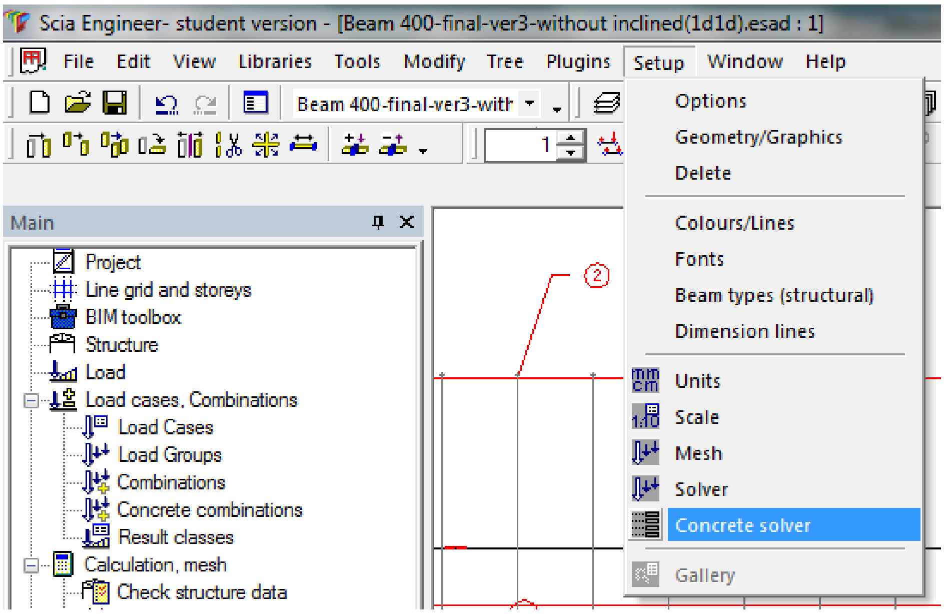
SETUP→Concrete solver→concrete setup window→concrete→ULS→Shea→2D structures→Shear strut inclination control 6.2.3



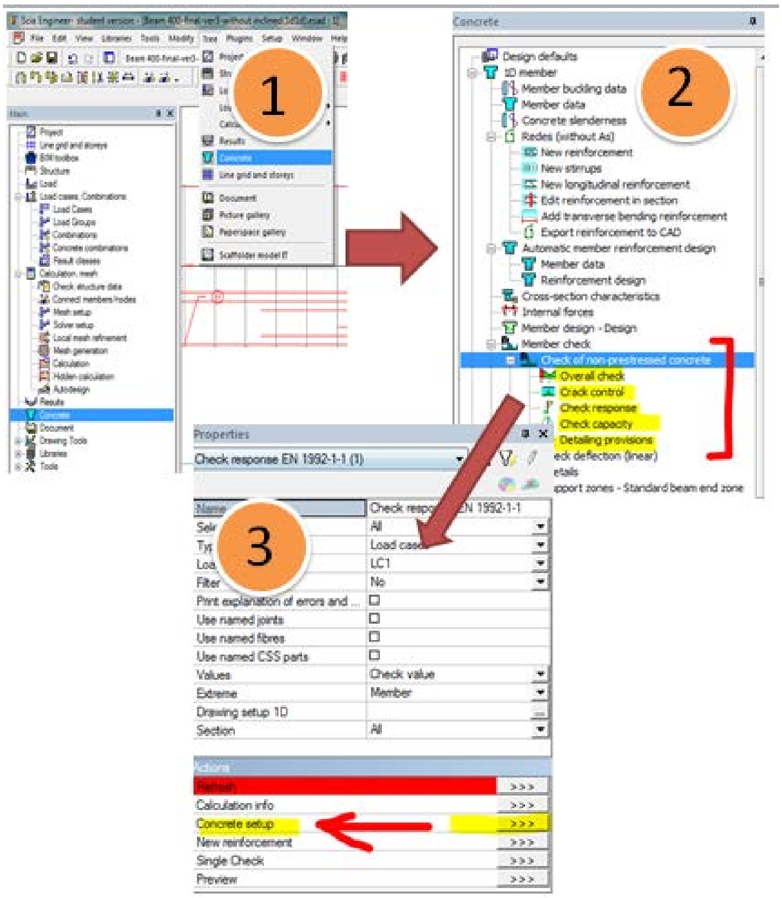
Requirements for 1D element in Scia Engineer 2011

Reinforcement

Setup tab in the main menu→concrete solver



Or



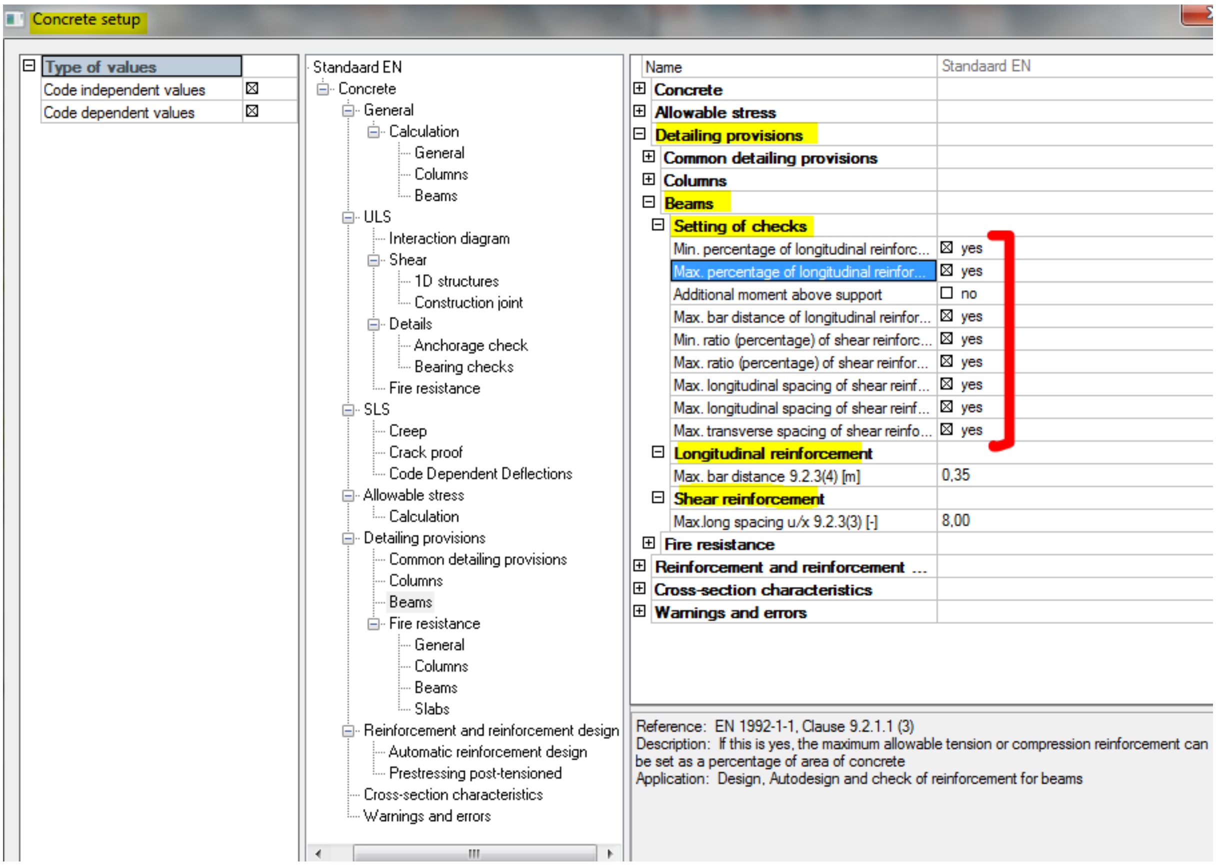
In Concrete solve menu→detailing provisions→beams→one can see that Scia using the following articles from NEN EN-1992-1-1, for design checks and control:

In Concrete solve menu→detailing provisions→beams→setting of checks

Minimum percentage of longitudinal reinforcement EN 1992-1-1 cl.9.2.1.1 (1)

Maximum percentage of longitudinal reinforcement EN 1992-1-1 cl.9.2.1.1 (3)

Norm independent (1)
Maximum distance between longitudinal rebars
Norm independent (2)
Minimum ratio for shear reinforcements
Maximum ratio(percentage) of shear reinforcement EN 1992-1-1 eq 6.12
Norm independent (4)
Maximum longitudinal distance between shear reinforcements for shear.
Norm independent (5)
Maximum longitudinal distance between shear reinforcements for Torsion.
Norm independent (6)
Maximum transversal distance between shear reinforcement.



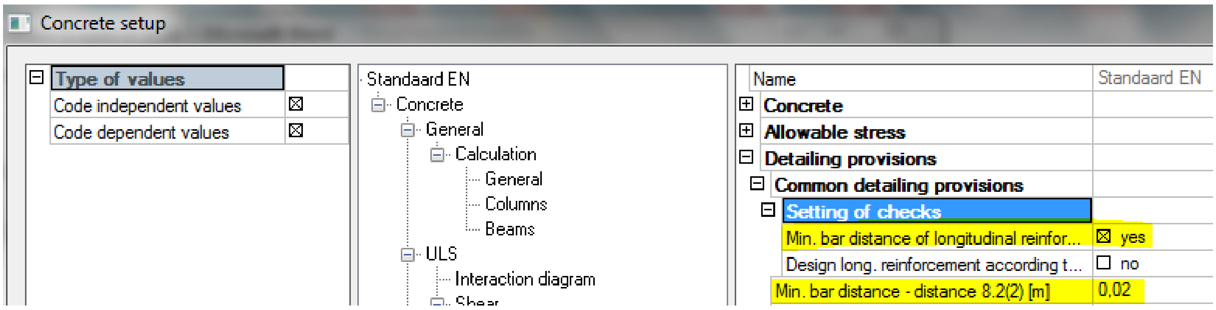
In Concrete solve menu→detailing provisions→beams→longitudinal reinforcement

Maximum bar distance according to EN 1992-1-1 cl.9.2.3(4) (350 mm)

In Concrete solve menu→detailing provisions→beams→Shear reinforcement

Maximum longitudinal distance between the torsion links in a beam be set according to EN 1992-1-1 cl.9.2.3(3)

In the same Concrete setup menu→detailing provisions→Common detailing provisions

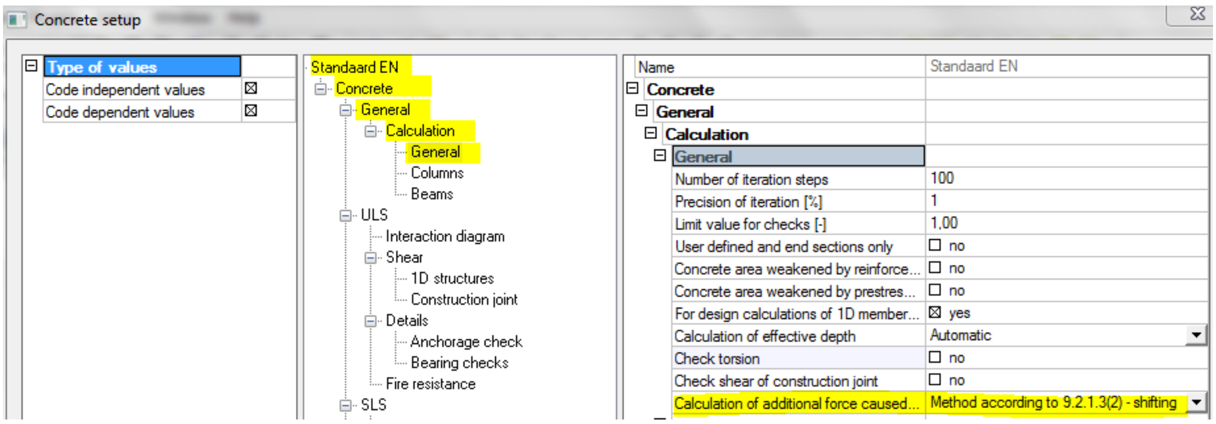


Here one can recognize that Scia for minimum distance between bars, uses EN 1992-1-1 cl.8.2(2) from Eurocode.

NEN-EN 1992-1-1 8.2 Spacing of bars

NEN-EN 1992-1-1 8.3 Permissible mandrel diameters for bent bars

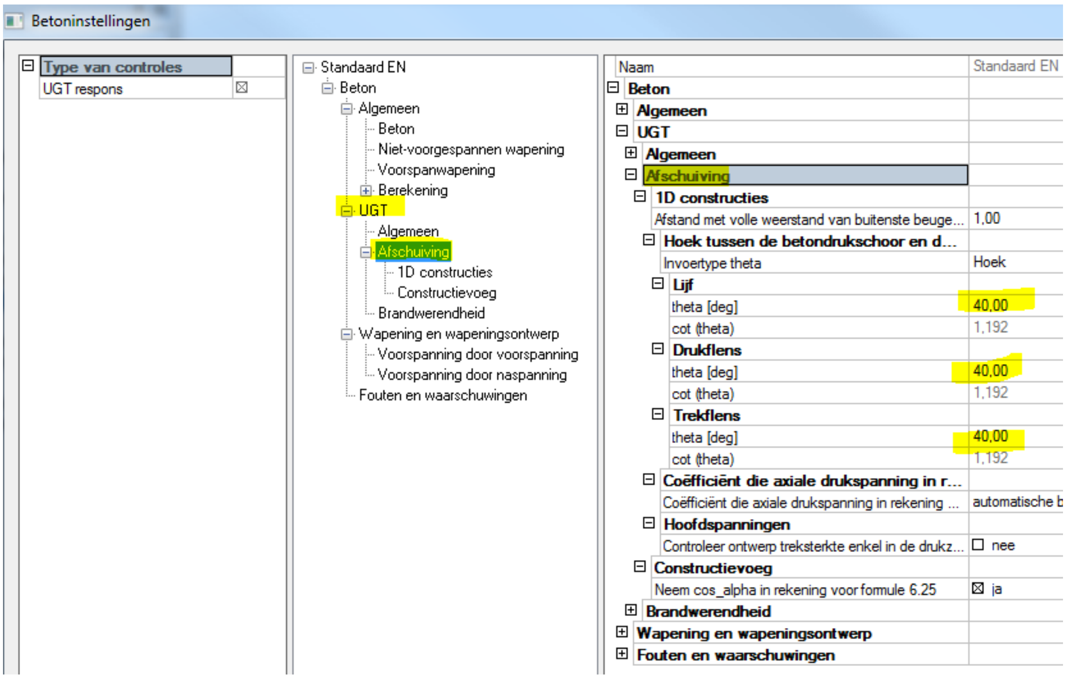
In Concrete solve menu→General→calculation→general



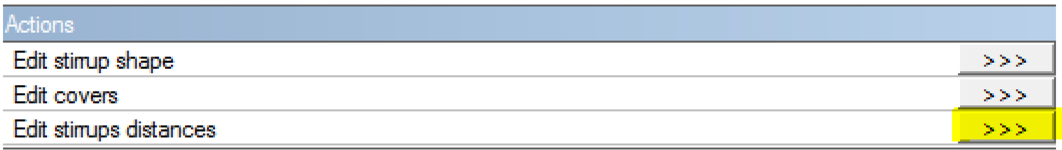
In the general tab , one can see that Scia engineer uses moment shift method according to -EN 9.2.1.3(2) – NEN-EN 1992-1-1 6.2.2(5).

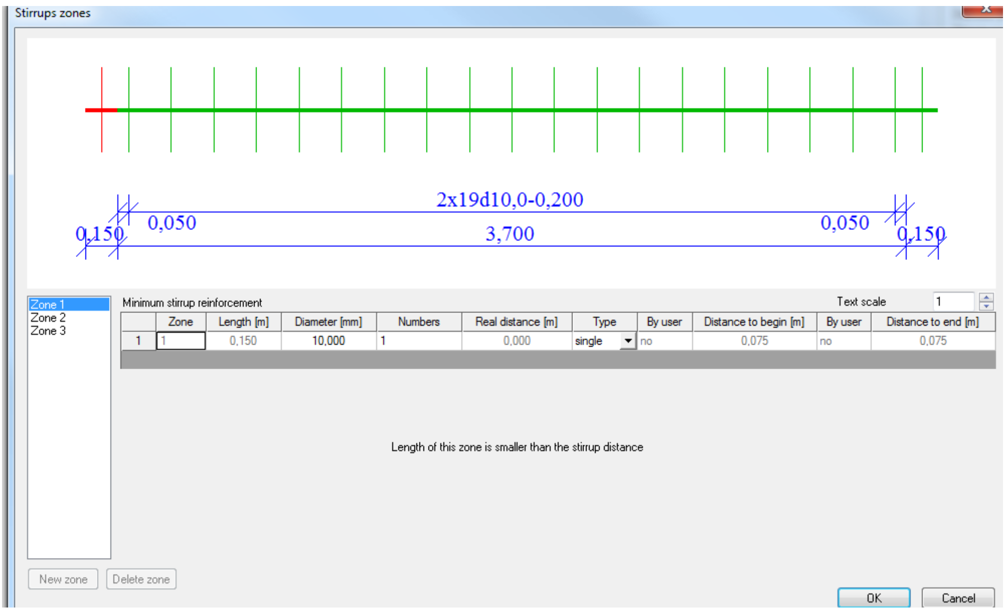
NEN-EN 1992-1-1 9.2.1.3 Curtailment of longitudinal tension reinforcement
NEN-EN 1992-1-1 Cl.. 6.2.3 , Concrete setup menu→ULS→shear

In contrary to 2D modeling, 1D modeling in Scia Engineer software, uses fixed strut inclination method with a default value for $\theta$is set to 40 degrees.



With mouse choose shear reinforcement→right bottom of the main window "action window"→edit stirrups distances

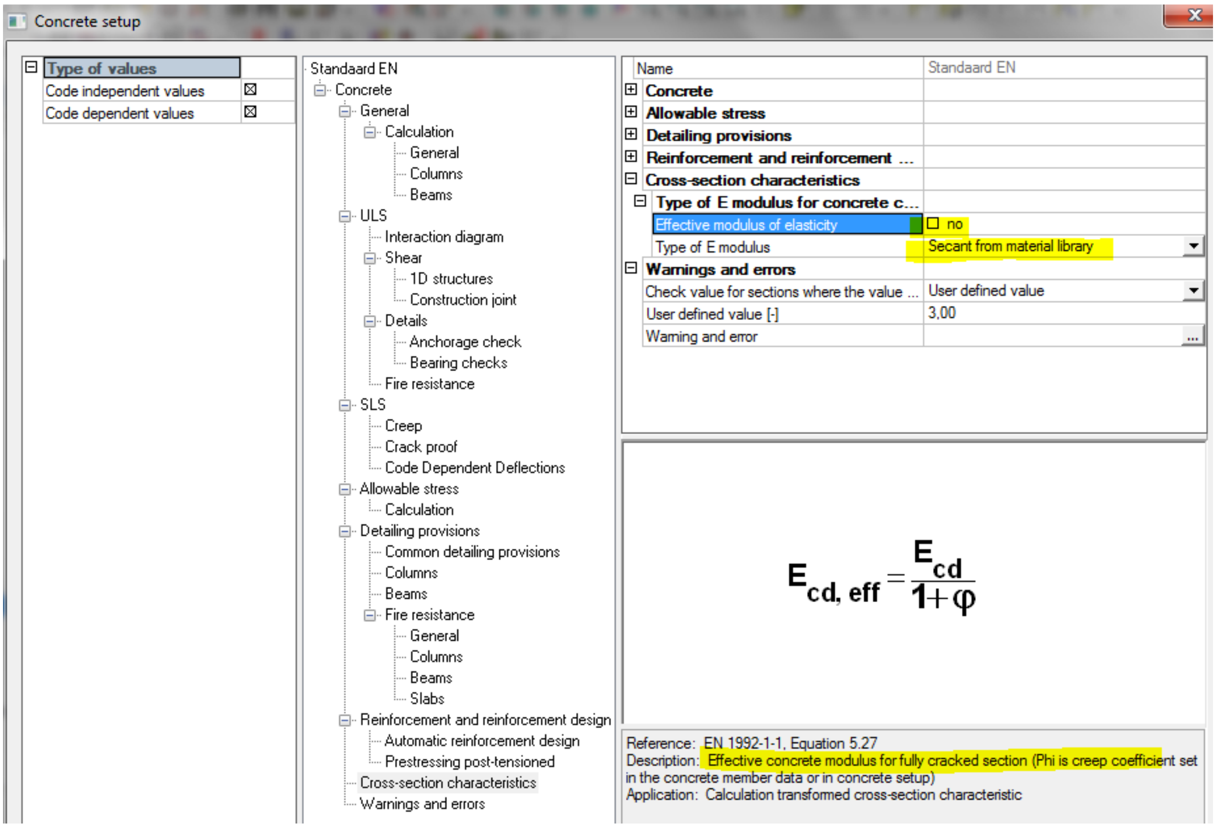




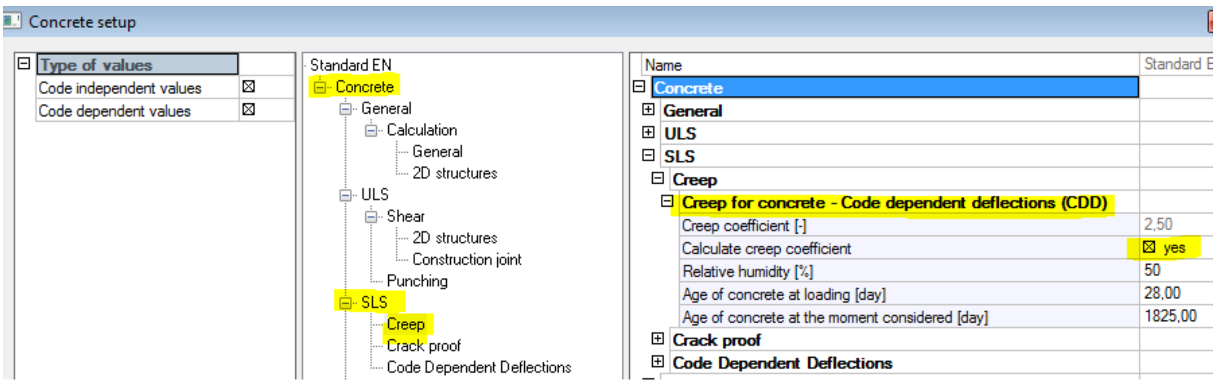
Note: because at support there are always the higher shear stresses, Scia engineer uses smaller distances between stirrups nearby support areas. This distance also can be edited if needed.

Concrete solver menu→cross-section characteristics→type of E modulus

It is possible for Scia to use effective concrete elasticity modulus for fully cracked section according to EN 1992-1-1 eq5.27. Here stiffness is based on an effective concrete modulus. By using equation 5.27 form Eurocode the effect of creep would be also taken into account.



Concrete→SLS→Creep, Creep factor is only used if CDD or Code dependent deflection method is used. This method is more for plate analysis where load is perpendicular to the plane. More information about CDD refers to Scia Engineering document “Advanced concept training”. NEN-EN 1992-1-1 cl. 5.8.4 Creep



Annex 5

Scia Engineer 2011 examples can be found at the following address

www.babak-dadvar.com/thesis/babak.html

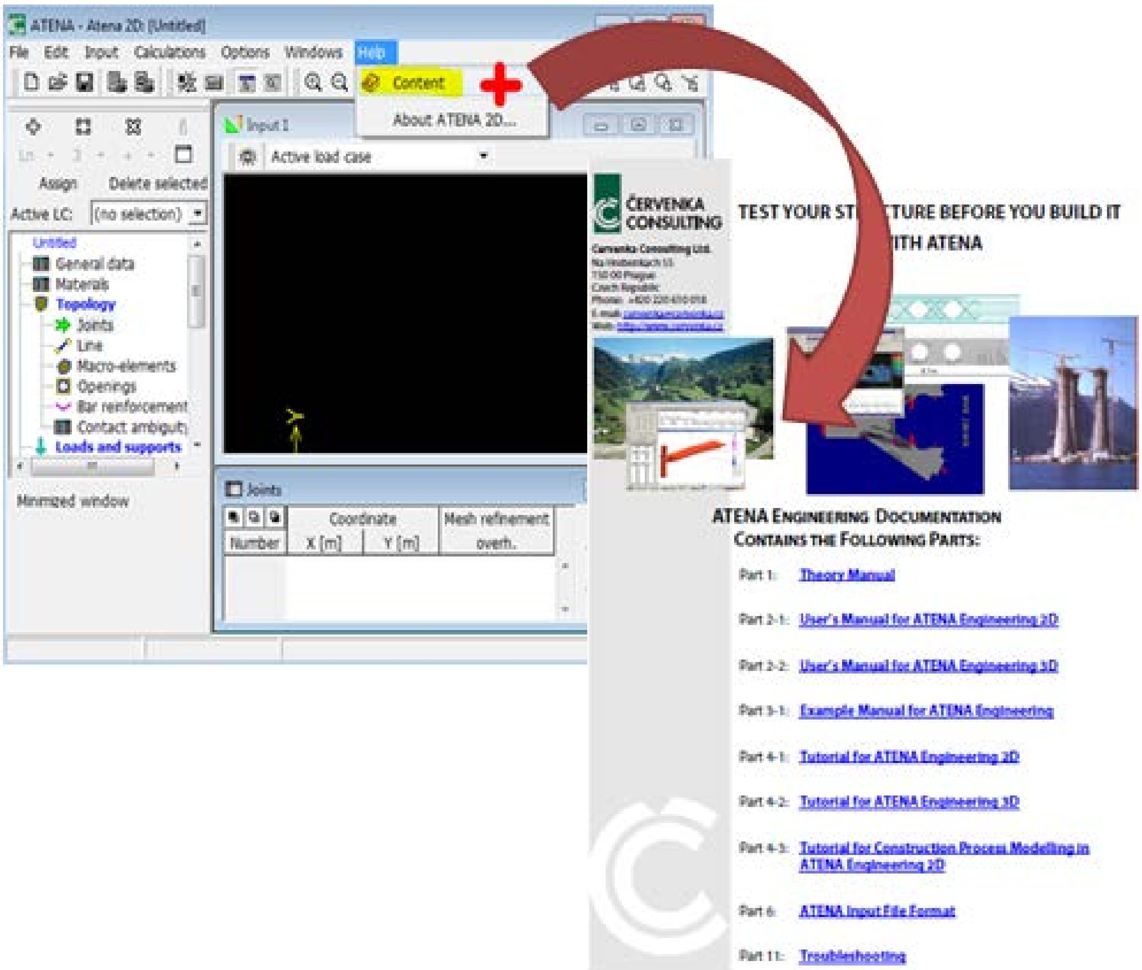
Otherwise contact

babak_dadvar@yahoo.com

Annex 6

Making the model in ATENA

For more detail and explanation refer to ATENA documentations. Help menu in the ATENA software.



Adding Materials

From the left tree menu in ATENA one can choose materials with left click of mouse (figure 1). This can be done also from the main menu at top (figure 2).By doing this, material window at the bottom of the ATENA interface appears. Here user by clicking add button, can define the materials and material properties. For details about materials and material properties refer to chapter 4 and chapter 8.3 of the thesis.

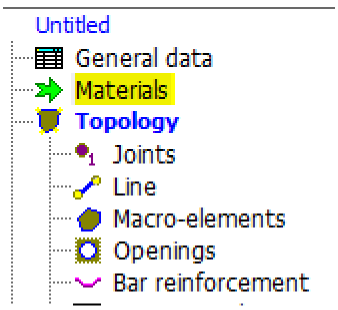


Figure1 option1

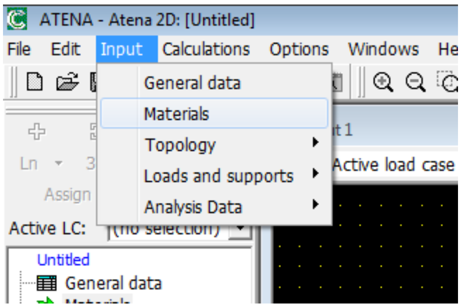


Figure2 option2

Joints

After definition of all materials which is going to be used in the model, the next step in ATENA is to determining joints. Joints can be defined easily by mouse or by giving coordinated of the specimens. Example below:

If it is needed mesh refinement can be applied at support areas. In the deep beam part of this thesis, this option is used (chapter 9).

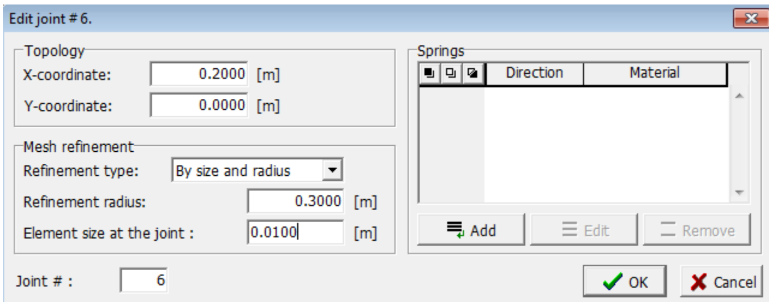
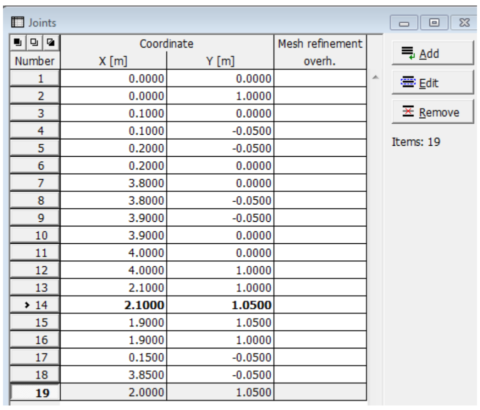


Figure 3



Joints

Number	Coordinate X [m]	Coordinate Y [m]	Mesh refinement overh.
1	0.0000	0.0000	
2	0.0000	1.0000	
3	0.1000	0.0000	
4	0.1000	-0.0500	
5	0.2000	-0.0500	
6	0.2000	0.0000	
7	3.8000	0.0000	
8	3.8000	-0.0500	
9	3.9000	-0.0500	
10	3.9000	0.0000	
11	4.0000	0.0000	
12	4.0000	1.0000	
13	2.1000	1.0000	
14	**2.1000**	**1.0500**	
15	1.9000	1.0500	
16	1.9000	1.0000	
17	0.1500	-0.0500	
18	3.8500	-0.0500	
19	2.0000	1.0500	

Add
Edit
Remove
Items: 19

Figure 4

Lines

By choosing lines from the left tree menu (figure 6) or by choosing geometrical lines from top menu (figure 5) one can define lines between joints. The easiest way is that after choosing lines from left menu then one can chose tab , then just using left click of mouse between joints in the graphic zone of the program desired lines will be produced.

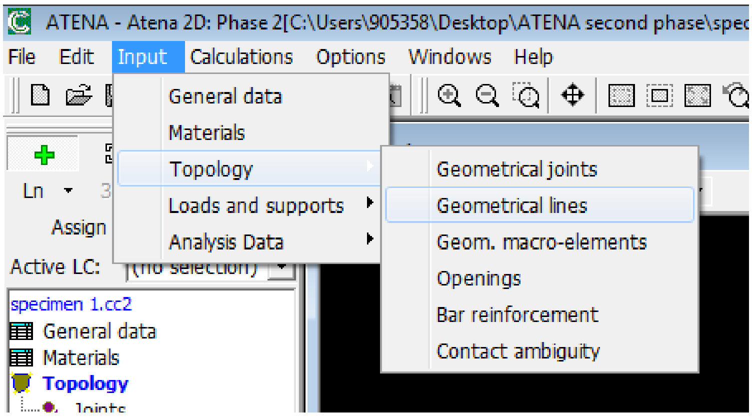


Figure 5

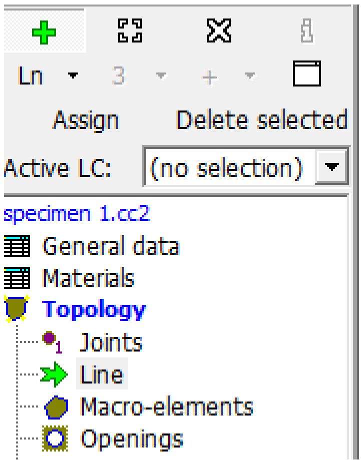


Figure 6

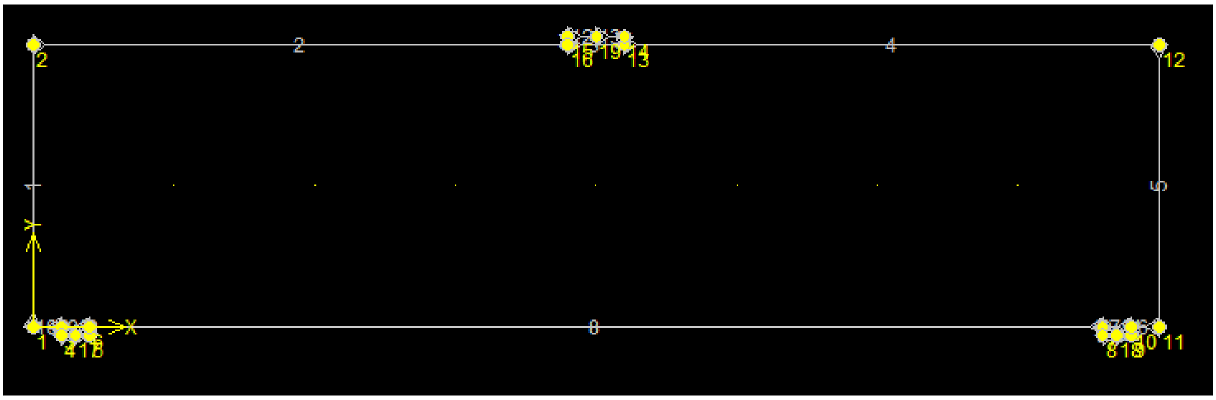


Figure7

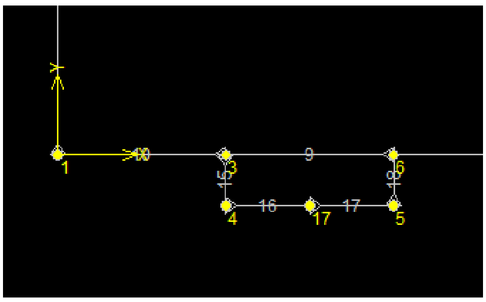


Figure 8

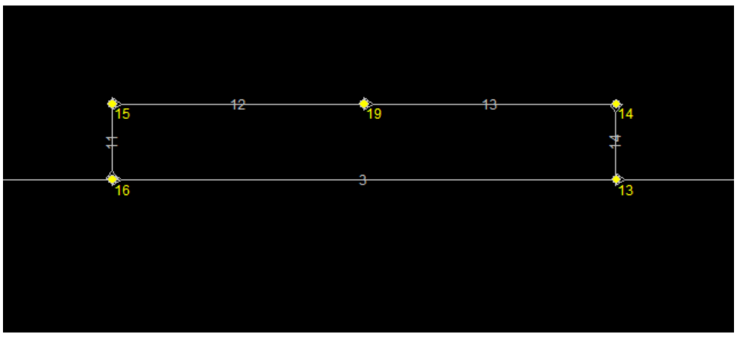


Figure 9

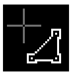
Defining macro elements

After definition of geometrical lines, the next step is to connect these lines to form regions, which are called Macro – elements.

Macro elements properties:

- Finite element mesh type
- Element size
  Initially 50 mm is chosen like in the 2D models.
- Material
  Depends on which material is going to be addressed by macro- elements.
- Thickness
  Thickness is equal to thickness of the specimen
- Quadrilateral elements

By choosing macro elements from left tree menu and then choosing add button at the bottom menu or by clicking on add button at top ✣ , one can define the macro elements.

Important note: After defining the mesh size, mesh type and thickness of the element, the user should push the end button, after that choose ✣ button from the left menu till the mouse in the graphical view changes to  . Now user can choose lines which make a closed region.

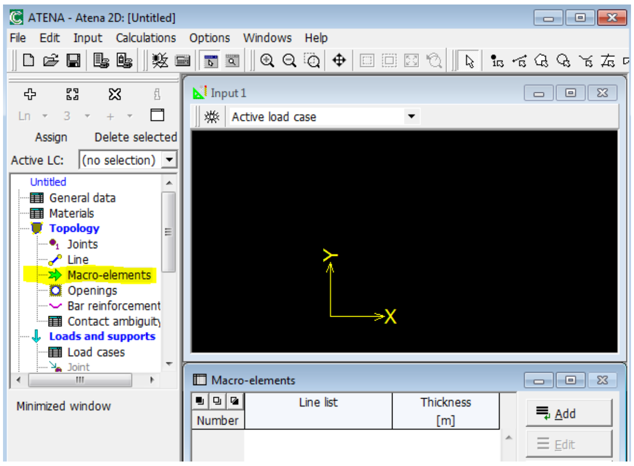


Figure 10

Note: thickness of the macro elements is equal to the thickness of the specimens.
Note: the mesh size now or later can be defines from macro element menu.

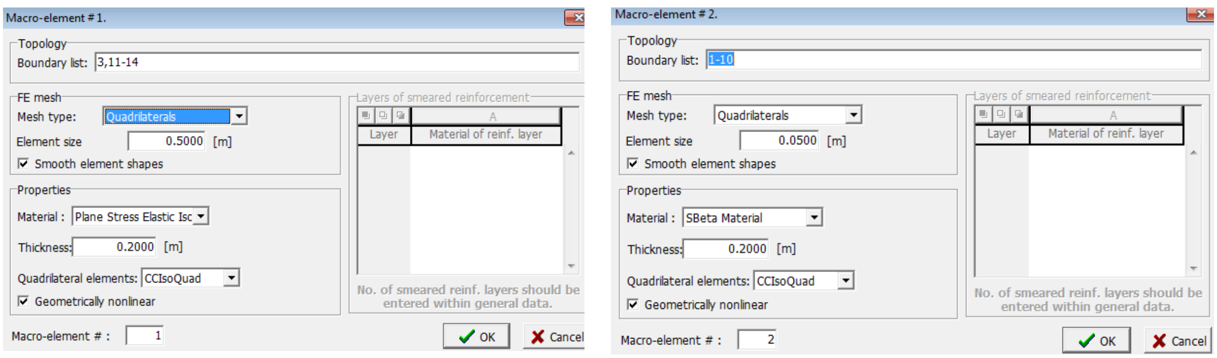
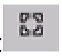


Figure 11 macro element definitions for steel plate and concrete

Interface elements

After defining different macro elements then user have to come back to the line command and define the interface elements as following:

Go to Menu line  and then edit  and choosing the specific line, then a dialog box pops up and at the edit contact choose interface in connection type.

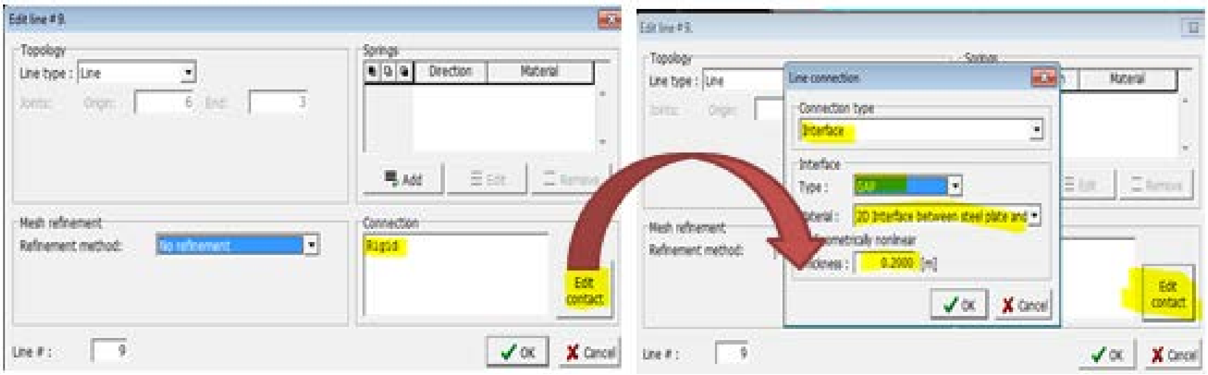


Figure 12 applying the interface element into the model, so between concrete beam and steel plate support.

Mesh generation

Based on the element size which s defined in the macro- elements, a finite element mesh is generated.

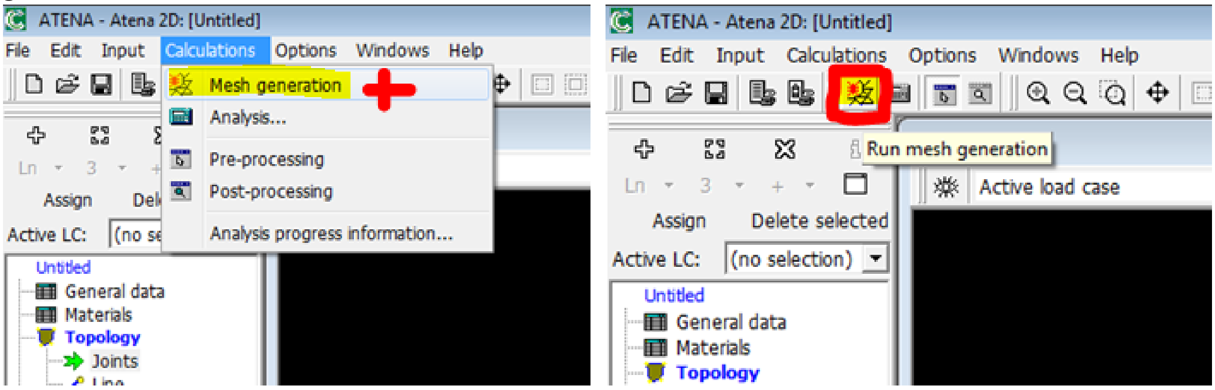


Figure 13 running mesh generation is possible in two ways

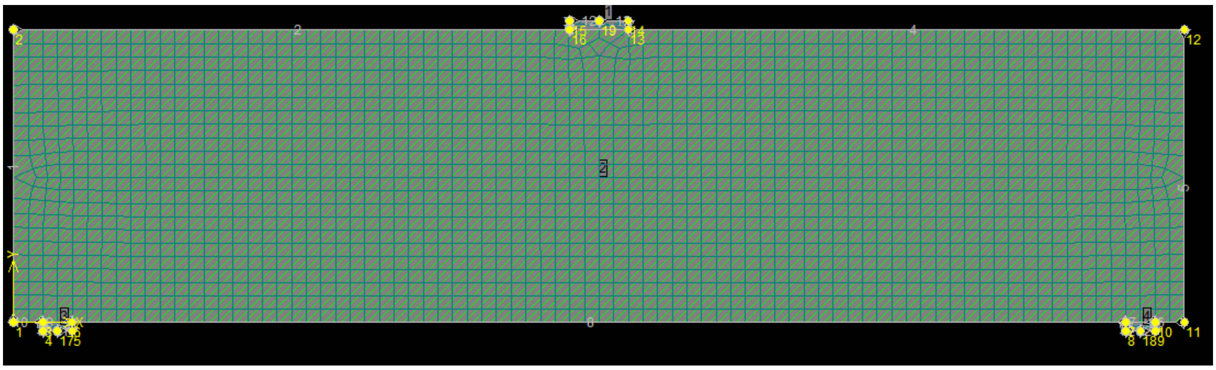


Figure 14 mesh is generated

Appling bar reinforcements

Adding required reinforcement bars according to the 2D model in Scia Engineer. Concrete cover is assumed 35 mm.

- In the "topology"→Bar reinforcement→Add button, in ATENA user can give the coordination of the reinforcements.

