



## Analysis using finite element method

### Topology

#### Project

Date : 28.10.2015

#### Global settings

Project type : Plane strain  
Analysis type : Stress  
Tunnels : no  
Advanced input : yes  
Detailed results : yes  
Concrete structures : CSN 73 1201 R

#### Interface

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-20,00	0,00	0,00	0,00	20,00	0,00
2		-20,00	-3,00	0,00	-3,00	20,00	-3,00
3		-20,00	-3,50	0,00	-3,50	20,00	-3,50
4		-20,00	-5,50	0,00	-5,50	20,00	-5,50

#### Soil parameters

##### Soil n. 1 - Class S4

Material model : Modified Mohr - Coulomb  
Unit weight :  $\gamma = 18,00 \text{ kN/m}^3$   
Poisson's ratio :  $\nu = 0,30$   
Elastic modulus :  $E = 10,00 \text{ MPa}$   
Biot parameter :  $\alpha = 1,00$   
Angle of internal friction :  $\varphi_{ef} = 29,00^\circ$   
Cohesion of soil :  $c_{ef} = 4,00 \text{ kPa}$   
Dilation angle :  $\psi = 0,00^\circ$   
Saturated unit weight :  $\gamma_{sat} = 18,00 \text{ kN/m}^3$



### Soil n. 2 - Class F6, rigid consistency

Material model :	Modified Mohr - Coulomb
Unit weight :	$\gamma = 21,00 \text{ kN/m}^3$
Poisson's ratio :	$\nu = 0,40$
Elastic modulus :	$E = 4,50 \text{ MPa}$
Biot parameter :	$\alpha = 1,00$
Angle of internal friction :	$\varphi_{ef} = 19,00^\circ$
Cohesion of soil :	$c_{ef} = 10,00 \text{ kPa}$
Dilation angle :	$\psi = 0,00^\circ$
Saturated unit weight :	$\gamma_{sat} = 21,00 \text{ kN/m}^3$

### Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		0,00	-3,00	20,00	-3,00	Soil n. 1 - Class S4 
		20,00	0,00	0,00	0,00	
		-20,00	0,00	-20,00	-3,00	
2		0,00	-3,50	20,00	-3,50	Soil n. 2 - Class F6, rigid consistency 
		20,00	-3,00	0,00	-3,00	
		-20,00	-3,00	-20,00	-3,50	
3		0,00	-5,50	20,00	-5,50	Soil n. 2 - Class F6, rigid consistency 
		20,00	-3,50	0,00	-3,50	
		-20,00	-3,50	-20,00	-5,50	
4		0,00	-5,50	-20,00	-5,50	Soil n. 2 - Class F6, rigid consistency 
		-20,00	-15,50	20,00	-15,50	
		20,00	-5,50			

### Contact types

#### Contact n. 1

Material model :	Mohr-Coulomb
Shear stiffness :	$K_s = 10000,00 \text{ kN/m}^3$
Normal stiffness :	$K_n = 10000,00 \text{ kN/m}^3$
Reduction c :	$\delta c = 0,30$
Reduction $\mu$ :	$\delta \mu = 0,30$
Dilation angle :	$\psi = 0,00^\circ$
Tensile strength :	$R_t = 0,000 \text{ kPa}$

### Free points

No.	Location		No.	Location		No.	Location		No.	Location	
	x [m]	z [m]		x [m]	z [m]		x [m]	z [m]		x [m]	z [m]
1	0,00	-10,00									



### Free lines

No.	Type of line	Mode of input	Lines topology
1	segment		Origin (0,00; -10,00) [m] , end (0,00; 0,00) [m]

