Slope stability analysis

Input data

Project

Task : Zemeljski plaz na parceli št. 466/2 k.o. 752 pri hiši Okoška gora 51
Part : GP
Description : Konzolna pilotna stena
Customer : Občina Oplotnica
Author : GEOING d.o.o.
Date : 28/01/2025

Settings

Slovenia - EN 1997 (31)

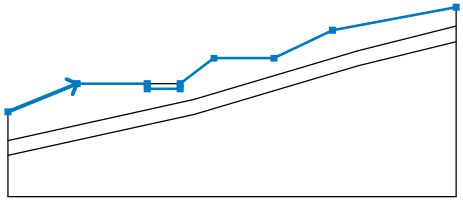
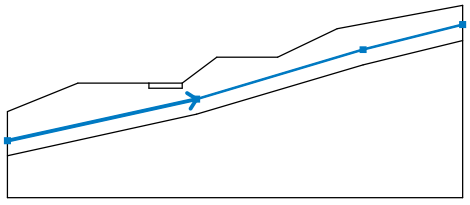
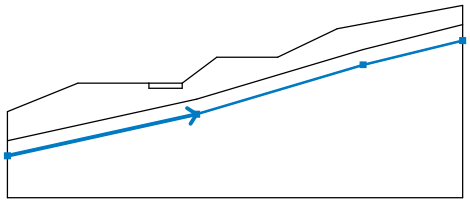
Stability analysis

Earthquake analysis : Standard
Verification methodology : according to EN 1997
Design approach : 2 - reduction of actions and resistances

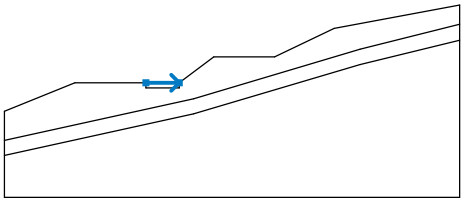
Partial factors on actions (A)					
Permanent design situation					
		Unfavourable		Favourable	
Permanent actions :	γ_G =	1,35	[–]	1,00	[–]
Variable actions :	γ_Q =	1,50	[–]	0,00	[–]
Water load :	γ_w =	1,35	[–]		

Partial factors for resistances (R)			
Permanent design situation			
Partial factor on sliding resistance (on slip surface) :	γ_{Rs} =	1,10	[–]

Interface

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0,00	13,50	8,40	16,90	16,90	16,90
		16,90	16,30	20,90	16,30	20,90	16,90
		25,00	20,00	32,30	20,00	39,40	23,40
		54,40	26,20				
2		0,00	10,00	22,60	15,00	42,50	20,90
		54,40	23,90				
3		0,00	8,20	22,60	13,20	42,50	19,10
		54,40	22,00				

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No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
4		16,90	16,90	20,90	16,90		

Soil parameters - effective stress state

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m^3]
1	Glina		14,00	0,00	19,00
2	Preperina		30,00	10,00	21,00
3	Hribina		32,00	40,00	23,00
4	AB konzola		45,00	100,00	23,00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m^3]	γ_s [kN/m^3]	n [–]
1	Glina		19,00		
2	Preperina		21,00		
3	Hribina		23,00		
4	AB konzola		23,00		

Soil parameters

Glina

Unit weight : γ = 19,00 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 14,00 °
Cohesion of soil : c_{ef} = 0,00 kPa
Saturated unit weight : γ_{sat} = 19,00 kN/m^3