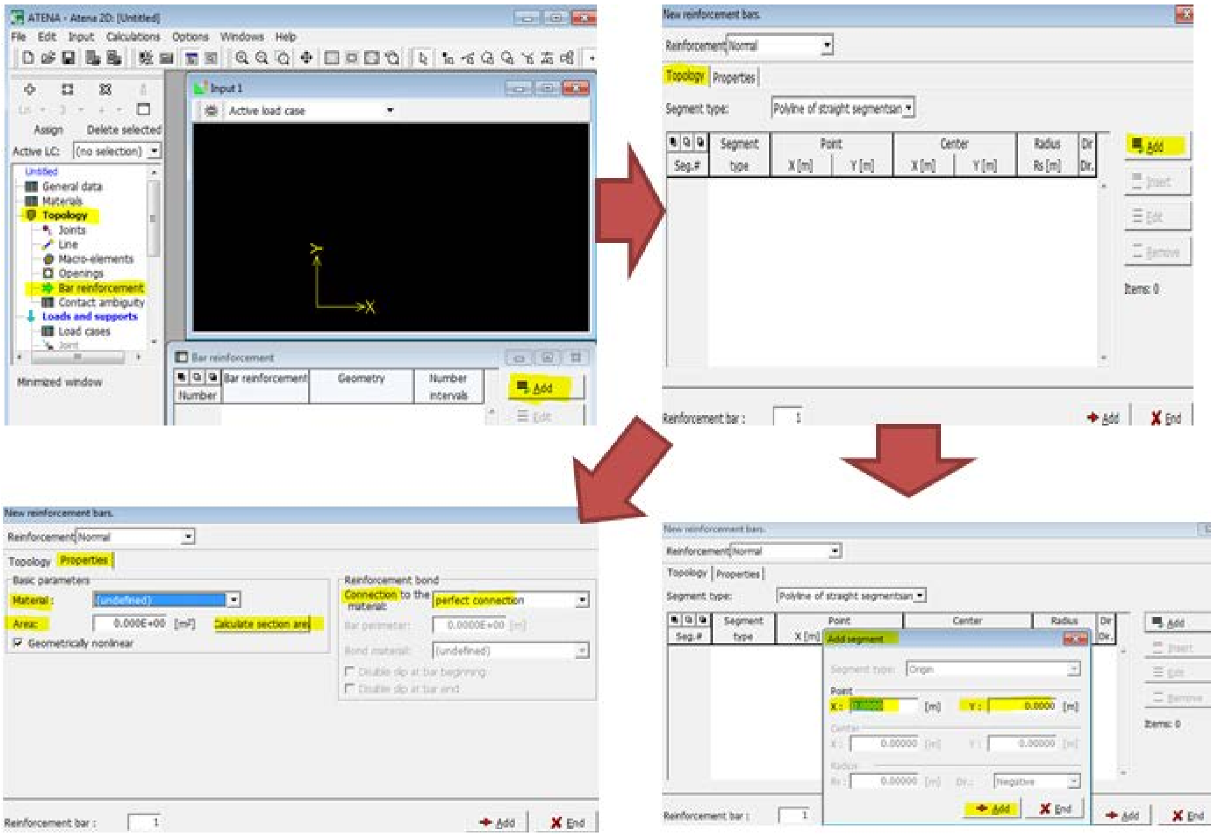


Figure 15

- In the property tab, user can define the following:
  - User can apply reinforcement bond model which is already defined in the "materials".
  - User can also adjust the number and diameter of the reinforcements
  - Geometrical nonlinearity
  - Disabling Slip at beginning or ending of reinforcement bars, this option depends on the location of the rebars, if rebars continue till the end of the beam then the slip at beginning and end should be disables. If the rebars are shorter than the total length of the beam then this option should not be checked.

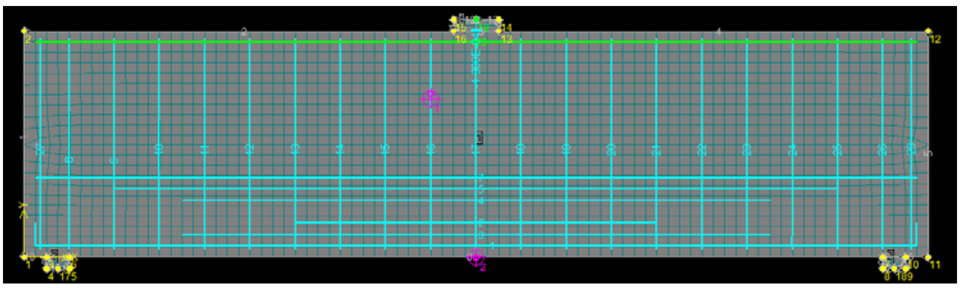


Figure 16

Support and actions

Load cases

All specimens are loaded at the top steel plate. The goal is to determine the maximum load-carrying capacity of the beam, which means to be able to trace the structural response also in the post-peak regime. The easiest method to accomplish this is by loading the beam by prescribed displacements at the top steel plate. Three load cases are defined: one containing the vertical supports, and second is with dead load and third is with the prescribed deformations at the top steel plate.

Load case 1: vertical and horizontal support

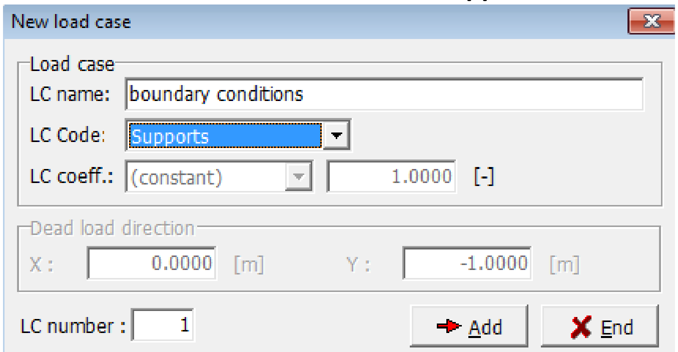


Figure 17

Load case 2: prescribed deformation at the top steel plate

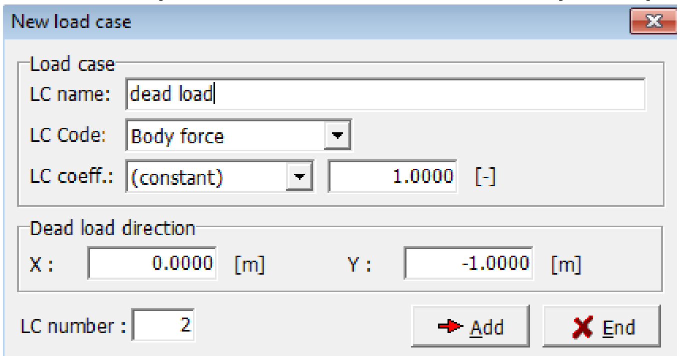


Figure 18

Load case 3: prescribe deformation

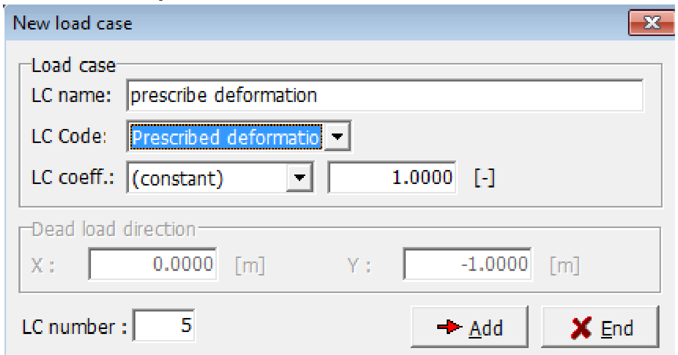


Figure 19

Method Displacement control

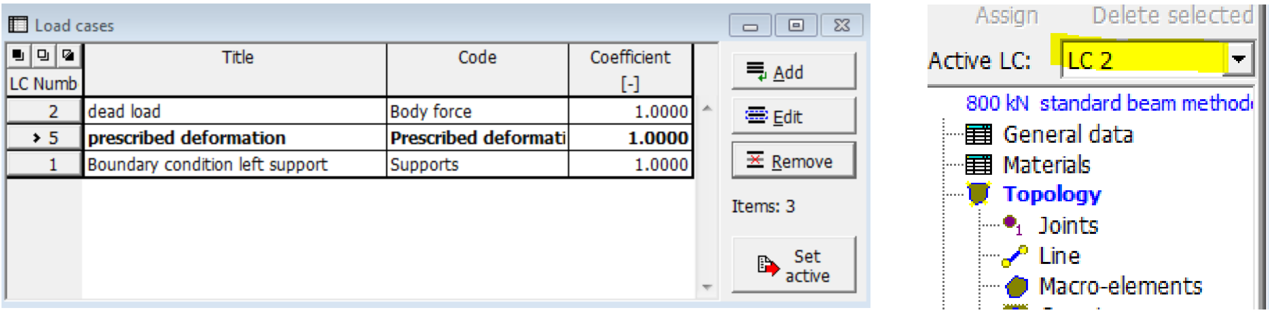


Figure 20

After activation of the Boundary conditions (supports) from left top menu, pin joint is chosen to be placed under the center line of the steel plates to allow rotation of the specimens.

- Load case 1 support load case, so by choosing the joint in the middle bottom of the steel plate the degree of freedom at support can be defined.(first always activate the Load case)(if you select a joint and define the support condition one have to deselect it again to select another joint) by clocking the replace button one can define the support conditions for each joint.

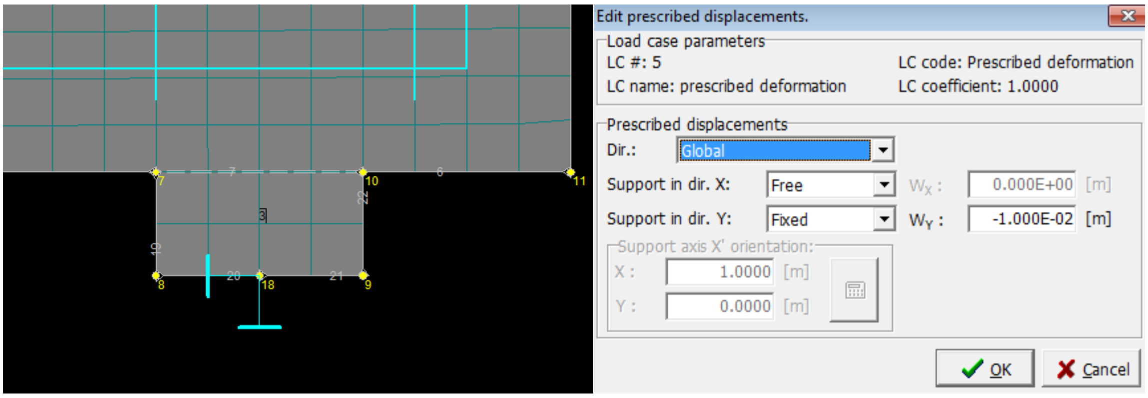


Figure 21

- After activation of load case 5 which is prescribe deformation, the joint on the top above the steel plate should be chosen and the amount of the prescribed deformation should be edited. It can be approximated about the deformations based on deformations in 2D SCIA Engineering model or 1D model , or just assume a deformation let's say 10 mm.

Note: be sure to de-active any zoom tabs at the top of the main menu, to be able to apply Load cases to the joints.

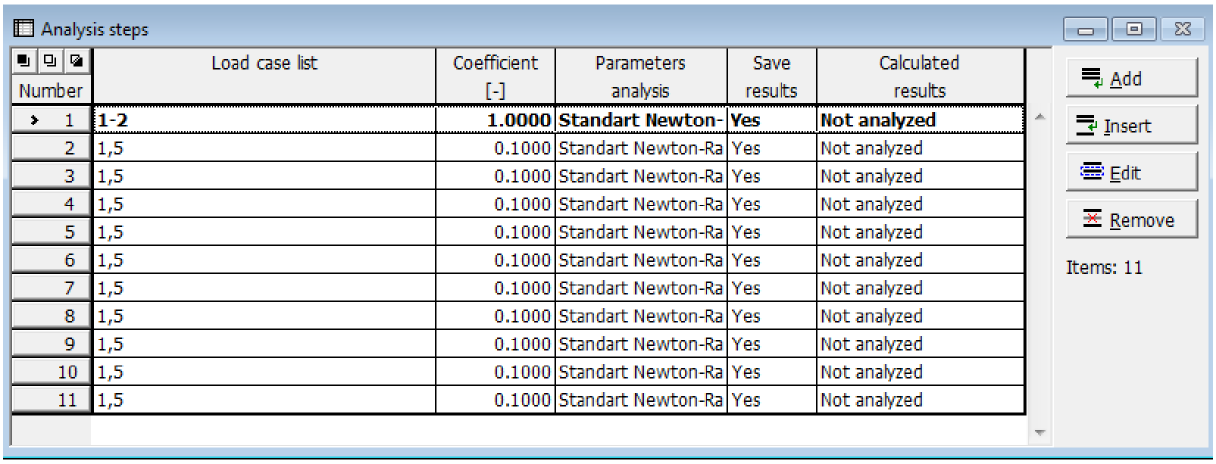
- **Load case 2 (dead load)**
- **Load case 3 prescribe deformation**

CHECK data Step OK

This option does a data check. Errors and inconsistencies in data are reported in the list of the numerical window.

Analysis steps

The load history is generated by this process.



Number	Load case list	Coefficient [-]	Parameters analysis	Save results	Calculated results
1	1-2	1.0000	Standart Newton-	Yes	Not analyzed
2	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
3	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
4	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
5	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
6	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
7	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
8	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
9	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
10	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed
11	1,5	0.1000	Standart Newton-Ra	Yes	Not analyzed

Figure 22

First load step includes, only load case 1 (dead load) and load case 2 (supports) which are there in full capacity which means coefficient 1 should be chosen. From step 2 the Loads include dead load and prescribe deformation, with a coefficient 0.1. This coefficient determines the speed of the growth of the applied forces and deformations to the full values.

Monitoring point

During non-linear analysis it is useful to monitor forces, displacements or stresses in the model. To be able to find the capacity and compare with the 2D model and 1D model analysis which is done by Scia engineer. The monitoring point should be chosen such that in the analysis step the following components can be directly or indirectly derived (IF NEEDED):

1. maximum moment capacity and moment developments
   This component can be determined by knowing the reaction forces at the node in which prescribed deformation is defined (**monitoring point 1**)

2. maximum crack width, and crack developments
   This component can be determined as the results “**Run”** procedure in Atena

3. maximum deflection, and deflection developments
   This component can be determined by **monitoring point 2,** and **3**, to monitor the deflections at these areas of the specimens.

4. maximum Applicable load (Load capacity)
   This component can be determined by **monitoring point 1.**

5. maximum shear capacity and shear development
   This component can be found with a **monitoring point 4,** to monitor the reaction forces at supports.

6. Stress development in the one reinforcement
   this component can be found in the results

Monitoring point 1

Because of the use of displacement control, one is intended to find the maximum capacity of the considered specimen. To find out what is the maximum applicable load, in ATENA is important to know that the reaction force monitoring point should be defined. So the first Monitoring point is the point where the prescribed deformation is defined.

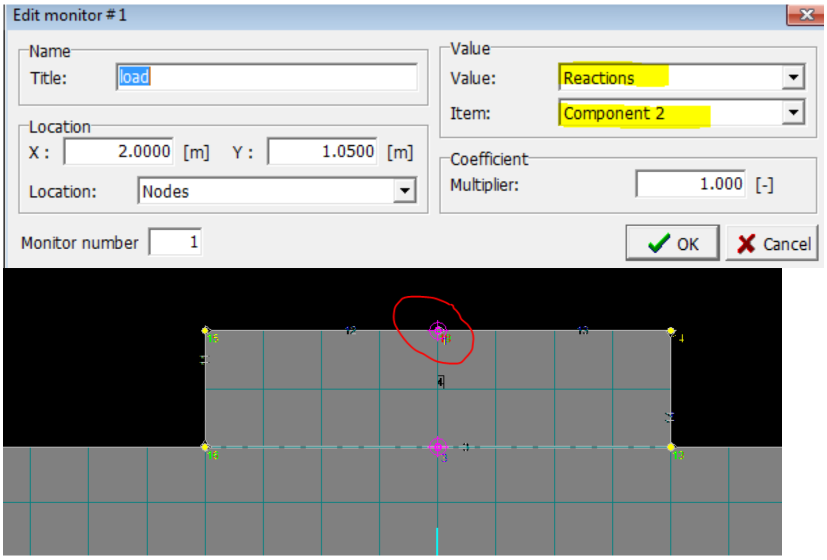


Figure 23

Monitoring point 2

The second monitoring point should be added at the bottom middle of the beam to monitor the displacements. The second component of nodal applied forces should be monitored at this point.
It is not necessary to define a location exactly at the finite element node. The program automatically selects the closest FE node. In case monitoring at integration points is required, the closest finite element integration point is selected.

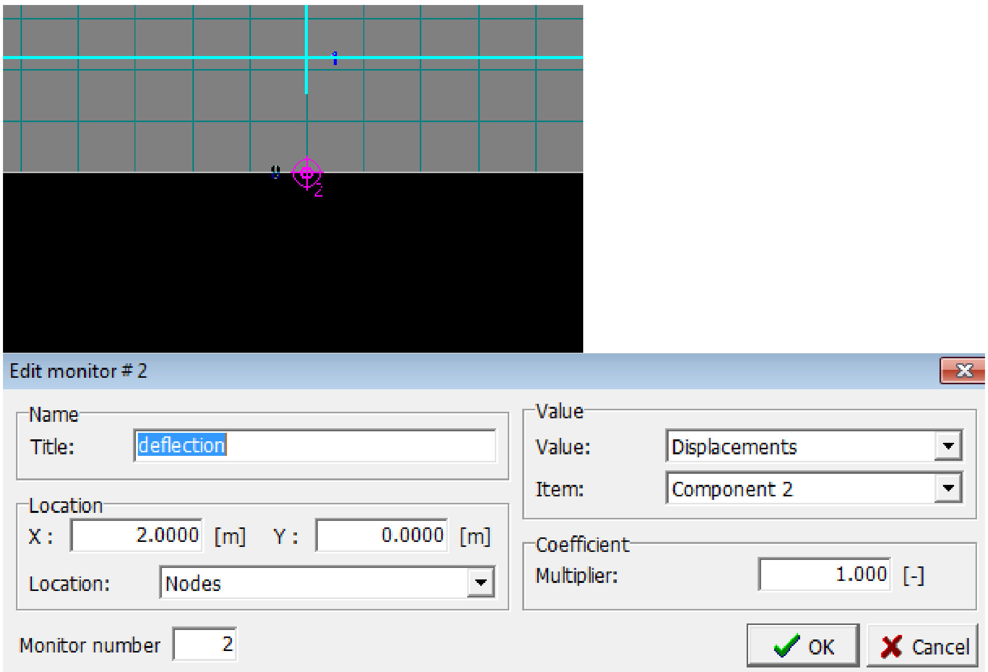


Figure 24

Monitoring point 3

With the third monitoring point, one may want to check the displacements under the steel plate, for extra check for prescribed displacements.

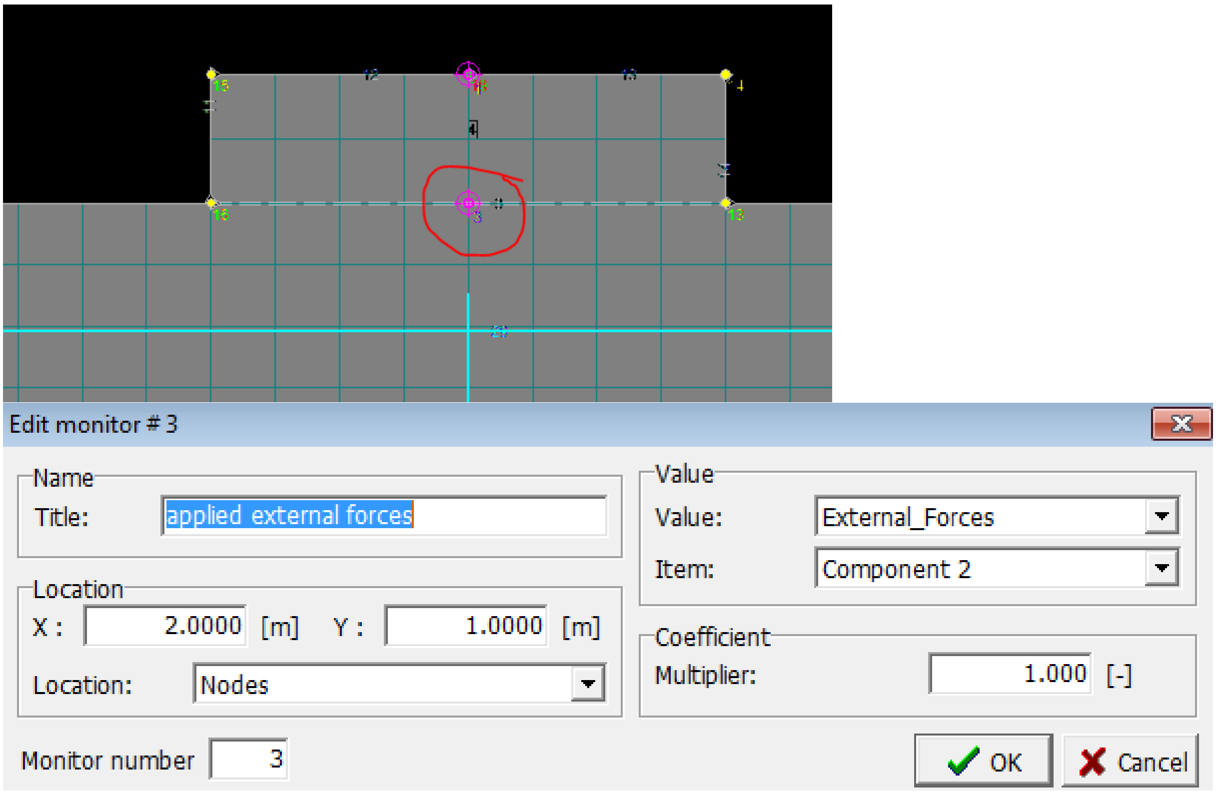


Figure 25

Monitoring Point 4

To be able to determine the reaction forces at supports, one may define also a monitoring point for reactions at support areas.

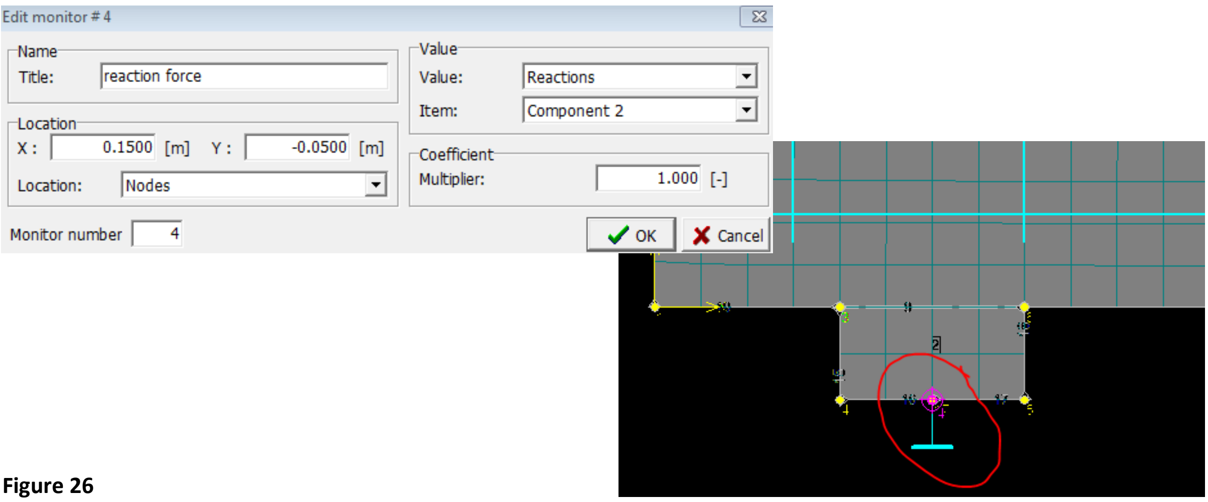


Figure 26

Summary of monitoring points

These possible four monitoring points (as an example) will allow the user to monitor the load and displacement curve during the non-linear finite element analysis. It makes it possible to see the changes of action forces and displacement at each load step and at each iteration point. Eventually all 6 components which is mentioned earlier in this section can be fully determined and prepared for further research.

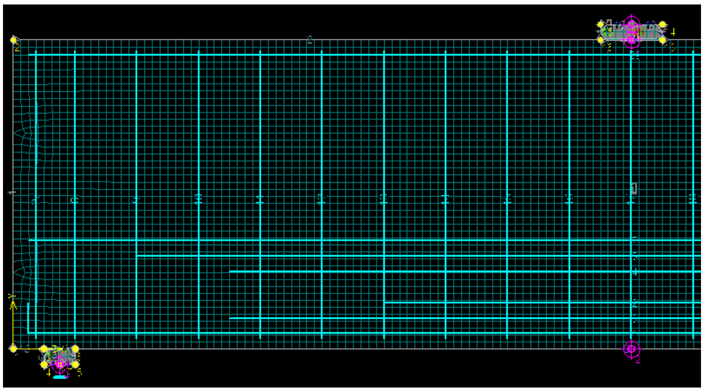


Figure 27

Starting analysis

After check data and analysis steps in the tree menu one can run the analysis. Running of the analysis can be done in two ways (figure 28).

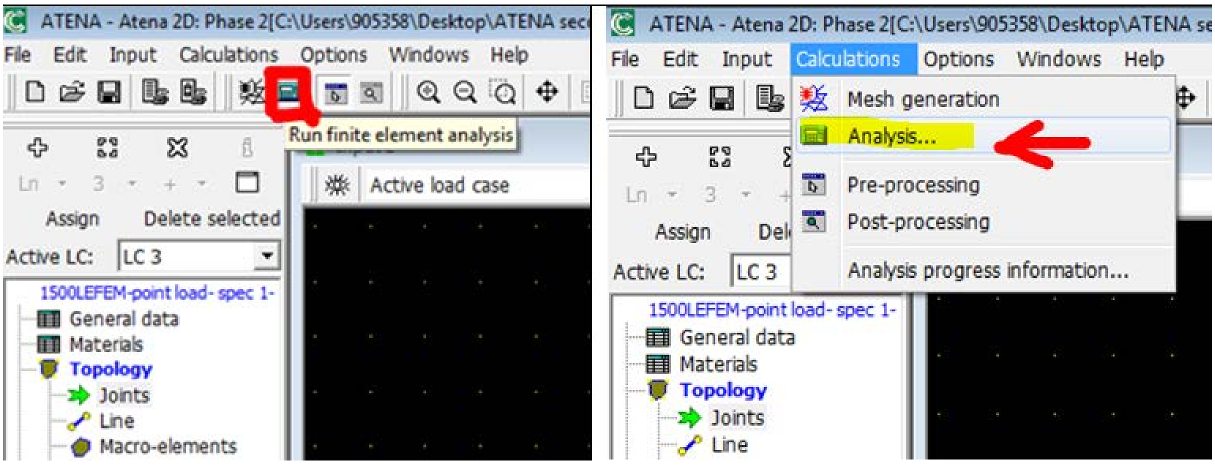


Figure 28

By clicking on the analysis button the window “solution parameters” pops up. Here one can X and Y value to get load displacement diagram during the running of the analysis.

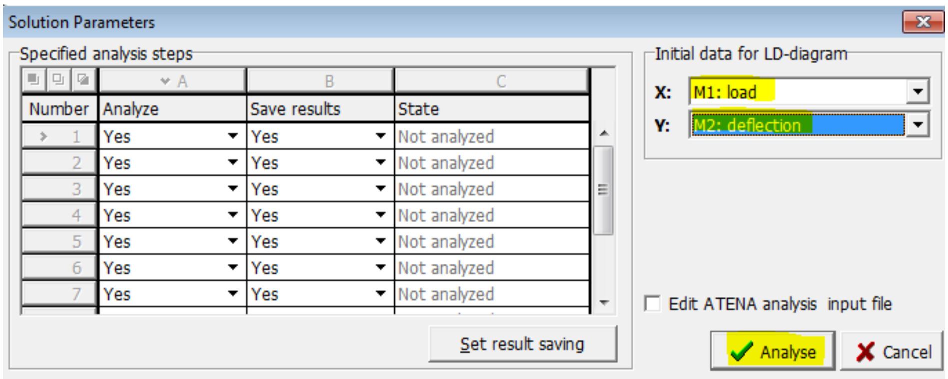


Figure 29

After running of the analysis one can add cuts into the model with the help of run tree menu.

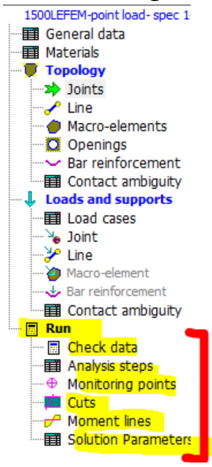


Figure 30

note: Figure below is an example for load deflection (LD) diagram as a result of ATENA Analysis.

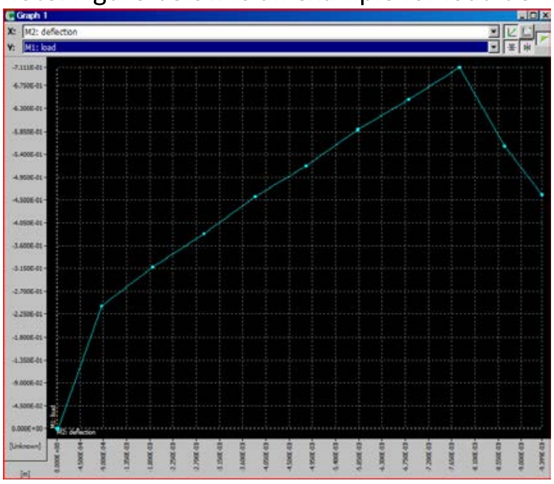


Figure 31

To be able to show the critical point like cracking point and failure load more exactly, refining the load steps in these areas of loading might be handy.

Annex 7

Files of ATENA Validation process can be found on the following address

www.babak-dadvar.com/thesis/babak.html

Otherwise contact

babak_dadvar@yahoo.com

Annex 8

Non-linear finite element analyses –Process

ATENA Results and recommendations

ATENA example files can be found in the following web address:

www.babak-dadvar.com/thesis/babak.html

Otherwise contact

Babak_dadvar@yahoo.com

First Phase –Slender Beam

1) **Specimen 1-1-1**
2) **Specimen 1-1-2**
3) **Specimen 1-1-3**
4) **Specimen 1-1-4**
5) **Specimen 1-2-1**
6) **Specimen 1-2-2**
7) **Specimen 1-2-3**
8) **Specimen 1-2-4**
9) **Specimen 1-3-1**
10) **Specimen 1-3-2**
11) **Specimen 1-3-3**
12) **Specimen 1-3-4**

- In this Annex , ULS, SLS behavior and crack width of the specimens is determined by using nonlinear finite element program ATENA.
- In ULS or failure the following two aspects are shown
    a) Maximum principle stresses in the rebars , to find out if yielding of the rebars occur or not.
    b) Minimum Principle strains in concrete, to find out whether the concrete crushes or not.

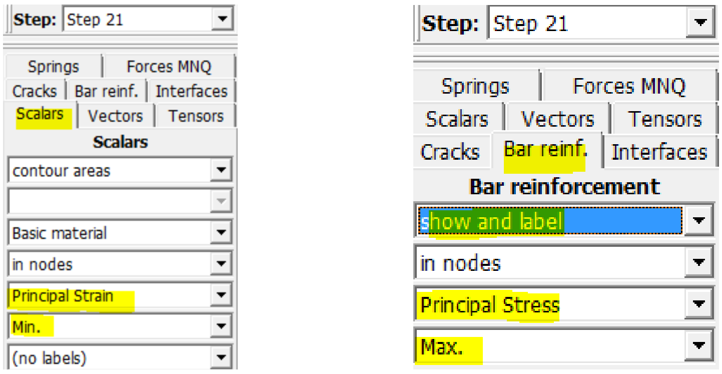


Figure 1

Based on the material properties of the concrete in SBETA material model compressive strain at compressive strength in the uniaxial compressive test is -1,906E-03. To be able to see the appropriate figure in ATENA strain values should be filtered by using a tool in the menu toolbar. (Figures below)

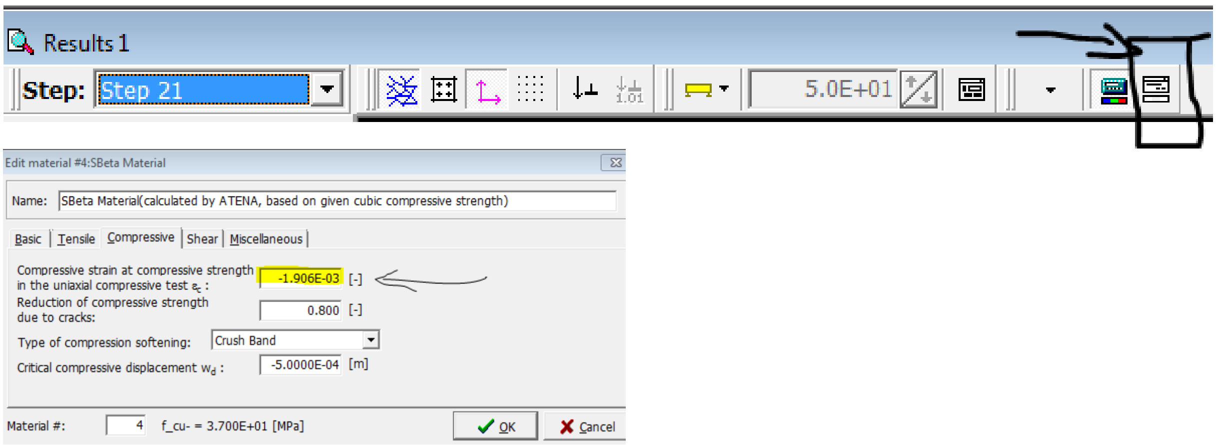


Figure 2

(Example)

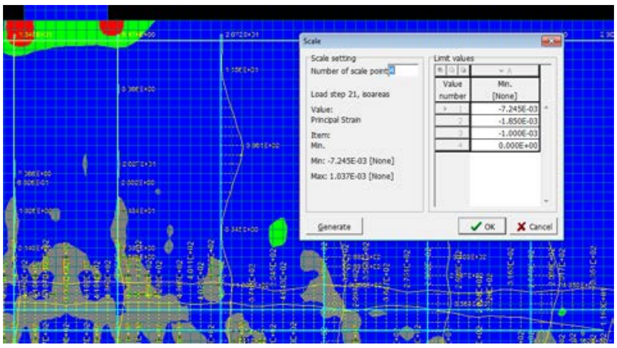


Figure 3

In SLS the following points are determines

- crack width based on theory
- Stresses in the rebars in the middle x=2 meter and also nearby middle where cracks is happening

Specimen 1-1-1(with 1d1d reinforcement configuration)

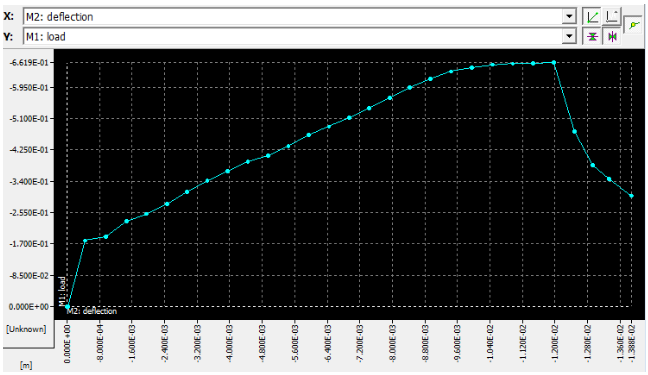


Figure 4

Results

Monitoring points after load step

	[MN]
13	-4.646E-01
14	-4.877E-01
15	-5.125E-01
16	-5.384E-01
17	-5.657E-01
18	-5.941E-01
19	-6.171E-01
20	-6.375E-01
21	-6.475E-01
22	-6.559E-01
23	-6.585E-01
24	-6.603E-01
25	-6.619E-01
26	-4.749E-01
27	-3.834E-01
28	-3.456E-01
29	-3.005E-01

Step	Value [m]
14	-6.438E-03
15	-6.936E-03
16	-7.433E-03
17	-7.931E-03
18	-8.429E-03
19	-8.932E-03
20	-9.440E-03
21	-9.952E-03
22	-1.046E-02
23	-1.096E-02
24	-1.146E-02
25	-1.197E-02
26	-1.248E-02
27	-1.292E-02
28	-1.333E-02
29	-1.388E-02

Table 1

Looking at failure **load step 25 (white pen is yielding points of the reinforcements).**

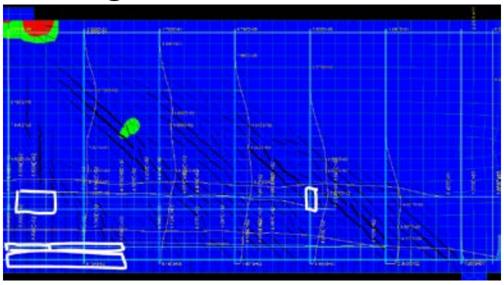


Figure 5

- After load step 19 one can see from deflection loading graph that the yielding phase begins. Here there is ductile behavior of the beam before failure.
- .yielding begins in longitudinal reinforcements due to bending and then also shear. Bending is more governing. Failure of the concrete compression struts due to bending is the governing failure mode.
- Yielding of the bars due to bending and shear(mostly Bending)) as it can be observed from figures , Yielding of the rebars leads into the crushing of the compression struts leads to the failure

looking at SLS

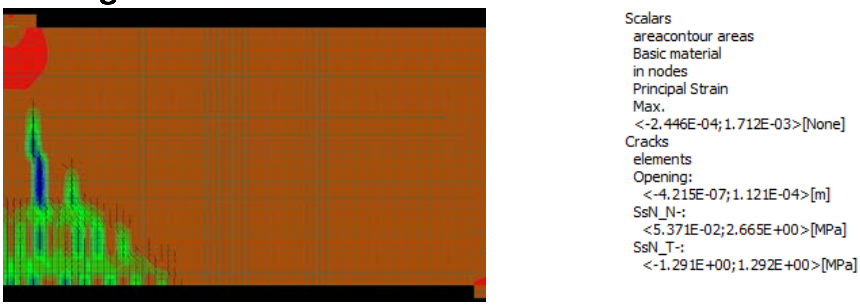


Figure 6

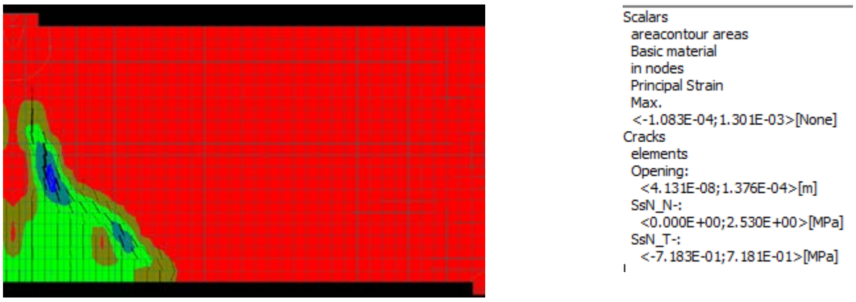


Figure 7

- Based on the theory, the maximum crack width can be approximated round 0,15 mm.

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-50	-54
2 m	Rebar 1 Rebar2 Rebar 3	+127 +96 +46	231 216 168		

	Rebar 4	**+24**	**152**		
Near by 2m	**Rebar 1** **Rebar 2** **Rebar3** **Rebar 4**	**250** **126** **119** **142**	**295** **275** **253** **209**	**-**	**-**

Table2

Specimen 1-1-2 1d2d

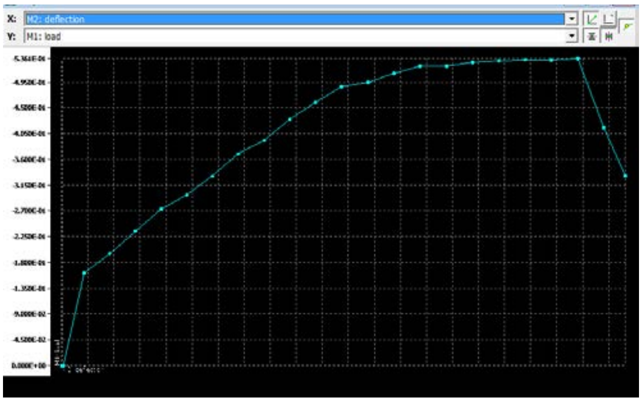


Figure 8

Results

Monitoring points after load step

Monitoring p. specif.

----------------- Step Value [MN] ----------------- 1 0.000E+00 2 -1.624E-01 3 -1.953E-01 4 -2.349E-01 5 -2.735E-01 15 -5.233E-01 16 -5.236E-01 17 -5.294E-01 18 -5.322E-01 19 -5.341E-01 20 -5.340E-01 21 -5.361E-01 22 -4.157E-01 23 -3.313E-01	----------------- Step Value [m] ----------------- 1 -2.670E-05 2 -4.216E-04 3 -9.186E-04 4 -1.411E-03 5 -1.903E-03 6 -2.398E-03 15 -6.878E-03 16 -7.385E-03 17 -7.888E-03 18 -8.392E-03 19 -8.896E-03 20 -9.399E-03 21 -9.902E-03 22 -1.040E-02

Table 3

looking at Failure

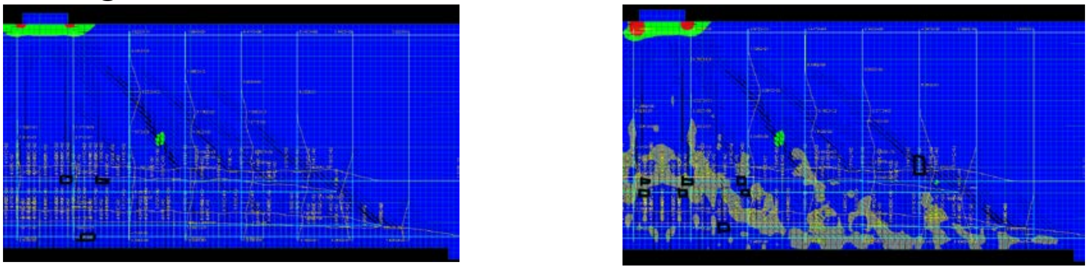


Figure9 load step 17 left and load step 21 right figure

- After load step 17 one can see from deflection loading graph that the yielding phase begins. Here there is ductile behavior of the beam before failure.
- Yielding of the reinforcement bars are starting from load step 17till load step 21.
- Yielding begins in longitudinal reinforcements due to bending and then also shear. Bending is more governing. Failure of the concrete compression struts due to bending is the governing failure mode.

looking at crack width

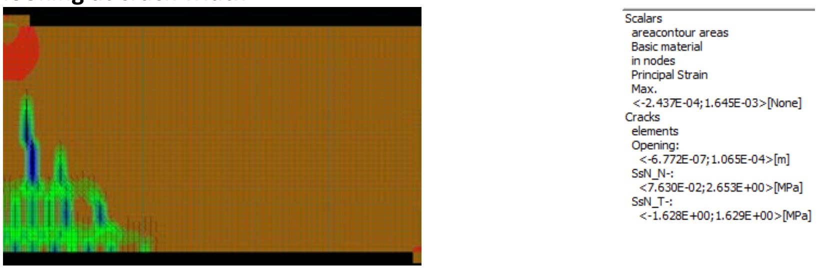


Figure 10

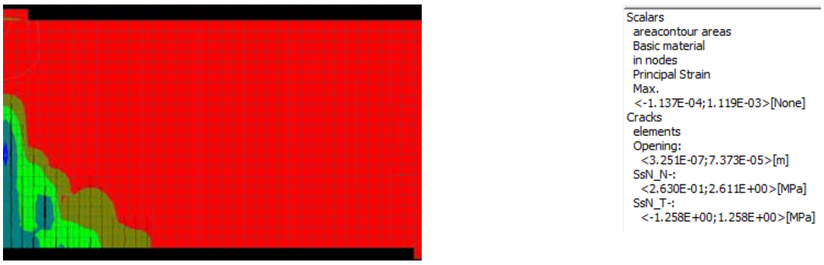


Figure 11

- Based on the theory, the maximum crack width can be approximated round 0,15 mm.