### Lines refinement

No.	Location	Radius r [m]	Length l [m]
1	Free line No. 1	5,00	0,50

### Mesh generation

#### Mesh generation parameters

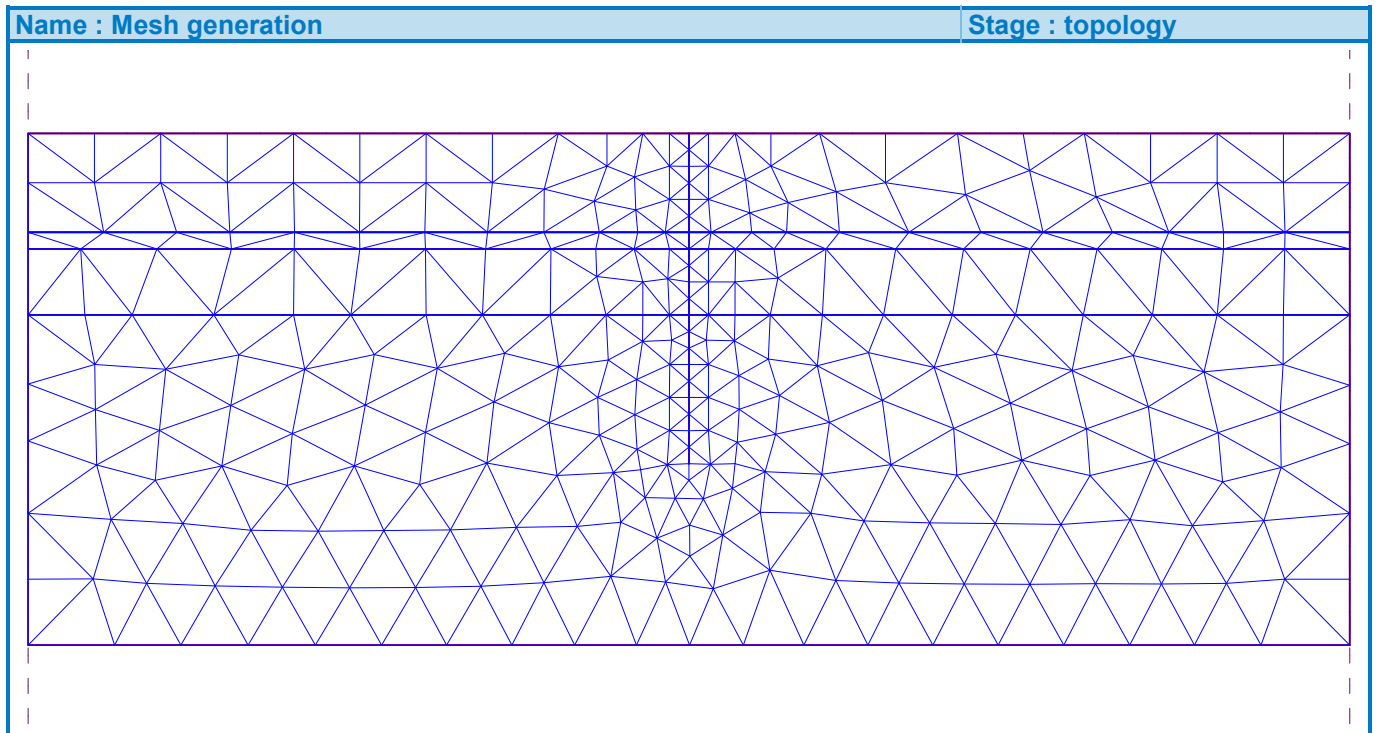
Element edge length : 2,00 [m]  
Mesh smoothing : yes  
Generate multinode elements : yes

#### Mesh generation result

**Finite element mesh was successfully generated.**


Number of nodes 1809

Number of elements 1162 (region 546, beam 154, interface 462)



### Input data (Stage of construction 1)

#### Assignment and activation

No.	Region	Active / inactive	Assigned soil								
1	<table border="1" style="width: 100%; height: 80px;"> <tr><td style="width: 50%;"></td><td style="width: 50%;"></td></tr> <tr><td></td><td></td></tr> <tr><td></td><td></td></tr> <tr><td></td><td></td></tr> </table>									Active	Soil n. 1 - Class S4 



No.	Region		Active / inactive	Assigned soil
2			Active	Soil n. 1 - Class S4
3			Active	Soil n. 2 - Class F6, rigid consistency
4			Active	Soil n. 2 - Class F6, rigid consistency
5			Active	Soil n. 2 - Class F6, rigid consistency
6			Active	Soil n. 2 - Class F6, rigid consistency
7			Active	Soil n. 2 - Class F6, rigid consistency