Preperina

Unit weight : γ = 21,00 kN/m^3

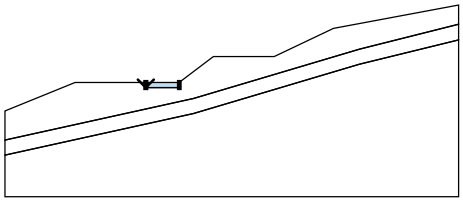
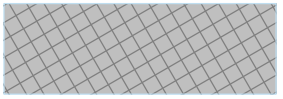
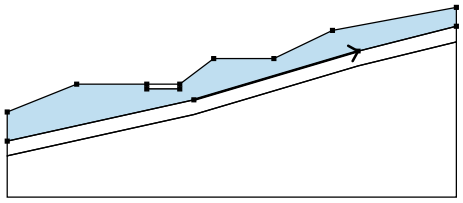
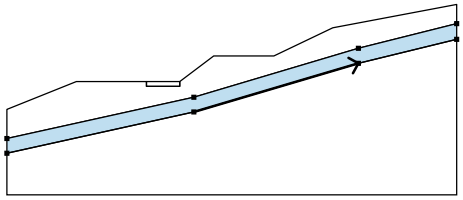
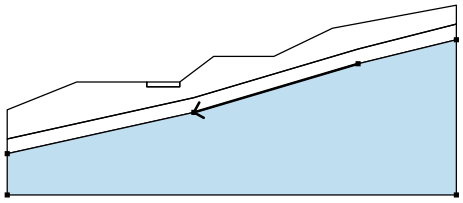
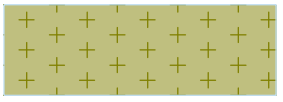
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Stress-state : effective
Angle of internal friction : φ_{ef} = 30,00 °
Cohesion of soil : c_{ef} = 10,00 kPa
Saturated unit weight : γ_{sat} = 21,00 kN/m^3

Hribina
Unit weight : γ = 23,00 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 32,00 °
Cohesion of soil : c_{ef} = 40,00 kPa
Saturated unit weight : γ_{sat} = 23,00 kN/m^3

AB konzola
Unit weight : γ = 23,00 kN/m^3
Stress-state : effective
Angle of internal friction : φ_{ef} = 45,00 °
Cohesion of soil : c_{ef} = 100,00 kPa
Saturated unit weight : γ_{sat} = 23,00 kN/m^3

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		16,90	16,90	16,90	16,30	AB konzola
		20,90	16,30	20,90	16,90	
2		22,60	15,00	42,50	20,90	Glina
		54,40	23,90	54,40	26,20	
		39,40	23,40	32,30	20,00	
		25,00	20,00	20,90	16,90	
		20,90	16,30	16,90	16,30	
		16,90	16,90	8,40	16,90	
		0,00	13,50	0,00	10,00	
3		22,60	13,20	42,50	19,10	Preperina
		54,40	22,00	54,40	23,90	
		42,50	20,90	22,60	15,00	
		0,00	10,00	0,00	8,20	
4		42,50	19,10	22,60	13,20	Hribina
		0,00	8,20	0,00	3,20	
		54,40	3,20	54,40	22,00	

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Anti-Slide piles

No.	Point		Length	Pile spacing	Cross-section	Pile bearing capacity			
	x [m]	z [m]	l [m]	b [m]	[m]	Distribution along the pile	Max. bearing capacity V_u [kN]	Gradient K [–]	Passive force direction
1	17,40	16,90	8,60	1,00	d = 0,50	linear	150,00	0,50	perpendicular to pile
2	18,40	16,90	8,60	1,00	d = 0,50	linear	150,00	0,50	perpendicular to pile

Water

Water type : No water

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)

Analysis 1

Polygonal slip surface

Coordinates of slip surface points [m]									
x	z	x	z	x	z	x	z	x	z
0,30	13,62	3,08	13,24	5,57	13,19	9,89	13,24	13,97	13,66
17,96	14,23	22,84	15,30	45,31	21,78	47,28	22,81	48,88	23,84
49,81	25,34								
Analysis of the slip surface without optimization.									