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-50	-54
2 m	Rebar 1 Rebar2 Rebar 3 Rebar 4	+121 +104 +54 +30	231 216 168 152		
Near by 2m	Rebar 1 Rebar 2 Rebar3 Rebar 4	114 114 113 141	231 216 168 152	-	-

Table 4

Specimen 1-1-3 (2d1d)

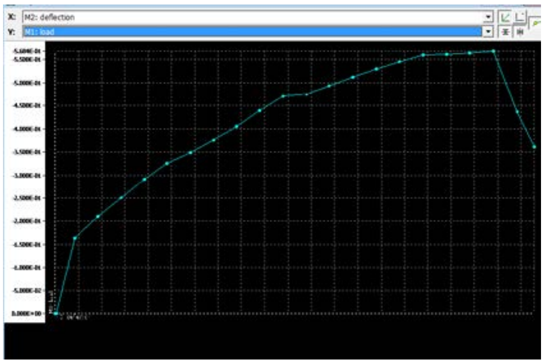


Figure 12

Results

Monitoring points after load step

Step	Value [MN]
1	0.000E+00
2	-1.630E-01
3	-2.099E-01
4	-2.505E-01
5	-2.907E-01
15	-5.296E-01
16	-5.457E-01
17	-5.606E-01
18	-5.614E-01
19	-5.647E-01
20	-5.684E-01
21	-4.371E-01
22	-3.607E-01

Step	Value [m]
1	-2.665E-05
2	-4.207E-04
3	-9.230E-04
4	-1.420E-03
5	-1.915E-03
6	-2.411E-03
7	-2.908E-03
8	-3.404E-03
9	-3.899E-03
10	-4.395E-03
11	-4.891E-03
12	-5.391E-03
13	-5.888E-03
14	-6.387E-03
15	-6.891E-03
16	-7.395E-03
17	-7.896E-03
18	-8.403E-03
19	-8.909E-03
20	-9.412E-03
21	-9.919E-03
22	-1.028E-02

Table 5

looking at failure

load step 17 **load step 20**

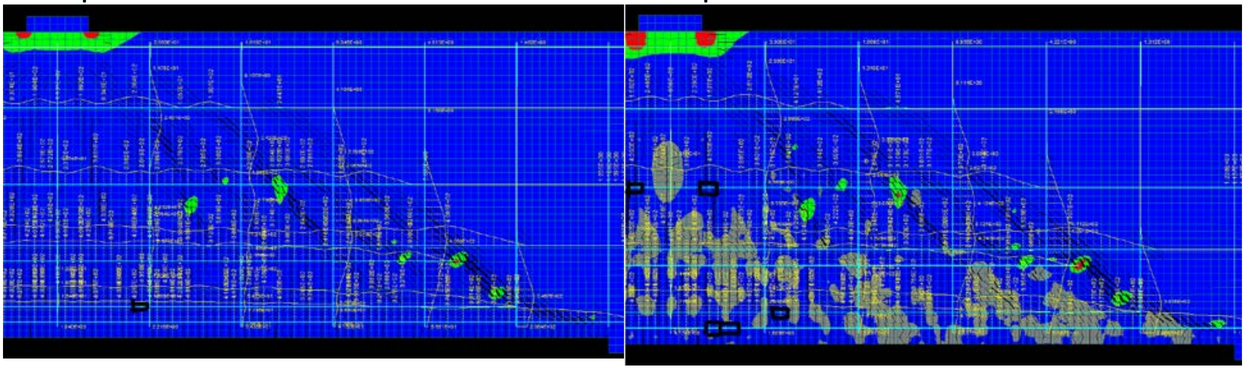


Figure 13 crushing begins locally at earlier step to the failure. (red places are crushing)

- After load step 17 one can see from deflection loading graph that the yielding phase begins. Here there is ductile behavior of the beam before failure.
- Yielding of the reinforcement bars are starting from load step 17till load step 20
- Yielding of the bars due to bending and shear(mostly Bending)) as it can be observed from figures , Yielding of the rebars leads into the crushing of the compression struts leads to the failure
- Yielding begins in longitudinal reinforcements due to bending. Failure of the concrete compression struts due to bending is the governing failure mode.

Looking at SLS

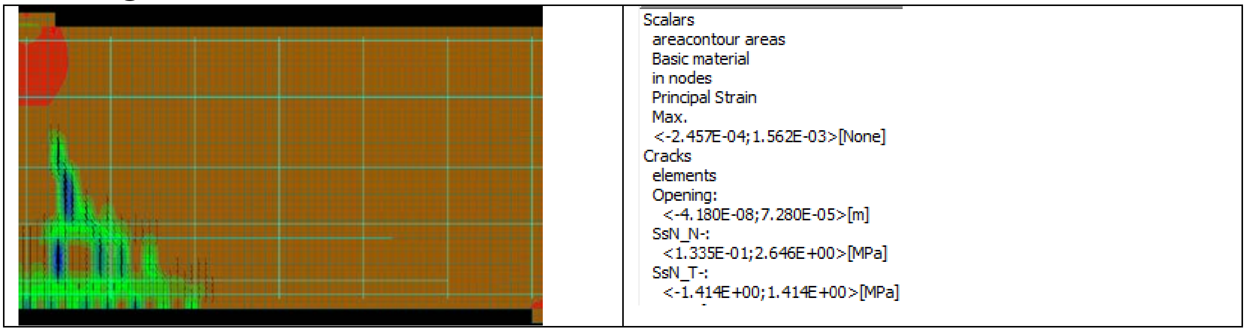


Figure 11

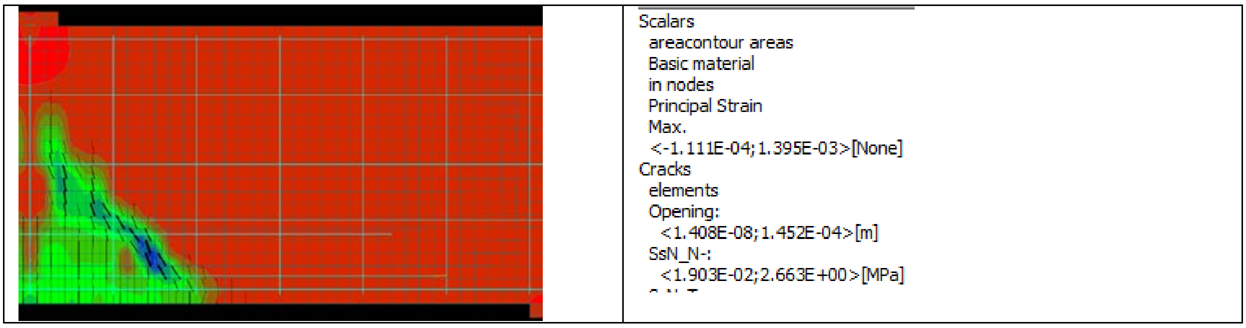


Figure 12

- Based on the theory, the maximum crack width can be approximated round 0,15 mm.

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)

2m	top	-	-	-52 -6 -	-54 - -
2 m	Rebar 1 Rebar2 Rebar 3 Rebar 4 Rebar 5 Rebar 6	+107 +58 +19 +15 - -	225 210 163 148 84 6		
Near by 2m	Rebar 1 Rebar 2 Rebar3 Rebar 4 Rebar 5 Rebar 6	108 132 116 120 111 -	225 210 163 148 84 6	-	-

Table 6

Specimen 1-1-4 reinforcement configuration 2d2d

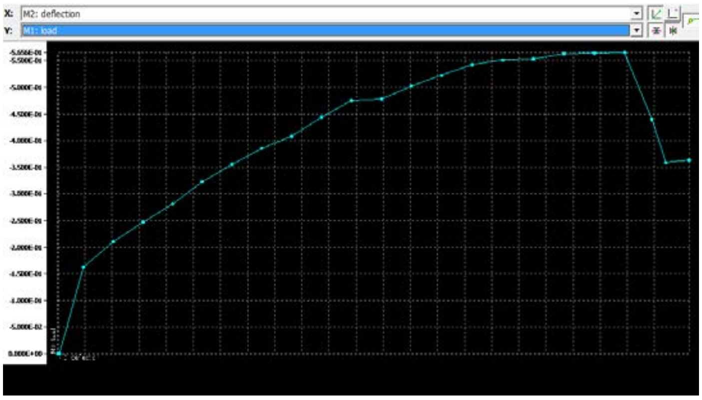


Figure 13

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.663E-05
2	-1.630E-01	2	-4.207E-04
3	-2.099E-01	3	-9.193E-04
4	-2.478E-01	4	-1.413E-03
5	-2.816E-01	5	-1.904E-03
6	-3.230E-01	6	-2.396E-03
7	-3.549E-01	7	-2.889E-03
8	-3.859E-01	8	-3.384E-03
9	-4.089E-01	9	-3.881E-03
10	-4.445E-01	10	-4.375E-03
11	-4.750E-01	11	-4.871E-03
12	-4.779E-01	12	-5.372E-03
13	-5.023E-01	13	-5.868E-03
14	-5.226E-01	14	-6.368E-03
15	-5.427E-01	15	-6.872E-03
16	-5.513E-01	16	-7.384E-03
17	-5.537E-01	17	-7.894E-03
18	-5.631E-01	18	-8.398E-03

19 -5.643E-01 20 -5.656E-01 21 -4.404E-01 22 -3.586E-01 23 -3.632E-01	19 -8.904E-03 20 -9.407E-03 21 -9.855E-03 22 -1.009E-02 23 -1.048E-02

Table 7

looking at failure

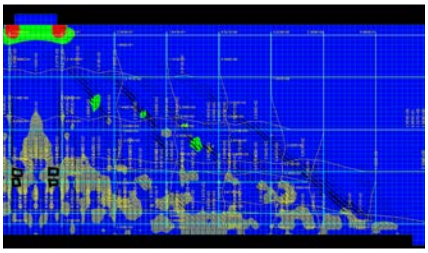


Figure 17

- Yielding of the bars at middle point
- crushing of the concrete at top which is indicated by red area.
- Yielding begins in longitudinal reinforcements due to bending . Failure of the concrete compression struts due to bending is the governing failure mode.

looking at SLS

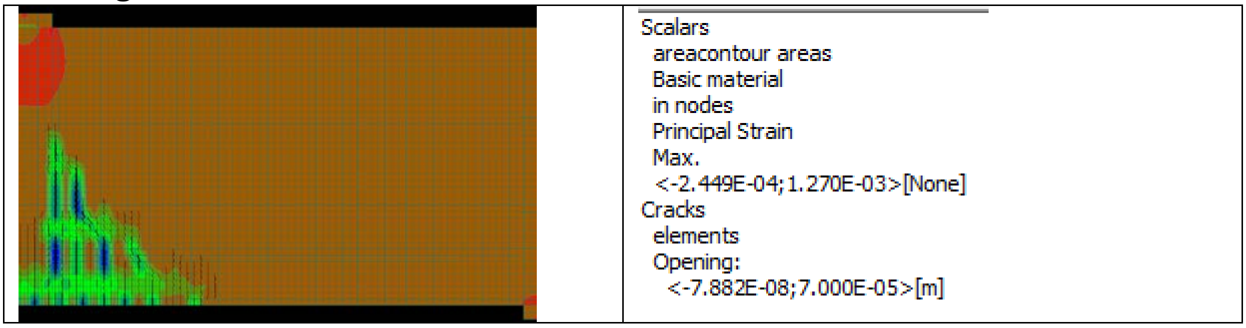


Figure 18

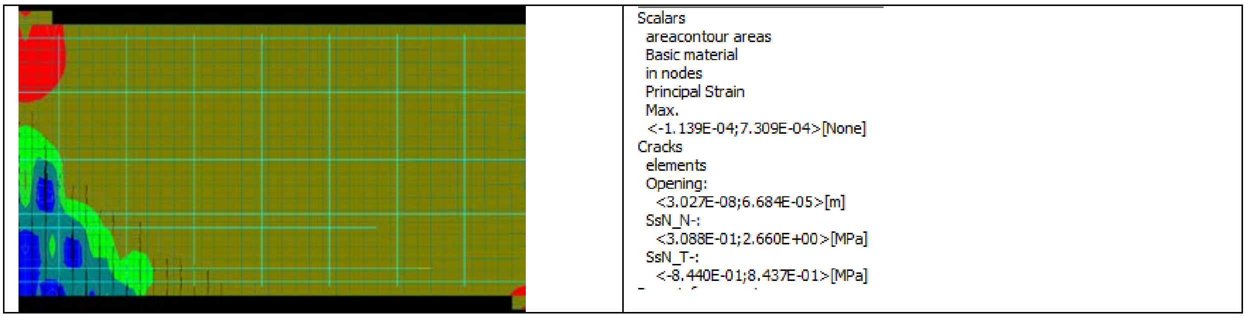


Figure 19

Location rebars	**Location height**	**Tensile stresses(ATENA)**	**Tensile Stresses(SCIA)**	**Compression stresses(ATENA)**	**Compression stresses(SCIA)**	
2m	**top**	**-**	**-**	**-52** **-6** **-**	**-54** **-** **-**	

2 m	**Rebar 1** **Rebar2** **Rebar 3** **Rebar 4** **Rebar 5** **Rebar 6**	**+103** **+67** **+19** **+14** **-** **-**	**+225** **+210** **+163** **+148** **+84** **+6**			
Near by 2m	**Rebar 1** **Rebar 2** **Rebar3** **Rebar 4** **Rebar 5** **Rebar 6**	**+111** **+130** **+120** **+110** **+97** **-**	**+225** **+210** **+163** **+148** **+84** **+6**	**-**	**-**	

Table 8

Specimen 1-2-1(400 kN Applied SLS load model)

(with 1d1d reinforcement configuration)
Reinforcement configuration

- Sbeta Material model
- Longitudinal and vertical reinforcements according to the optimized configurations in 1D Scia model(based on 2D Scia model)

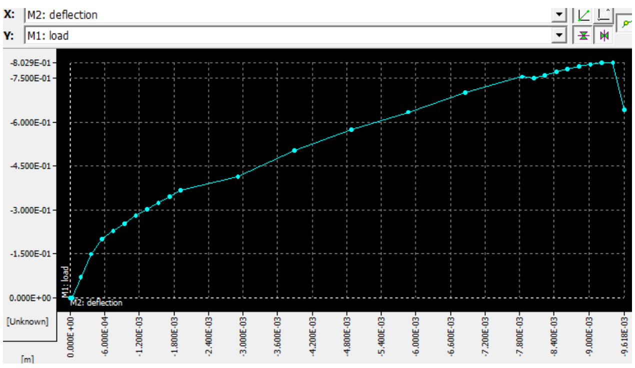


Figure 20

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
17	-7.553E-01	17	-7.847E-03
18	-7.497E-01	18	-8.049E-03
19	-7.605E-01	19	-8.240E-03
20	-7.725E-01	20	-8.437E-03
21	-7.822E-01	21	-8.635E-03
22	-7.905E-01	22	-8.832E-03
23	-7.972E-01	23	-9.028E-03
24	-8.022E-01	24	-9.225E-03
25	-8.029E-01	25	-9.420E-03
26	-6.433E-01	26	-9.618E-03

Table 9

- After load step 22 one can see from deflection loading graph that the yielding phase begins. Here there is Ductile behavior of the beam before failure.
- Yielding of the reinforcement bars are starting from load step 22(900Kn) till load step 25(940kN). The failure load is at load step 22, so 900 kN.
- Yielding of the bars due to shear as it can be observed from figures on the next page, Failure of the concrete compressive zone(crushing of the compression struts) due to shear is the governing failure mode**.**

Development of Yielding and crushing of the beam

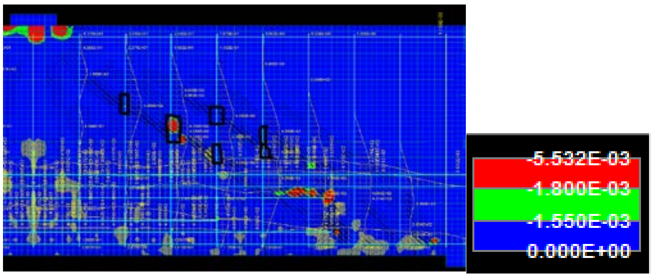


Figure 21

SLS 400 kN

Results

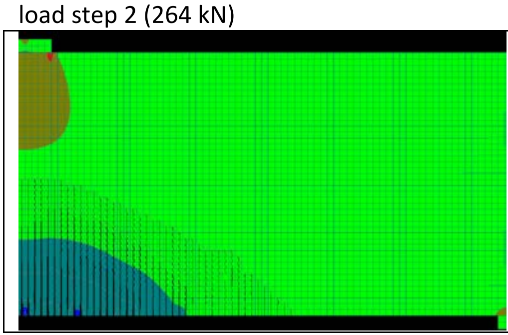
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.619E-05
2	-1.684E-01	2	-4.177E-04
3	-2.649E-01	3	-8.983E-04
4	-3.182E-01	4	-1.391E-03
5	-3.534E-01	5	-1.885E-03
6	-4.045E-01	6	-2.375E-03
7	-4.019E-01	7	-2.476E-03
8	-4.072E-01	8	-2.575E-03
9	-4.133E-01	9	-2.673E-03
10	-4.208E-01	10	-2.772E-03

Table 10

Crack Evolution

load step 2 (264 kN)



Scalars
areacontour areas
Basic material
in nodes
Principal Strain
Max.
<-2.550E-04;6.052E-04>[None]
Cracks
elements
Opening:
<5.256E-09;1.425E-05>[m]

Figure 22

load step 4(318 kN)

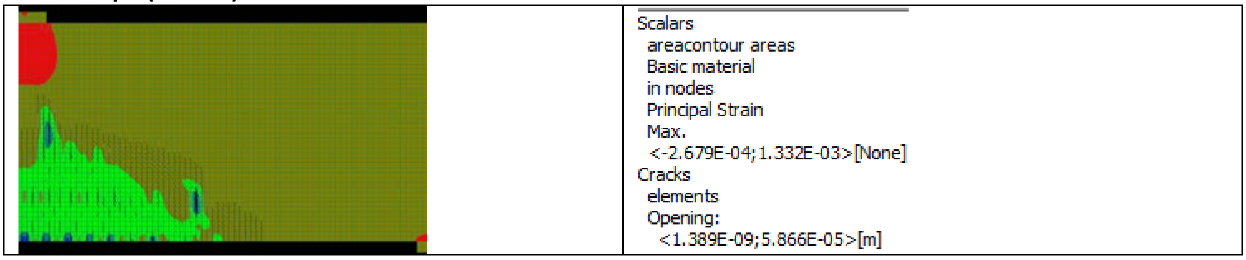


Figure 23

load step 6(353 kN)

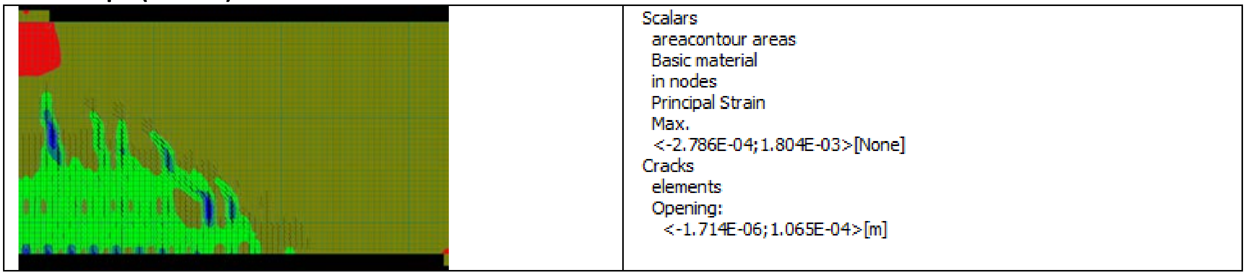


Figure 24

Loa dstep 10 (400 kN) (mesh 25mm)

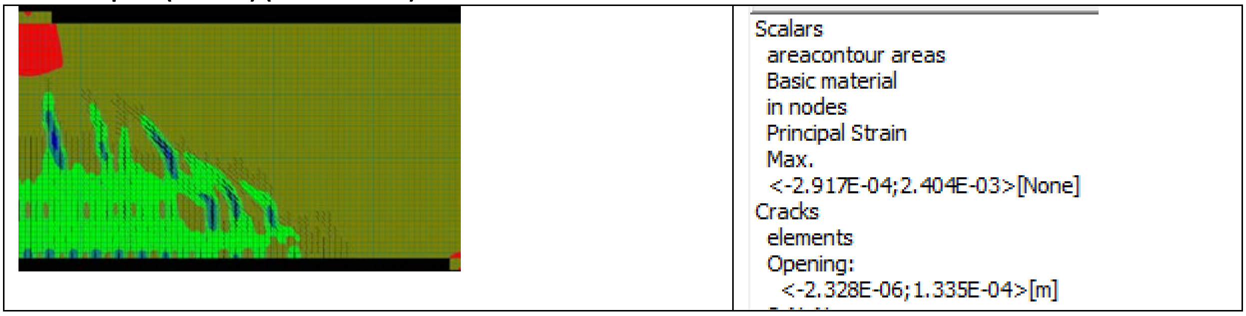


Figure 25

Mesh 50 mm

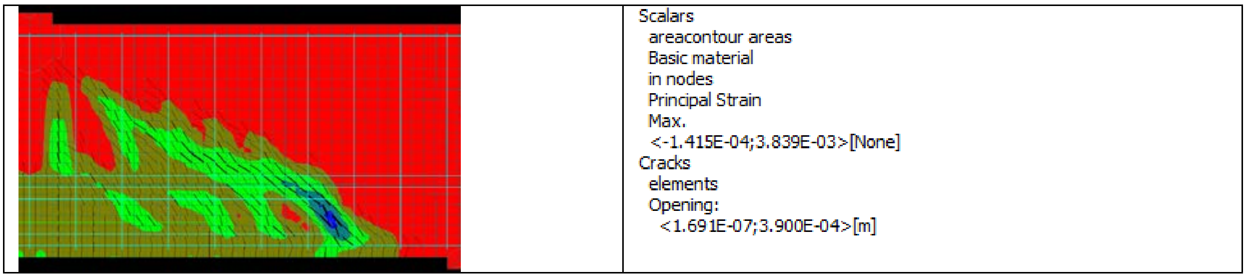


Figure26

Crack width

The important point about calculation of cracks in the graphical way in ATENA is that small cracks mostly results in a larger cracks. ATENA can only give the crack opening in each mesh element, so it is upon the user to somehow integrate small cracks and approximate the actual crack width. For more accuracy and also to be able to approximate the actual crack width at SLS, ATENA analysis is also have done with mesh size of 50 mm, because with bigger mesh size the program results in smaller amount of cracks and it is easier to approximate and integrate the nearby cracks.(according to chapter 8.4.2)

Crack width can be calculated by summation of the adjacent cracks in the mesh elements which is minimum 0,8 mm. Crack width criterion is defined the maximum acceptable crack width as 0,3 mm, so this reinforcement configuration is not satisfied in the SLS(serviceability limit state).

There is also another way of crack calculation in ATENA which is explained in chapter 10.5.2 of thesis. This method is used for deep beam specimens. This method is general method which is for all sort of specimens and situations. The graphical method which is explained before is also accurate for simple cases which are discussed in this thesis.

Deformation and crack width

	ATENA [mm]	**Scia [mm]**
Deflection of the beam at load 400 kN SLS	**2,4**	**-1,2**
Crack width	**0,8**	**Smaller than 0,3**

Table 11

At 400 kN SLS situation

Location rebars	**Location height**	**Tensile stresses(ATENA)**	**Tensile Stresses(SCIA)**	**Compression stresses(ATENA)**	**Compression stresses(SCIA)**
2m	**top**	**-**	**-**	**-100**	**-95**
2 m	**Rebar 1**	**+200**	**282**		
	Rebar2	**+184**	**263**		
	Rebar 3	**+163**	**242**		
	Rebar 4	**+126**	**199**		
	Rebar 5	**+128**	**178**		
	Rebar 6	**+77**	**157**		
Near by 2m	**Rebar 1**	**+200**	**282**	**-**	**-**
	Rebar 2	**+184**	**263**		
	Rebar3	**+171**	**242**		
	Rebar 4	**+145**	**199**		
	Rebar 5	**+138**	**178**		
	Rebar 6	**+160**	**157**		

Table 12

Figure 27

Left figure in figure 27 is at middle of the beam x=2m and the right figure is near by the middle of the beam where cracks occurring at load step 400 kN

- One can see that Tensile Stresses in the rebars at the middle of the beam x=2 m have between 50 N/mm^2 and 150 N/mm^2 difference in ATENA and Scia Engineer. The reason is due to the fact that ATENA considers cracked concrete so the stresses in the rebars are dependent to the place of cracks. At places where large cracks occur tensile stresses in the rebars are higher than other places.

- ATENA gives in general lower tensile stresses in the rebars than Scia Engineering
- Crack pattern begins in the middle height of the cross section and bottom, because of the lack of reinforcement in the middle height of the cross section.
- Crack pattern develops in the inclined way to the supports and at places which are drop in reinforcement area. They are mostly due to the Shear cracks and not Bending.
- Deflection in ATENA at load 400 kN is twice as big as in Scia Engineering.

Specimen 1-2-1 (Concrete fc_u 44,7 steel 435)

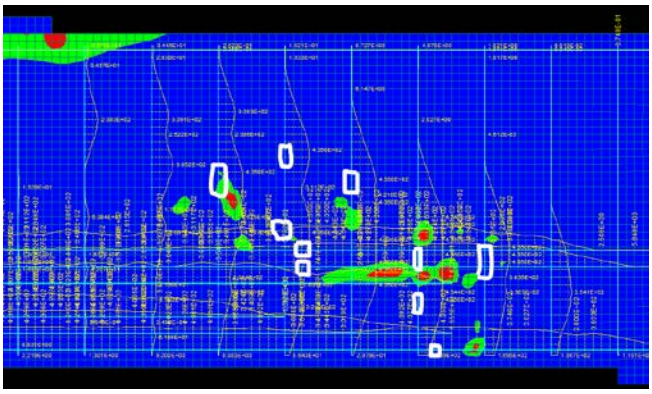


Figure 28

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.453E-05
2	-7.576E-02	2	-1.775E-04
3	-1.601E-01	3	-3.558E-04
4	-2.118E-01	4	-5.485E-04
5	-2.454E-01	5	-7.449E-04
6	-2.682E-01	6	-9.429E-04
7	-3.006E-01	7	-1.138E-03
8	-3.204E-01	8	-1.335E-03
9	-3.434E-01	9	-1.531E-03
10	-3.665E-01	10	-1.726E-03
11	-3.877E-01	11	-1.921E-03
12	-4.404E-01	12	-2.911E-03
13	-5.289E-01	13	-3.896E-03
14	-5.940E-01	14	-4.886E-03
15	-6.668E-01	15	-5.873E-03
16	-7.235E-01	16	-6.863E-03
17	-7.759E-01	17	-7.854E-03
18	-7.820E-01	18	-8.053E-03
19	-7.878E-01	19	-8.253E-03

Step	Value	Step	Value
20	-7.961E-01	20	-8.452E-03
21	-8.047E-01	21	-8.651E-03
22	-8.097E-01	22	-8.851E-03
23	-8.150E-01	23	-9.051E-03
24	-8.201E-01	24	-9.252E-03
25	-8.265E-01	25	-9.451E-03
26	-8.184E-01	26	-9.656E-03
27	-8.256E-01	27	-9.855E-03
28	-8.314E-01	28	-1.005E-02
29	-8.314E-01	29	-1.026E-02
30	-6.491E-01	30	-1.042E-02
31	-5.334E-01	31	-1.039E-02

Table 13

Concrete 44,8 fcm N/mm2+STEEL 550 N/mm2

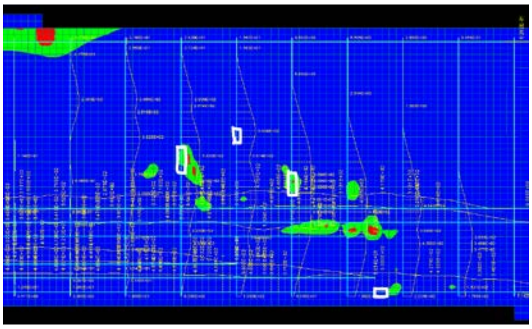


Figure 29

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.453E-05
2	-7.576E-02	2	-1.775E-04
3	-1.601E-01	3	-3.558E-04
4	-2.118E-01	4	-5.485E-04
5	-2.454E-01	5	-7.449E-04
6	-2.682E-01	6	-9.429E-04
7	-3.006E-01	7	-1.138E-03
8	-3.204E-01	8	-1.335E-03
9	-3.434E-01	9	-1.531E-03
10	-3.665E-01	10	-1.726E-03
11	-3.877E-01	11	-1.921E-03
12	-4.404E-01	12	-2.911E-03
13	-5.264E-01	13	-3.896E-03
14	-5.976E-01	14	-4.885E-03
15	-6.741E-01	15	-5.871E-03
16	-7.143E-01	16	-6.865E-03
17	-7.896E-01	17	-7.851E-03
18	-7.965E-01	18	-8.050E-03
		19	-8.248E-03

19 -8.090E-01	20 -8.446E-03
20 -8.201E-01	21 -8.646E-03
21 -8.267E-01	22 -8.845E-03
22 -8.333E-01	23 -9.044E-03
23 -8.412E-01	24 -9.242E-03
24 -8.488E-01	25 -9.440E-03
25 -8.585E-01	26 -9.637E-03
26 -8.685E-01	27 -9.835E-03
27 -8.734E-01	28 -1.003E-02
28 -8.783E-01	29 -1.015E-02
29 -6.648E-01	30 -1.033E-02
30 -6.987E-01	

Table 14

Specimen 1-2-3

Reinforcement configuration

- **Sbeta Material model**
- **25 mm**
- **Longitudinal 2Dand vertical reinforcements 1D**

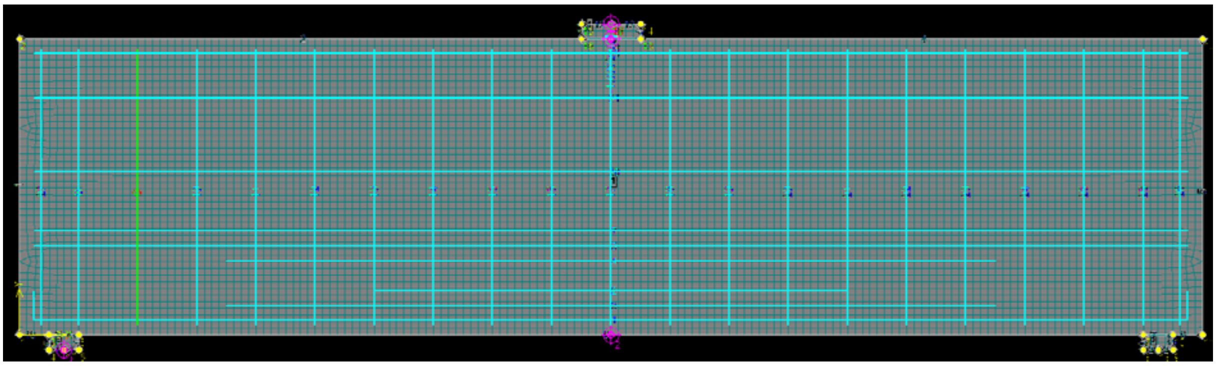


Figure 30

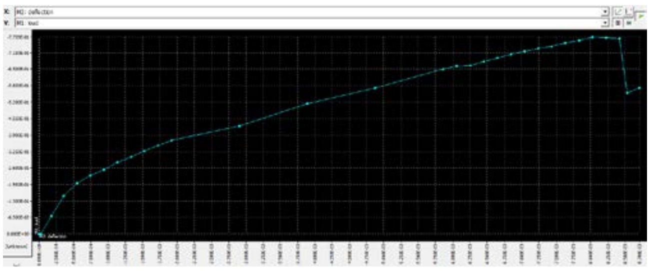


Figure 31

Results

Monitoring points after load step

-----------------	-----------------
Step Value	Step Value
[MN]	[m]
-----------------	-----------------
1 0.000E+00	1 -2.616E-05
2 -7.165E-02	2 -1.807E-04
3 -1.495E-01	3 -3.598E-04
4 -2.002E-01	4 -5.516E-04

5 -2.310E-01	5 -7.449E-04
6 -2.526E-01	6 -9.426E-04
7 -2.832E-01	7 -1.137E-03
8 -3.045E-01	8 -1.333E-03
9 -3.272E-01	9 -1.529E-03
10 -3.480E-01	10 -1.724E-03
11 -3.685E-01	11 -1.919E-03
12 -4.255E-01	12 -2.907E-03
13 -5.132E-01	13 -3.889E-03
14 -5.758E-01	14 -4.876E-03
15 -6.495E-01	15 -5.859E-03
16 -6.622E-01	16 -6.056E-03
17 -6.642E-01	17 -6.256E-03
18 -6.801E-01	18 -6.453E-03
19 -6.943E-01	19 -6.649E-03
20 -7.091E-01	20 -6.845E-03
21 -7.197E-01	21 -7.042E-03
22 -7.318E-01	22 -7.239E-03
23 -7.395E-01	23 -7.438E-03
24 -7.534E-01	24 -7.634E-03
25 -7.632E-01	25 -7.832E-03
26 -7.759E-01	26 -8.028E-03
27 -7.741E-01	27 -8.226E-03
28 -7.710E-01	28 -8.420E-03
29 -5.564E-01	29 -8.526E-03
30 -5.757E-01	30 -8.708E-03

Table 15

Yielding of the rebars

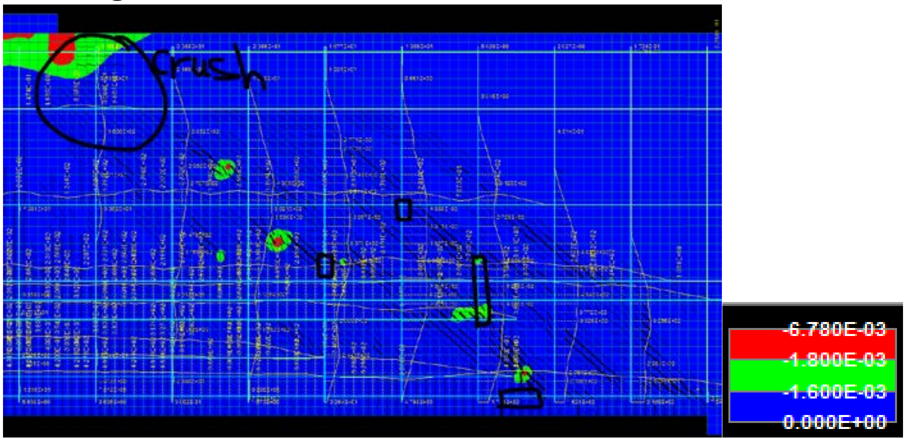


Figure 32

- The only different between this configuration and the previous one is that here the skin reinforcements are also in the cross section.
- Yielding of the rebars are mostly happening in the shear reinforcements, because here there is the same amount of shear reinforcement as previous configuration.
- As it is shown in the figure above, the black circle area is indication of the cracking of the concrete due to crushing.
- Failure of the concrete compression struts due to the shear is the governing failure mode.

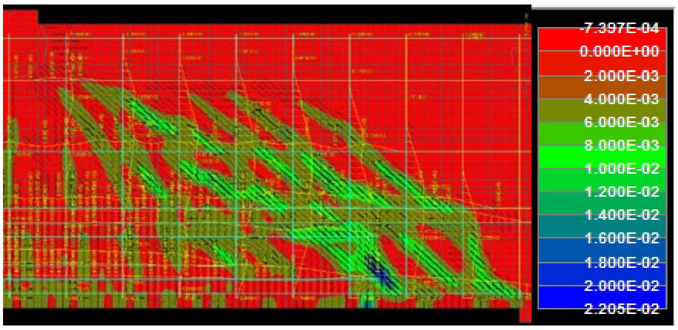


Figure 33

Looking at 400 kN applied load

Results

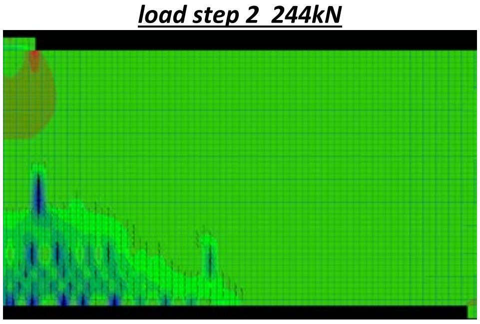
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.616E-05
2	-2.445E-01	2	-8.610E-04
3	-3.415E-01	3	-1.849E-03
4	-3.901E-01	4	-2.345E-03
5	-4.360E-01	5	-2.839E-03

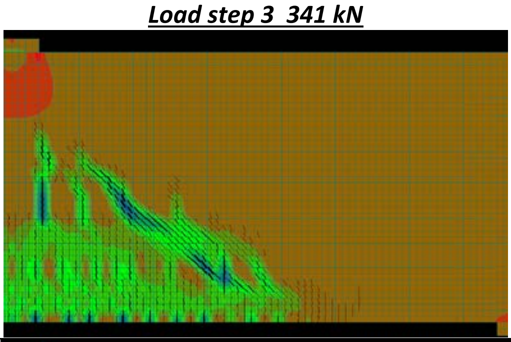
Table 16

Crack Evolution

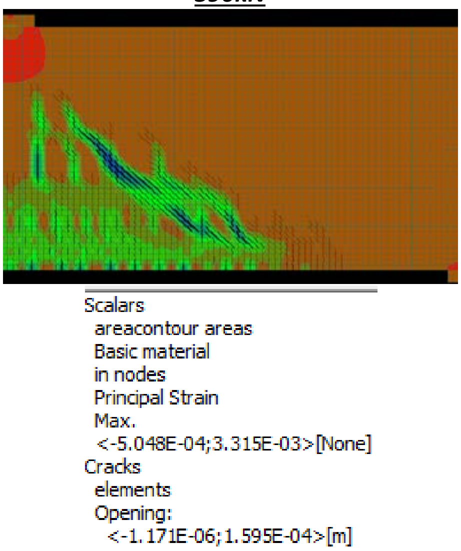
load step 2 244kN



Load step 3 341 kN



390kN



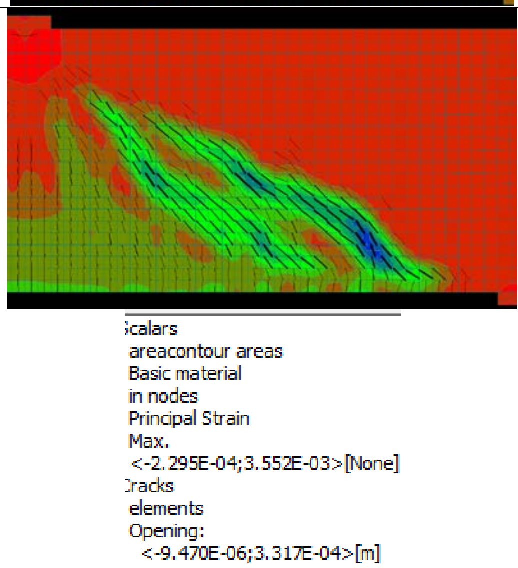


Figure 34

Crack width

As it is already explained in the previous reinforcement configuration, here Crack width as a result of summation of the near by cracks is minimum 0,6 mm .This crack width is not acceptable according to eurocode crack width criterium wich is defined as 0,3 mm.Here the crack width is smaller than the 1d1d(previous case) because here there are skin reinfrocment available which have positief influence on the controling of the crack width in SLS.

	ATENA	***Scia***
Deflection of the beam at load 400 kN SLS	***2,4***	***1.2***

Table 17

- ***rebar 1 is always the out side bar, if it is at the bottom means that rebar 1 is near by the bottom edge if it is at top means rebar 1 is the nearest rebar to the top edge***

At 400 kN SLS situation

Location rebars	**Location height**	**Tensile stresses(ATENA)**	**Tensile Stresses(SCIA)**	**Compression stresses(ATENA)**	**Compression stresses(SCIA)**
2m	**Rebar 1** **Rebar 2**	**-**	**-**	**-110** **-12**	**-96** **-32,8**
2 m	**Rebar1** **Rebar 2** **Rebar3** **Rebar 4** **Rebar 5** **Rebar 6** **Rebar 7**	**+182** **+174** **+144** **+125** **+111** **+45** **+11**	**+280** **+260** **+239** **+197** **+176** **+155** **+72**		
Near by 2 m	**Rebar1** **Rebar 2** **Rebar3** **Rebar 4** **Rebar 5** **Rebar 6** **Rebar 7**	**+192** **+167** **+175** **+150** **+127** **+175** **+126**	**+280** **+260** **+239** **+197** **+176** **+155** **+72**		

Table 18

- Crack pattern begins from middle of the beam bottom and in the middle height of the cross section, they are all acceptable crack widths. Cracks develop in the inclined way to the supports , they are mostly due to the shear cracks.
- deflection in ATENA is twice as big as in the Scia Engineering at the load 400 kN SLS.
- ATENA in general gives lower tensile stresses in the rebars.
- Tensile stresses in the rebars in ATENA is dependent on the occurring of the cracks.