### Line supports

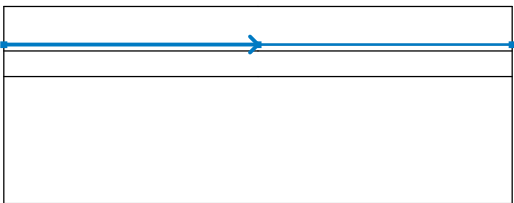
No.	Location	Support	
		Direction X	Direction Z
A1	Mesh line No. 15	fixed	free
A2	Mesh line No. 13	fixed	free
A3	Mesh line No. 9	fixed	free
A4	Mesh line No. 5	fixed	free
A5	Mesh line No. 17	fixed	free
A6	Mesh line No. 12	fixed	free
A7	Mesh line No. 8	fixed	free
A8	Mesh line No. 2	fixed	free
A1 up to A9 - automatically generated line supports along model edges			



No.	Location	Support	
		Direction X	Direction Z
A9	Mesh line No. 16	fixed	fixed
A1 up to A9 - automatically generated line supports along model edges			

### Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		-20,00	-3,00	0,00	-3,00	20,00	-3,00

### Analysis settings

#### General

Method : Newton - Raphson  
 Stiffness matrix change : after each iteration  
 Max. number of iterations for one calc. step : 100  
 Initial calculation step : 0,25  
 Displacement error : 0,0100  
 Imbalanced forces error : 0,0100  
 Energy error : 0,0100  
 Respect material interfaces : no

#### Newton - Raphson

Relaxation factor of calculation step : 2  
 Maximum number of relaxations of calculation step : 2  
 Min. number of iterations for one calc. step : 1

#### Line search

Solution method : iterate no  
 Line search limit - minimum : 0,100  
 Line search limit - maximum : 1,000

#### Plasticity

Return mapping error : 0,00100  
 Max. number of iterations for one plast. step : 20

### Results (Stage of construction 1)

**Stress analysis was successfully completed.**

Analysis settings : **user-defined**

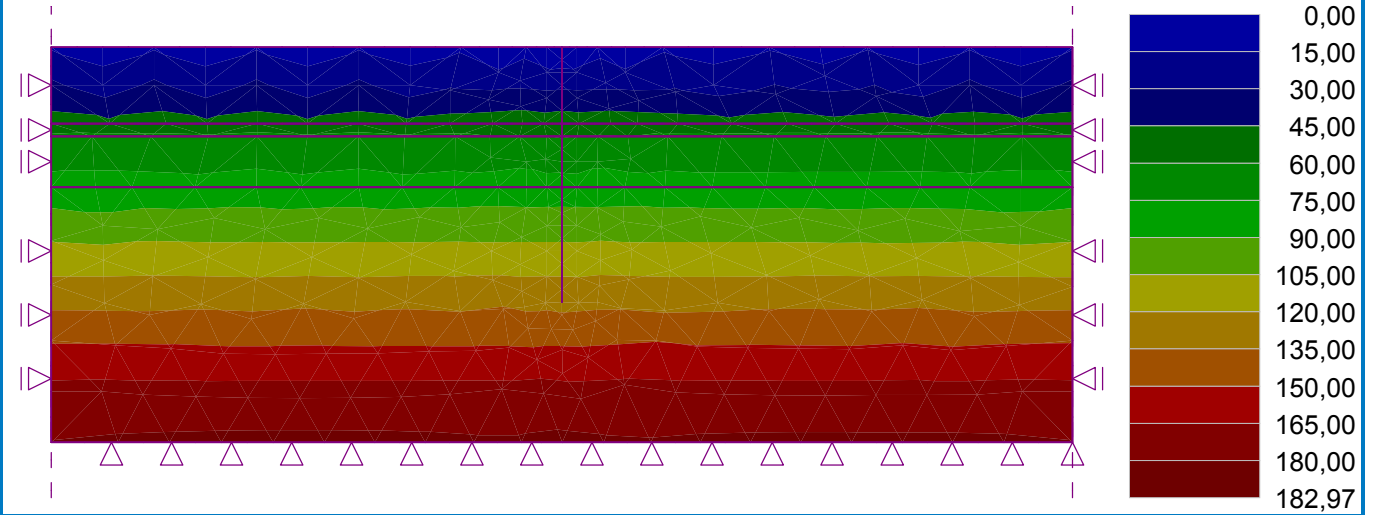
Attained loading = 100,00 %



Name : Analysis

Stage : 1

Results : overall; variable :  $\sigma_{z, \text{eff.}}$ ; range : <0,00; 182,97> kPa