The forces acting on the pile

Anti-Slide Pile No. 1 (17,40; 16,90 [m])
- Horizontal active force: 157,40 kN/m
- Horizontal passive force: 150,84 kN/m
- Depth of slip surface: 2,75 m
- The length of pile below terrain: 8,60 m

Anti-Slide Pile No. 2 (18,40; 16,90 [m])
- Horizontal active force: 166,74 kN/m
- Horizontal passive force: 160,26 kN/m
- Depth of slip surface: 2,57 m
- The length of pile below terrain: 8,60 m

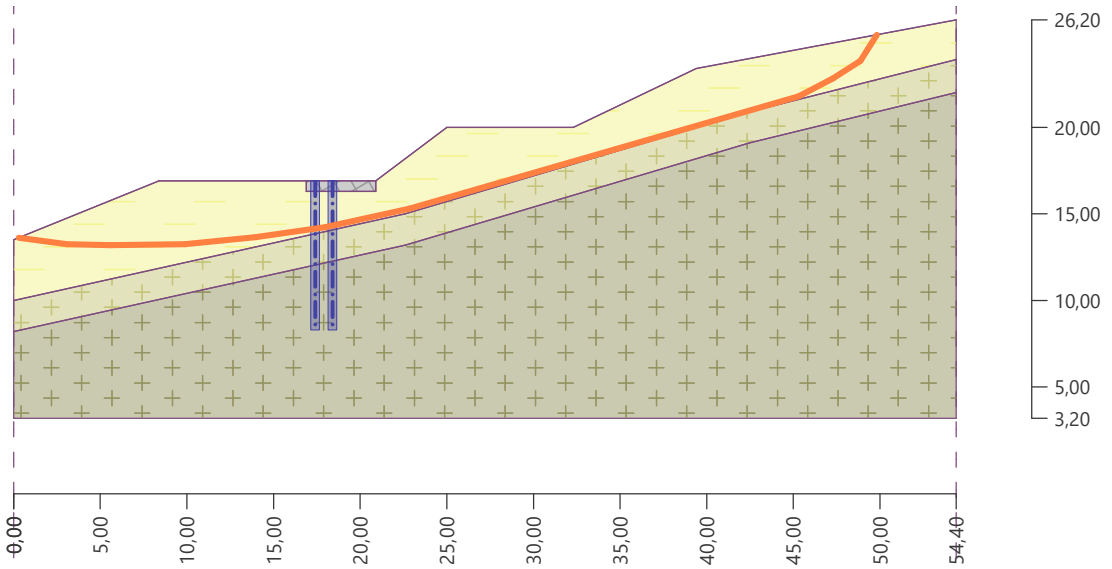
Slope stability verification (Morgenstern-Price)