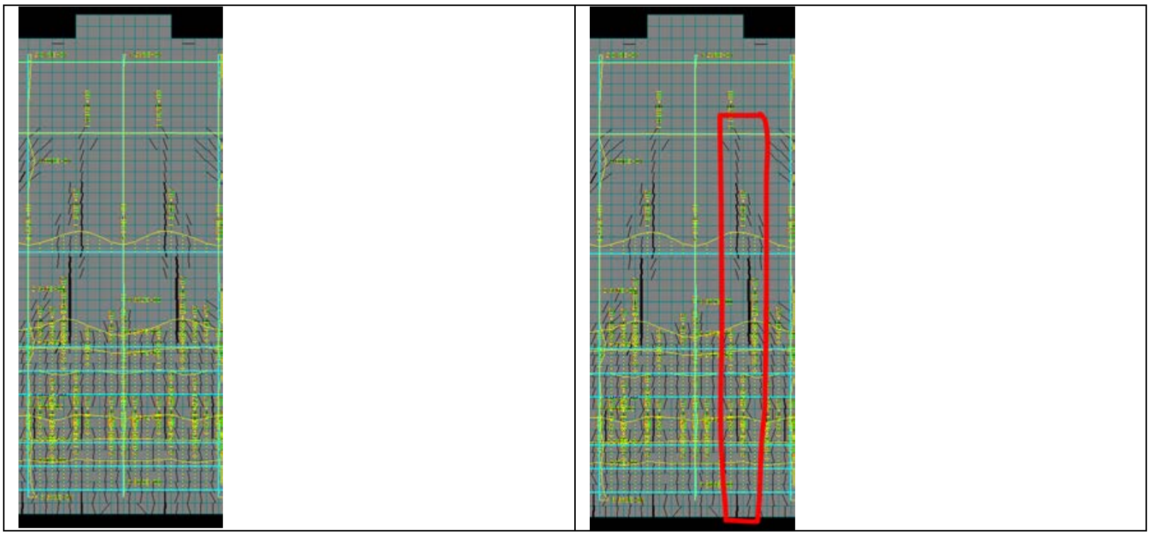


Figure 35

Concrete fcm38 fcu 44,7

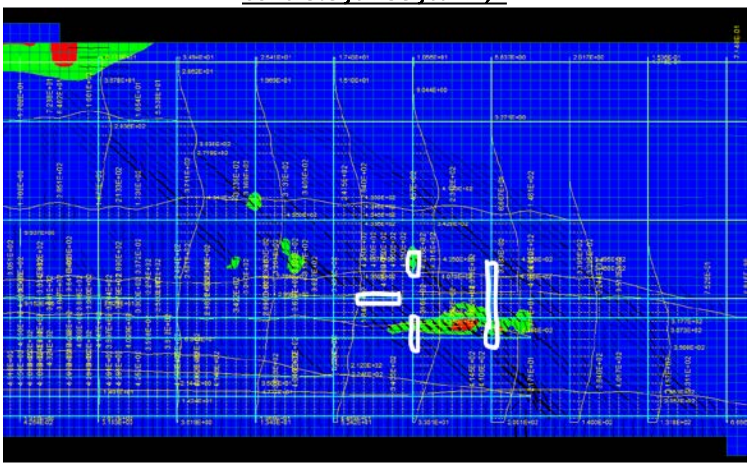


Figure 36

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.451E-05
2	-7.580E-02	2	-1.774E-04
4	-2.193E-01	4	-5.436E-04
5	-2.508E-01	5	-7.408E-04
6	-2.807E-01	6	-9.368E-04
7	-3.102E-01	7	-1.132E-03
8	-3.307E-01	8	-1.328E-03
9	-3.522E-01	9	-1.524E-03
10	-3.746E-01	10	-1.719E-03
11	-3.976E-01	11	-1.915E-03
12	-4.604E-01	12	-2.900E-03
13	-5.483E-01	13	-3.883E-03
14	-6.217E-01	14	-4.869E-03
15	-6.729E-01	15	-5.862E-03
16	-6.875E-01	16	-6.059E-03

17 -7.000E-01	17 -6.256E-03
18 -7.110E-01	18 -6.455E-03
19 -7.257E-01	19 -6.652E-03
20 -7.398E-01	20 -6.849E-03
21 -7.537E-01	21 -7.046E-03
22 -7.638E-01	22 -7.244E-03
23 -7.736E-01	23 -7.443E-03
24 -7.835E-01	24 -7.641E-03
25 -7.906E-01	25 -7.839E-03
26 -8.011E-01	26 -8.038E-03
27 -8.112E-01	27 -8.236E-03
28 -8.222E-01	28 -8.434E-03
29 -8.312E-01	29 -8.633E-03
30 -8.369E-01	30 -8.832E-03
31 -8.427E-01	31 -9.032E-03
32 -8.478E-01	32 -9.233E-03
33 -8.615E-01	33 -9.734E-03
34 -5.952E-01	34 -1.012E-02
35 -6.903E-01	35 -1.059E-02

Table 19

Concrete fcm38 fcu 44,7 steel 550N-mm2

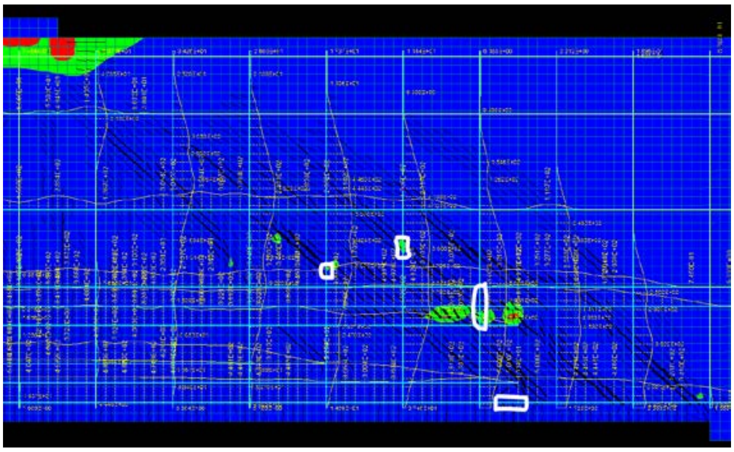


Figure 37

Results

Monitoring points after load step

----------------- Step Value [MN] -----------------	----------------- Step Value [m] -----------------
1 0.000E+00	1 -2.451E-05
2 -7.580E-02	2 -1.774E-04
3 -1.602E-01	3 -3.557E-04
4 -2.141E-01	4 -5.486E-04
5 -2.451E-01	5 -7.434E-04
6 -2.777E-01	6 -9.393E-04
7 -3.072E-01	7 -1.134E-03

8 -3.287E-01 9 -3.527E-01 10 -3.720E-01 11 -3.944E-01 12 -4.466E-01 13 -5.313E-01 14 -6.110E-01 15 -6.877E-01 16 -6.948E-01 17 -7.045E-01 18 -7.174E-01 19 -7.243E-01 20 -7.360E-01 21 -7.510E-01 22 -7.630E-01 23 -7.777E-01 24 -7.925E-01 25 -8.055E-01 26 -8.163E-01 27 -8.266E-01 28 -8.414E-01 29 -8.544E-01 30 -8.648E-01 31 -8.747E-01 32 -8.834E-01 33 -9.065E-01 34 -7.002E-01 35 -5.449E-01	8 -1.331E-03 9 -1.527E-03 10 -1.724E-03 11 -1.920E-03 12 -2.910E-03 13 -3.897E-03 14 -4.884E-03 15 -5.872E-03 16 -6.071E-03 17 -6.269E-03 18 -6.467E-03 19 -6.666E-03 20 -6.864E-03 21 -7.061E-03 22 -7.259E-03 23 -7.456E-03 24 -7.653E-03 25 -7.851E-03 26 -8.049E-03 27 -8.247E-03 28 -8.444E-03 29 -8.642E-03 30 -8.840E-03 31 -9.038E-03 32 -9.236E-03 33 -9.724E-03 34 -1.022E-02 35 -1.043E-02

Table 20

Specimen 1-2-2

Reinforcement configuration

- **Sbeta Material model**
- **25 mm**

Longitudinal 1Dand vertical reinforcements 2D

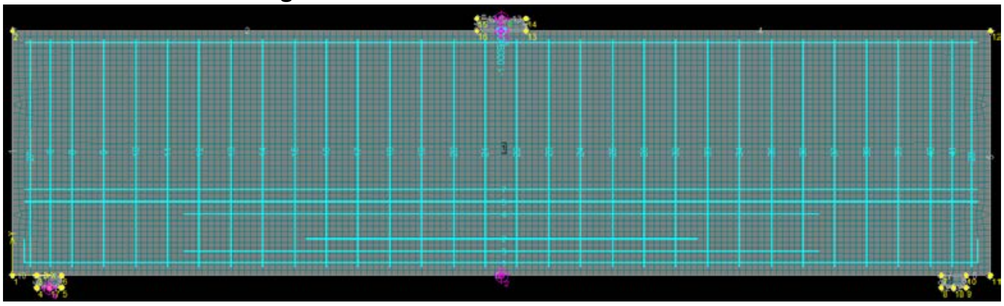


Figure 38

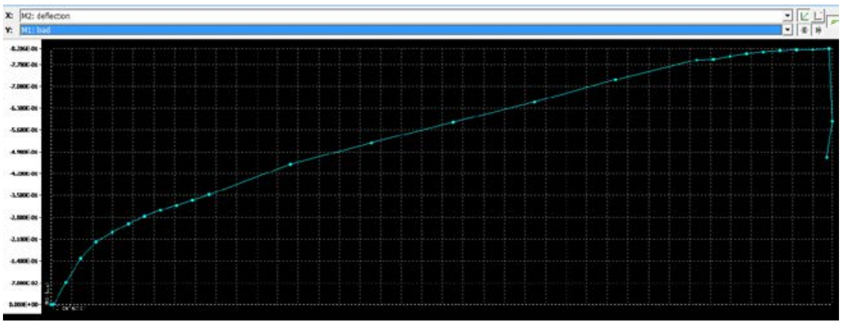


Figure 39

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
11	-3.525E-01	11	-1.921E-03
12	-4.504E-01	12	-2.903E-03
13	-5.184E-01	13	-3.891E-03
14	-5.849E-01	14	-4.879E-03
15	-6.492E-01	15	-5.867E-03
16	-7.220E-01	16	-6.851E-03
17	-7.841E-01	17	-7.841E-03
18	-7.873E-01	18	-8.041E-03
19	-7.970E-01	19	-8.240E-03
20	-8.042E-01	20	-8.440E-03
21	-8.097E-01	21	-8.640E-03
22	-8.148E-01	22	-8.840E-03
23	-8.168E-01	23	-9.042E-03
24	-8.176E-01	24	-9.243E-03
25	-8.206E-01	25	-9.440E-03
26	-5.877E-01	26	-9.479E-03
27	-4.710E-01	27	-9.415E-03

Table 21

- the only difference between this configuration and the first configuration in the beginning of this chapter is the here the distance between shear reinforcements are 130 mm in place of 200 mm in the first reinforcement configuration.
- Yielding of the bars begins at load step 18 which is only due to bending .more loading process leads to shear reinforcements also to yield in higher loads at load step 26 which definite failure happens, one can see that extensive yielding of the reinforcement bars bending and shear, also crushing of the compression strut, leads to the failure of the beam.
- It is important to mention that shear yielding is happening in the later phases of yielding. Because of extra shear reinforcements, consequently extra shear capacity of the beam.
- Failure of the compression struts due to the bending is the governing failure mode

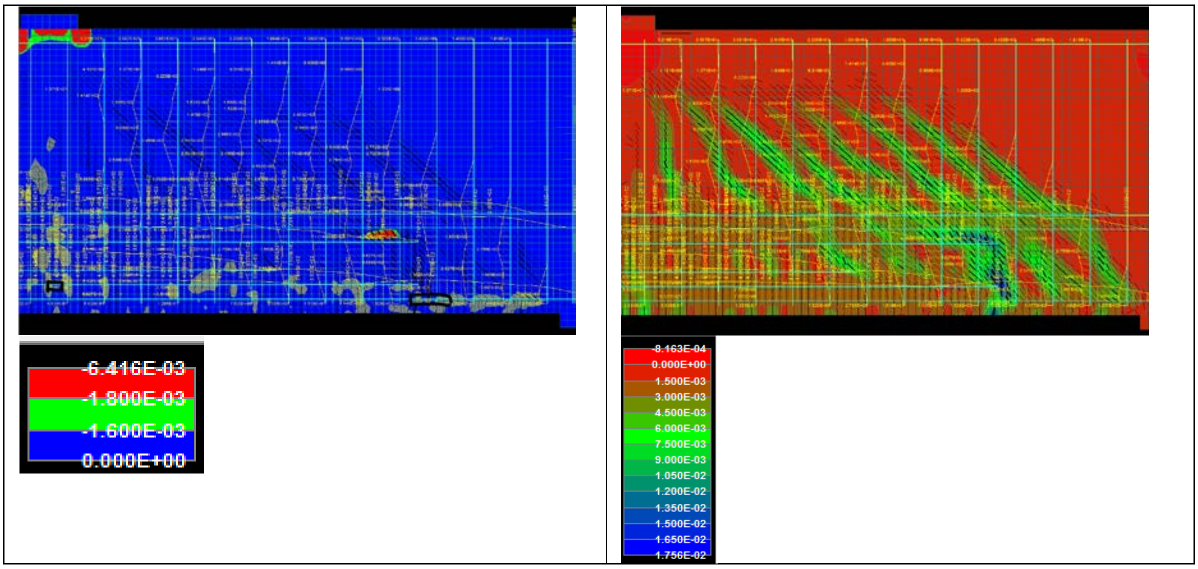


Figure 40

looking at 400 kN SLS

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.624E-05
2	-7.150E-02	2	-1.810E-04
3	-1.492E-01	3	-3.602E-04
4	-2.019E-01	4	-5.489E-04
5	-2.316E-01	5	-7.425E-04
6	-2.602E-01	6	-9.364E-04
7	-2.827E-01	7	-1.131E-03
8	-3.029E-01	8	-1.326E-03
9	-3.183E-01	9	-1.523E-03
10	-3.354E-01	10	-1.719E-03
11	-3.525E-01	11	-1.921E-03
12	-3.682E-01	12	-2.118E-03
13	-3.752E-01	13	-2.317E-03
14	-3.941E-01	14	-2.514E-03
15	-4.130E-01	15	-2.710E-03
16	-4.317E-01	16	-2.906E-03

Table 22

Crack evolution

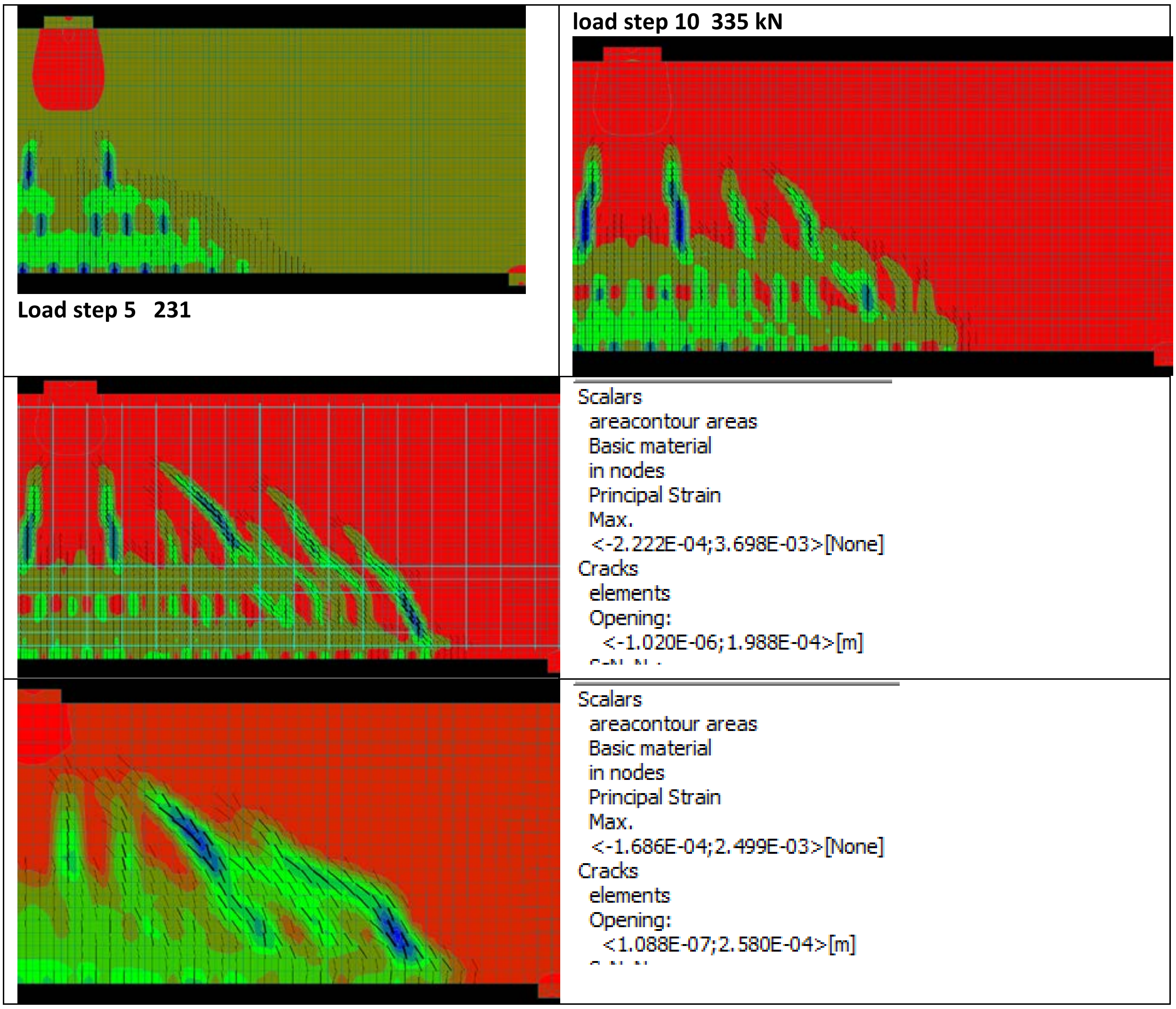


Figure 4

Crack width

Crack width is the summation of cracks near each other which is here approximatly 0,5 mm.

	ATENA	Scia
Deflection of the bam at load 400 kN SLS	**2,5**	**1,2**
Crack width	**0,5**	**Smaller than 0,3**

Table 23

At 400 kN SLS situation

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-97	-94
2 m	bottom	+215 196	282 263	-	-

		189 157 133 94	242 199 178 157		
Near by 2m		217 196 163 134 146 174	282 263 242 199 178 157		

Table 24

- In general ATENA gives lower ensile stresses on the rebars
- Because of the lack of reinforcements in the middle height of cross section of the beam at middle of the beam, cracking begins at this point and obviously at bottom. At load stp 400 kN crack pattern is developed till the inclined crack. all crack widths are 0,1 mm which is far from the criterion of crack width which is 0,3 mm.
- Deflection in ATENA is twice as big as in Scia Engineering.

concrete- fcm 38 steel 435

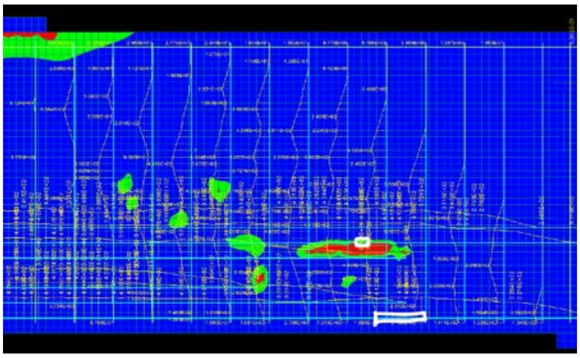


Figure 42

-----------------	-----------------
Step Value [MN]	Step Value [m]
-----------------	-----------------
11 -3.869E-01	11 -1.906E-03
12 -4.488E-01	12 -2.897E-03
13 -5.363E-01	13 -3.881E-03
14 -6.199E-01	14 -4.865E-03
15 -6.697E-01	15 -5.858E-03
16 -7.415E-01	16 -6.845E-03
17 -7.993E-01	17 -7.837E-03
18 -8.063E-01	18 -8.037E-03
19 -8.132E-01	19 -8.237E-03
20 -8.212E-01	20 -8.438E-03
21 -8.278E-01	21 -8.640E-03
22 -8.339E-01	22 -8.843E-03
23 -8.398E-01	23 -9.046E-03
24 -8.458E-01	24 -9.250E-03
25 -8.511E-01	25 -9.453E-03
26 -8.457E-01	26 -9.657E-03
27 -8.442E-01	27 -9.862E-03
28 -8.518E-01	28 -1.006E-02
29 -8.491E-01	29 -1.027E-02

30 -8.503E-01 31 -8.507E-01 32 -8.080E-01	30 -1.047E-02 31 -1.067E-02 32 -1.086E-02

Table 25

Concrete fcm38 and steel 550

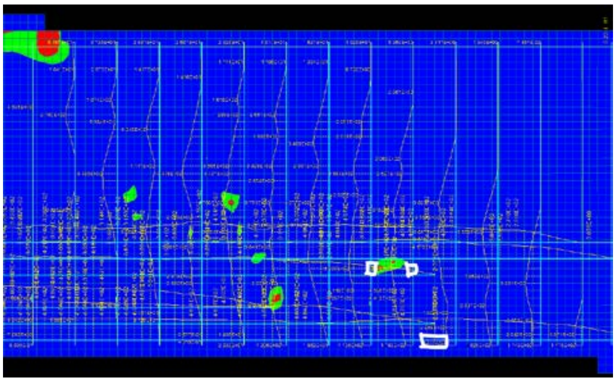


Figure 43

Results
Monitoring points after load step

----------------- Step Value [MN] ----------------- 10 -3.656E-01 11 -3.869E-01 12 -4.488E-01 13 -5.363E-01 14 -6.199E-01 15 -6.698E-01 16 -7.492E-01 17 -8.105E-01 18 -8.210E-01 19 -8.341E-01 20 -8.477E-01 21 -8.598E-01 22 -8.711E-01 23 -8.785E-01 24 -8.874E-01 25 -8.932E-01 26 -8.990E-01 27 -9.073E-01 28 -9.164E-01 29 -9.214E-01 30 -9.271E-01 31 -9.259E-01 32 -6.327E-01	----------------- Step Value [m] ----------------- 10 -1.708E-03 11 -1.906E-03 12 -2.897E-03 13 -3.881E-03 14 -4.865E-03 15 -5.858E-03 16 -6.843E-03 17 -7.831E-03 18 -8.029E-03 19 -8.227E-03 20 -8.424E-03 21 -8.621E-03 22 -8.819E-03 23 -9.019E-03 24 -9.219E-03 25 -9.419E-03 26 -9.618E-03 27 -9.816E-03 28 -1.001E-02 29 -1.021E-02 30 -1.041E-02 31 -1.061E-02 32 -1.067E-02

Table 26

Reinforcement configuration

- **Sbeta Material model**
- **25 mm**

Longitudinal and vertical based on 2D Scia 2d2d

Looking at failure load and crack development

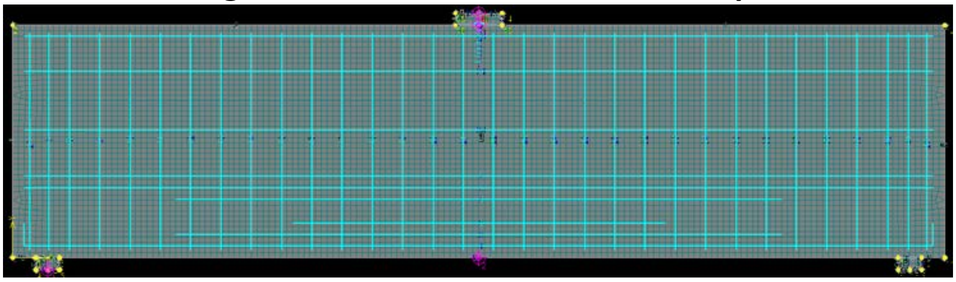


Figure 44

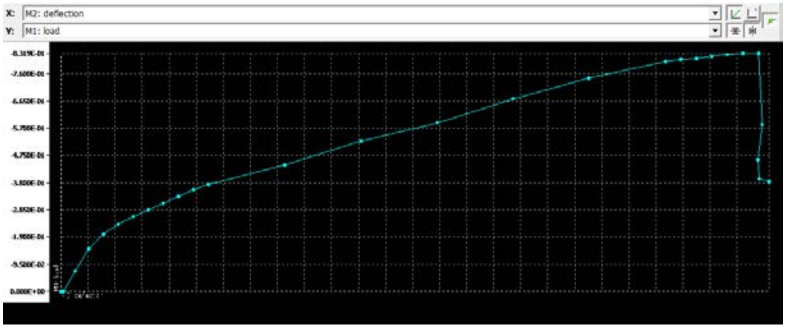


Figure 45

Results

Monitoring points after load step

Step	Value [MN]
1	0.000E+00
2	-7.173E-02
3	-1.497E-01
4	-2.024E-01
5	-2.352E-01
6	-2.606E-01
7	-2.854E-01
8	-3.091E-01
9	-3.325E-01
10	-3.553E-01
11	-3.739E-01
12	-4.427E-01
13	-5.259E-01
14	-5.898E-01
15	-6.734E-01
16	-7.453E-01
17	-8.037E-01

18 -8.108E-01 19 -8.142E-01 20 -8.222E-01 21 -8.281E-01 22 -8.318E-01 23 -8.319E-01 24 -5.835E-01 25 -4.604E-01 26 -3.937E-01 27 -3.846E-01	

Table 27

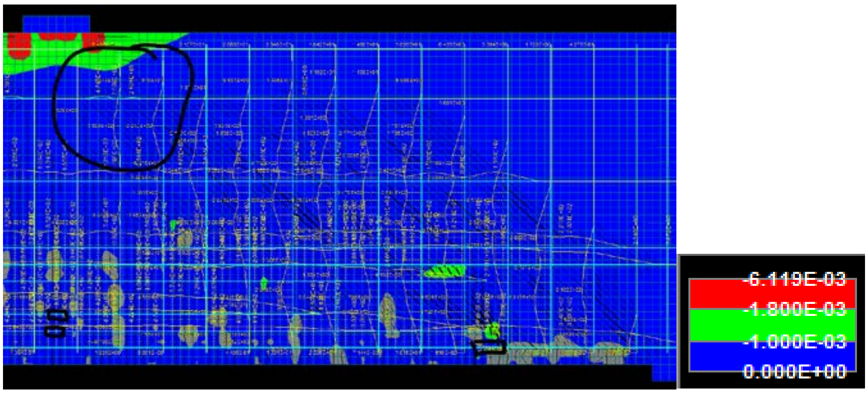


Figure 46

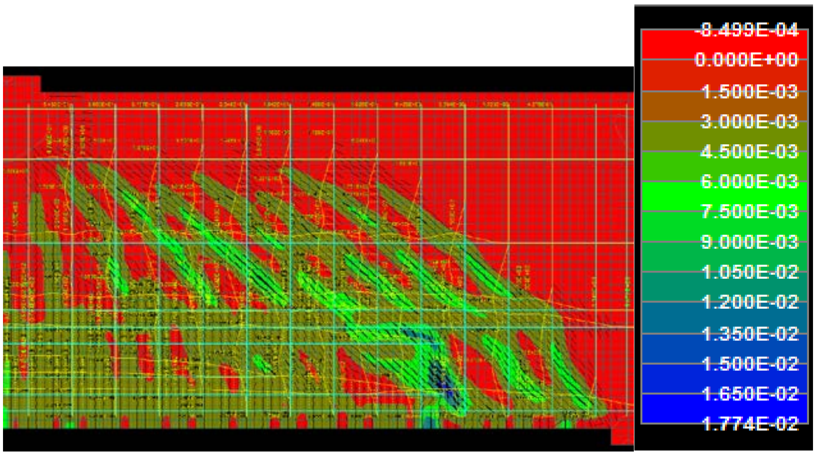


Figure47

- One can recognize the yielding part of the load-deformation diagram, which indicates that at load step 20 the failure is beginning by yielding of the rebars and at load step 23 definite failure happens.

- One can see from diagrams above that only yielding is happening in the bending rebars near by the support , and crushing of the concrete compressive struts is also happening. Crushing of compression zone in the specimen due to bending is the failure mode.

- ductile behavior of the bam at the failure mode.

Looking at 400 kN

Results
Monitoring points after load step

----------------- Step Value [MN] -----------------	----------------- Step Value [m] -----------------
1 0.000E+00	1 -2.613E-05
2 -2.436E-01	2 -8.567E-04
3 -3.481E-01	3 -1.841E-03
4 -3.648E-01	4 -2.040E-03
5 -3.832E-01	5 -2.238E-03
6 -4.017E-01	6 -2.435E-03
7 -4.202E-01	7 -2.632E-03
8 -4.343E-01	8 -2.830E-03

Table 28

Crack Evolution

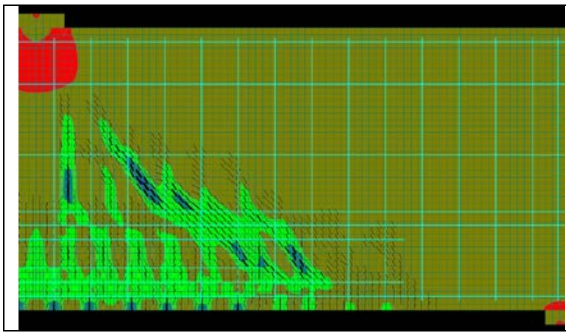


Figure 49

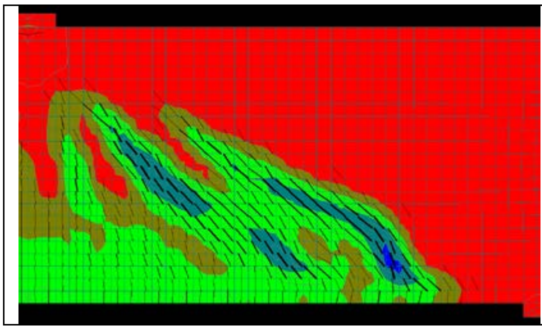


Figure 50

Crack width

As it is observed from the ATENA analysis for mesh 25mm and 50 mm, one can estimate that critical crack width is reaching 0,4mm.
Explanation for smaller crack width in comparison with the previous configuration(1d2d) is that here there are skin reinforcements available which have positive influence on the cracking behavior in SLS. This can be easily concluded by looking at the tensile stresses of the rebars which in the 2d2d case are smaller than in the 1d2d case.

	Atena	**Scia**
deflection	**2,4**	**1,2**

Table 29

At 400 kN SLS situation

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-110 -12	-96,1 -32,8
2 m	bottom	+184 175 186 158 115 47 12	280 260 239 197 176 155 72	-	-
Near by 2 m		185 174 182 158 131 174 135	280 260 239 197 176 155 72		

Table 30

- In general tensile stresses are lower than tensile stresses in Scia Engineer.
- Cracks beginning at the bottom of the beam element .
- Most of the cracks are vertical cracks , so Bending cracks rather than shear cracks.
- crack width is 0,14 mm which is far acceptable in comparison with the crack width criterion which is 0,3 mm.
- deflection in ATENA is twice as big as in Scia in SLS .

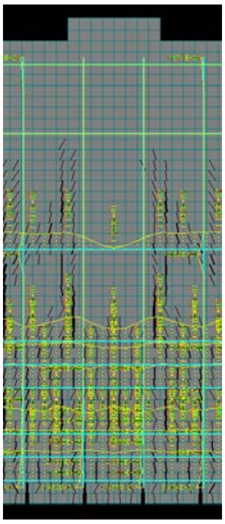


Figure 51

Concrete fcm38 fcu 44,7 steel 435

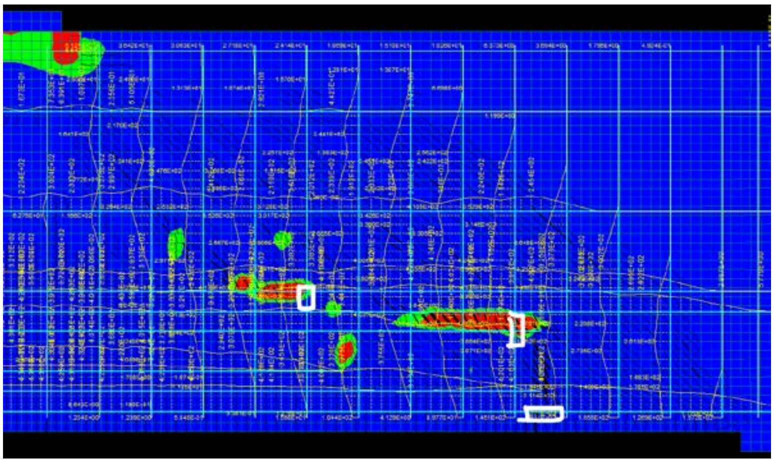


Figure 52

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
24	-8.463E-01	20	-8.429E-03
25	-8.540E-01	21	-8.628E-03
26	-8.561E-01	22	-8.827E-03
27	-8.623E-01	23	-9.027E-03
28	-8.674E-01	24	-9.228E-03
29	-8.665E-01	25	-9.429E-03
30	-8.660E-01	26	-9.632E-03
31	-8.621E-01	27	-9.833E-03
32	-5.980E-01	28	-1.003E-02
		29	-1.023E-02
		30	-1.043E-02
		31	-1.063E-02
		32	-1.071E-02

Table 31

FCM 38 fcu 44,8 steel 550

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.448E-05
2	-7.588E-02	2	-1.775E-04
3	-1.603E-01	3	-3.558E-04
4	-2.192E-01	4	-5.437E-04
5	-2.525E-01	5	-7.364E-04
6	-2.742E-01	6	-9.312E-04
7	-2.957E-01	7	-1.126E-03
8	-3.239E-01	8	-1.319E-03
9	-3.480E-01	9	-1.513E-03
10	-3.677E-01	10	-1.709E-03
11	-3.867E-01	11	-1.908E-03
12	-4.680E-01	12	-2.893E-03
13	-5.423E-01	13	-3.880E-03
14	-6.208E-01	14	-4.866E-03
15	-6.967E-01	15	-5.851E-03
16	-7.518E-01	16	-6.842E-03
17	-8.100E-01	17	-7.832E-03
18	-8.159E-01	18	-8.031E-03
19	-8.275E-01	19	-8.229E-03
20	-8.370E-01	20	-8.427E-03
21	-8.450E-01	21	-8.627E-03
22	-8.519E-01	22	-8.827E-03
23	-8.574E-01	23	-9.028E-03
24	-8.586E-01	24	-9.231E-03
25	-8.624E-01	25	-9.433E-03
26	-8.694E-01	26	-9.633E-03
27	-8.759E-01	27	-9.834E-03
28	-8.766E-01	28	-1.004E-02
29	-8.828E-01	29	-1.023E-02
30	-8.866E-01	30	-1.043E-02
31	-8.884E-01	31	-1.063E-02
32	-6.445E-01	32	-1.078E-02

Table 32

Specimens

1-3-1

1-3-2

1-3-3

1-3-4

Specimen 1-3-1   reinforcement config 1d1d

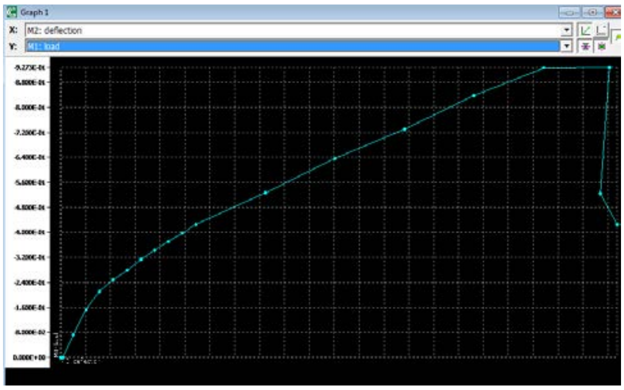


Figure 53

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.569E-05
2	-7.272E-02	2	-1.798E-04
3	-1.526E-01	3	-3.587E-04
4	-2.108E-01	4	-5.458E-04
5	-2.487E-01	5	-7.391E-04
6	-2.787E-01	6	-9.358E-04
7	-3.137E-01	7	-1.129E-03
8	-3.435E-01	8	-1.323E-03
9	-3.708E-01	9	-1.516E-03
10	-3.975E-01	10	-1.709E-03
11	-4.257E-01	11	-1.903E-03
12	-5.269E-01	12	-2.881E-03
13	-6.359E-01	13	-3.861E-03
14	-7.304E-01	14	-4.842E-03
15	-8.372E-01	15	-5.817E-03
16	-9.259E-01	16	-6.794E-03
17	-9.273E-01	17	-7.723E-03
18	-5.233E-01	18	-7.591E-03
19	-4.262E-01	19	-7.830E-03

Table 33

looking at failure

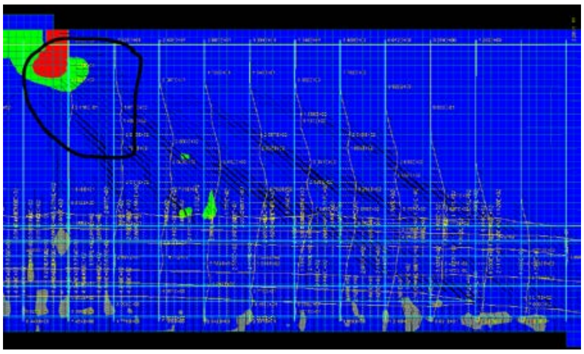


Figure 54

- No yielding of the bars happen
- only crushing of the concrete at top , and crushing of the compression strut.
- brittle failure

looking at SLS

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
4	-2.108E-01	4	-5.458E-04
5	-2.487E-01	5	-7.391E-04
6	-2.787E-01	6	-9.358E-04
7	-3.137E-01	7	-1.129E-03
8	-3.435E-01	8	-1.323E-03
9	-3.708E-01	9	-1.516E-03
10	-3.975E-01	10	-1.709E-03
11	-4.257E-01	11	-1.903E-03
12	-5.269E-01	12	-2.881E-03
13	-5.476E-01	13	-3.077E-03
14	-5.716E-01	14	-3.273E-03
15	-5.914E-01	15	-3.469E-03
16	-6.147E-01	16	-3.665E-0

Table 34

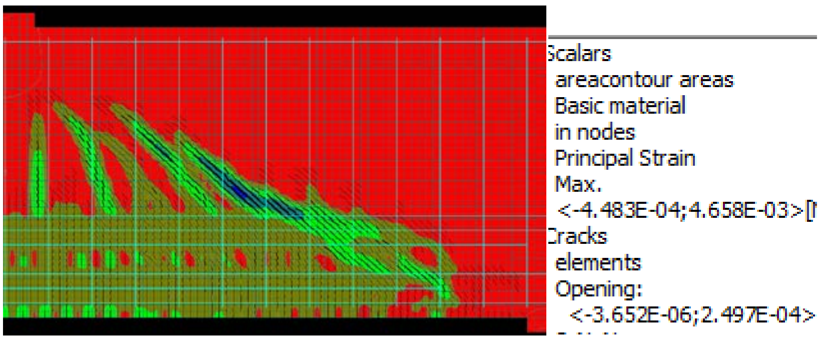


Figure 55

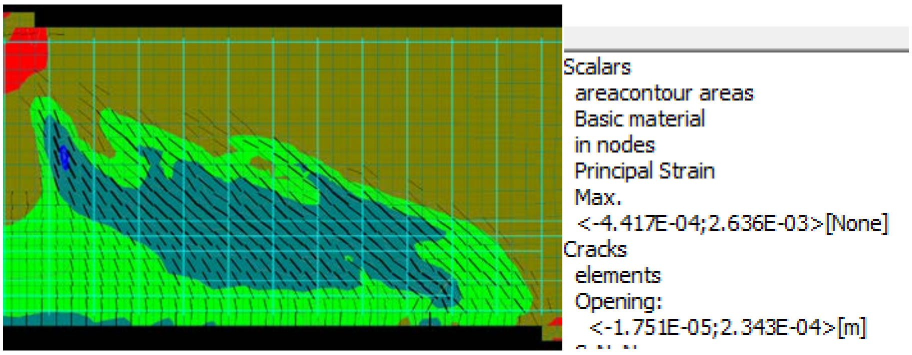


Figure 56

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-194	-127
2 m	Rebar 1 Rebar2 Rebar 3 Rebar 4 Rebar 5 Rebar 6	+240 +221 +202 +173 +146 +77	311 289 264 215 190 164		
Near by 2m	Rebar 1 Rebar 2 Rebar3 Rebar 4 Rebar 5 Rebar 6	+240 +221 +202 +173 +146 +195	311 289 264 215 190 164	-	-

Table 35

Specimen 1-3-2   reinforcement config 1d2d

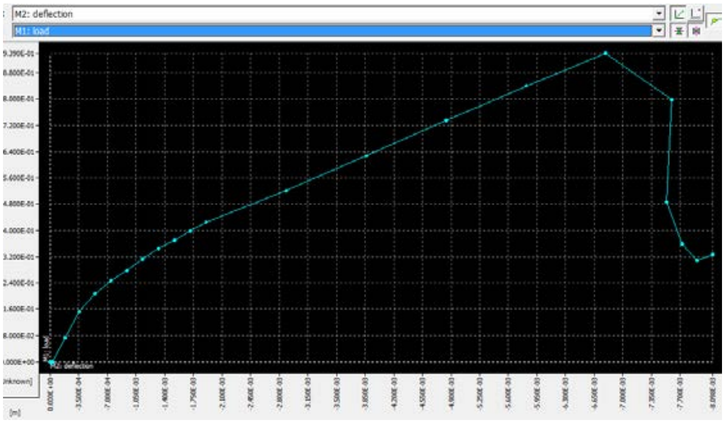


Figure 57

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.568E-05
2	-7.277E-02	2	-1.798E-04
3	-1.533E-01	3	-3.582E-04
4	-2.073E-01	4	-5.469E-04
5	-2.477E-01	5	-7.417E-04
6	-2.780E-01	6	-9.376E-04
7	-3.134E-01	7	-1.131E-03
8	-3.440E-01	8	-1.324E-03
9	-3.700E-01	9	-1.518E-03
10	-3.981E-01	10	-1.712E-03
11	-4.252E-01	11	-1.906E-03
12	-5.206E-01	12	-2.886E-03
13	-6.273E-01	13	-3.865E-03
14	-7.341E-01	14	-4.843E-03
15	-8.402E-01	15	-5.819E-03
16	-9.390E-01	16	-6.789E-03
17	-7.979E-01	17	-7.598E-03
18	-4.867E-01	18	-7.532E-03
19	-3.587E-01	19	-7.727E-03
20	-3.094E-01	20	-7.905E-03
21	-3.265E-01	21	-8.098E-03

Table 36

looking at failure

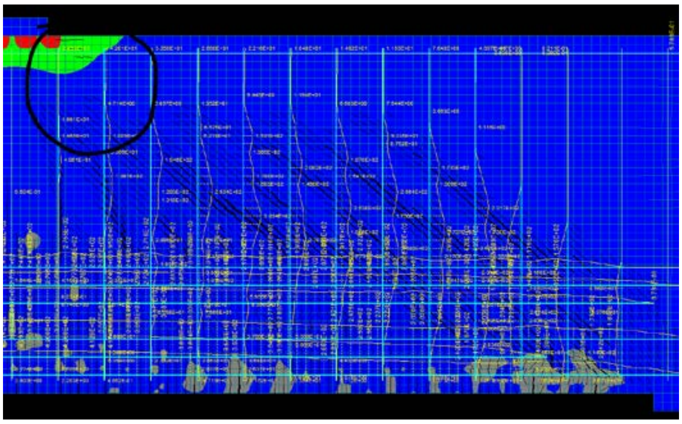


Figure 58

- no yielding of the bars
- Crushing of the concrete at the top, and crushing of the compression struts.
- brittle failure

Looking at SLS

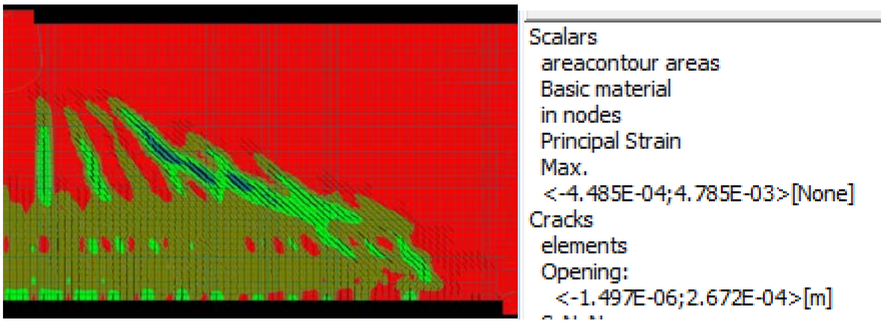


Figure 59

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-140	-127
2 m	Rebar 1	+242	311		
	Rebar2	+224	289		
	Rebar 3	+190	264		
	Rebar 4	+150	215		
	Rebar 5	+150	190		
	Rebar 6	+120	164		
Near by 2m	Rebar 1	+242	311	-	-
	Rebar 2	+224	289		
	Rebar3	+190	264		
	Rebar 4	+150	215		
	Rebar 5	+150	190		
	Rebar 6	+194	164		

Table 37

Specimen 1-3-3   2d1d

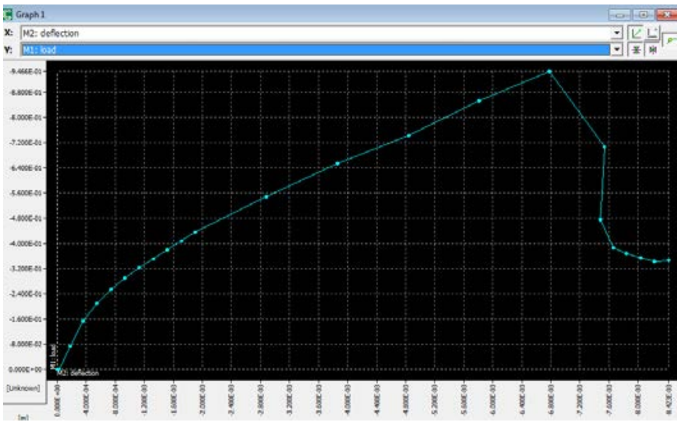


Figure 60

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.564E-05
2	-7.282E-02	2	-1.797E-04
3	-1.528E-01	3	-3.585E-04
4	-2.091E-01	4	-5.476E-04
5	-2.536E-01	5	-7.388E-04
6	-2.897E-01	6	-9.330E-04
7	-3.233E-01	7	-1.127E-03
8	-3.510E-01	8	-1.323E-03
9	-3.792E-01	9	-1.517E-03
10	-4.082E-01	10	-1.710E-03
11	-4.356E-01	11	-1.903E-03
12	-5.488E-01	12	-2.878E-03
13	-6.533E-01	13	-3.857E-03
14	-7.422E-01	14	-4.837E-03
15	-8.523E-01	15	-5.808E-03
16	-9.466E-01	16	-6.779E-03
17	-7.070E-01	17	-7.538E-03
18	-4.755E-01	18	-7.484E-03
19	-3.861E-01	19	-7.658E-03
20	-3.677E-01	20	-7.838E-03
21	-3.543E-01	21	-8.033E-03
22	-3.437E-01	22	-8.228E-03
23	-3.464E-01	23	-8.423E-03