Extremes

Stress (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
$\sigma_{z, \text{tot.}}$ [kPa]	0,00	0,00	0,00	-9,30	-15,50	307,97
$\sigma_{z, \text{eff.}}$ [kPa]	0,00	0,00	0,00	-9,30	-15,50	182,97
$\sigma_{x, \text{tot.}}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	246,98
$\sigma_{x, \text{eff.}}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	121,98
$\tau_{xz}$ [kPa]	0,00	-10,50	0,00	-14,14	-10,07	0,00
$\sigma_{m, \text{tot.}}$ [kPa]	0,00	0,00	1,86	-9,30	-15,50	267,31
$\sigma_{m, \text{eff.}}$ [kPa]	0,00	0,00	1,86	-9,30	-15,50	142,31
$\sigma_{\text{eq.}}$ [kPa]	0,00	0,00	0,99	-9,30	-15,50	35,21
$\sigma_1, \text{tot.}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	246,98
$\sigma_1, \text{eff.}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	121,98
$\sigma_2, \text{tot.}$ [kPa]	0,00	0,00	3,00	-9,30	-15,50	307,97
$\sigma_2, \text{eff.}$ [kPa]	0,00	0,00	3,00	-9,30	-15,50	182,97
$\sigma_3, \text{tot.}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	246,98
$\sigma_3, \text{eff.}$ [kPa]	0,00	0,00	1,29	-9,30	-15,50	121,98

Strain (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
$\epsilon_{\text{eq.}}$ [%]	0,00	0,00	0,03	-9,30	-15,50	2,19
$\epsilon_{\text{eq., pl.}}$ [%]	0,00	-0,50	0,00	0,00	-0,50	0,00
$\epsilon_x$ [%]	1,32	-10,75	0,00	-5,22	-11,94	0,00
$\epsilon_z$ [%]	0,00	0,00	0,02	-9,30	-15,50	1,90
$\gamma_{xz}$ [%]	0,00	-10,50	0,00	-14,14	-10,07	0,00
$\epsilon_{x, \text{pl.}}$ [%]	0,00	-0,50	0,00	0,00	-0,50	0,00
$\epsilon_{z, \text{pl.}}$ [%]	0,00	-0,50	0,00	0,00	-0,50	0,00
$\gamma_{xz, \text{pl.}}$ [%]	0,00	-0,50	0,00	0,00	-0,50	0,00
$\epsilon_{\text{vol.}}$ [%]	0,00	0,00	0,02	-9,30	-15,50	1,90
$\epsilon_{\text{vol., pl.}}$ [%]	0,00	-0,50	0,00	0,00	-0,50	0,00
$\epsilon_1$ [%]	1,32	-10,75	0,00	-5,22	-11,94	0,00



	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Epsilon <sub>2</sub> [%]	0,00	0,00	0,02	-9,30	-15,50	1,90
Epsilon <sub>3</sub> [%]	0,00	-0,50	0,00	0,00	-0,50	0,00

**Pore pressures (extremes)**

	Location		Max
	x [m]	z [m]	
Pore pressure u [kPa]	5,42	-15,50	125,00

**Input data (Stage of construction 2)**

**Assignment and activation**

No.	Region	Active / inactive	Assigned soil
1		Inactive	
2		Active	Soil n. 1 - Class S4 
3		Inactive	
4		Active	Soil n. 2 - Class F6, rigid consistency 
5		Active	Soil n. 2 - Class F6, rigid consistency 
6		Active	Soil n. 2 - Class F6, rigid consistency 



No.	Region	Active / inactive	Assigned soil
7		Active	Soil n. 2 - Class F6, rigid consistency 

### Beams

No.	Beam		Location	Support [m]		Include self weight	Cross-section	Material	Contacts	
	new	modified		Start pt.	End pt.				left	right
1	Yes		Free line No. 1	0,50		Yes	1,00 (b) x 0,50 (h) m	B 20	Contact n. 1	Contact n. 1

No.	Cross-section		Material	
	I <sub>y</sub> [m <sup>4</sup> /m]	A [m <sup>2</sup> /m]	E [MPa]	G [MPa]
1	1,04E-02	5,00E-01	27000,00	11340,00

### Line supports

No.	Line support		Location	Support	
	new	modified		Direction X	Direction Z
A1	Yes		Mesh line No. 15	fixed	free
A2	Yes		Mesh line No. 13	fixed	free
A3	Yes		Mesh line No. 17	fixed	free
A4	Yes		Mesh line No. 12	fixed	free
A5	Yes		Mesh line No. 8	fixed	free
A6	Yes		Mesh line No. 2	fixed	free
A7	Yes		Mesh line No. 16	fixed	fixed