Table 38

looking at failure

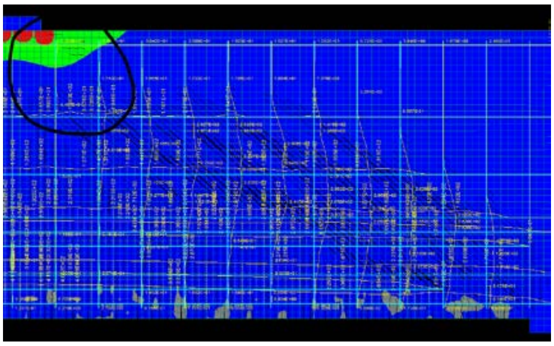


Figure 61

- No Yielding of the bars
- brittle failure
- crushing of the compression struts

looking at SLS

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.564E-05
2	-7.282E-02	2	-1.797E-04
3	-1.528E-01	3	-3.585E-04
4	-2.091E-01	4	-5.476E-04
5	-2.536E-01	5	-7.388E-04
6	-2.897E-01	6	-9.330E-04
7	-3.233E-01	7	-1.127E-03
8	-3.510E-01	8	-1.323E-03
9	-3.792E-01	9	-1.517E-03
10	-4.082E-01	10	-1.710E-03
11	-4.356E-01	11	-1.903E-03
12	-5.488E-01	12	-2.878E-03
13	-5.646E-01	13	-3.075E-03
14	-5.843E-01	14	-3.272E-03
15	-6.282E-01	15	-3.460E-03

Table 39

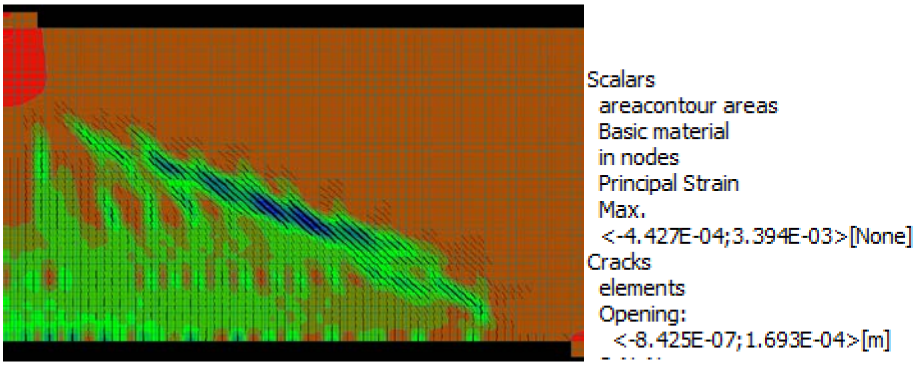


Figure 62

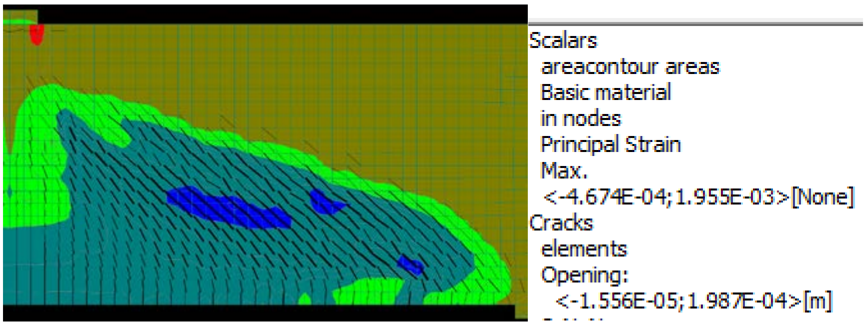


Figure 63

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-147 -	-128 -10
2 m	Rebar 1 Rebar2 Rebar 3 Rebar 4 Rebar 5 Rebar 6	+230 +210 +104 +147 +127 +81 +36 +13	305 283 259 210 186 160 85 -		
Near by 2m	Rebar 1 Rebar 2 Rebar3 Rebar 4 Rebar 5 Rebar 6	+230 +210 +104 +147 +127 +140 +122 +44	305 283 259 210 186 160 85 -	-	-

Table 40

Specimen 1-3-4 2d2d

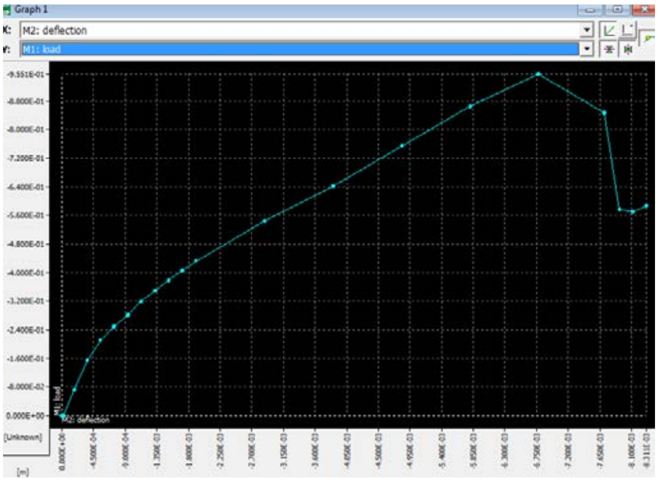


Figure 64

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.562E-05
2	-7.287E-02	2	-1.797E-04
3	-1.535E-01	3	-3.580E-04
4	-2.110E-01	4	-5.460E-04
5	-2.485E-01	5	-7.393E-04
6	-2.822E-01	6	-9.354E-04
7	-3.197E-01	7	-1.128E-03
8	-3.493E-01	8	-1.323E-03
9	-3.775E-01	9	-1.517E-03
10	-4.063E-01	10	-1.711E-03
11	-4.326E-01	11	-1.906E-03
12	-5.446E-01	12	-2.880E-03
13	-6.416E-01	13	-3.861E-03
14	-7.546E-01	14	-4.835E-03
15	-8.653E-01	15	-5.807E-03
16	-9.551E-01	16	-6.778E-03
17	-8.470E-01	17	-7.715E-03
18	-5.761E-01	18	-7.929E-03
19	-5.693E-01	19	-8.118E-03
20	-5.871E-01	20	-8.311E-03

Table 41

looking at failure

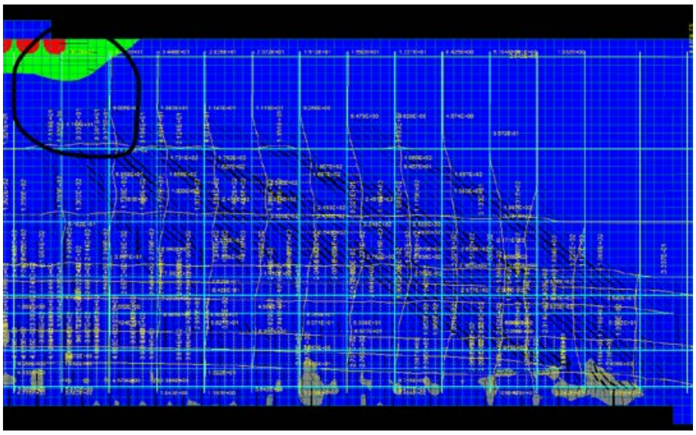


Figure 65

- No yielding of the bars
- Brittle failure
- crushing of the compression struts

looking at SLS

Step	Value [MN]
1	0.000E+00
2	-7.287E-02
3	-1.535E-01
8	-3.493E-01
9	-3.775E-01
10	-4.063E-01
11	-4.326E-01
12	-5.446E-01
13	-5.647E-01
14	-5.865E-01
15	-6.304E-01

Step	Value [m]
1	-2.562E-05
2	-1.797E-04
3	-3.580E-04
8	-1.323E-03
9	-1.517E-03
10	-1.711E-03
11	-1.906E-03
12	-2.880E-03
13	-3.076E-03
14	-3.271E-03
15	-3.459E-03

Table 42

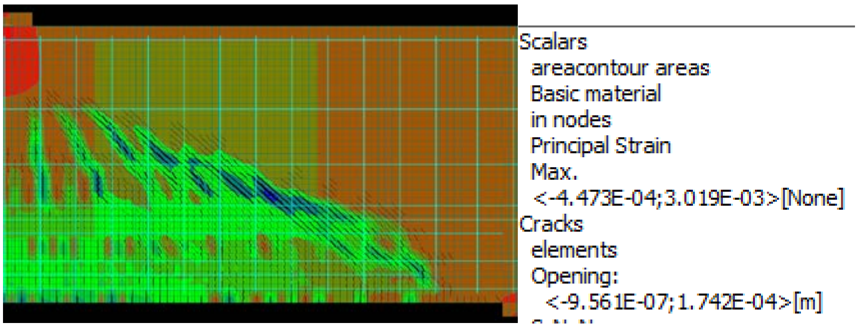


Figure 66

Location rebars	Location height	Tensile stresses(ATENA)	Tensile Stresses(SCIA)	Compression stresses(ATENA)	Compression stresses(SCIA)
2m	top	-	-	-140 -	-128 -10
2 m	Rebar 1 Rebar2 Rebar 3 Rebar 4 Rebar 5 Rebar 6	+200 +211 +180 +153 +105 +100 +40 +10	305 283 259 210 186 160 85 -		
Near by 2m	Rebar 1 Rebar 2 Rebar3 Rebar 4 Rebar 5 Rebar 6	+200 +211 +180 +153 +105 +158 +120 +48	305 283 259 210 186 160 85 -	-	-

Table 43

SPECIMENS

1-4-1

1-4-2

1-4-3

1-4-4

Specimen 1-4-1

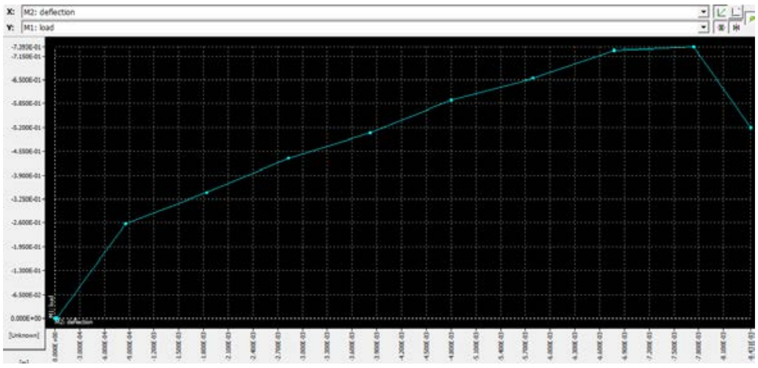


Figure 67

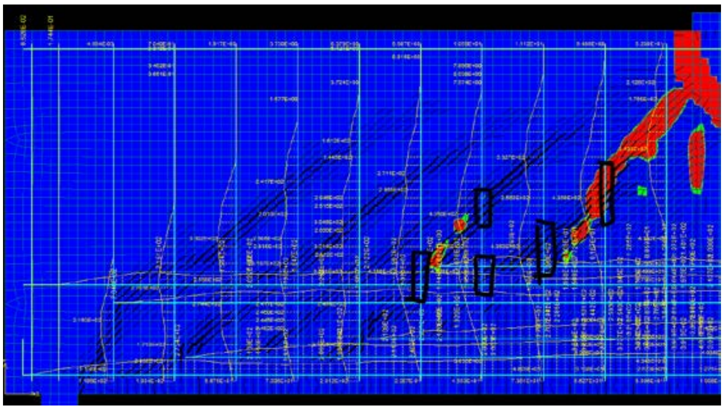


Figure 68

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.598E-05
2	-2.570E-01	2	-8.531E-04
3	-3.420E-01	3	-1.839E-03
4	-4.365E-01	4	-2.826E-03
5	-5.059E-01	5	-3.817E-03
6	-5.940E-01	6	-4.802E-03
7	-6.543E-01	7	-5.793E-03
8	-7.311E-01	8	-6.778E-03
9	-7.393E-01	9	-7.740E-03
10	-5.194E-01	10	-8.431E-03

Table 44

Looking at SLS

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.598E-05
2	-2.570E-01	2	-8.531E-04
3	-3.420E-01	3	-1.839E-03
4	-4.365E-01	4	-2.826E-03
5	-4.577E-01	5	-3.023E-03
6	-4.769E-01	6	-3.220E-03
7	-4.995E-01	7	-3.416E-03

Table 45

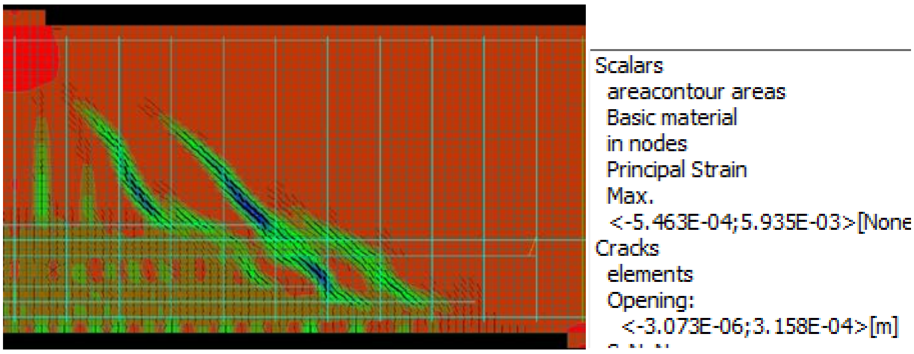


Figure 69

Bottom 0,23 Crack width 0,6 mm

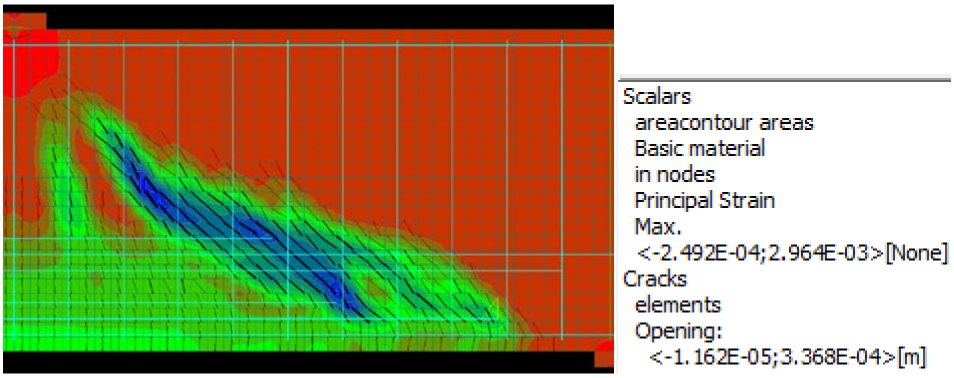


Figure 70

FCm 38 fcu 44,7 steel 435

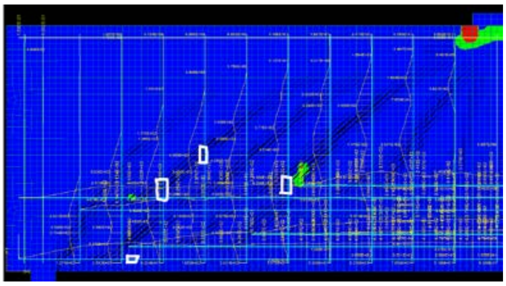


Figure 71

Results

Monitoring points after load step

----------------- Step Value [MN] ----------------- 1 0.000E+00 2 -2.722E-01 3 -3.600E-01 4 -4.486E-01 5 -5.274E-01 6 -6.078E-01 7 -6.749E-01 8 -7.539E-01 9 -8.208E-01 10 -8.819E-01 11 -5.934E-01 12 -4.848E-01	----------------- Step Value [m] ----------------- 1 -2.434E-05 2 -8.458E-04 3 -1.838E-03 4 -2.829E-03 5 -3.820E-03 6 -4.810E-03 7 -5.802E-03 8 -6.790E-03 9 -7.780E-03 10 -8.763E-03 11 -9.532E-03 12 -1.015E-02

Table 46

Concrete 44,7 fcm 38 steel 550

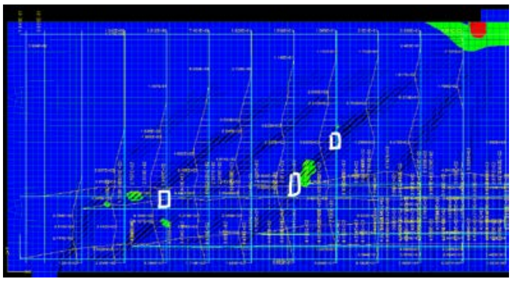


Figure 72

Results

Monitoring points after load step

----------------- Step Value [MN] ----------------- 1 0.000E+00	----------------- Step Value [m] ----------------- 1 -2.434E-05

2 -2.722E-01	2 -8.458E-04
3 -3.600E-01	3 -1.838E-03
4 -4.486E-01	4 -2.829E-03
5 -5.274E-01	5 -3.819E-03
6 -6.078E-01	6 -4.810E-03
7 -6.750E-01	7 -5.802E-03
8 -7.543E-01	8 -6.790E-03
9 -8.248E-01	9 -7.780E-03
10 -9.034E-01	10 -8.758E-03
11 -6.179E-01	11 -9.528E-03

Table 47

Specimen 1-4-2

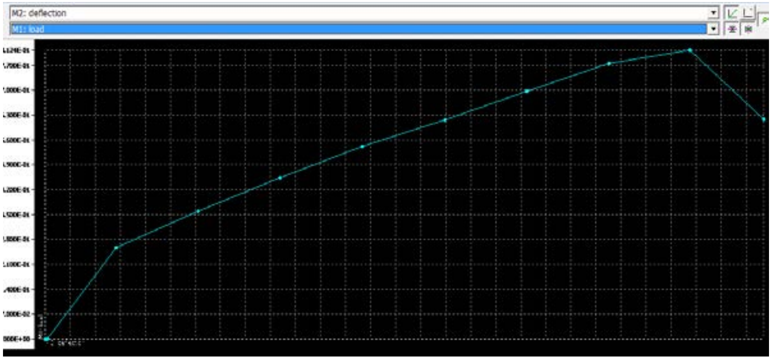


Figure 73

Results

Monitoring points after load step

-----------------	-----------------
Step Value [MN]	Step Value [m]
-----------------	-----------------
1 0.000E+00	1 -2.595E-05
2 -2.566E-01	2 -8.496E-04
3 -3.584E-01	3 -1.832E-03
4 -4.531E-01	4 -2.817E-03
5 -5.420E-01	5 -3.801E-03
6 -6.167E-01	6 -4.789E-03
7 -6.959E-01	7 -5.773E-03
8 -7.750E-01	8 -6.755E-03
9 -8.124E-01	9 -7.728E-03
10 -6.184E-01	10 -8.610E-03

Table 48

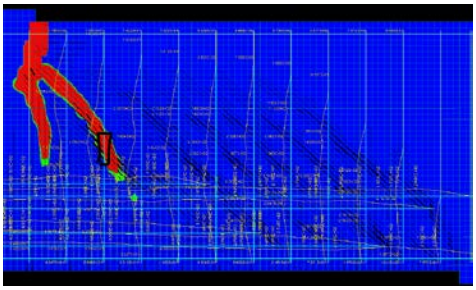


Figure 74

Looking at SLS

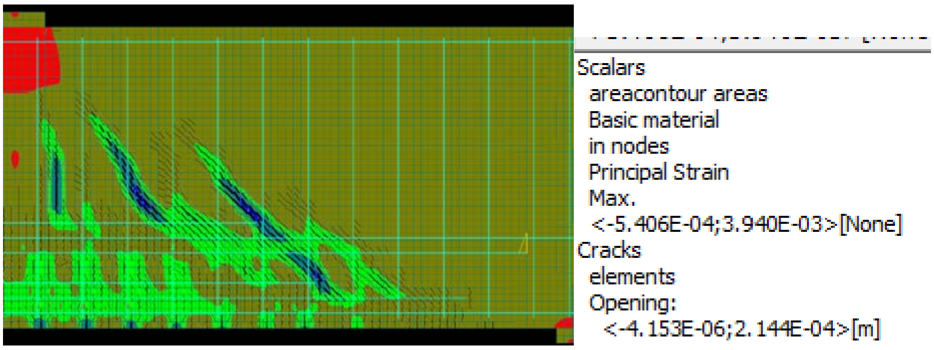


Figure 75

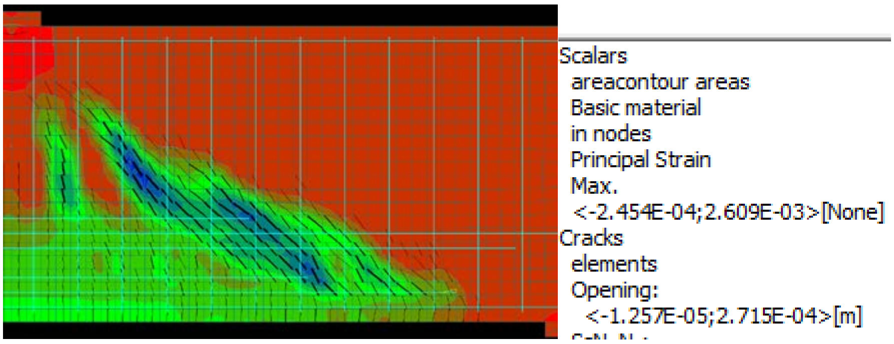


Figure 76

Bottom 0,25, Body minimum 0,4

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.579E-05
2	-2.473E-01	2	-9.052E-04
3	-3.298E-01	3	-1.895E-03
4	-4.300E-01	4	-2.882E-03
5	-4.455E-01	5	-3.080E-03
6	-4.783E-01	6	-3.575E-03

Table 49

Fcm 38 fcu 44,8 steel 435

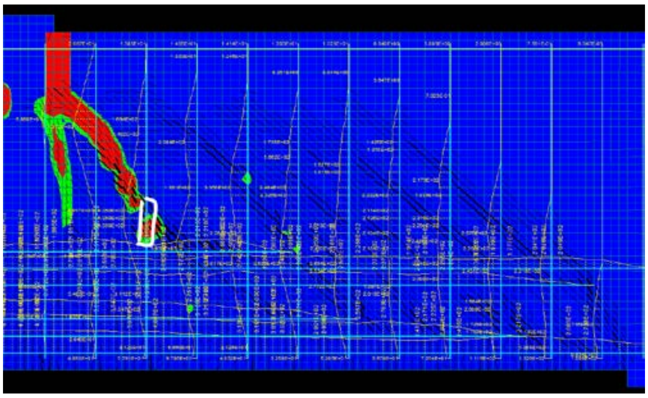


Figure 77

[Results](#)

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.432E-05
2	-2.725E-01	2	-8.420E-04
3	-3.815E-01	3	-1.828E-03
4	-4.677E-01	4	-2.819E-03
5	-5.597E-01	5	-3.805E-03
6	-6.468E-01	6	-4.793E-03
7	-7.295E-01	7	-5.780E-03
8	-8.078E-01	8	-6.768E-03
9	-8.847E-01	9	-7.758E-03
10	-9.282E-01	10	-8.750E-03
11	-6.410E-01	11	-9.691E-03

Table 50

Concrete fcm 38 steel 550

[Results](#)

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.417E-05
2	-2.667E-01	2	-8.956E-04
3	-3.457E-01	3	-1.888E-03
4	-4.408E-01	4	-2.878E-03
5	-4.529E-01	5	-3.077E-03
6	-5.075E-01	6	-3.568E-03
7	-5.510E-01	7	-4.062E-03
8	-6.344E-01	8	-5.052E-03
9	-7.220E-01	9	-6.040E-03

10 -8.059E-01 11 -8.901E-01 12 -9.259E-01 13 -9.670E-01 14 -7.718E-01 15 -8.223E-01	10 -7.027E-03 11 -8.014E-03 12 -8.507E-03 13 -8.998E-03 14 -9.903E-03 15 -1.085E-02

Table 51

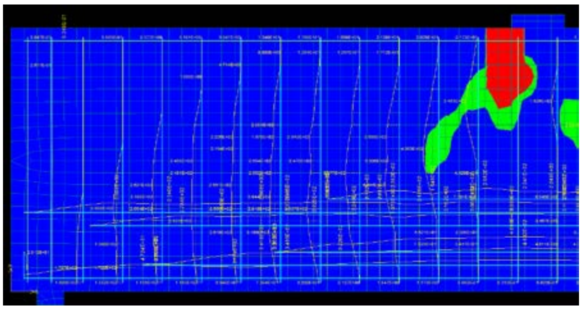


Figure 78

NO Yielding occurs brittle failure

Specimen 1-4-3 2d1d

Looking at failure

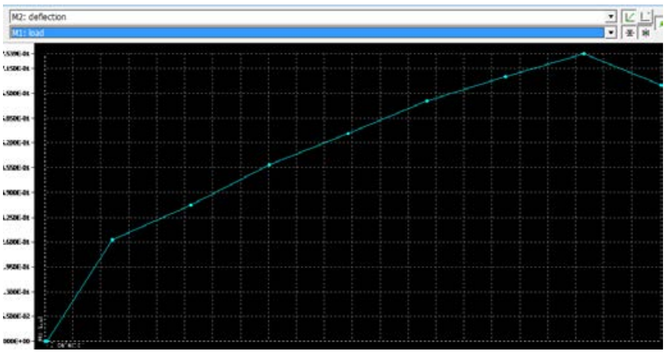


Figure 79

Results
Monitoring points after load step

Step Value [MN] ----------------- 4 -4.626E-01 5 -5.445E-01 6 -6.296E-01 7 -6.944E-01 8 -7.539E-01 9 -6.711E-01	----------------- Step Value [m] ----------------- 4 -2.812E-03 5 -3.798E-03 6 -4.783E-03 7 -5.771E-03 8 -6.754E-03 9 -7.720E-03

Table 52

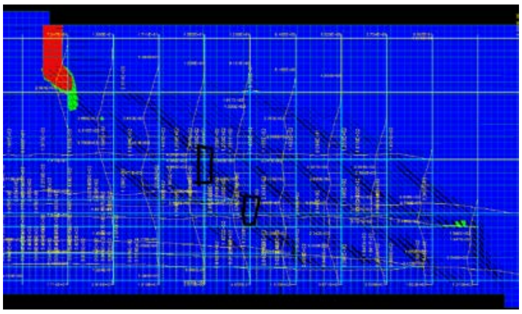


Figure 80

Looking at SLS

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.590E-05
2	-2.654E-01	2	-8.420E-04
3	-3.567E-01	3	-1.828E-03
4	-4.041E-01	4	-2.322E-03
5	-4.238E-01	5	-2.519E-03
6	-4.477E-01	6	-2.714E-03
7	-4.693E-01	7	-2.911E-03

Table 53

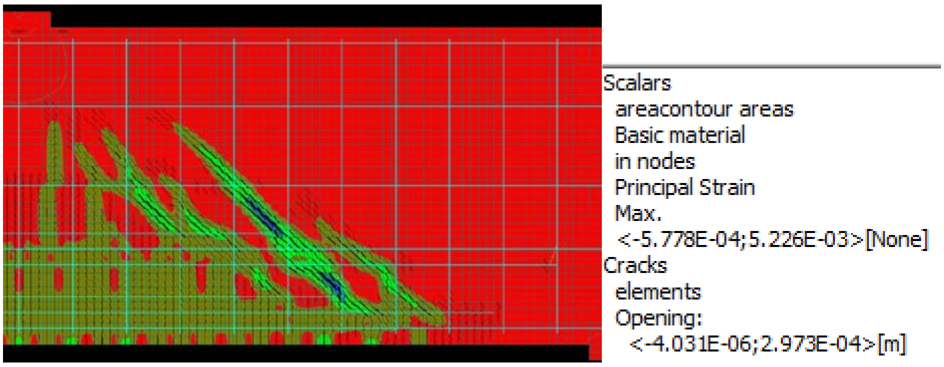


Figure 81

Body 0,6

Bottom 0,2

Concrete fcm 38 fcu 44,7 steel 435

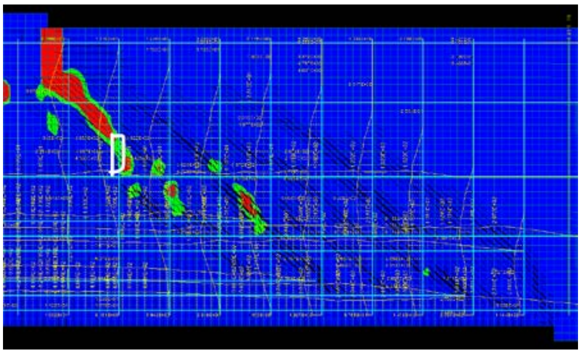


Figure 82

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.427E-05
2	-2.855E-01	2	-8.256E-04
3	-3.828E-01	3	-1.817E-03
4	-4.935E-01	4	-2.803E-03
5	-5.891E-01	5	-3.788E-03
6	-6.303E-01	6	-4.782E-03
7	-7.205E-01	7	-5.766E-03
8	-7.918E-01	8	-6.754E-03
9	-8.650E-01	9	-7.734E-03
10	-8.342E-01	10	-8.714E-03
11	-6.063E-01	11	-9.650E-03
12	-5.805E-01	12	-1.060E-02

Table 54

Concrete fcm 38 fcu 44,7 steel 550

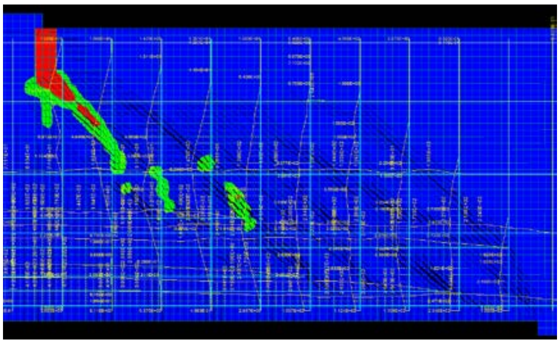


Figure 83

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.427E-05
2	-2.855E-01	2	-8.256E-04
3	-3.830E-01	3	-1.817E-03
4	-4.857E-01	4	-2.805E-03
5	-5.601E-01	5	-3.793E-03
6	-6.476E-01	6	-4.778E-03
7	-7.133E-01	7	-5.768E-03
8	-7.954E-01	8	-6.753E-03
9	-8.648E-01	9	-7.735E-03
10	-6.446E-01	10	-8.715E-03
11	-6.600E-01	11	-9.688E-03

Table 55

Specimen 1-4-4 2d2d

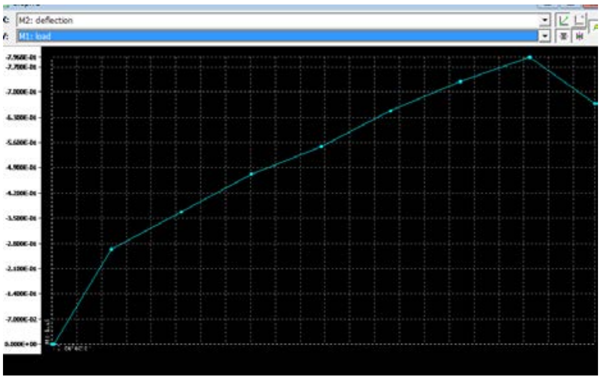


Figure 84

Looking at failure

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.587E-05
2	-2.642E-01	2	-8.413E-04
3	-3.666E-01	3	-1.826E-03
4	-4.724E-01	4	-2.808E-03
5	-5.482E-01	5	-3.793E-03
6	-6.477E-01	6	-4.774E-03
7	-7.290E-01	7	-5.757E-03
8	-7.968E-01	8	-6.738E-03
9	-6.671E-01	9	-7.652E-03

Table 56

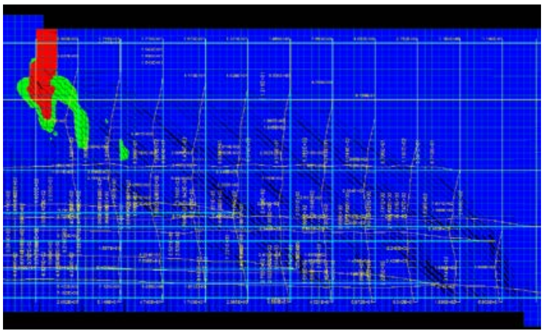


Figure 85

Looking at SLS

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.587E-05
2	-2.642E-01	2	-8.413E-04
3	-3.666E-01	3	-1.826E-03
4	-4.118E-01	4	-2.319E-03
5	-4.430E-01	5	-2.613E-03
6	-4.545E-01	6	-2.711E-03
7	-4.661E-01	7	-2.809E-03

Table 57

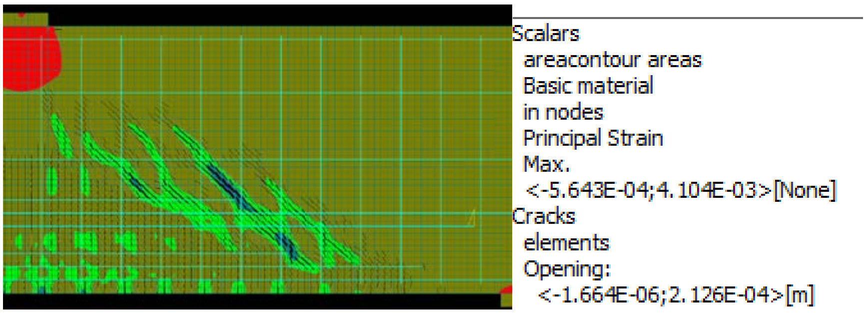


Figure 86

Bottom 0,2 Boddy 0,5

Fcm 38 fcu 44,8 steel 435

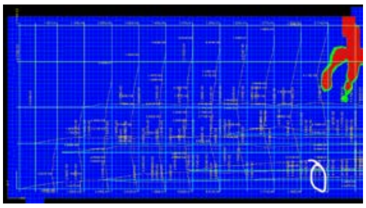


Figure 87

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.425E-05
2	-2.856E-01	2	-8.257E-04
3	-4.015E-01	3	-1.809E-03
4	-4.986E-01	4	-2.799E-03
5	-5.768E-01	5	-3.787E-03
6	-6.731E-01	6	-4.771E-03
7	-7.624E-01	7	-5.756E-03
8	-8.385E-01	8	-6.742E-03
9	-9.078E-01	9	-7.727E-03
10	-9.626E-01	10	-8.718E-03
11	-6.984E-01	11	-9.563E-03
12	-8.924E-01	12	-1.050E-02

Table 58

Fcm 38 fcu 44,7 steel 550

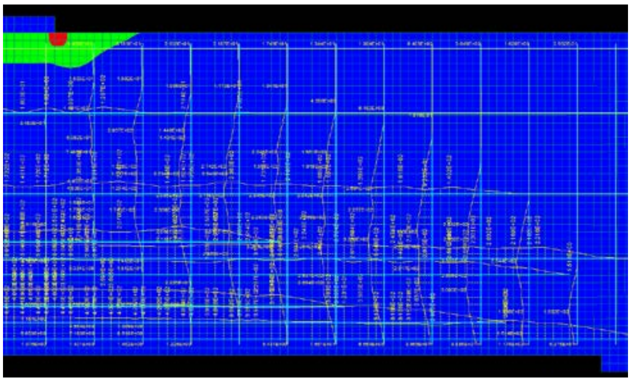


Figure 88

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.425E-05
2	-2.856E-01	2	-8.257E-04
3	-4.014E-01	3	-1.809E-03
4	-5.012E-01	4	-2.799E-03
5	-5.750E-01	5	-3.787E-03
6	-6.709E-01	6	-4.771E-03
7	-7.625E-01	7	-5.756E-03
8	-8.440E-01	8	-6.741E-03
9	-9.054E-01	9	-7.726E-03
10	-8.673E-01	10	-8.675E-03
11	-6.284E-01	11	-9.476E-03
12	-5.467E-01	12	-1.039E-02

Table 59

ATENA EVALUATION based on Laboratory test van Hulten,

Option 1 (chapter 7.5.1)

Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-8.950E-06
2	-1.433E-01	2	-1.445E-04
3	-2.619E-01	3	-3.239E-04
4	-2.798E-01	4	-5.269E-04
5	-3.296E-01	5	-7.187E-04
6	-3.539E-01	6	-9.108E-04
7	-3.867E-01	7	-1.906E-03
8	-5.092E-01	8	-2.896E-03
9	-5.706E-01	9	-3.890E-03
10	-6.832E-01	10	-4.883E-03
11	-7.529E-01	11	-5.888E-03
12	-7.831E-01	12	-6.911E-03
13	-7.853E-01	13	-7.948E-03
14	-6.210E-01	14	-8.959E-03

Table 60

Option 2(chapter 7.5.2)

results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-8.540E-06
2	-1.489E-01	2	-1.428E-04
3	-2.712E-01	3	-3.244E-04
4	-3.157E-01	4	-5.213E-04
5	-3.601E-01	5	-7.110E-04
6	-3.572E-01	6	-9.019E-04
7	-4.058E-01	7	-1.392E-03
8	-4.625E-01	8	-1.885E-03
9	-5.107E-01	9	-2.380E-03
10	-5.731E-01	10	-2.871E-03
11	-6.093E-01	11	-3.368E-03
12	-6.441E-01	12	-3.867E-03
13	-6.570E-01	13	-4.368E-03
14	-7.049E-01	14	-4.866E-03
15	-7.417E-01	15	-5.367E-03
16	-7.634E-01	16	-5.872E-03
17	-7.763E-01	17	-6.914E-03
18	-7.952E-01	18	-7.920E-03
19	-8.035E-01	19	-8.924E-03
20	-7.947E-01	20	-9.932E-03

Table 61

Annex 9

All Maple Sheets are available and can be downloaded from the following web address:

www.babak-dadvar.com/thesis/babak.html

Otherwise contact

babak_dadvar@yahoo.com

Annex 10

All Scia Engineer and ATENA models related to Deep beam specimens can be downloaded from the following web address:

www.babak-dadvar.com/thesis/babak.html

Otherwise contact

babak_dadvar@yahoo.com

Second Phase

1) D1P1SBM
2) D1P1STM
3) D1P1LFEM
4) D1P1NLFEM

5) D2P1SBM
6) D2P1STM
7) D2P1LFEM
8) D2P1NLFEM

9) D3P1SBM
10) D3P1STM
11) D3P1LFEM
12) D3P1NLFEM

D1P1SBM (without adjustment of criterion 3 in chapter 9.5.3)

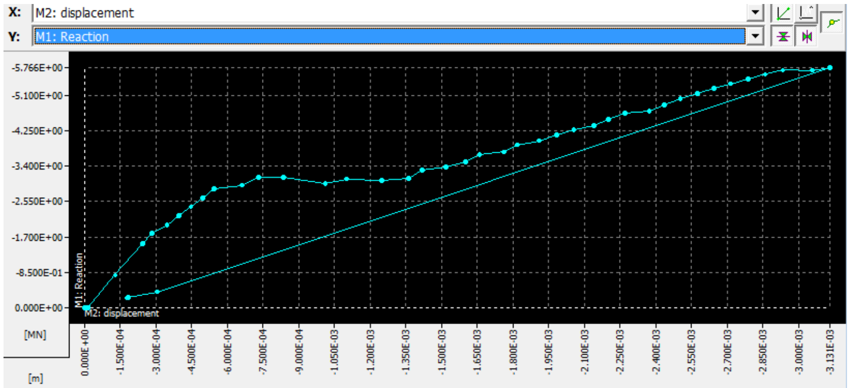


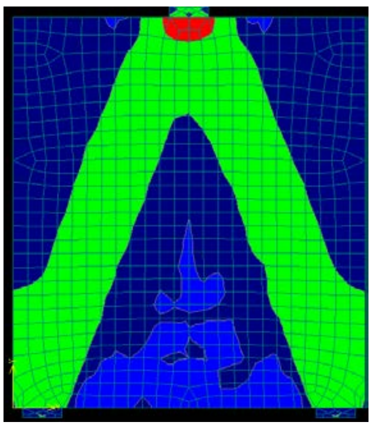
Figure 1

Step	Value [MN]
1	0.000E+00
2	-7.836E-01
3	-1.544E+00
4	-1.784E+00
5	-1.983E+00
6	-2.205E+00
7	-2.425E+00
8	-2.642E+00
9	-2.855E+00
10	-2.945E+00
11	-3.130E+00
12	-3.140E+00
13	-2.985E+00
14	-3.094E+00
15	-3.055E+00
16	-3.111E+00
17	-3.299E+00
18	-3.380E+00
19	-3.502E+00
20	-3.677E+00
21	-3.742E+00
22	-3.914E+00
23	-4.011E+00
24	-4.142E+00
25	-4.280E+00
26	-4.378E+00
27	-4.530E+00
28	-4.670E+00
29	-4.732E+00
30	-4.880E+00
31	-5.014E+00
32	-5.140E+00

Step	Value [m]
1	-1.312E-05
2	-1.281E-04
3	-2.424E-04
4	-2.819E-04
5	-3.458E-04
6	-3.970E-04
7	-4.458E-04
8	-4.945E-04
9	-5.424E-04
10	-6.614E-04
11	-7.305E-04
12	-8.347E-04
13	-1.011E-03
14	-1.101E-03
15	-1.247E-03
16	-1.360E-03
17	-1.419E-03
18	-1.518E-03
19	-1.600E-03
20	-1.659E-03
21	-1.760E-03
22	-1.819E-03
23	-1.908E-03
24	-1.983E-03
25	-2.055E-03
26	-2.140E-03
27	-2.202E-03
28	-2.269E-03
29	-2.372E-03
30	-2.435E-03
31	-2.502E-03
32	-2.572E-03

33	-5.262E+00	33	-2.642E-03
34	-5.379E+00	34	-2.714E-03
35	-5.494E+00	35	-2.786E-03
36	-5.605E+00	36	-2.859E-03
37	-5.706E+00	37	-2.933E-03
38	-5.703E+00	38	-3.057E-03
39	-5.766E+00	39	-3.131E-03
40	-3.835E-01	40	-3.041E-04
41	-2.420E-01	41	-1.812E-04
42	-2.381E-01	42	-1.777E-04
43	-2.377E-01	43	-1.770E-04

Table 1



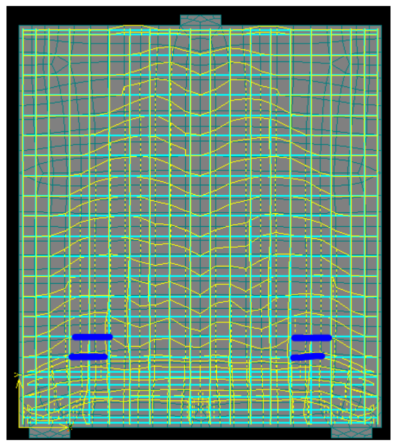


Figure 2

The plastic behavior is not happening the failure is almost brittle failure.

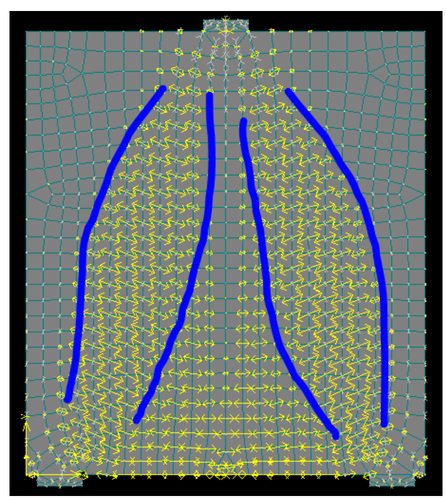


Figure 3

Looking at the reinforcements:

At load step 35 yielding of the reinforcements are happening. Yielding of the reinforcement is check by comparing 550 /200000=2,75*10^-3

Displacement 3mm at failure

Principle strain

The bottle shaped struts is distinguishable in figure 3.

Failure reason:

Yielding of the reinforcements is partial and in the failure status it remains partial.

In the middle bottom of the cross section the stresses and strains are limited. Bottle shape stress flow in deep beams is the characteristic feature of these types of structures (figure 3).

The main reason for failure is crushing of the concrete at top middle of the cross section. Due to the excessive concrete compressive force which is bigger than concrete compressive strength.

This crushing mode can be avoided by increasing the dimension of the applied load area but this is not the point. The point is that design ULS is 800*1,3=1040 kN and the ULS in ATENA is 5700 kN which is a factor of 5 difference between them. Which is too high .

The brittle failure leads also to the conclusion that there is too much reinforcement in the specimens which is dangerous.

The reinforcement is not efficient in this method.

Shear effective height

As it can be seen in the figure below, shear effective height is estimated by the value “d” (figure 4).

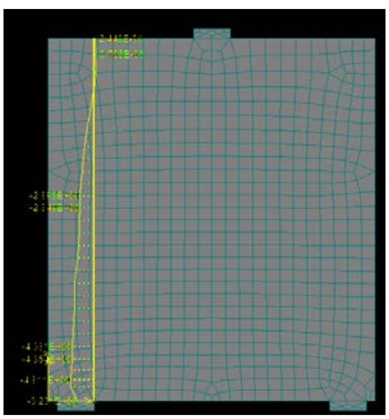


Figure 4

Looking at SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.312E-05
2	-2.637E-01	2	-5.153E-05
3	-3.947E-01	3	-7.071E-05
4	-5.250E-01	4	-8.987E-05
5	-6.547E-01	5	-1.090E-04
6	-7.838E-01	6	-1.281E-04
7	-9.122E-01	7	-1.472E-04
8	-1.040E+00	8	-1.663E-04

Table 2

SLS load is 800 kN

Calculating srmax at middle bottom and at the maximum crack in the middle of the cross section

Calculating the mean value of steel strain

Multiplying these two together

Also compare with the sum of the crack openings given in ATENA.

The mean value of steel strain is estimated as 5,3 *10^-5 and

srmax is calculated in based on method approximately 275 mm

The crack is minimum 0.0127mm < 0,3 mm .

Crack SBM 0,2mm < 0,3 mm

ATENA graphical method gives NO results for formation of cracks

D1P1STM(without adjustment of criterion 3 in chapter 9.5.3)

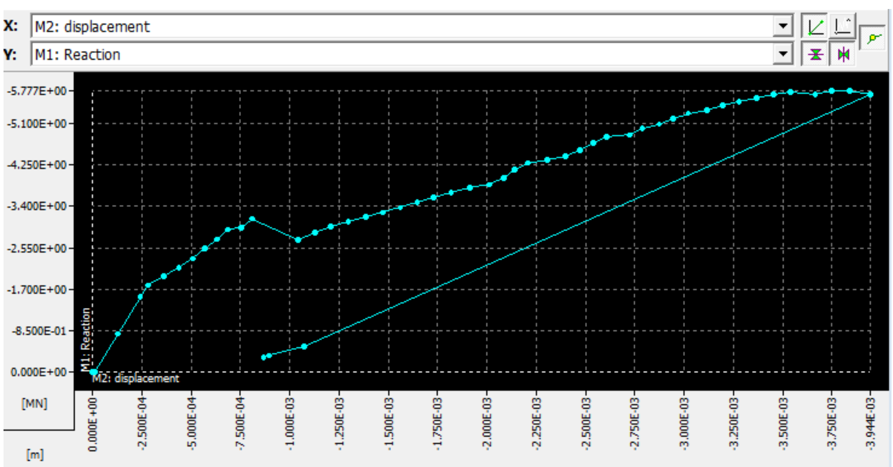


Figure 5

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.312E-05
2	-7.835E-01	2	-1.281E-04
3	-1.542E+00	3	-2.427E-04
4	-1.783E+00	4	-2.821E-04
5	-1.963E+00	5	-3.617E-04
6	-2.149E+00	6	-4.383E-04
7	-2.329E+00	7	-5.102E-04
8	-2.536E+00	8	-5.702E-04

9	-2.724E+00	9	-6.321E-04
20	-3.478E+00	20	-1.647E-03
21	-3.585E+00	21	-1.731E-03
22	-3.688E+00	22	-1.818E-03
23	-3.780E+00	23	-1.912E-03
24	-3.848E+00	24	-2.014E-03
25	-3.989E+00	25	-2.083E-03
26	-4.150E+00	26	-2.143E-03
27	-4.293E+00	27	-2.209E-03
28	-4.361E+00	28	-2.306E-03
29	-4.442E+00	29	-2.397E-03
30	-4.556E+00	30	-2.474E-03
31	-4.699E+00	31	-2.538E-03
32	-4.825E+00	32	-2.609E-03
33	-4.870E+00	33	-2.721E-03
34	-5.001E+00	34	-2.789E-03
35	-5.092E+00	35	-2.874E-03
36	-5.208E+00	36	-2.947E-03
37	-5.314E+00	37	-3.021E-03
38	-5.379E+00	38	-3.115E-03
39	-5.475E+00	39	-3.195E-03
40	-5.560E+00	40	-3.278E-03
41	-5.636E+00	41	-3.365E-03
42	-5.696E+00	42	-3.454E-03
43	-5.746E+00	43	-3.542E-03
44	-5.702E+00	44	-3.665E-03
45	-5.777E+00	45	-3.747E-03
46	-5.775E+00	46	-3.842E-03
47	-5.695E+00	47	-3.944E-03
48	-5.312E-01	48	-1.074E-03
49	-3.362E-01	49	-8.957E-04
50	-2.896E-01	50	-8.675E-04

Table 3

Looking at failure 5440 kN

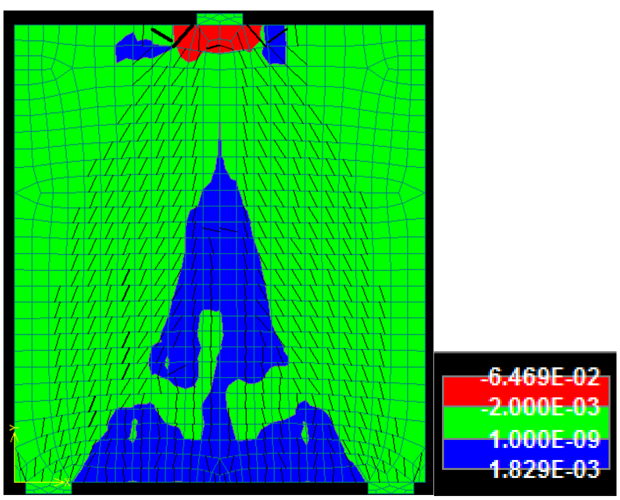


Figure 6

As it is observable in figure 7 reinforcement bars are yielding but the failure is mostly due to the crushing of the concrete at support area. Yielding of reinforcment bars gives plastic deformation of the speciemsn

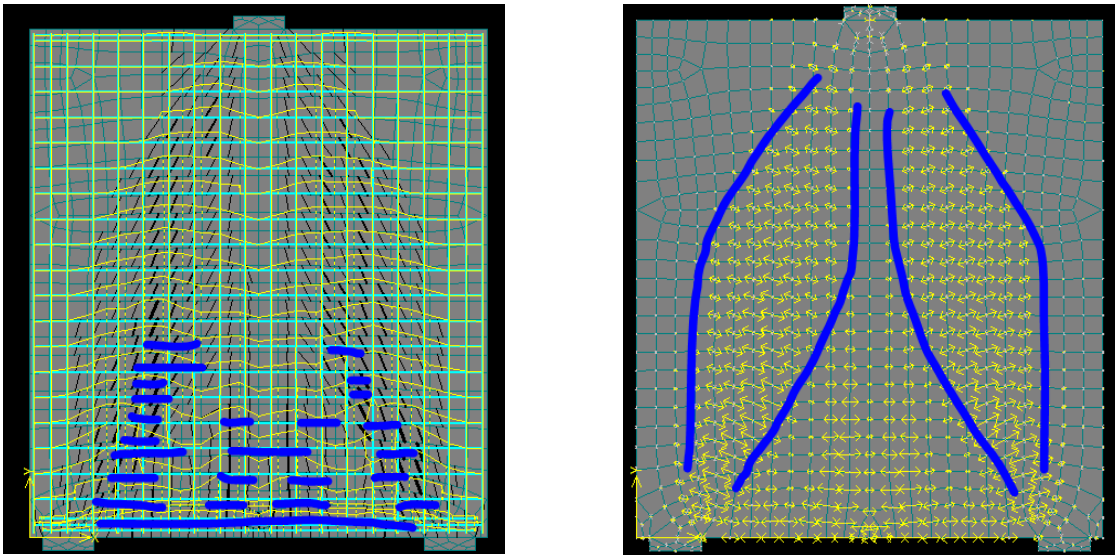


Figure 7

According to figure 8 the effective shear height of the specimens can be estimated by the value “d” in to the hand calculation.

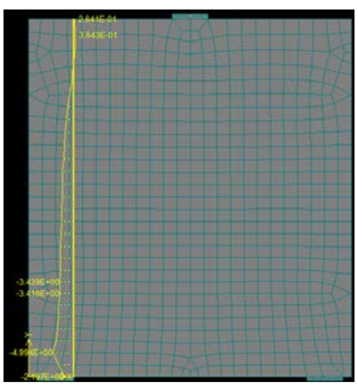


Figure 8

Looking at SLS 800 kN

Input data

Results

Monitoring points after load step

Monitoring p. specif.		Monitoring p. specif.	
Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.312E-05
2	-2.636E-01	2	-5.153E-05
		3	-8.987E-05

3 -5.249E-01 4 -7.836E-01 5 -1.040E+00	4 -1.281E-04 5 -1.663E-04

Table 4

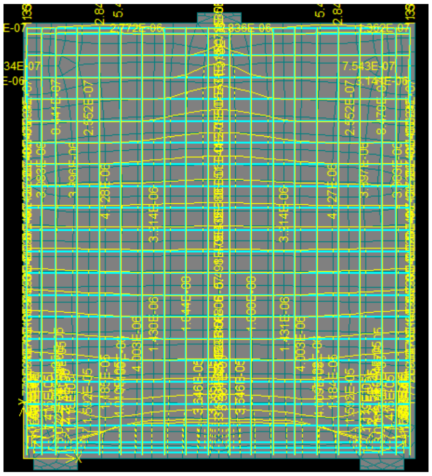


Figure 9

Graphical methode

ATENA shows no Crack formation.

Methode exact

Crack at middle bottom 0,012 mm

Crack middle top 0,019

D1P1LFEM (without adjustment of criterion 3 in chapter 9.5.3)

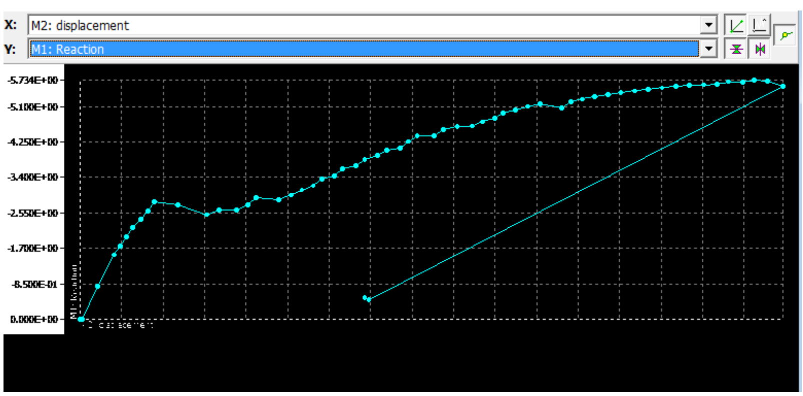


Figure 10

Input data
Results
Monitoring points after load step

Step	Value [MN]
1	0.000E+00
2	-7.852E-01
3	-1.545E+00
4	-1.756E+00
5	-1.986E+00
6	-2.207E+00
7	-2.392E+00
8	-2.601E+00
9	-2.822E+00
10	-2.742E+00
11	-2.506E+00
12	-2.624E+00
13	-2.621E+00
14	-2.745E+00
15	-2.922E+00
16	-2.862E+00
17	-2.979E+00
18	-3.100E+00
19	-3.203E+00
20	-3.359E+00
21	-3.442E+00
22	-3.608E+00
23	-3.677E+00
24	-3.837E+00
25	-3.923E+00
26	-4.055E+00
27	-4.104E+00
28	-4.261E+00
29	-4.399E+00
30	-4.406E+00
31	-4.556E+00
32	-4.613E+00
33	-4.634E+00
34	-4.734E+00
35	-4.815E+00
36	-4.945E+00
37	-5.027E+00
38	-5.102E+00
39	-5.172E+00
40	-5.068E+00
41	-5.206E+00
42	-5.277E+00
43	-5.339E+00
44	-5.391E+00
45	-5.436E+00
46	-5.477E+00
47	-5.516E+00
48	-5.551E+00
49	-5.578E+00
50	-5.602E+00
51	-5.621E+00
52	-5.637E+00
53	-5.697E+00

Step	Value [m]
1	-1.311E-05
2	-1.283E-04
3	-2.432E-04
4	-2.901E-04
5	-3.335E-04
6	-3.803E-04
7	-4.412E-04
8	-4.916E-04
9	-5.354E-04
10	-7.065E-04
11	-9.171E-04
12	-1.007E-03
13	-1.129E-03
14	-1.214E-03
15	-1.275E-03
16	-1.437E-03
17	-1.525E-03
18	-1.604E-03
19	-1.685E-03
20	-1.751E-03
21	-1.839E-03
22	-1.900E-03
23	-1.995E-03
24	-2.057E-03
25	-2.149E-03
26	-2.218E-03
27	-2.314E-03
28	-2.372E-03
29	-2.437E-03
30	-2.561E-03
31	-2.623E-03
32	-2.726E-03
33	-2.833E-03
34	-2.911E-03
35	-2.996E-03
36	-3.060E-03
37	-3.146E-03
38	-3.234E-03
39	-3.324E-03
40	-3.481E-03
41	-3.548E-03
42	-3.633E-03
43	-3.721E-03
44	-3.814E-03
45	-3.909E-03
46	-4.009E-03
47	-4.108E-03
48	-4.207E-03
49	-4.306E-03
50	-4.407E-03
51	-4.506E-03
52	-4.606E-03
53	-4.688E-03

54	-5.686E+00	-4.790E-03
55	-5.734E+00	-4.872E-03
56	-5.707E+00	-4.970E-03
57	-5.592E+00	-5.081E-03
58	-4.725E-01	-2.087E-03
59	-5.203E-01	-2.057E-03

Table 5

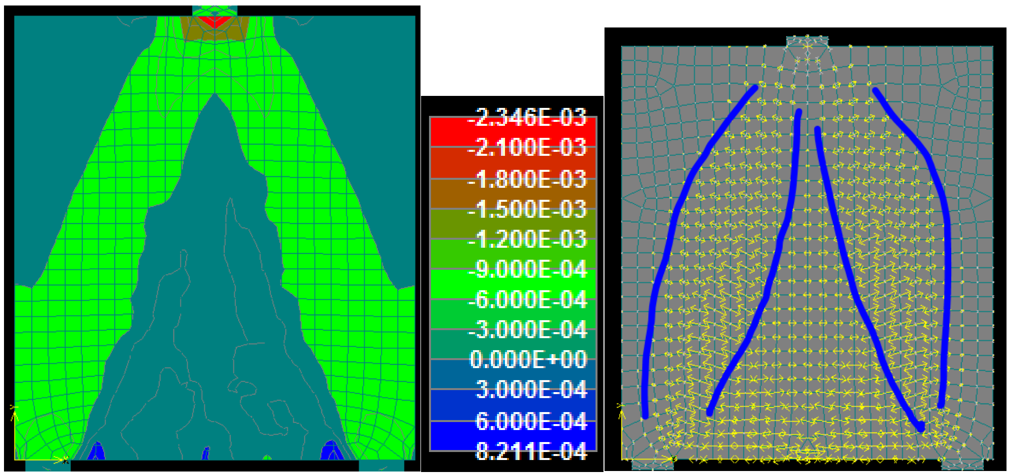


Figure 11

According to figure below, the reinforcements are yielding. The failure happens because of the excessive yielding of the reinforcements. The big plastic deformation is going on. The plastic behavior of the specimens is considerably higher than SBM and STM.

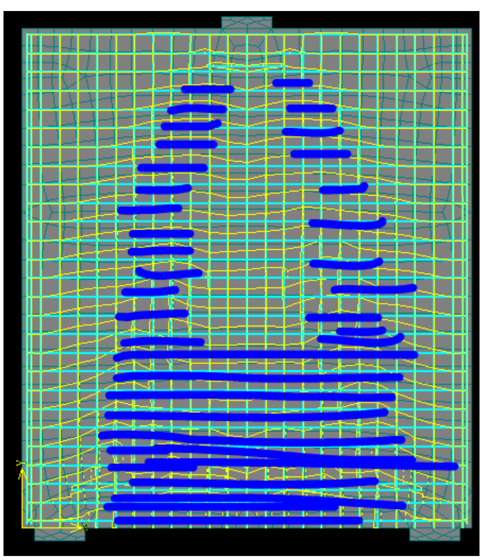


Figure 12

SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.311E-05
2	-2.642E-01	2	-5.161E-05
3	-5.260E-01	3	-9.003E-05
4	-7.853E-01	4	-1.284E-04
5	-1.042E+00	5	-1.666E-04

Table 6

Displacement 0,012

D1P1NLFEM(without adjustment of criterion 3 in chapter 9.5.3)

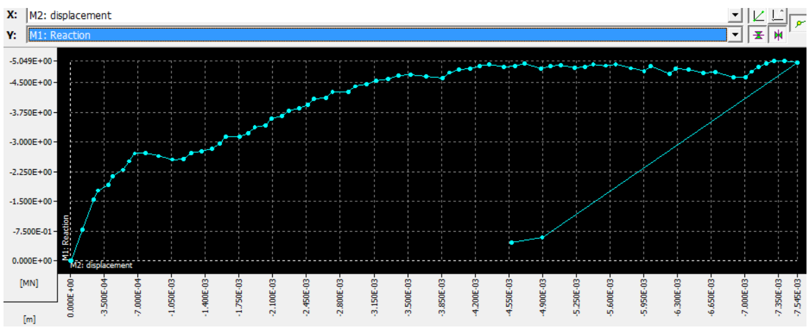


Figure 13

Input data

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
25	-3.789E+00		
26	-3.848E+00	25	-2.264E-03
27	-3.938E+00	26	-2.372E-03
28	-4.089E+00	27	-2.464E-03
29	-4.112E+00	28	-2.528E-03
30	-4.261E+00	29	-2.652E-03
31	-4.269E+00	30	-2.719E-03
32	-4.409E+00	31	-2.882E-03
33	-4.468E+00	32	-2.957E-03
34	-4.553E+00	33	-3.072E-03
35	-4.599E+00	34	-3.175E-03
36	-4.673E+00	35	-3.299E-03
37	-4.706E+00	36	-3.402E-03
38	-4.666E+00	37	-3.528E-03
39	-4.622E+00	38	-3.692E-03

40	-4.756E+00	39	-3.861E-03
41	-4.825E+00	40	-3.933E-03
42	-4.852E+00	41	-4.031E-03
43	-4.912E+00	42	-4.147E-03
44	-4.961E+00	43	-4.246E-03
45	-4.905E+00	44	-4.347E-03
46	-4.913E+00	45	-4.496E-03
47	-4.980E+00	46	-4.616E-03
48	-4.859E+00	47	-4.710E-03
49	-4.913E+00	48	-4.883E-03
50	-4.947E+00	49	-4.980E-03
51	-4.868E+00	50	-5.086E-03
52	-4.898E+00	51	-5.233E-03
53	-4.968E+00	52	-5.339E-03
54	-4.929E+00	53	-5.425E-03
55	-4.964E+00	54	-5.555E-03
56	-4.866E+00	55	-5.659E-03
57	-4.796E+00	56	-5.816E-03
58	-4.924E+00	57	-5.954E-03
59	-4.718E+00	58	-6.019E-03
60	-4.862E+00	59	-6.220E-03
61	-4.834E+00	60	-6.284E-03
62	-4.748E+00	61	-6.416E-03
63	-4.759E+00	62	-6.570E-03
64	-4.641E+00	63	-6.695E-03
65	-4.629E+00	64	-6.880E-03
66	-4.778E+00	65	-7.010E-03
67	-4.889E+00	66	-7.069E-03
68	-4.976E+00	67	-7.140E-03
69	-5.048E+00	68	-7.218E-03
70	-5.049E+00	69	-7.303E-03
71	-5.013E+00	70	-7.413E-03
72	-5.949E-01	71	-7.545E-03
73	-4.538E-01	72	-4.897E-03
		73	-4.581E-03

Table 7

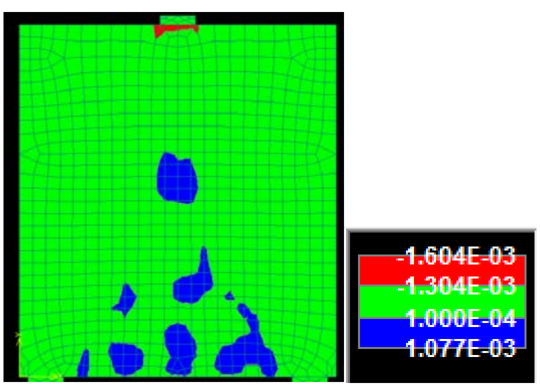


Figure 14

Failure is more due to the execcive yielding of the rebars.

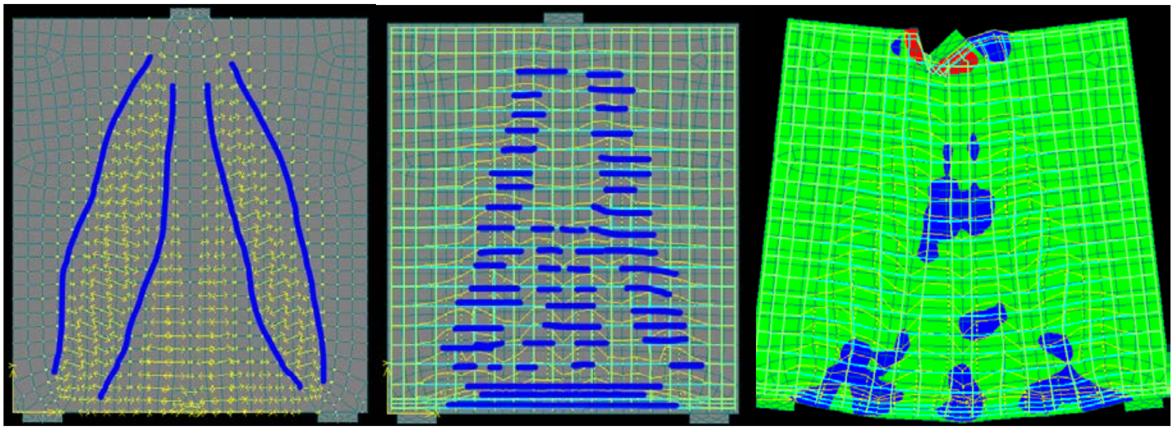


Figure 15

HIGH plastic behavior of the specimen with NLFEM. 7,5 mm displacement in ULS.

SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.315E-05
2	-2.635E-01	2	-5.163E-05
3	-5.245E-01	3	-9.004E-05
4	-7.831E-01	4	-1.284E-04
5	-1.039E+00	5	-1.666E-04

Table8

Specimens

D1P2SBM

D1P2STM

D1P2LEFEM

D1P2NLFEM

D1P2SBM(without adjustment of criterion 3 in chapter 9.5.3)

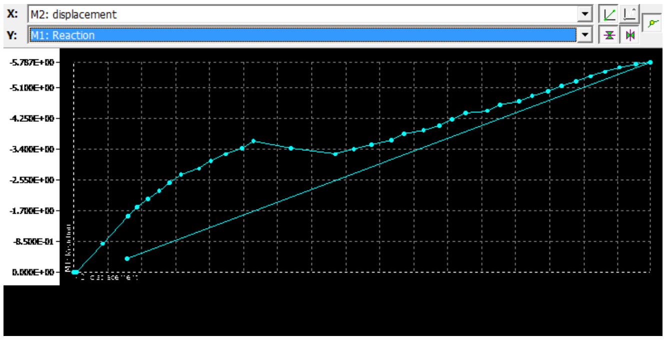


Figure 16

Looking at ULS

Step	Value [MN]	Step	Value [m]
11	-3.256E+00	11	-6.705E-04
12	-3.409E+00	12	-7.436E-04
13	-3.613E+00	13	-7.926E-04
14	-3.413E+00	14	-9.593E-04
15	-3.256E+00	15	-1.153E-03
16	-3.394E+00	16	-1.235E-03
17	-3.525E+00	17	-1.313E-03
18	-3.635E+00	18	-1.401E-03
19	-3.821E+00	19	-1.456E-03
20	-3.913E+00	20	-1.543E-03
21	-4.049E+00	21	-1.613E-03
22	-4.222E+00	22	-1.668E-03
23	-4.381E+00	23	-1.730E-03
24	-4.450E+00	24	-1.824E-03
25	-4.614E+00	25	-1.880E-03
26	-4.710E+00	26	-1.964E-03
27	-4.868E+00	27	-2.022E-03
28	-4.994E+00	28	-2.092E-03
29	-5.136E+00	29	-2.153E-03
30	-5.271E+00	30	-2.216E-03
31	-5.402E+00	31	-2.280E-03
32	**-5.528E+00**	**32**	**-2.344E-03**
33	**-5.649E+00**	**33**	**-2.408E-03**
34	**-5.731E+00**	**34**	**-2.478E-03**
35	**-5.787E+00**	**35**	**-2.543E-03**
36	-3.696E-01	36	-2.340E-04

Table 9

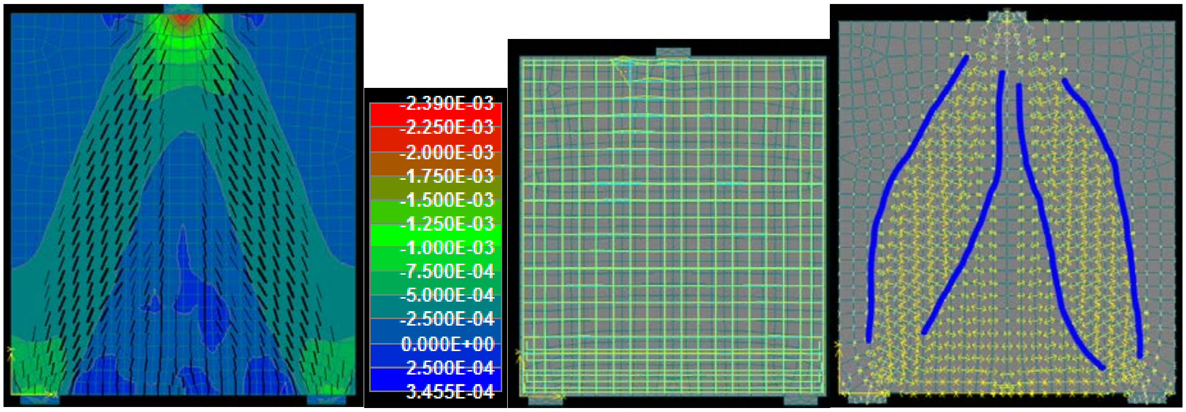


Figure 17

Failure is absolutely due to the crushing of the concrete at the place of loading at top middle of the specimen.

SLS

Step	Value [MN]
1	0.000E+00
2	-2.643E-01
3	-5.263E-01
4	-7.857E-01
5	-1.043E+00
6	-1.297E+00
7	-1.548E+00
8	-1.790E+00

Step	Value [m]
1	-1.302E-05
2	-5.124E-05
3	-8.937E-05
4	-1.274E-04
5	-1.654E-04
6	-2.032E-04
7	-2.410E-04
8	-2.800E-04

Table 10

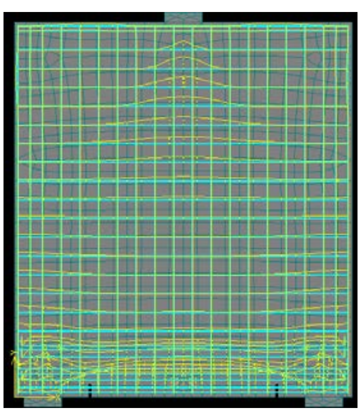


Figure 18

Crack ATENA => 0,007 mm , Crack calculation => 0,02 mm

D1P2STM

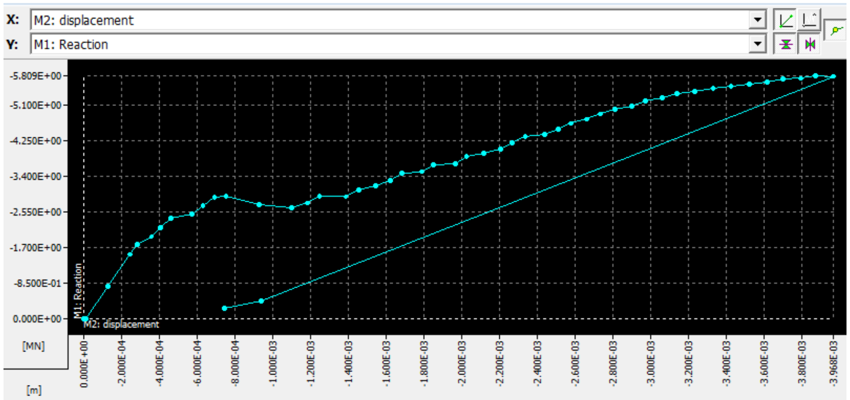


Figure 19

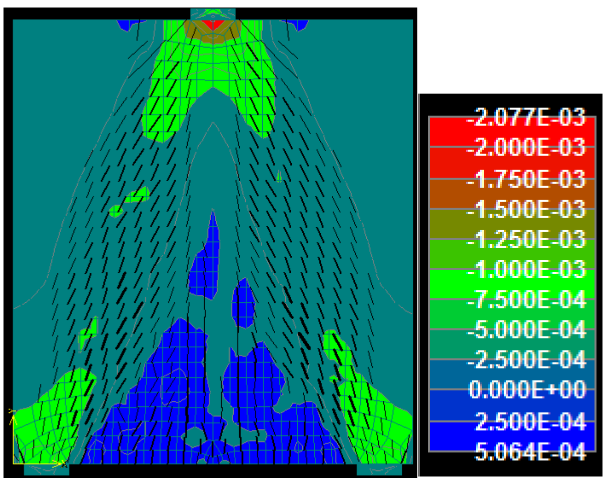


Figure 20

Looking at ULS

Step	Value [MN]
10	-2.897E+00
11	-2.926E+00
12	-2.739E+00
13	-2.649E+00
14	-2.769E+00
15	-2.939E+00
16	-2.917E+00
17	-3.078E+00
18	-3.183E+00
19	-3.304E+00
20	-3.478E+00

Step	Value [m]
10	-6.913E-04
11	-7.531E-04
12	-9.289E-04
13	-1.099E-03
14	-1.182E-03
15	-1.247E-03
16	-1.387E-03
17	-1.457E-03
18	-1.543E-03
19	-1.623E-03
20	-1.683E-03

21	-3.518E+00	21	-1.790E-03
22	-3.690E+00	22	-1.849E-03
23	-3.702E+00	23	-1.967E-03
24	-3.874E+00	24	-2.026E-03
25	-3.962E+00	25	-2.117E-03
26	-4.052E+00	26	-2.207E-03
27	-4.210E+00	27	-2.269E-03
28	-4.350E+00	28	-2.336E-03
29	-4.404E+00	29	-2.440E-03
30	-4.532E+00	30	-2.513E-03
31	-4.671E+00	31	-2.580E-03
32	-4.771E+00	32	-2.663E-03
33	-4.897E+00	33	-2.735E-03
34	-5.012E+00	34	-2.810E-03
35	-5.092E+00	35	-2.901E-03
36	-5.205E+00	36	-2.974E-03
37	-5.279E+00	37	-3.063E-03
38	-5.384E+00	38	-3.138E-03
39	-5.442E+00	39	-3.235E-03
40	-5.501E+00	40	-3.331E-03
41	-5.560E+00	41	-3.426E-03
42	-5.614E+00	42	-3.523E-03
43	-5.658E+00	43	-3.619E-03
44	-5.735E+00	44	-3.699E-03
45	-5.748E+00	45	-3.795E-03
46	-5.809E+00	46	-3.875E-03
47	-5.795E+00	47	-3.968E-03
48	-4.293E-01	48	-9.396E-04
49	-2.521E-01	49	-7.426E-04

Table 11

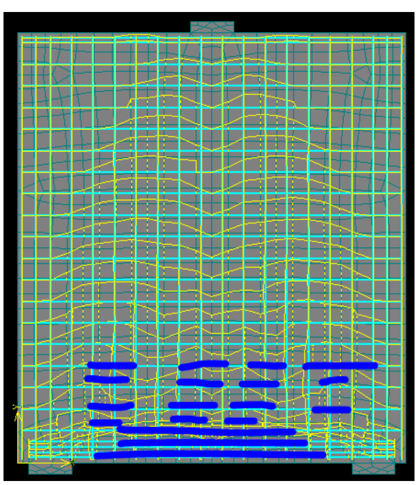


Figure 21

Yielding of the reinforcement is happening at middle of the specimens but the failure is due to the crushing of the concrete at support area.

SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.313E-05
2	-2.636E-01	2	-5.156E-05
3	-5.248E-01	3	-8.991E-05
4	-7.835E-01	4	-1.282E-04
5	-1.040E+00	5	-1.664E-04
6	-1.293E+00	6	-2.044E-04
7	-1.542E+00	7	-2.428E-04
8	-1.777E+00	8	-2.833E-04

Table 12

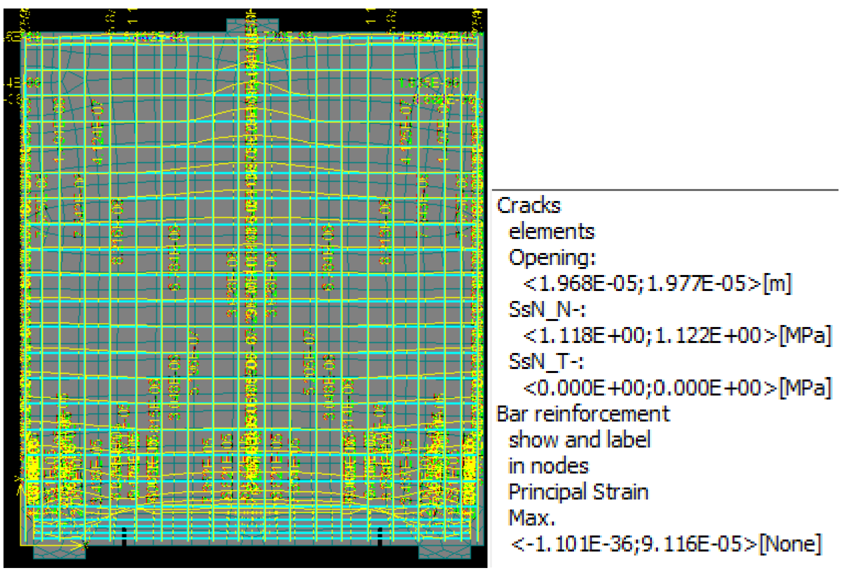


Figure 22

Crack calculation 0,029 mm

D1P2LEFEM

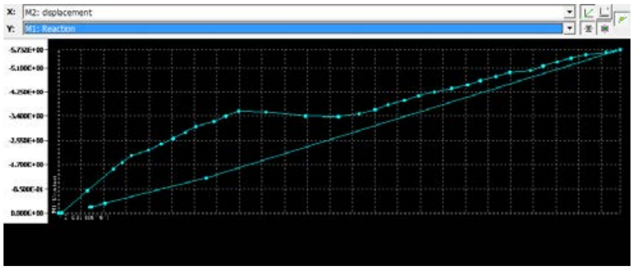


Figure 23

Input data

Results

Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.309E-05
2	-7.842E-01	2	-1.280E-04
3	-1.545E+00	3	-2.422E-04
4	-1.787E+00	4	-2.813E-04
5	-2.024E+00	5	-3.218E-04
6	-2.210E+00	6	-3.962E-04
7	-2.415E+00	7	-4.539E-04
8	-2.623E+00	8	-5.075E-04
9	-2.831E+00	9	-5.589E-04
10	-3.046E+00	10	-6.052E-04
11	-3.213E+00	11	-6.868E-04
12	-3.413E+00	12	-7.399E-04
13	-3.589E+00	13	-7.972E-04
14	-3.546E+00	14	-9.170E-04
15	-3.411E+00	15	-1.091E-03
16	-3.382E+00	16	-1.237E-03
17	-3.481E+00	17	-1.329E-03
18	-3.635E+00	18	-1.398E-03
19	-3.813E+00	19	-1.457E-03
20	-3.948E+00	20	-1.531E-03
21	-4.114E+00	21	-1.592E-03
22	-4.252E+00	22	-1.662E-03
23	-4.366E+00	23	-1.738E-03
24	-4.492E+00	24	-1.809E-03
25	-4.655E+00	25	-1.866E-03
		26	-1.934E-03
26	-4.787E+00	27	-1.995E-03
27	-4.936E+00	28	-2.086E-03
28	-5.001E+00	29	-2.143E-03
29	-5.159E+00	30	-2.204E-03

30	-5.303E+00
31	-5.436E+00
32	-5.564E+00
33	-5.634E+00
34	-5.732E+00
35	-1.237E+00
36	-3.482E-01
37	-2.082E-01
38	-2.222E-01
39	-2.177E-01
40	-2.220E-01
41	-2.244E-01
42	-2.259E-01
43	-2.270E-01
44	-2.279E-01
45	-2.308E-01

31	-2.267E-03
32	-2.332E-03
33	-2.420E-03
34	-2.484E-03
35	-6.534E-04
36	-2.042E-04
37	-1.363E-04
38	-1.424E-04
39	-1.406E-04
40	-1.425E-04
41	-1.437E-04
42	-1.443E-04
43	-1.448E-04
44	-1.452E-04
45	-1.465E-04

Table 13

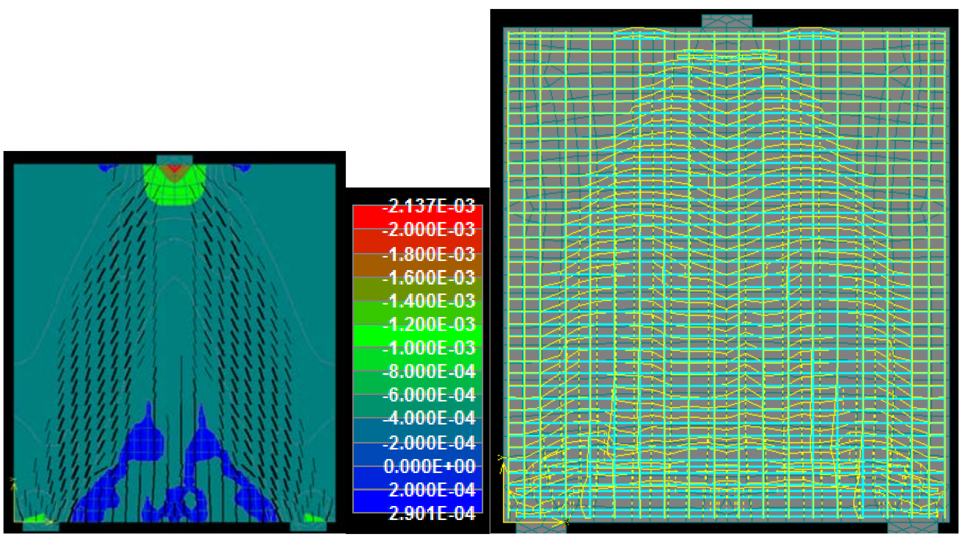


Figure 24

No Yielding of the reinforcement, failure happen due to pure concrete crushing at the applied load area.

SLS

tep	Value [MN]
1	0.000E+00
2	-2.639E-01
3	-5.254E-01
4	-7.844E-01
5	-1.041E+00
6	-1.295E+00

Step	Value [m]
1	-1.309E-05
2	-5.147E-05
3	-8.977E-05
4	-1.280E-04
5	-1.661E-04

Step	Value	Step	Value
7	-1.545E+00	6	-2.041E-04
8	-1.787E+00	7	-2.422E-04
9	-2.024E+00	8	-2.814E-04
		9	-3.219E-04

Table 14

Cracks are acceptable

D1P2NLFEM

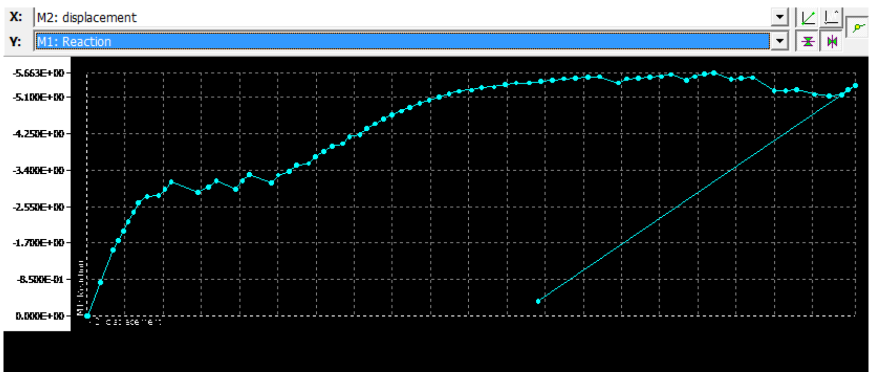


Figure 25

Input data
Results
Monitoring points after load step

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.316E-05
2	-7.829E-01	2	-1.284E-04
3	-1.541E+00	3	-2.433E-04
4	-1.749E+00	4	-2.906E-04
5	-1.978E+00	5	-3.338E-04
6	-2.202E+00	6	-3.785E-04
7	-2.413E+00	7	-4.282E-04
8	-2.638E+00	8	-4.709E-04
9	-2.778E+00	9	-5.517E-04
10	-2.798E+00	10	-6.583E-04
11	-2.953E+00	11	-7.164E-04
12	-3.115E+00	12	-7.741E-04
13	-2.883E+00	13	-1.016E-03
14	-3.002E+00	14	-1.116E-03
15	-3.145E+00	15	-1.187E-03
16	-2.961E+00	16	-1.365E-03
17	-3.148E+00	17	-1.426E-03
18	-3.304E+00	18	-1.493E-03
19	-3.093E+00	19	-1.688E-03
20	-3.282E+00	20	-1.754E-03
21	-3.360E+00	21	-1.856E-03
22	-3.513E+00	22	-1.920E-03

23	-3.551E+00	23	-2.031E-03
24	-3.717E+00	24	-2.092E-03
25	-3.842E+00	25	-2.168E-03
26	-3.960E+00	26	-2.246E-03
27	-4.015E+00	27	-2.347E-03
28	-4.166E+00	28	-2.406E-03
29	-4.221E+00	29	-2.503E-03
30	-4.371E+00	30	-2.562E-03
31	-4.478E+00	31	-2.640E-03
32	-4.581E+00	32	-2.720E-03
33	-4.679E+00	33	-2.799E-03
34	-4.773E+00	34	-2.880E-03
35	-4.862E+00	35	-2.962E-03
36	-4.947E+00	36	-3.050E-03
37	-5.029E+00	37	-3.138E-03
38	-5.105E+00	38	-3.227E-03
39	-5.174E+00	39	-3.319E-03
40	-5.237E+00	40	-3.413E-03
41	-5.262E+00	41	-3.523E-03
42	-5.319E+00	42	-3.617E-03
43	-5.336E+00	43	-3.732E-03
44	-5.387E+00	44	-3.830E-03
45	-5.429E+00	45	-3.934E-03
46	-5.429E+00	46	-4.057E-03
47	-5.468E+00	47	-4.162E-03
48	-5.500E+00	48	-4.267E-03
49	-5.526E+00	49	-4.372E-03
50	-5.548E+00	50	-4.480E-03
51	-5.566E+00	51	-4.591E-03
52	-5.577E+00	52	-4.701E-03
53	-5.430E+00	53	-4.872E-03
54	-5.528E+00	54	-4.951E-03
55	-5.551E+00	55	-5.057E-03
56	-5.567E+00	56	-5.162E-03
57	-5.578E+00	57	-5.265E-03
58	-5.629E+00	58	-5.348E-03
59	-5.492E+00	59	-5.495E-03
60	-5.579E+00	60	-5.571E-03
61	-5.632E+00	61	-5.657E-03
62	-5.663E+00	62	-5.743E-03
63	-5.510E+00	63	-5.905E-03
64	-5.544E+00	64	-5.999E-03
65	-5.555E+00	65	-6.098E-03
66	-5.245E+00	66	-6.299E-03
67	-5.240E+00	67	-6.404E-03
68	-5.273E+00	68	-6.502E-03
69	-5.165E+00	69	-6.668E-03
70	-5.124E+00	70	-6.805E-03
71	-5.142E+00	71	-6.914E-03
72	-5.278E+00	72	-6.972E-03
73	-5.370E+00	73	-7.043E-03
74	-3.427E-01	74	-4.136E-03

Table 15

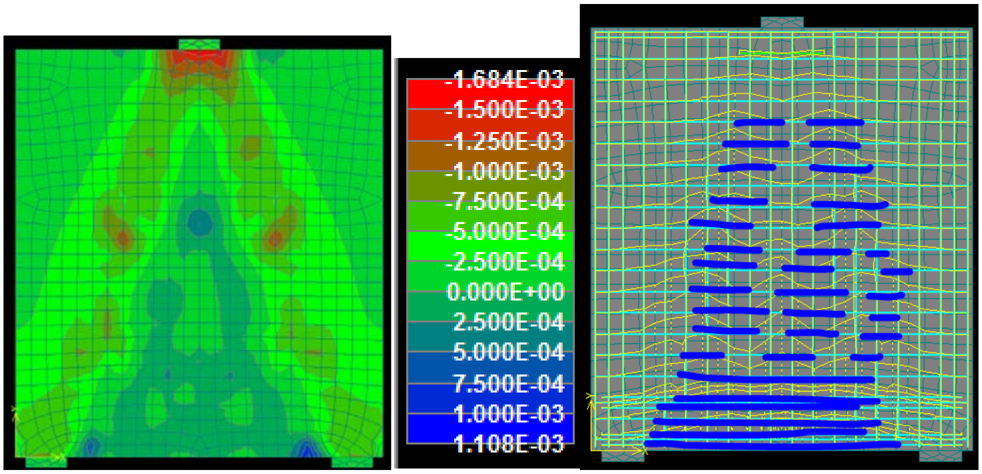


Figure 26

Yielding of the bars are extensively are happening which give high plastic deformations.