A1 up to A7 - automatically generated line supports along model edges

### Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		-20,00	-3,90	0,00	-3,90	0,00	-3,00
		20,00	-3,00				

### Analysis settings

#### General

Method : Newton - Raphson  
 Stiffness matrix change : after each iteration  
 Max. number of iterations for one calc. step : 100  
 Initial calculation step : 0,25  
 Displacement error : 0,0100  
 Imbalanced forces error : 0,0100  
 Energy error : 0,0100  
 Respect material interfaces : no

#### Newton - Raphson

Relaxation factor of calculation step : 2  
 Maximum number of relaxations of calculation step : 2  
 Min. number of iterations for one calc. step : 1





### Line search

Solution method :  
Line search limit - minimum :  
Line search limit - maximum :

iterate no  
0,100  
1,000

### Plasticity

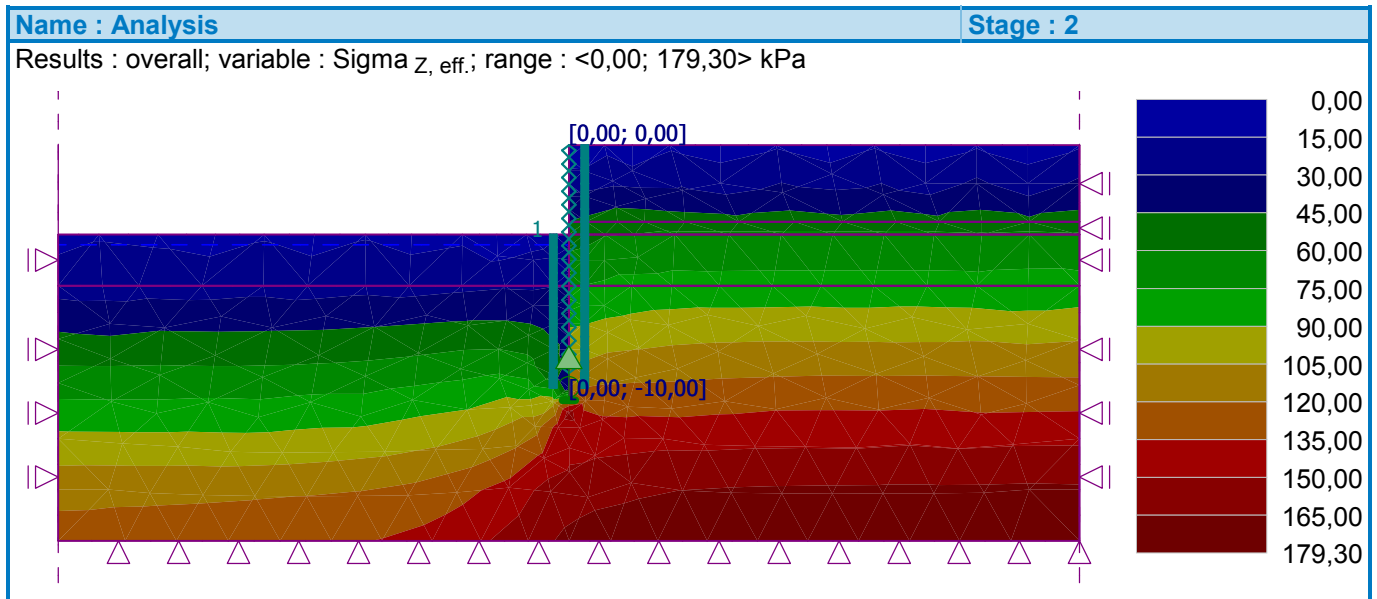
Return mapping error :  
Max. number of iterations for one plast. step :

0,00100  
20

## Results (Stage of construction 2)

Stress analysis was successfully completed.