But the failure is due to the excessive yielding of the bars.

SLS

Step	Value [MN]
1	0.000E+00
2	-2.634E-01
3	-5.245E-01
4	-7.830E-01
5	-1.039E+00
6	-1.292E+00
7	-1.541E+00
8	-1.749E+00

Step	Value [m]
1	-1.316E-05
2	-5.166E-05
3	-9.009E-05
4	-1.284E-04
5	-1.667E-04
6	-2.048E-04
7	-2.433E-04
8	-2.906E-04

Table 16

D3P1SBM
D3P1STM
D3P1LFEM
D3P1NLFEM

D3P1SBM(without adjustment of criterion 3 in chapter 9.5.3)

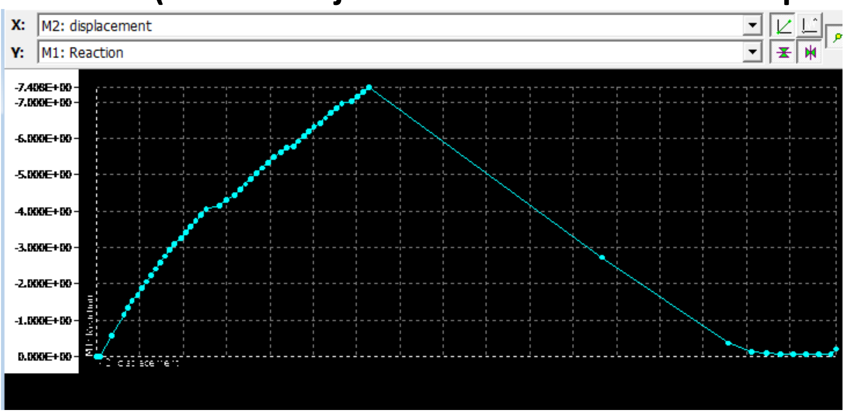


Figure 27

Step	Value [MN]
1	0.000E+00
2	-5.846E-01
3	-1.160E+00
4	-1.350E+00
5	-1.538E+00
6	-1.696E+00
7	-1.878E+00
8	-2.058E+00
9	-2.235E+00
10	-2.411E+00
11	-2.587E+00
12	-2.762E+00
13	-2.929E+00
14	-3.101E+00
15	-3.251E+00
16	-3.417E+00
17	-3.583E+00
18	-3.744E+00
19	-3.902E+00
20	-4.063E+00
21	-4.157E+00
22	-4.303E+00
23	-4.435E+00
24	-4.591E+00

Step	Value [m]
1	-2.942E-05
2	-1.250E-04
3	-2.209E-04
4	-2.530E-04
5	-2.851E-04
6	-3.329E-04
7	-3.677E-04
8	-4.033E-04
9	-4.407E-04
10	-4.783E-04
11	-5.147E-04
12	-5.515E-04
13	-5.928E-04
14	-6.298E-04
15	-6.815E-04
16	-7.210E-04
17	-7.593E-04
18	-8.006E-04
19	-8.442E-04
20	-8.841E-04
21	-9.953E-04
22	-1.051E-03
23	-1.114E-03
24	-1.157E-03
25	-1.203E-03

25	-4.743E+00	26	-1.248E-03
26	-4.893E+00	27	-1.294E-03
27	-5.041E+00	28	-1.340E-03
28	-5.189E+00	29	-1.386E-03
29	-5.336E+00	30	-1.434E-03
30	-5.480E+00	31	-1.486E-03
31	-5.616E+00	32	-1.533E-03
32	-5.759E+00	33	-1.593E-03
33	-5.788E+00	34	-1.633E-03
34	-5.925E+00	35	-1.672E-03
35	-6.062E+00	36	-1.714E-03
36	-6.197E+00	37	-1.756E-03
37	-6.329E+00	38	-1.809E-03
38	-6.424E+00	39	-1.849E-03
39	-6.564E+00	40	-1.894E-03
40	-6.694E+00	41	-1.937E-03
41	-6.826E+00	42	-1.980E-03
42	-6.956E+00	43	-2.060E-03
43	-7.037E+00	44	-2.106E-03
44	-7.165E+00	45	-2.151E-03
45	-7.289E+00	46	-2.197E-03
46	-7.408E+00	47	-4.081E-03
47	-2.729E+00	48	-5.101E-03
48	-3.684E-01	49	-5.291E-03
49	-1.385E-01	50	-5.413E-03
50	-8.529E-02	51	-5.523E-03
51	-6.476E-02	52	-5.627E-03
52	-5.565E-02	53	-5.729E-03
53	-5.259E-02	54	-5.830E-03
54	-5.257E-02	55	-5.931E-03
55	-5.389E-02	56	-5.973E-03
56	-2.044E-01		

Table 17

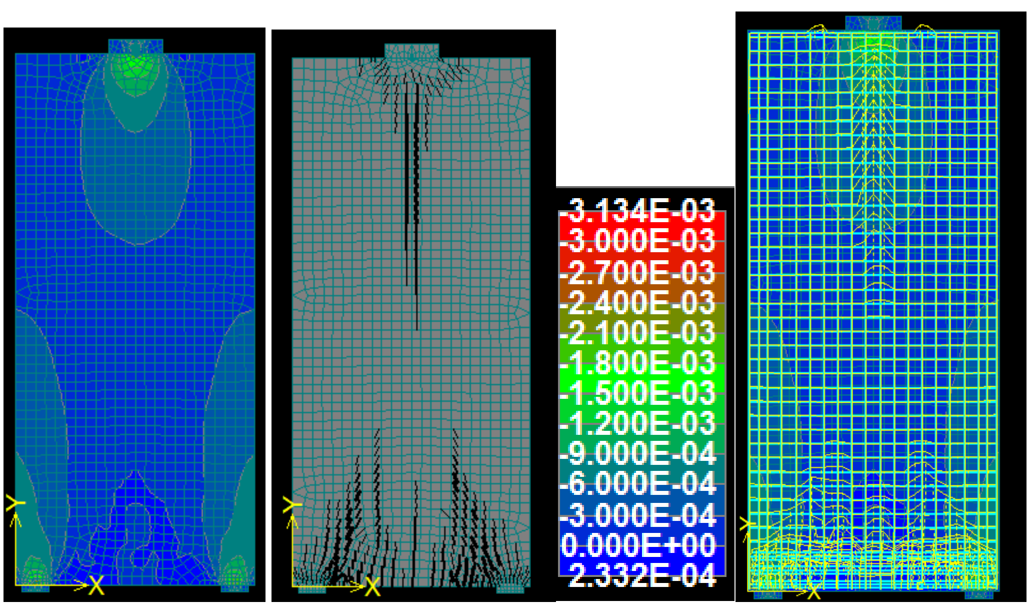


Figure 28

- No yielding
- Failure due to crushing of the concrete at support area
- Displacement 2,1 mm

SLS

Step	Value [MN]
1	0.000E+00
2	-1.959E-01
3	-3.909E-01
4	-5.848E-01
5	-7.777E-01
6	-7.969E-01
7	-8.162E-01

Step	Value [m]
1	-2.942E-05
2	-6.126E-05
3	-9.313E-05
4	-1.250E-04
5	-1.570E-04
6	-1.602E-04
7	-1.634E-04

Table 18

Crack 0,013<0,3mm OK

D3P1STM

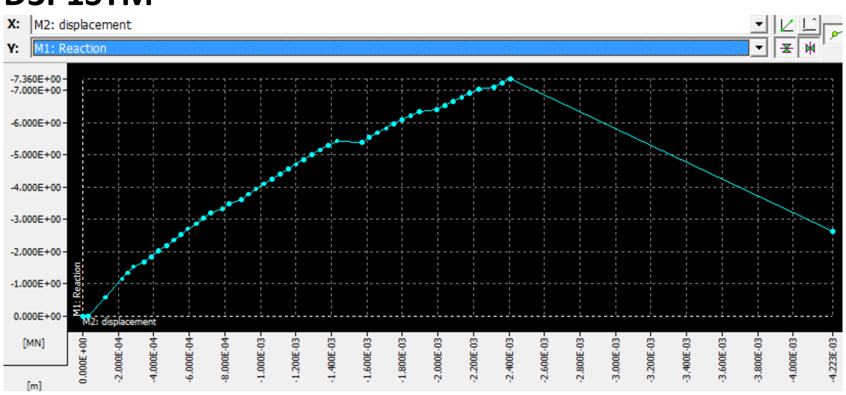


Figure 29

Step	Value [MN]
11	-2.537E+00
12	-2.710E+00
13	-2.868E+00
14	-3.039E+00
15	-3.204E+00
16	-3.334E+00
17	-3.499E+00
18	-3.627E+00
19	-3.790E+00

Step	Value [m]
11	-5.520E-04
12	-5.907E-04
13	-6.403E-04
14	-6.785E-04
15	-7.209E-04
16	-7.861E-04
17	-8.257E-04
18	-8.926E-04
19	-9.334E-04
20	-9.761E-04
21	-1.019E-03

20	-3.948E+00
21	-4.105E+00
22	-4.260E+00
23	-4.408E+00
24	-4.562E+00
25	-4.712E+00
26	-4.862E+00
27	-5.010E+00
28	-5.156E+00
29	-5.299E+00
30	-5.440E+00
31	-5.396E+00
32	-5.556E+00
33	-5.694E+00
34	-5.823E+00
35	-5.961E+00
36	-6.094E+00
37	-6.226E+00
38	-6.355E+00
39	-6.403E+00
40	-6.540E+00
41	-6.667E+00
42	-6.792E+00
43	-6.921E+00
44	-7.040E+00
45	-7.117E+00
46	-7.241E+00
47	-7.360E+00
48	-2.622E+00

22	-1.064E-03
23	-1.112E-03
24	-1.156E-03
25	-1.201E-03
26	-1.246E-03
27	-1.291E-03
28	-1.337E-03
29	-1.384E-03
30	-1.432E-03
31	-1.575E-03
32	-1.614E-03
33	-1.658E-03
34	-1.708E-03
35	-1.752E-03
36	-1.799E-03
37	-1.846E-03
38	-1.893E-03
39	-1.993E-03
40	-2.039E-03
41	-2.086E-03
42	-2.134E-03
43	-2.179E-03
44	-2.228E-03
45	-2.315E-03
46	-2.361E-03
47	-2.407E-03
48	-4.223E-03

Table 19

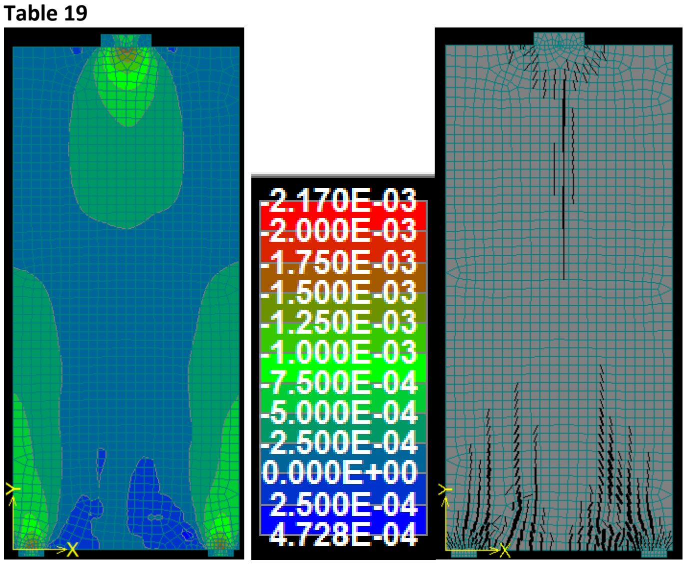


Figure 30

The failure is due to the crushing of the concrete at applied load area at top.

SLS

Crack 0,015 bottom
Crack top 0,02

D3P1LEFEM(without adjustment of criterion 3 in chapter 9.5.3)

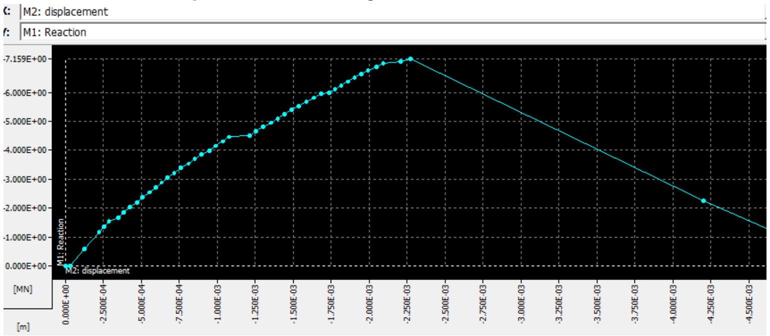


Figure 31

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-2.941E-05
2	-5.861E-01	2	-1.252E-04
3	-1.165E+00	3	-2.213E-04
4	-1.353E+00	4	-2.535E-04
5	-1.542E+00	5	-2.856E-04
6	-1.676E+00	6	-3.475E-04
7	-1.857E+00	7	-3.835E-04
8	-2.030E+00	8	-4.258E-04
9	-2.202E+00	9	-4.691E-04
10	-2.379E+00	10	-5.060E-04
11	-2.543E+00	11	-5.524E-04
12	-2.712E+00	12	-5.947E-04
13	-2.884E+00	13	-6.331E-04
14	-3.055E+00	14	-6.725E-04
15	-3.220E+00	15	-7.153E-04
16	-3.384E+00	16	-7.583E-04
17	-3.534E+00	17	-8.099E-04
18	-3.696E+00	18	-8.508E-04
19	-3.855E+00	19	-8.933E-04
20	-3.992E+00	20	-9.499E-04
21	-4.153E+00	21	-9.893E-04
22	-4.306E+00	22	-1.034E-03
23	-4.462E+00	23	-1.076E-03
24	-4.503E+00	24	-1.212E-03
25	-4.662E+00	25	-1.256E-03
26	-4.813E+00	26	-1.300E-03
27	-4.953E+00	27	-1.353E-03
28	-5.102E+00	28	-1.397E-03
29	-5.249E+00	29	-1.443E-03
30	-5.393E+00	30	-1.490E-03
31	-5.535E+00	31	-1.538E-03
32	-5.675E+00	32	-1.586E-03
33	-5.814E+00	33	-1.634E-03
34	-5.951E+00	34	-1.682E-03
35	-5.975E+00	35	-1.734E-03
36	-6.100E+00	36	-1.775E-03
37	-6.239E+00	37	-1.816E-03

38	-6.373E+00	38	-1.859E-03
39	-6.503E+00	39	-1.904E-03
40	-6.631E+00	40	-1.949E-03
41	-6.762E+00	41	-1.993E-03
42	-6.874E+00	42	-2.046E-03
43	-6.999E+00	43	-2.093E-03
44	-7.056E+00	44	-2.206E-03
45	-7.159E+00	45	-2.271E-03
46	-2.256E+00	46	-4.203E-03
47	-4.660E-01	47	-4.978E-03
48	-4.714E-01	48	-5.079E-03

Table 20

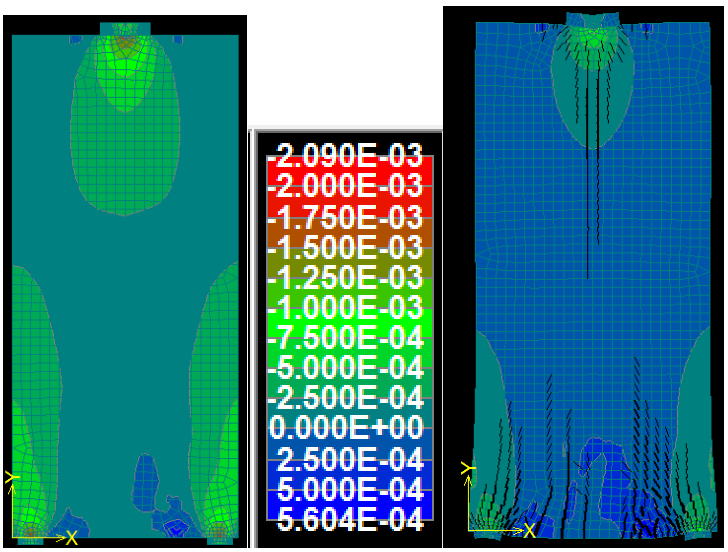


Figure 32

SLS
OK

D3P1NLFEM (without adjustment of criterion 3 in chapter 9.5.3)

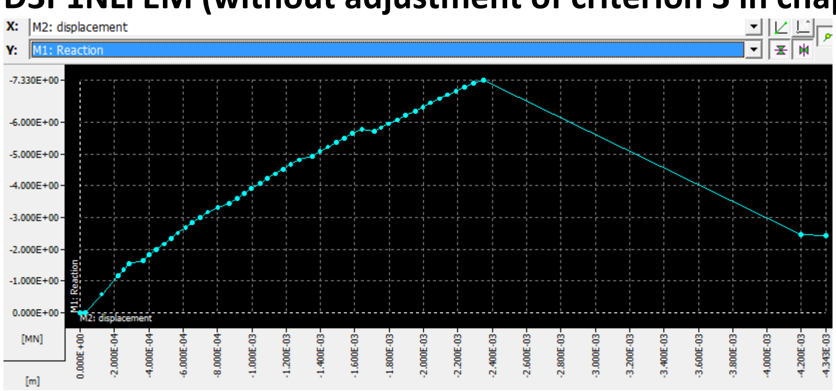


Figure 33

Step	Value [MN]	Step	Value [m]
13	-2.847E+00	13	-6.548E-04
14	-3.010E+00	14	-6.988E-04
15	-3.174E+00	15	-7.426E-04
16	-3.316E+00	16	-8.021E-04
17	-3.447E+00	17	-8.668E-04
18	-3.601E+00	18	-9.146E-04
19	-3.764E+00	19	-9.551E-04
20	-3.923E+00	20	-9.974E-04
21	-4.069E+00	21	-1.048E-03
22	-4.224E+00	22	-1.092E-03
23	-4.377E+00	23	-1.136E-03
24	-4.528E+00	24	-1.181E-03
25	-4.677E+00	25	-1.227E-03
26	-4.819E+00	26	-1.277E-03
27	-4.931E+00	27	-1.352E-03
28	-5.080E+00	28	-1.397E-03
29	-5.226E+00	29	-1.443E-03
30	-5.368E+00	30	-1.490E-03
31	-5.508E+00	31	-1.538E-03
32	-5.647E+00	32	-1.587E-03
33	-5.776E+00	33	-1.641E-03
34	-5.707E+00	34	-1.712E-03
35	-5.832E+00	35	-1.752E-03
36	-5.957E+00	36	-1.798E-03
37	-6.080E+00	37	-1.849E-03
38	-6.219E+00	38	-1.896E-03
39	-6.342E+00	39	-1.951E-03
40	-6.480E+00	40	-1.997E-03
41	-6.615E+00	41	-2.042E-03
42	-6.746E+00	42	-2.091E-03
43	-6.871E+00	43	-2.140E-03
44	-6.994E+00	44	-2.189E-03
45	-7.110E+00	45	-2.240E-03
46	-7.223E+00	46	-2.292E-03
47	-7.330E+00	47	-2.350E-03
48	-2.454E+00	48	-4.197E-03
49	-2.423E+00	49	-4.343E-03

Table 21

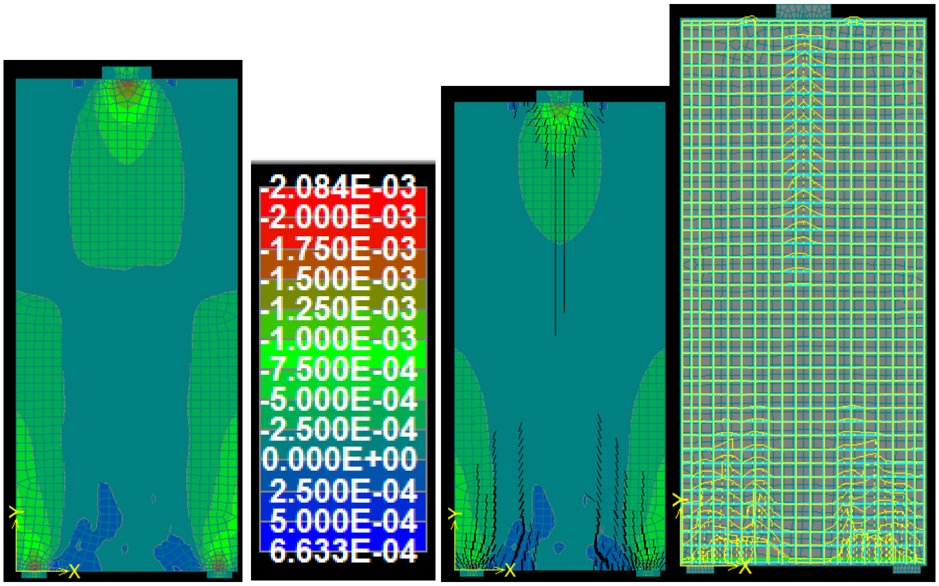


Figure 34

SLS

Crack OK

D1P2SBM
D1P2STM
D1P2LFEM
D1P2NLFEM

D1P2SBM 1500 kN(without adjustment of criterion 3 in chapter 9.5.3)

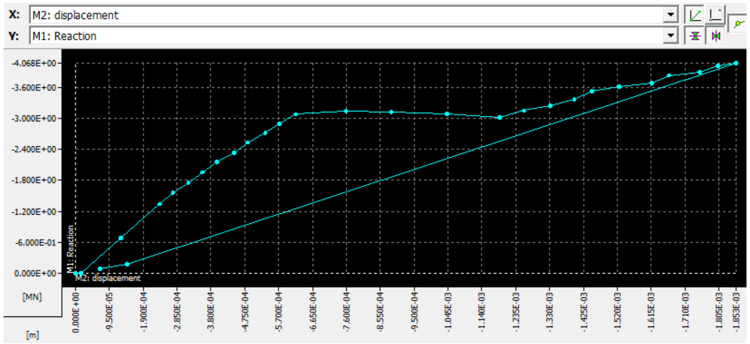


Figure 35

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.464E-05
2	-6.812E-01	2	-1.263E-04
3	-1.342E+00	3	-2.368E-04
4	-1.557E+00	4	-2.734E-04
5	-1.751E+00	5	-3.166E-04
6	-1.955E+00	6	-3.557E-04
7	-2.155E+00	7	-3.957E-04
8	-2.337E+00	8	-4.441E-04
9	-2.532E+00	9	-4.836E-04
10	-2.711E+00	10	-5.324E-04
11	-2.900E+00	11	-5.727E-04
12	-3.079E+00	12	-6.187E-04
13	-3.134E+00	13	-7.587E-04
14	-3.121E+00	14	-8.860E-04
15	-3.080E+00	15	-1.042E-03
16	-3.011E+00	16	-1.190E-03
17	-3.149E+00	17	-1.258E-03
18	-3.249E+00	18	-1.332E-03
19	-3.370E+00	19	-1.399E-03
20	-3.528E+00	20	-1.450E-03
21	-3.618E+00	21	-1.526E-03
22	-3.679E+00	22	-1.616E-03
23	-3.829E+00	23	-1.665E-03
24	-3.889E+00	24	-1.753E-03
25	-4.020E+00	25	-1.803E-03
26	-4.068E+00	26	-1.853E-03
27	-1.796E-01	27	-1.446E-04
28	-8.700E-02	28	-6.980E-05
29	-8.506E-02	29	-6.857E-05
30	-8.774E-02	30	-7.003E-05

Table 22

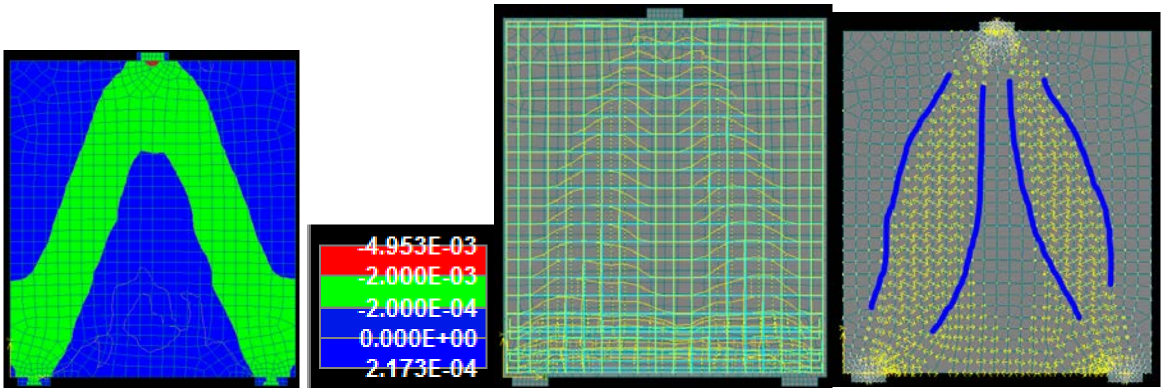


Figure 36

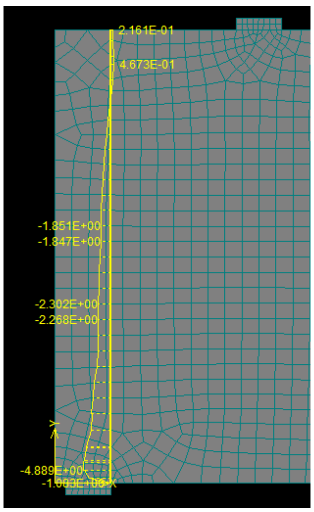


Figure 37

- There is no plastic behavior observed
- NO yielding of the reinforcement happening
- Shear effective height is set to be “d” is the correct estimated value for hand calculation and checks of shear capacity.
- Failure is happened due to the crushing of the concrete at the applied load area.

SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.464E-05
2	-2.293E-01	2	-5.197E-05
3	-4.564E-01	3	-8.918E-05
4	-6.813E-01	4	-1.263E-04
5	-9.039E-01	5	-1.633E-04
6	-1.124E+00	6	-2.001E-04
7	-1.342E+00	7	-2.368E-04
8	-1.557E+00	8	-2.734E-04

Table 23

D1P2STM(without adjustment of criterion 3 in chapter 9.5.3)

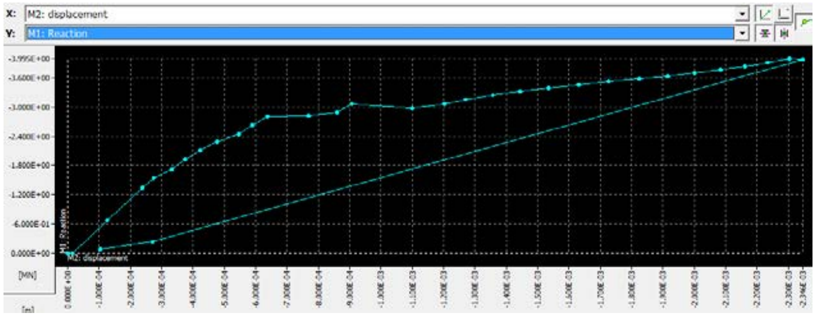


Figure 38

Step	Value [MN]
1	0.000E+00
2	-6.797E-01
3	-1.339E+00
4	-1.554E+00
5	-1.722E+00
6	-1.922E+00
7	-2.114E+00
8	-2.292E+00
9	-2.444E+00
10	-2.634E+00
11	-2.812E+00
12	-2.823E+00
13	-2.894E+00
14	-3.070E+00
15	-2.982E+00
16	-3.062E+00
17	-3.159E+00
18	-3.248E+00
19	-3.330E+00
20	-3.399E+00
21	-3.461E+00
22	-3.524E+00
23	-3.579E+00
24	-3.638E+00
25	-3.703E+00
26	-3.774E+00
27	-3.844E+00
28	-3.917E+00
29	-3.995E+00
30	-3.977E+00
31	-2.326E-01
32	-8.631E-02

Step	Value [m]
1	-1.474E-05
2	-1.269E-04
3	-2.380E-04
4	-2.748E-04
5	-3.329E-04
6	-3.760E-04
7	-4.231E-04
8	-4.773E-04
9	-5.460E-04
10	-5.885E-04
11	-6.373E-04
12	-7.679E-04
13	-8.605E-04
14	-9.064E-04
15	-1.099E-03
16	-1.202E-03
17	-1.269E-03
18	-1.357E-03
19	-1.444E-03
20	-1.536E-03
21	-1.632E-03
22	-1.727E-03
23	-1.824E-03
24	-1.916E-03
25	-2.002E-03
26	-2.083E-03
27	-2.161E-03
28	-2.233E-03
29	-2.304E-03
30	-2.346E-03
31	-2.696E-04
32	-1.041E-04

Table 24

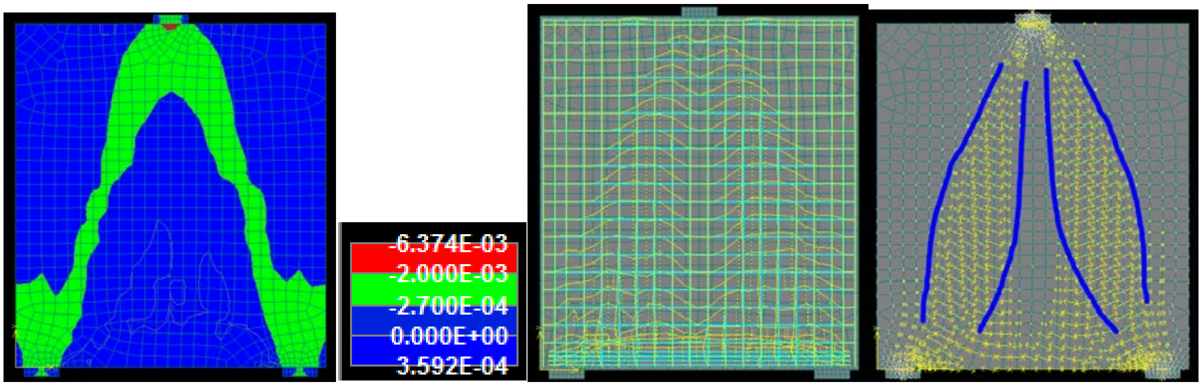


Figure 39

Bar reinforcement
show
in nodes
Principal Strain
Max.
<-6.889E-36;2.526E-03>[None]

- There is small plastic behavior observed
- NO yielding of the reinforcement happening
- Shear effective height is set to be “d” is the correct estimated value for hand calculation and checks of shear capacity.
- Failure is happened due to the crushing of the concrete at the applied load area.

SlS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.474E-05
2	-2.288E-01	2	-5.224E-05
3	-4.554E-01	3	-8.963E-05
4	-6.798E-01	4	-1.269E-04
5	-9.019E-01	5	-1.641E-04
6	-1.122E+00	6	-2.011E-04
7	-1.339E+00	7	-2.380E-04
8	-1.554E+00	8	-2.748E-04

Table 25

S1P2LEFEM

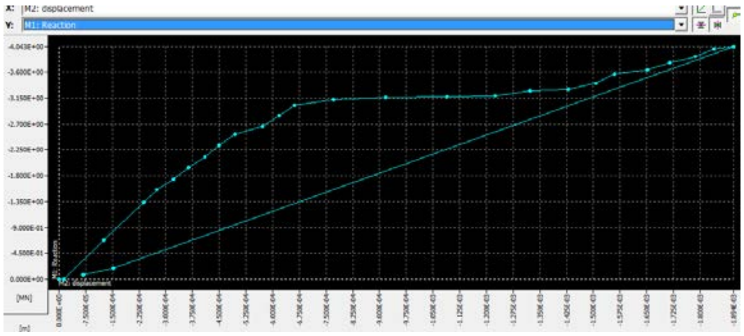


Figure 40

Step	Value [MN]
1	0.000E+00
2	-6.803E-01
3	-1.340E+00
4	-1.555E+00
5	-1.743E+00
6	-1.941E+00
7	-2.131E+00
8	-2.329E+00
9	-2.518E+00
10	-2.662E+00
11	-2.843E+00
12	-3.027E+00
13	-3.122E+00
14	-3.162E+00
15	-3.175E+00
16	-3.192E+00
17	-3.270E+00
18	-3.299E+00
19	-3.407E+00
20	-3.566E+00
21	-3.644E+00
22	-3.769E+00
23	-3.872E+00
24	-4.004E+00
25	-4.043E+00
26	-1.850E-01
27	-7.692E-02
28	-7.438E-02
29	-7.450E-02
30	-7.526E-02
31	-7.517E-02
32	-7.558E-02
33	-7.550E-02
34	-7.538E-02

Step	Value [m]
1	-1.470E-05
2	-1.267E-04
3	-2.377E-04
4	-2.744E-04
5	-3.207E-04
6	-3.634E-04
7	-4.100E-04
8	-4.497E-04
9	-4.937E-04
10	-5.712E-04
11	-6.183E-04
12	-6.608E-04
13	-7.702E-04
14	-9.173E-04
15	-1.089E-03
16	-1.225E-03
17	-1.322E-03
18	-1.430E-03
19	-1.508E-03
20	-1.559E-03
21	-1.651E-03
22	-1.714E-03
23	-1.786E-03
24	-1.839E-03
25	-1.894E-03
26	-1.518E-04
27	-6.887E-05
28	-6.773E-05
29	-6.805E-05
30	-6.853E-05
31	-6.851E-05
32	-6.867E-05
33	-6.861E-05
34	-6.857E-05

Table 26

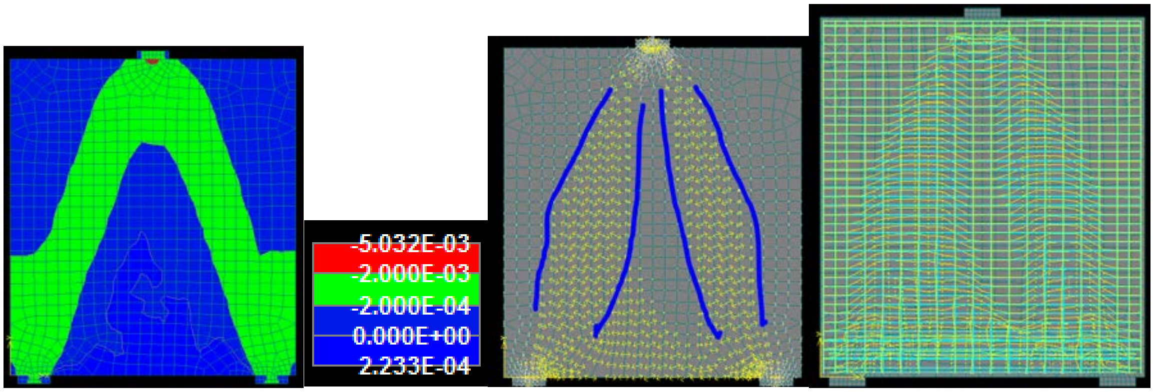


Figure 41

- No yielding of the reinforcements
- Failure due to the concrete crushing at support
- small plastic behavior

SLS

Step	Value [MN]	Step	Value [m]
1	0.000E+00	1	-1.470E-05
2	-2.290E-01	2	-5.216E-05
3	-4.559E-01	3	-8.951E-05
4	-6.805E-01	4	-1.267E-04
5	-9.028E-01	5	-1.639E-04
6	-1.123E+00	6	-2.009E-04
7	-1.340E+00	7	-2.377E-04
8	-1.555E+00	8	-2.745E-04
9	-1.743E+00	9	-3.207E-04

Table 27

D1P2NLFEM(without adjustment of criterion 3 in chapter 9.5.3)

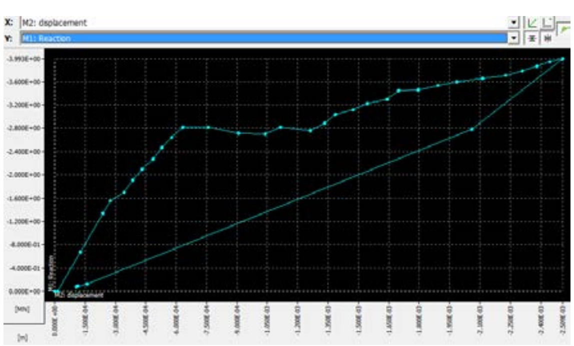


Figure 42

Step	Value [MN]	Step	Value [m]
11	-2.813E+00	11	-6.322E-04
12	-2.818E+00	12	-7.588E-04
13	-2.713E+00	13	-9.080E-04
14	-2.697E+00	14	-1.040E-03
15	-2.814E+00	15	-1.114E-03
16	-2.757E+00	16	-1.263E-03
17	-2.886E+00	17	-1.333E-03
18	-3.041E+00	18	-1.387E-03
19	-3.115E+00	19	-1.475E-03
20	-3.229E+00	20	-1.545E-03
21	-3.297E+00	21	-1.642E-03
22	-3.443E+00	22	-1.697E-03
23	-3.460E+00	23	-1.796E-03
24	-3.532E+00	24	-1.892E-03
25	-3.601E+00	25	-1.985E-03
26	-3.653E+00	26	-2.113E-03
27	-3.707E+00	27	-2.228E-03
28	-3.781E+00	28	-2.309E-03
29	-3.862E+00	29	-2.381E-03
30	-3.941E+00	30	-2.445E-03
31	-3.993E+00	31	-2.509E-03
32	-2.787E+00	32	-2.059E-03
33	-1.275E-01	33	-1.606E-04
34	-8.691E-02	34	-1.100E-04
35	-8.450E-02	35	-1.085E-04
36	-8.354E-02	36	-1.082E-04
37	-8.970E-02	37	-1.144E-04

Table 28

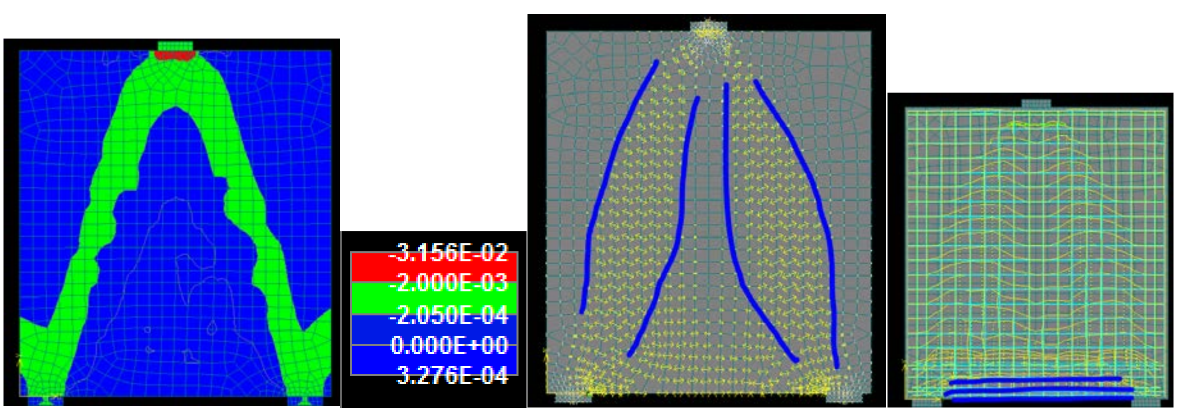


Figure 43

- Yielding begins but not decisive
- Failure is due to the concrete crushing
- Small plastic behavior

SLS

Step	Value [MN]
1	0.000E+00
2	-2.287E-01
3	-4.552E-01
4	-6.795E-01
5	-9.015E-01
6	-1.121E+00
7	-1.338E+00
8	-1.553E+00

Step	Value [m]
1	-1.478E-05
2	-5.234E-05
3	-8.980E-05
4	-1.271E-04
5	-1.644E-04
6	-2.015E-04
7	-2.385E-04
8	-2.753E-04

Table 29

Second Phase (No refinement around the support areas)

D2P1SBM
D2P1STM
D2P1LFEM
D2P1NLFEM

Principle strain min

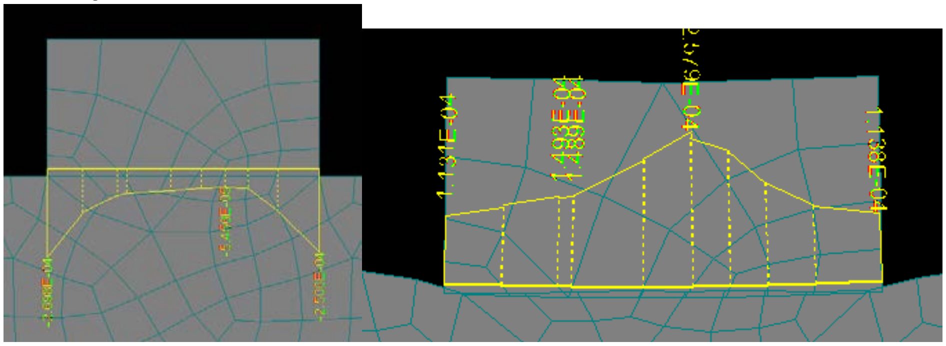


Figure 44

Max

Principle stress

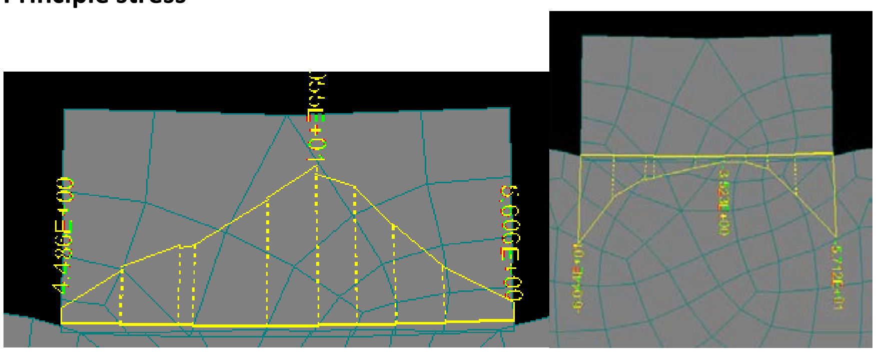


Figure 45

Principle stress min

D1P1SBM

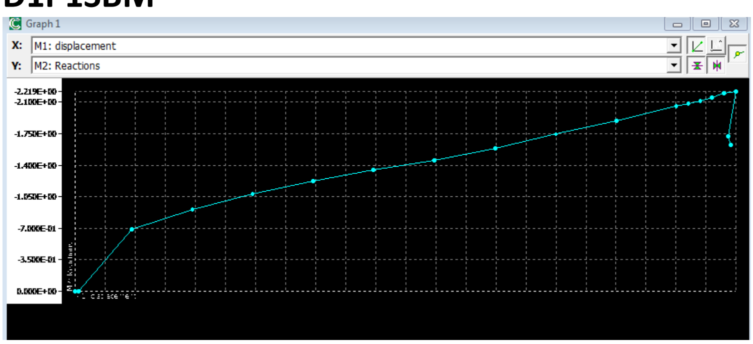


Figure 46

Step	Value [m]
1	-5.592E-05
2	-9.429E-04
3	-1.953E-03
4	-2.952E-03
5	-3.959E-03
6	-4.967E-03
7	-5.976E-03
8	-6.988E-03
9	-8.000E-03
10	-9.002E-03
11	-1.000E-02
12	-1.020E-02
13	-1.040E-02
14	-1.060E-02
15	-1.079E-02
16	-1.099E-02
17	-1.086E-02
18	-1.091E-02