Analysis settings : **user-defined**  
Attained loading = 100,00 %



### Extremes

#### Displacements (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Displacements x [m]	20,00	0,00	0,0	0,00	0,00	70,5
Displacements z [m]	-9,97	-3,50	-84,8	1,40	0,00	33,2

#### Stress (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
$\Sigma_{z, \text{tot.}}$ [kPa]	0,00	0,00	0,00	15,31	-15,50	304,30
$\Sigma_{z, \text{eff.}}$ [kPa]	0,00	0,00	0,00	15,31	-15,50	179,30
$\Sigma_{x, \text{tot.}}$ [kPa]	2,49	0,00	-3,12	15,31	-15,50	243,02
$\Sigma_{x, \text{eff.}}$ [kPa]	2,49	0,00	-3,12	15,31	-15,50	118,02
$\tau_{xz}$ [kPa]	1,72	-1,40	-0,87	-0,42	-11,05	22,67
$\Sigma_{m, \text{tot.}}$ [kPa]	2,49	0,00	1,39	15,31	-15,50	263,75
$\Sigma_{m, \text{eff.}}$ [kPa]	2,49	0,00	1,39	15,31	-15,50	138,75
$\Sigma_{\text{eq.}}$ [kPa]	0,00	0,00	1,58	0,00	-10,50	43,15
$\Sigma_{1, \text{tot.}}$ [kPa]	2,49	0,00	-3,12	15,31	-15,50	242,93
$\Sigma_{1, \text{eff.}}$ [kPa]	2,49	0,00	-3,12	15,31	-15,50	117,93
$\Sigma_{2, \text{tot.}}$ [kPa]	0,00	0,00	3,41	11,35	-15,50	304,45



	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Sigma 2, eff. [kPa]	0,00	0,00	3,41	11,35	-15,50	179,45
Sigma 3, tot. [kPa]	0,00	0,00	0,97	15,31	-15,50	243,93
Sigma 3, eff. [kPa]	0,00	0,00	0,97	15,31	-15,50	118,93

### Strain (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Epsilon eq. [%]	0,00	0,00	0,08	0,00	-10,50	2,71
Epsilon eq., pl. [%]	20,00	-3,50	0,00	0,00	-2,00	2,01
Epsilon x [%]	0,00	-2,00	-1,06	0,00	-9,50	0,82
Epsilon z [%]	-0,59	-3,50	-0,31	0,00	-10,50	1,89
Gamma xz [%]	1,72	-1,40	-0,10	0,00	-9,50	1,73
Epsilon x, pl. [%]	0,00	-2,00	-0,96	0,00	-9,50	0,17
Epsilon z, pl. [%]	0,00	-3,50	-0,13	0,00	-2,00	1,03
Gamma xz, pl. [%]	1,72	-1,40	-0,08	0,00	-9,50	0,69
Epsilon vol. [%]	2,49	0,00	0,02	15,31	-15,50	1,85
Epsilon vol., pl. [%]	0,00	0,00	0,00	0,00	0,00	0,00
Epsilon 1 [%]	0,00	-2,00	-1,07	-9,79	-8,23	0,25
Epsilon 2 [%]	0,00	0,00	0,05	0,00	-10,50	2,03
Epsilon 3 [%]	0,00	0,00	0,00	0,00	0,00	0,00

### Pore pressures (extremes)

	Location		Max
	x [m]	z [m]	
Pore pressure u [kPa]	5,42	-15,50	125,00

### Distributions on beams (extremes)




	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
N [kN/m]	0,00	-10,00	-107,2	0,00	0,00	0,0
M [kNm/m]	0,00	-8,00	-13,6	0,00	-4,00	12,9
Q [kN/m]	0,00	-10,00	-21,8	0,00	-5,50	9,9

## Input data (Stage of construction 3)

### Assignment and activation

No.	Region	Active / inactive	Assigned soil
1		Inactive	
2		Active	Soil n. 1 - Class S4 



No.	Region		Active / inactive	Assigned soil
3			Inactive	
4			Active	Soil n. 2 - Class F6, rigid consistency 
5			Inactive	
6			Active	Soil n. 2 - Class F6, rigid consistency 
7			Active	Soil n. 2 - Class F6, rigid consistency 

### Beams

No.	Beam		Location	Support [m]		Include self weight	Cross-section	Material	Contacts	
	new	modified		Start pt.	End pt.				left	right
1	No	No	Free line No. 1	0,50		Yes	without modification	without modification	Contact n. 1	Contact n. 1

No.	Cross-section		Material	
	$I_y$ [m <sup>4</sup> /m]	A [m <sup>2</sup> /m]	E [MPa]	G [MPa]
1	1,04E-02	5,00E-01	27000,00	11340,00

### Line supports

No.	Line support		Location	Support	
	new	modified		Direction X	Direction Z
A1	Yes		Mesh line No. 15	fixed	free
A2	Yes		Mesh line No. 17	fixed	free
A3	Yes		Mesh line No. 12	fixed	free
A4	Yes		Mesh line No. 8	fixed	free
A5	Yes		Mesh line No. 2	fixed	free

A1 up to A6 - automatically generated line supports along model edges



No.	Line support		Location	Support	
	new	modified		Direction X	Direction Z
A6	Yes		Mesh line No. 16	fixed	fixed
A1 up to A6 - automatically generated line supports along model edges					

### Anchors

No.	Anchor		Origin		Length and slope / coordinates		Anchor spacing b [m]	Diameter / area d [mm] / A [mm <sup>2</sup> ]	Elastic modulus E [MPa]	Tensile strength F <sub>c</sub> [kN]	Active in compress	Force F [kN]
	new	post-stress	x [m]	z [m]	l [m] / x [m]	α [°] / z [m]						
1	Yes		0,00	-2,90	l = 12,00	α = 15,00	1,00	d = 10,0	10000,00	1E80	No	185,00

### Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		-20,00	-5,90	0,00	-5,90	0,00	-3,00
		20,00	-3,00				

### Analysis settings

#### General

Method : Newton - Raphson  
 Stiffness matrix change : after each iteration  
 Max. number of iterations for one calc. step : 100  
 Initial calculation step : 0,25  
 Displacement error : 0,0100  
 Imbalanced forces error : 0,0100  
 Energy error : 0,0100  
 Respect material interfaces : no

#### Newton - Raphson

Relaxation factor of calculation step : 2  
 Maximum number of relaxations of calculation step : 2  
 Min. number of iterations for one calc. step : 1

#### Line search

Solution method : iterate no  
 Line search limit - minimum : 0,100  
 Line search limit - maximum : 1,000

#### Plasticity

Return mapping error : 0,00100  
 Max. number of iterations for one plast. step : 20

### Results (Stage of construction 3)

**Stress analysis was successfully completed.**

Analysis settings : **user-defined**

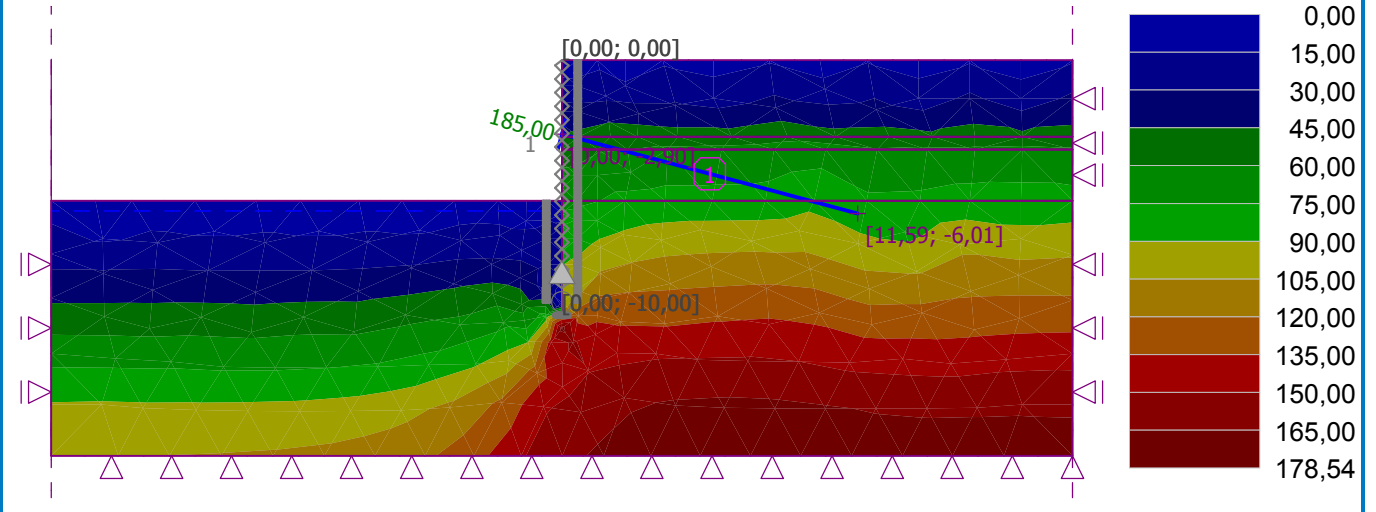
Attained loading = 100,00 %



**Name : Analysis**

**Stage : 3**

Results : overall; variable :  $\Sigma_{z, \text{eff.}}$ ; range : <0,00; 178,54> kPa