Step	Value [MN]
1	0.000E+00
2	-6.888E-01
3	-9.097E-01
4	-1.082E+00
5	-1.222E+00
6	-1.351E+00
7	-1.453E+00
8	-1.587E+00
9	-1.746E+00
10	-1.895E+00
11	-2.056E+00
12	-2.085E+00
13	-2.112E+00
14	-2.155E+00
15	-2.198E+00
16	-2.219E+00
17	-1.725E+00
18	-1.626E+00

Table 30

ULS ATENA 2200 kN

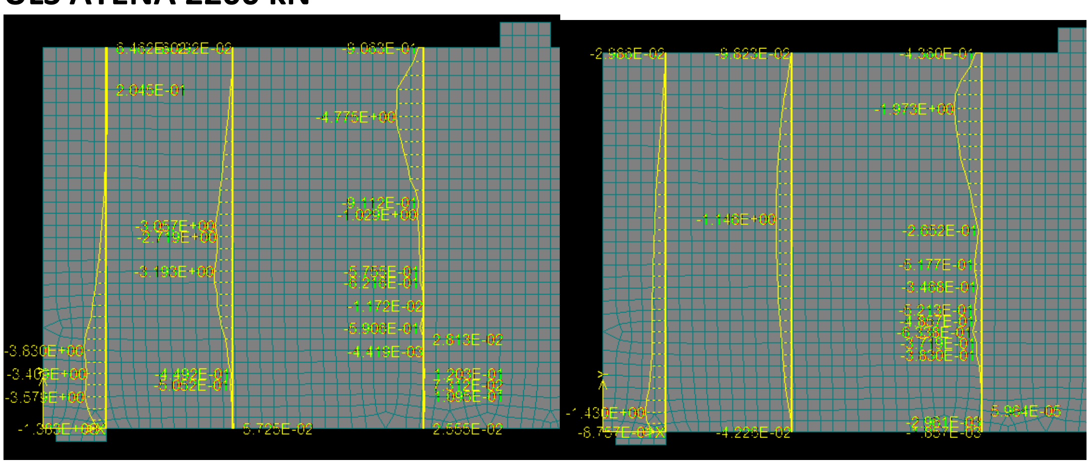


Figure 47

Design ULS 1040

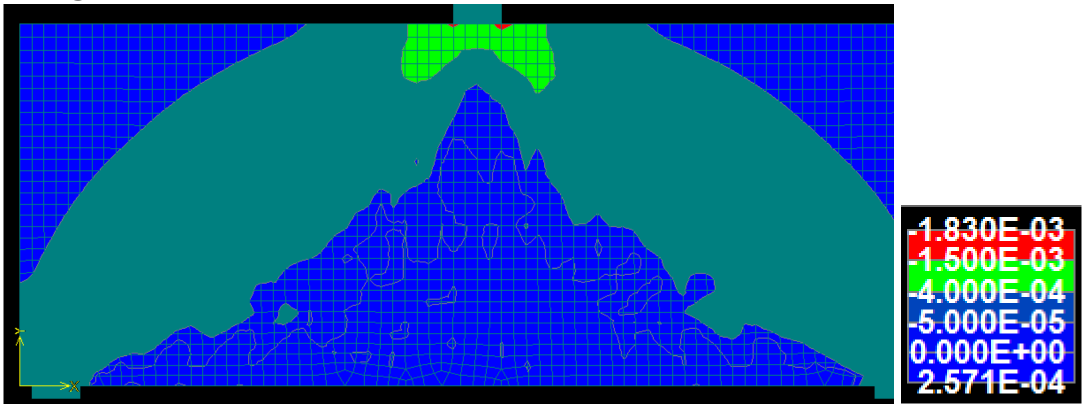


Figure 48

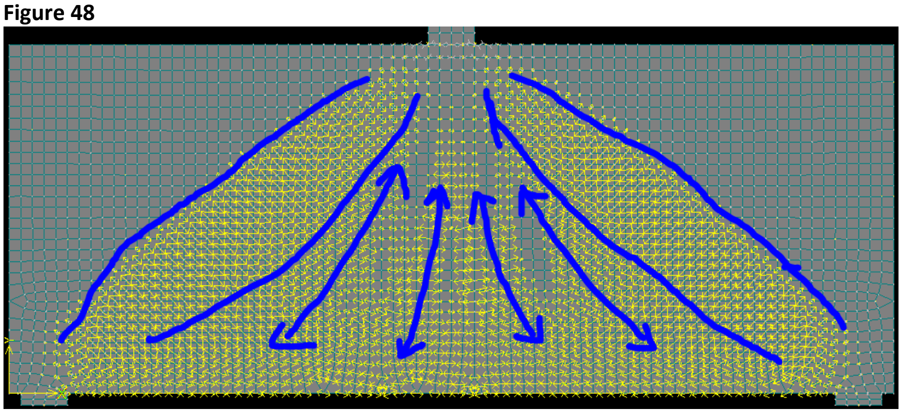


Figure 49

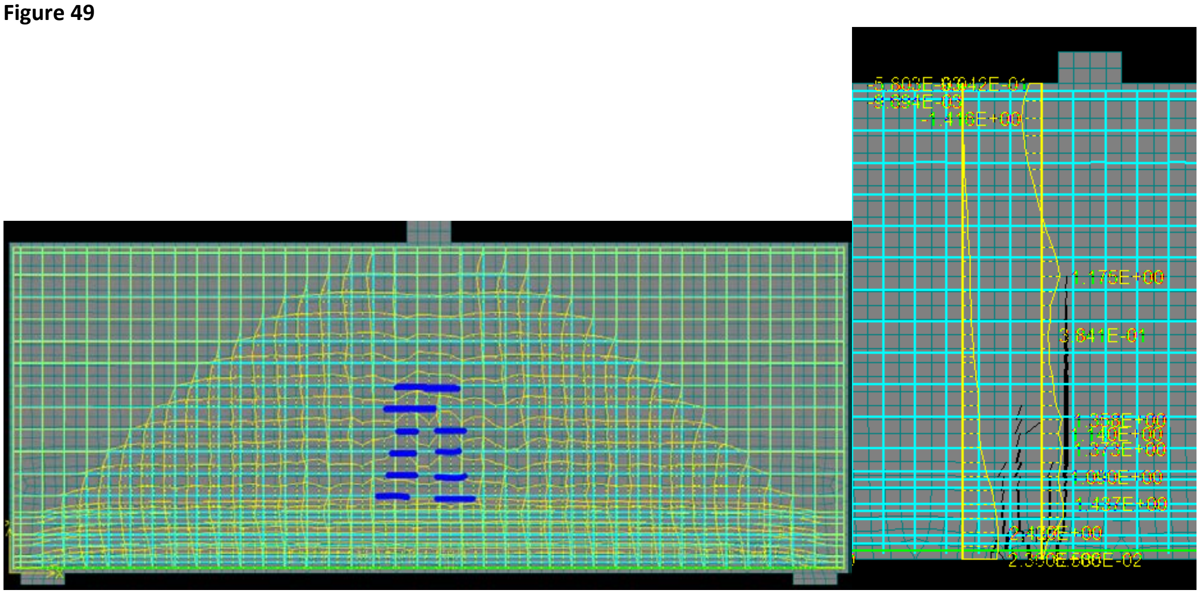


Figure 50

SLS

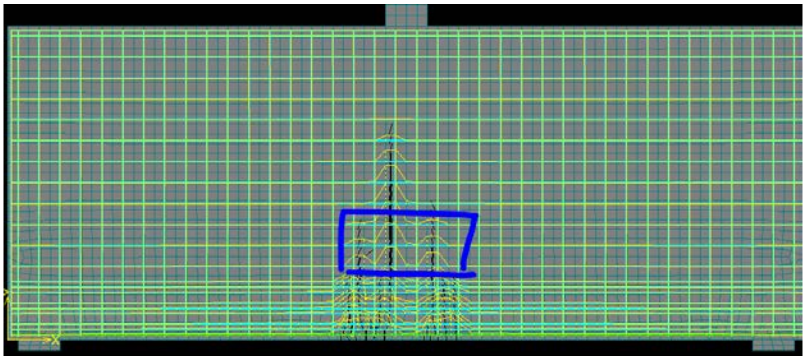


Figure 51

Step	Value	Step	Value [MN]
1	-5.592E-05	1	0.000E+00
2	-1.967E-04	2	-2.445E-01
3	-3.448E-04	3	-4.995E-01
4	-5.311E-04	4	-6.590E-01
5	-7.168E-04	5	-7.676E-01
6	-8.265E-04	6	-7.663E-01
7	-9.231E-04	7	-8.206E-01

Table 31

D2P1STM

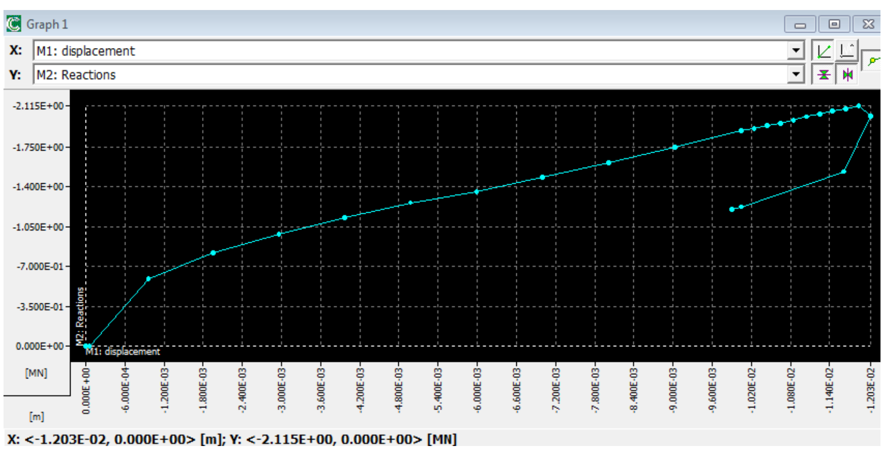


Figure 52

Step	Value [m]	Step	Value [MN]
1	-5.591E-05	1	0.000E+00
2	-9.606E-04	2	-5.926E-01
3	-1.958E-03	3	-8.191E-01
4	-2.960E-03	4	-9.876E-01
5	-3.968E-03	5	-1.132E+00
6	-4.976E-03		

7	-5.990E-03	6	-1.262E+00
8	-7.003E-03	7	-1.360E+00
9	-8.020E-03	8	-1.486E+00
10	-9.030E-03	9	-1.615E+00
11	-1.004E-02	10	-1.753E+00
12	-1.024E-02	11	-1.897E+00
13	-1.044E-02	12	-1.917E+00
14	-1.065E-02	13	-1.943E+00
15	-1.085E-02	14	-1.963E+00
16	-1.105E-02	15	-1.987E+00
17	-1.125E-02	16	-2.020E+00
18	-1.145E-02	17	-2.040E+00
19	-1.165E-02	18	-2.068E+00
20	-1.185E-02	19	-2.089E+00
21	-1.203E-02	20	-2.115E+00
22	-1.161E-02	21	-2.024E+00
23	-1.005E-02	22	-1.536E+00
24	-9.900E-03	23	-1.225E+00
		24	-1.203E+00

Table 32

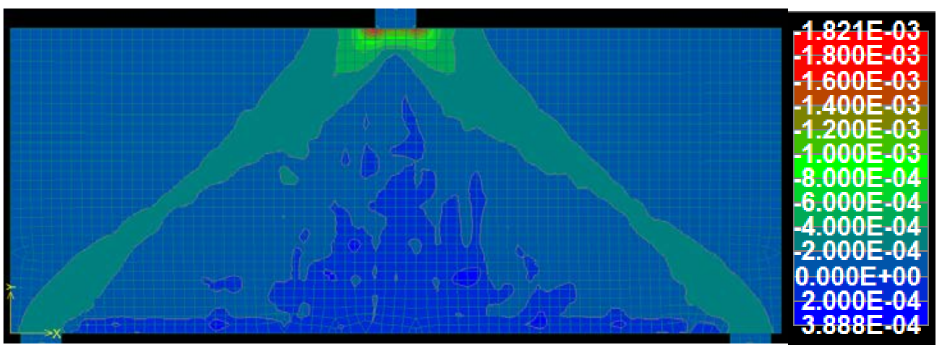


Figure 53

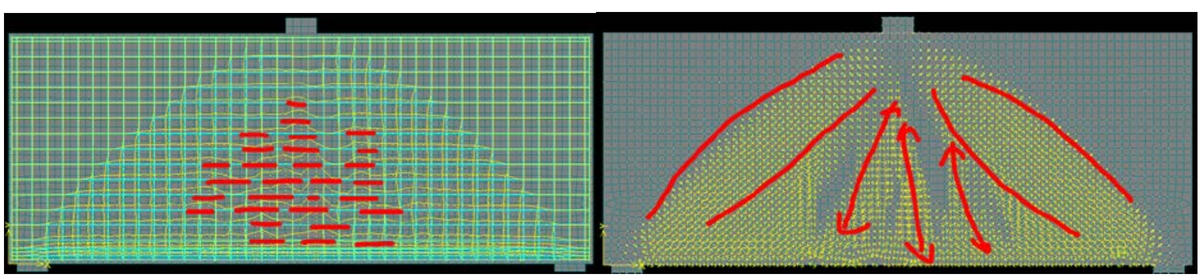


Figure 54

SLS

Step	Value [m]	Step	Value [MN]
1	-5.591E-05	1	0.000E+00
2	-1.967E-04	2	-2.444E-01
3	-3.447E-04	3	-4.994E-01

4	-5.497E-04	4	-5.825E-01
5	-7.998E-04	5	-6.468E-01
6	-1.003E-03	6	-7.507E-01
7	-1.198E-03	7	-8.004E-01
8	-1.412E-03	8	-7.708E-01
9	-1.618E-03	9	-7.743E-01
10	-1.819E-03	10	-8.306E-01
11	-2.016E-03	11	-9.092E-01

Table 33

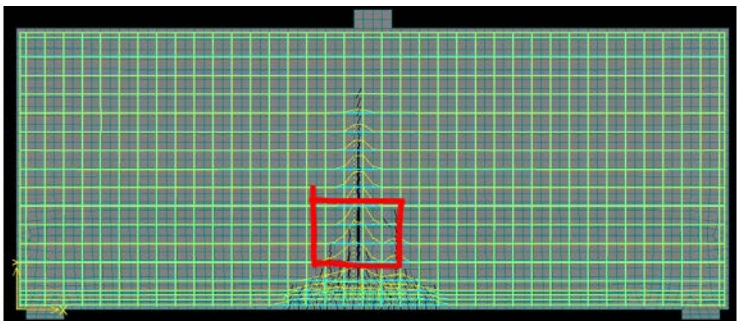


Figure 55

D2P1STM-OPTIE 2-(ORIGINAL)

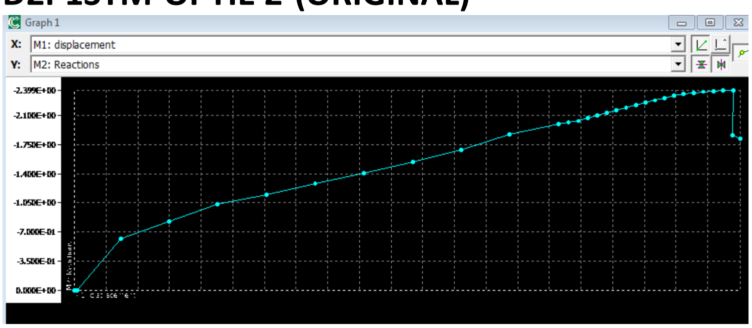


Figure 56

	[m]
5	-3.939E-03
6	-4.943E-03
7	-5.943E-03
8	-6.945E-03
9	-7.943E-03
10	-8.935E-03
11	-9.939E-03
12	-1.014E-02
13	-1.034E-02
14	-1.053E-02
15	-1.073E-02
16	-1.093E-02

Step	Value [MN]
5	-1.147E+00
6	-1.280E+00
7	-1.408E+00
8	-1.541E+00
9	-1.688E+00
10	-1.870E+00
11	-1.998E+00
12	-2.014E+00
13	-2.033E+00
14	-2.067E+00

17 -1.113E-02	15 -2.099E+00
18 -1.132E-02	16 -2.131E+00
19 -1.152E-02	17 -2.162E+00
20 -1.172E-02	18 -2.192E+00
21 -1.192E-02	19 -2.222E+00
22 -1.211E-02	20 -2.252E+00
23 -1.231E-02	21 -2.281E+00
24 -1.251E-02	22 -2.309E+00
25 -1.271E-02	23 -2.334E+00
26 -1.291E-02	24 -2.354E+00
27 -1.312E-02	25 -2.370E+00
28 -1.332E-02	26 -2.383E+00
29 -1.352E-02	27 -2.392E+00
30 -1.351E-02	28 -2.399E+00
31 -1.367E-02	29 -2.398E+00
	30 -1.864E+00
	31 -1.820E+00

Table 34

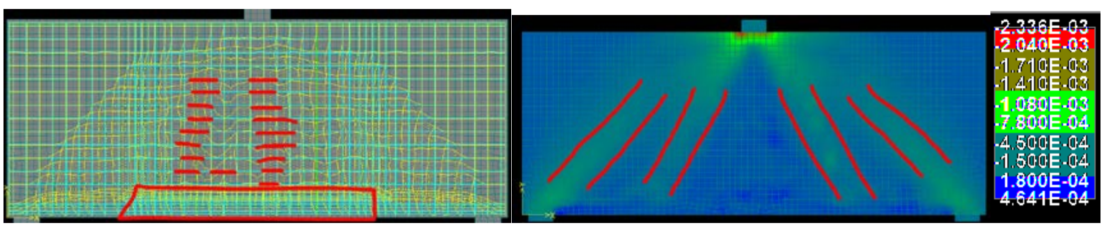


Figure 57

SLS

tep Value	-----------------
[m]	Step Value
-----------------	[MN]
1 -5.590E-05	-----------------
2 -1.967E-04	1 0.000E+00
3 -3.447E-04	2 -2.445E-01
4 -5.402E-04	3 -4.996E-01
5 -7.962E-04	4 -6.201E-01
6 -1.009E-03	5 -6.789E-01
7 -1.113E-03	6 -7.461E-01
	7 -7.928E-01

Table 35

D2P1STM-Option 3-(Original)

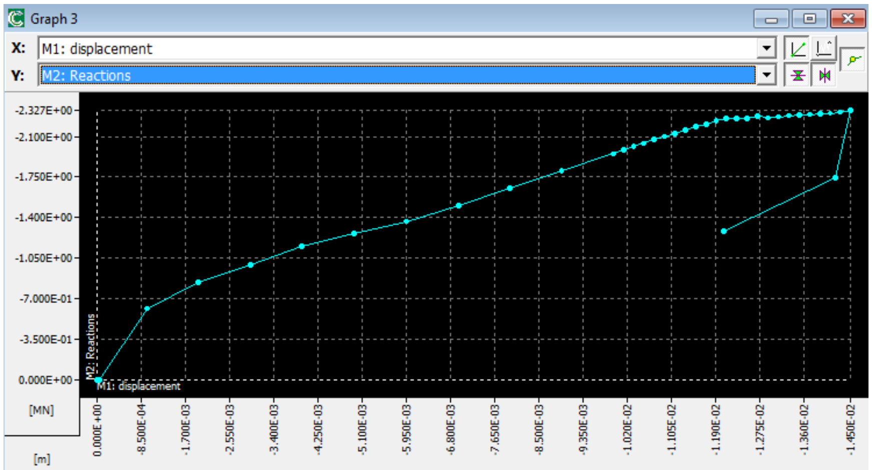


Figure 58

Step	Value [m]
1	-5.594E-05
2	-9.642E-04
3	-1.951E-03
4	-2.946E-03
5	-3.943E-03
6	-4.947E-03
7	-5.955E-03
8	-6.954E-03
9	-7.949E-03
10	-8.943E-03
11	-9.938E-03
12	-1.013E-02
13	-1.033E-02
14	-1.053E-02
15	-1.073E-02
16	-1.093E-02
17	-1.112E-02
18	-1.132E-02
19	-1.152E-02
20	-1.172E-02
21	-1.192E-02
22	-1.212E-02
23	-1.232E-02
24	-1.252E-02
25	-1.272E-02
26	-1.292E-02
27	-1.312E-02
28	-1.332E-02
29	-1.352E-02
30	-1.372E-02
31	-1.392E-02
32	-1.411E-02
33	-1.431E-02
34	-1.450E-02

Step	Value [MN]
1	0.000E+00
2	-6.164E-01
3	-8.442E-01
4	-9.930E-01
5	-1.156E+00
6	-1.261E+00
7	-1.368E+00
8	-1.506E+00
9	-1.656E+00
10	-1.804E+00
11	-1.951E+00
12	-1.984E+00
13	-2.012E+00
14	-2.042E+00
15	-2.072E+00
16	-2.100E+00
17	-2.129E+00
18	-2.157E+00
19	-2.186E+00
20	-2.209E+00
21	-2.233E+00
22	-2.254E+00
23	-2.260E+00
24	-2.260E+00
25	-2.274E+00
26	-2.261E+00
27	-2.271E+00
28	-2.281E+00
29	-2.284E+00
30	-2.291E+00
31	-2.293E+00
32	-2.301E+00
33	-2.311E+00
34	-2.327E+00

35	-1.421E-02	35	-1.747E+00
36	-1.206E-02	36	-1.281E+00

Table 36

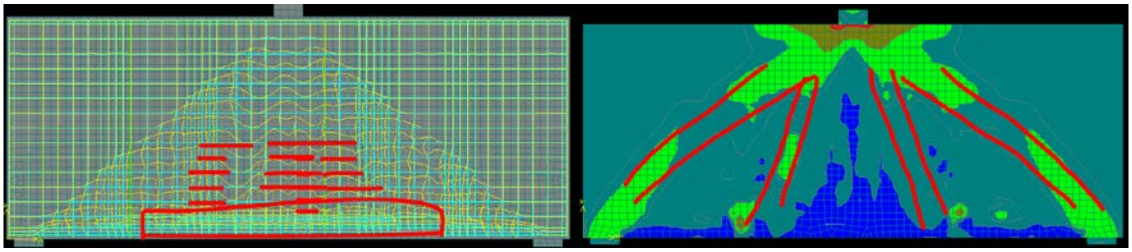


Figure 59

SLS

Step	Value [m]	Step	Value [MN]
1	-5.594E-05	1	0.000E+00
2	-1.967E-04	2	-2.444E-01
3	-3.448E-04	3	-4.994E-01
4	-5.396E-04	4	-6.053E-01
5	-7.925E-04	5	-6.583E-01
6	-1.008E-03	6	-7.293E-01
7	-1.216E-03	7	-7.818E-01
8	-1.318E-03	8	-7.730E-01
9	-1.423E-03	9	-7.737E-01
10	-1.524E-03	10	-7.902E-01

Table 37

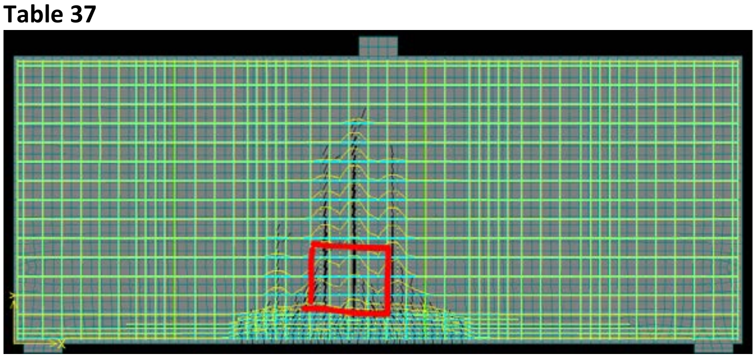


Figure 60

D2P1STM-OPTIE 2-(Adjusted)

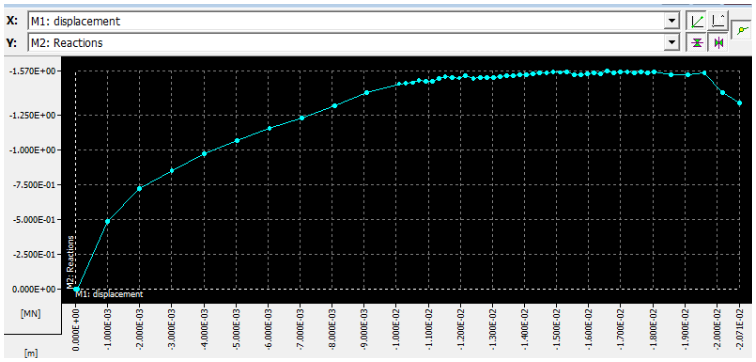


Figure 61

Step	Value [m]
1	-5.640E-05
2	-9.968E-04
3	-2.001E-03
4	-3.004E-03
5	-4.011E-03
6	-5.029E-03
7	-6.047E-03
8	-7.063E-03
9	-8.074E-03
10	-9.077E-03
11	-1.009E-02
12	-1.030E-02
13	-1.050E-02
14	-1.071E-02
15	-1.092E-02
16	-1.113E-02
17	-1.133E-02
18	-1.153E-02
19	-1.174E-02
20	-1.197E-02
21	-1.216E-02
22	-1.240E-02
23	-1.261E-02
24	-1.283E-02
25	-1.304E-02
26	-1.324E-02
27	-1.344E-02
28	-1.365E-02
29	-1.386E-02
30	-1.407E-02
31	-1.427E-02
32	-1.448E-02
33	-1.469E-02
34	-1.490E-02
35	-1.511E-02
36	-1.532E-02
37	-1.555E-02
38	-1.576E-02

Step	Value [MN]
1	0.000E+00
2	-4.861E-01
3	-7.219E-01
4	-8.510E-01
5	-9.744E-01
6	-1.069E+00
7	-1.156E+00
8	-1.234E+00
9	-1.321E+00
10	-1.412E+00
11	-1.479E+00
12	-1.481E+00
13	-1.486E+00
14	-1.501E+00
15	-1.495E+00
16	-1.497E+00
17	-1.515E+00
18	-1.527E+00
19	-1.523E+00
20	-1.519E+00
21	-1.539E+00
22	-1.517E+00
23	-1.522E+00
24	-1.523E+00
25	-1.521E+00
26	-1.529E+00
27	-1.537E+00
28	-1.537E+00
29	-1.543E+00
30	-1.545E+00
31	-1.553E+00
32	-1.556E+00
33	-1.555E+00
34	-1.561E+00
35	-1.561E+00
36	-1.561E+00
37	-1.546E+00
38	-1.541E+00

39	-1.596E-02	39	-1.551E+00
40	-1.617E-02	40	-1.557E+00
41	-1.638E-02	41	-1.551E+00
42	-1.658E-02	42	-1.570E+00
43	-1.679E-02	43	-1.559E+00
44	-1.700E-02	44	-1.561E+00
45	-1.721E-02	45	-1.565E+00
46	-1.742E-02	46	-1.559E+00
47	-1.762E-02	47	-1.562E+00
48	-1.784E-02	48	-1.559E+00
49	-1.804E-02	49	-1.562E+00
50	-1.858E-02	50	-1.545E+00
51	-1.910E-02	51	-1.545E+00
52	-1.961E-02	52	-1.555E+00
53	-2.018E-02	53	-1.413E+00
54	-2.071E-02	54	-1.342E+00

Table 38

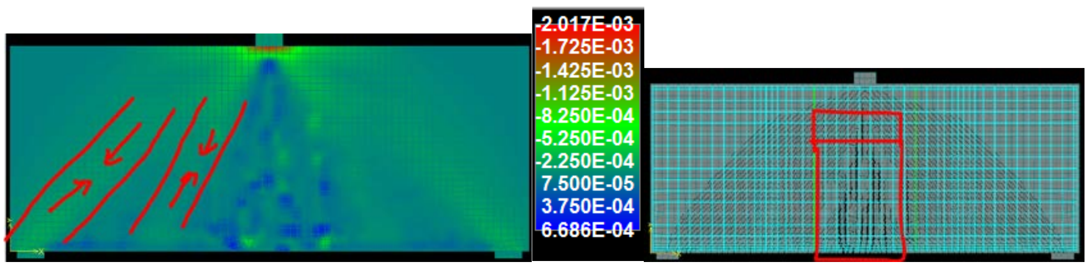


Figure 62

SLS

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		Step	Value [MN]

1	-5.640E-05	1	0.000E+00
2	-1.976E-04	2	-2.427E-01
3	-3.460E-04	3	-4.959E-01
4	-5.676E-04	4	-5.147E-01
5	-8.251E-04	5	-5.713E-01
6	-1.033E-03	6	-6.861E-01
7	-1.235E-03	7	-7.516E-01
8	-1.462E-03	8	-7.503E-01
9	-1.682E-03	9	-7.967E-01
10	-1.887E-03	10	-8.696E-01

Table 39

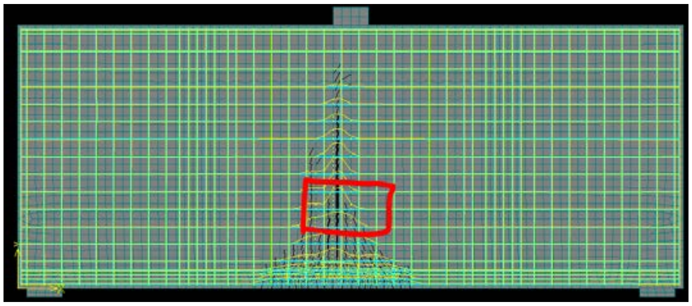

Figure 63

D2P1LEFEM

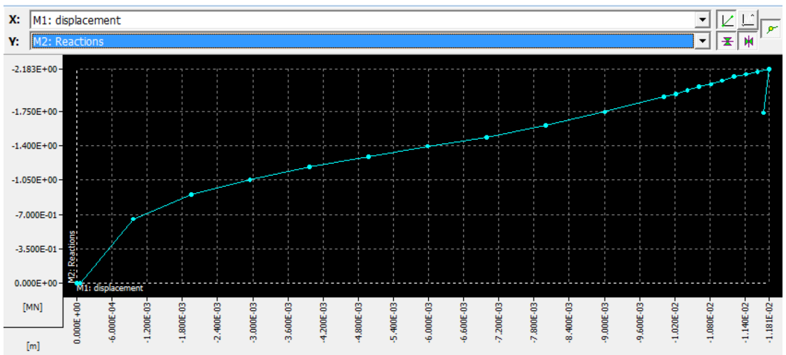

Figure 64

Step	Value [m]	Step	Value [MN]
1	-5.606E-05	1	0.000E+00
2	-9.573E-04	2	-6.539E-01
3	-1.949E-03	3	-9.046E-01
4	-2.953E-03	4	-1.051E+00
5	-3.963E-03	5	-1.184E+00
6	-4.977E-03	6	-1.290E+00
7	-5.987E-03	7	-1.397E+00
8	-6.993E-03	8	-1.490E+00
9	-8.002E-03	9	-1.607E+00
10	-9.012E-03	10	-1.746E+00
11	-1.002E-02	11	-1.899E+00
12	-1.022E-02	12	-1.931E+00
13	-1.042E-02	13	-1.966E+00
14	-1.061E-02	14	-2.002E+00
15	-1.081E-02	15	-2.028E+00
16	-1.101E-02	16	-2.065E+00
17	-1.121E-02	17	-2.106E+00
18	-1.141E-02	18	-2.131E+00
19	-1.161E-02	19	-2.154E+00
20	-1.181E-02	20	-2.183E+00
21	-1.171E-02	21	-1.737E+00

Table 40

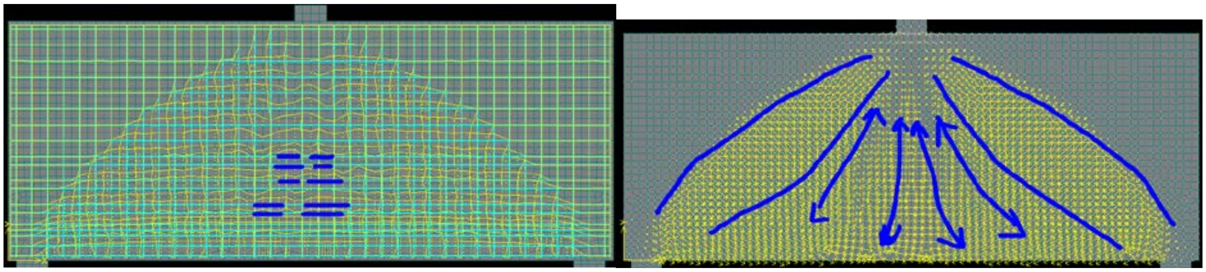

Figure 65

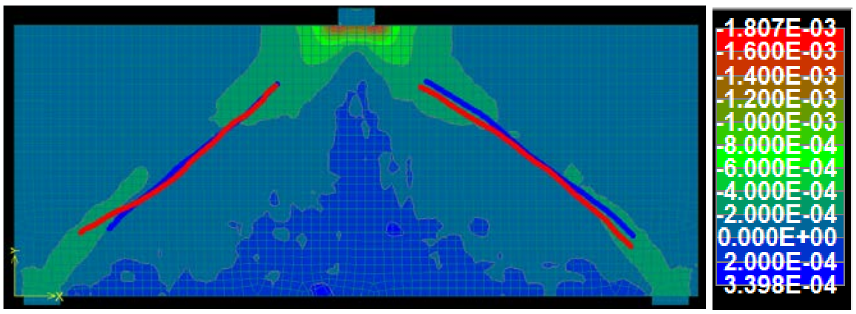

Figure 66

SIS

Step	Value [m]	Step	Value [MN]
1	-5.606E-05	1	0.000E+00
2	-1.265E-04	2	-1.222E-01
3	-2.007E-04	3	-2.501E-01
4	-2.748E-04	4	-3.776E-01
5	-3.489E-04	5	-5.046E-01
6	-4.229E-04	6	-6.311E-01
7	-5.472E-04	7	-6.356E-01
8	-6.446E-04	8	-7.114E-01
9	-7.323E-04	9	-7.918E-01
10	-8.540E-04	10	-7.787E-01
11	-9.688E-04	11	-7.983E-01

Table 41

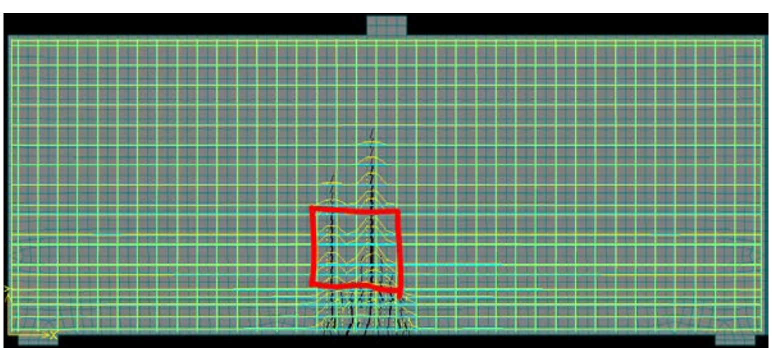

Figure 67

D2P1 NLFEM

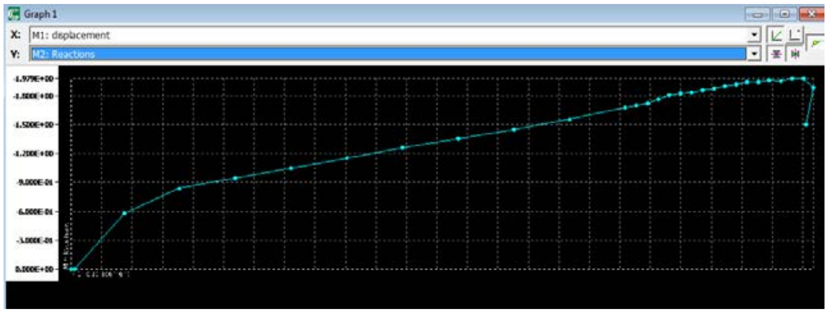

Figure 68

Step	Value [m]
8	-6.985E-03
9	-7.989E-03
10	-8.992E-03
11	-9.996E-03
12	-1.020E-02
13	-1.040E-02
14	-1.059E-02
15	-1.079E-02
16	-1.099E-02
17	-1.119E-02
18	-1.139E-02
19	-1.160E-02
20	-1.180E-02
21	-1.200E-02
22	-1.219E-02
23	-1.240E-02
24	-1.260E-02
25	-1.281E-02
26	-1.300E-02
27	-1.321E-02
28	-1.339E-02
29	-1.326E-02

Step	Value [MN]
8	-1.356E+00
9	-1.448E+00
10	-1.557E+00
11	-1.680E+00
12	-1.701E+00
13	-1.724E+00
14	-1.764E+00
15	-1.809E+00
16	-1.827E+00
17	-1.837E+00
18	-1.862E+00
19	-1.877E+00
20	-1.899E+00
21	-1.917E+00
22	-1.948E+00
23	-1.942E+00
24	-1.965E+00
25	-1.955E+00
26	-1.978E+00
27	-1.979E+00
28	-1.882E+00
29	-1.504E+00

Table 42

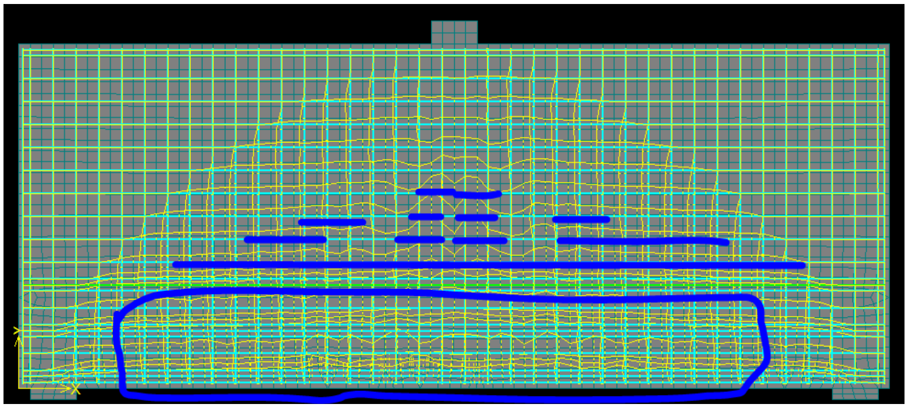

Figure 69

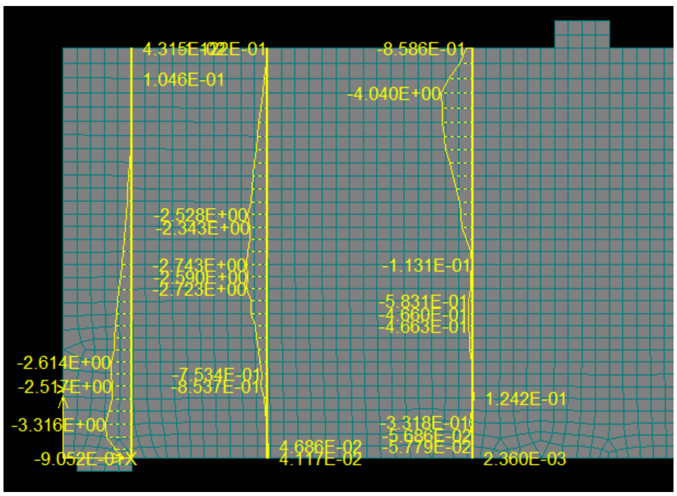

Figure 70

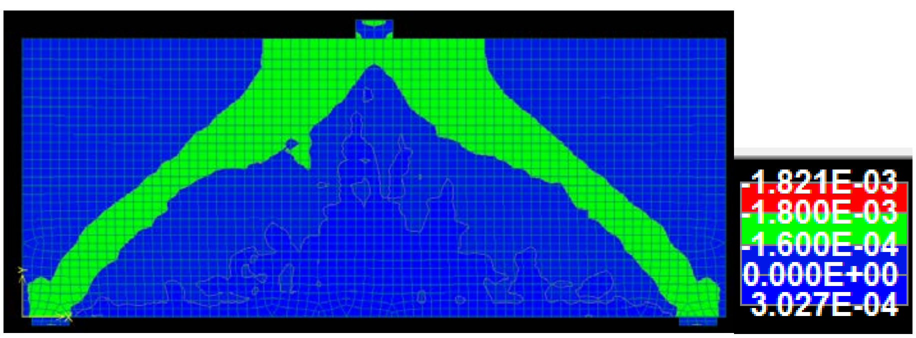

Figure 71

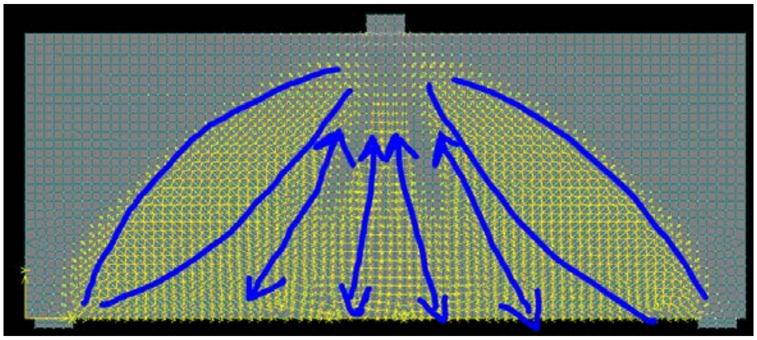

Figure 72

SLS

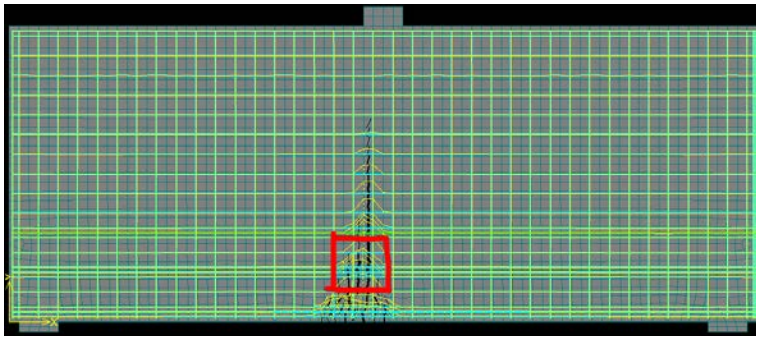

Figure 73

Step	Value [m]
1	-5.623E-05
2	-1.268E-04
3	-2.011E-04
4	-2.754E-04
5	-3.496E-04
6	-4.238E-04
7	-5.571E-04
8	-6.478E-04
9	-7.802E-04
10	-8.263E-04
11	-8.789E-04
12	-9.266E-04
13	-9.802E-04
14	-1.033E-03

Step	Value [MN]
1	0.000E+00
2	-1.219E-01
3	-2.495E-01
4	-3.766E-01
5	-5.033E-01
6	-6.295E-01
7	-6.018E-01
8	-6.825E-01
9	-6.942E-01
10	-7.372E-01
11	-7.572E-01
12	-7.937E-01
13	-8.109E-01
14	-8.363E-01

Table 43