**Extremes**

**Displacements (extremes)**

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Displacements x [m]	20,00	0,00	0,0	0,00	-9,50	104,7
Displacements z [m]	-6,25	-5,50	-105,9	1,40	0,00	44,8

**Stress (extremes)**

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
$\Sigma_{z, \text{tot.}}$ [kPa]	-1,40	-5,50	0,00	7,38	-15,50	303,54
$\Sigma_{z, \text{eff.}}$ [kPa]	0,00	-5,50	0,00	7,38	-15,50	178,54
$\Sigma_{x, \text{tot.}}$ [kPa]	10,11	0,00	-2,83	11,35	-15,50	239,14
$\Sigma_{x, \text{eff.}}$ [kPa]	10,11	0,00	-2,83	11,35	-15,50	114,14
$\tau_{xz}$ [kPa]	8,32	-3,50	-6,05	-0,42	-11,05	36,84
$\Sigma_{m, \text{tot.}}$ [kPa]	10,11	0,00	1,85	7,38	-15,50	261,24
$\Sigma_{m, \text{eff.}}$ [kPa]	10,11	0,00	1,85	7,38	-15,50	136,24
$\Sigma_{\text{eq.}}$ [kPa]	3,96	0,00	3,07	0,00	-10,50	51,71
$\Sigma_1, \text{tot.}$ [kPa]	10,11	0,00	-2,83	13,34	-15,50	238,32
$\Sigma_1, \text{eff.}$ [kPa]	10,11	0,00	-2,83	13,34	-15,50	113,32
$\Sigma_2, \text{tot.}$ [kPa]	10,11	0,00	6,70	5,42	-15,50	307,31
$\Sigma_2, \text{eff.}$ [kPa]	10,11	0,00	6,70	5,42	-15,50	182,31
$\Sigma_3, \text{tot.}$ [kPa]	10,11	0,00	1,68	7,38	-15,50	241,77
$\Sigma_3, \text{eff.}$ [kPa]	10,11	0,00	1,68	7,38	-15,50	116,77

**Strain (extremes)**

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
$\epsilon_{\text{eq.}}$ [%]	0,59	0,00	0,18	0,00	-9,50	7,34
$\epsilon_{\text{eq., pl.}}$ [%]	8,32	-3,50	0,00	0,00	-9,50	6,32
$\epsilon_x$ [%]	0,00	-10,50	-1,05	0,00	-9,50	2,91
$\epsilon_z$ [%]	0,00	-9,50	-2,64	0,00	-10,50	2,73
$\gamma_{xz}$ [%]	0,00	-9,50	-0,43	0,00	-9,50	4,80



	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
Epsilon $\epsilon_x$ , pl. [%]	0,00	-2,00	-0,96	0,00	-9,50	2,41
Epsilon $\epsilon_z$ , pl. [%]	0,00	-9,50	-2,33	0,00	-2,00	1,03
Gamma $\gamma_{xz}$ , pl. [%]	0,00	-9,50	-0,31	0,00	-9,50	4,17
Epsilon vol. [%]	10,11	0,00	0,02	7,38	-15,50	1,82
Epsilon vol., pl. [%]	0,00	0,00	0,00	0,00	0,00	0,00
Epsilon $\epsilon_1$ [%]	0,00	-9,50	-3,54	-17,92	-10,04	0,26
Epsilon $\epsilon_2$ [%]	0,59	0,00	0,16	0,00	-9,50	3,81
Epsilon $\epsilon_3$ [%]	0,00	0,00	0,00	0,00	0,00	0,00

#### Pore pressures (extremes)

	Location		Max
	x [m]	z [m]	
Pore pressure u [kPa]	5,42	-15,50	125,00

#### Distributions on beams (extremes)

	Location		Min	Location		Max
	x [m]	z [m]		x [m]	z [m]	
N [kN/m]	0,00	-10,00	-155,5	0,00	0,00	0,6
M [kNm/m]	0,00	-6,00	-77,1	0,00	-3,00	79,7
Q [kN/m]	0,00	-10,00	-62,1	0,00	-3,50	87,9