Utilization : 57,6 %

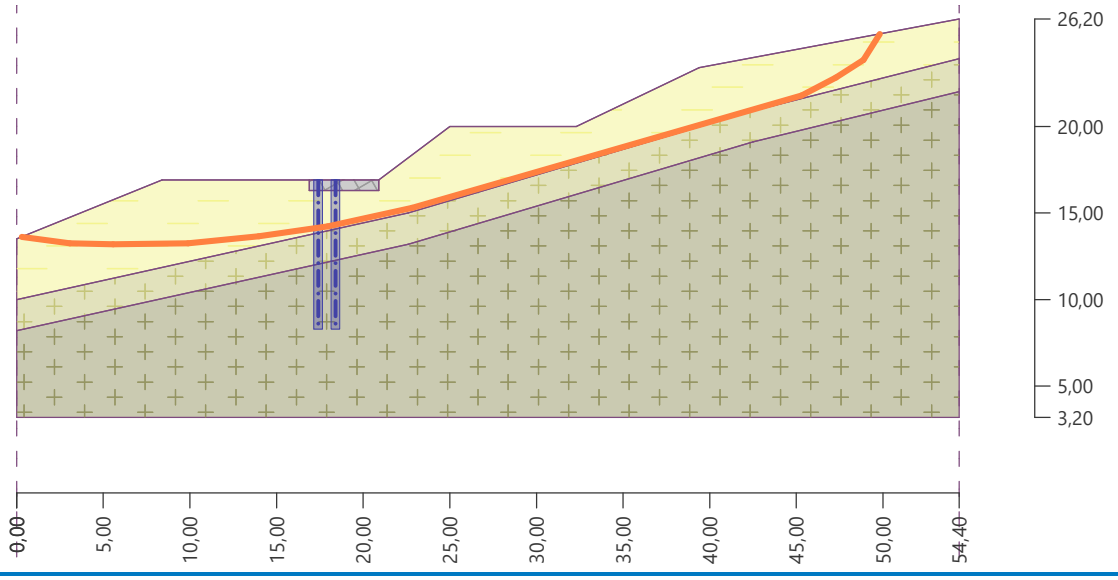
Slope stability ACCEPTABLE

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Name : Analysis | **Stage - analysis : 1 - 1**
Description : Porušnica



Name : Analysis | **Stage - analysis : 1 - 1**
Description : Drsina 1



Piles verification 1

Anti-Slide pile : Anti-Slide Pile No. 1 (17,40; 16,90 [m])
Analysis : Calculation 1 (slip surface polygonal)
Method : Morgenstern-Price

Analysis of anti-slide pile

Input data

Settings

Slovenia - EN 1997 (31)

Materials and standards

Concrete structures :	EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 :	standard
Steel structures :	EN 1993-1-1 (EC3)

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Partial factor on bearing capacity of steel cross section : γ_{M0} = 1,00

Pressure analysis

Active earth pressure calculation : Coulomb
Passive earth pressure calculation : Caquot-Kerisel
Earthquake analysis : Mononobe-Okabe
Modulus of subsoil reaction : standard
Consider reduction of the modulus of subsoil reaction for a braced sheeting
Verification methodology : according to EN 1997
Design approach : 2 - reduction of actions and resistances

Partial factors on actions (A)					
Permanent design situation					
		Unfavourable		Favourable	
Permanent actions :	γ_G =	1,35	[–]	1,00	[–]
Variable actions :	γ_Q =	1,50	[–]	0,00	[–]
Water load :	γ_w =	1,35	[–]		

Partial factors for resistances (R)			
Permanent design situation			
Partial factor on earth resistance :	γ_{Re} =	1,40	[–]

Anchors

Verification methodology : Limit states (LSD)

Reduction coefficients			
Reduction. coeff of steel strength :	γ_s =	1,35	[–]
Reduction coefficient of pull out resistance (soil) :	γ_e =	1,35	[–]
Reduction coefficient of pull out resistance (grouting) :	γ_c =	1,35	[–]

Geometry of structure

Structure length = 8,60 m

Cross-section name : Pile curtain d = 0,50 m; a = 1,00 m
Material of pile : concrete
Computed coefficient of pressure reduction below the ditch = 1,00
Area of cross-section A = 1,96E-01 m^2/m
Moment of inertia I = 3,07E-03 m^4/m
Elastic modulus E = 33000,00 MPa
Shear modulus G = 13750,00 MPa

Forces above the slip surface

Depth of slip surface h_{s1} = 2,75 m

Input of active horizontal force : residual active force
Input of passive horizontal force : residual passive force

Active horizontal force T = 157,40 kN/m
Passive horizontal force P = 150,84 kN/m

Distribution of active force : triangle
Distribution of passive force : triangle

Material of structure

Analysis of concrete structures carried out according to the standard EN 1992-1-1 (EC2).

Concrete : C 30/37
Cylinder compressive strength f_{ck} = 30,00 MPa
Tensile strength f_{ctm} = 2,90 MPa

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Elasticity modulus E_{cm} = 33000,00 MPa
Shear modulus G = 13750,00 MPa

Longitudinal steel : B500
Yield strength f_{yk} = 500,00 MPa

Transverse steel: B500
Yield strength f_{yk} = 500,00 MPa

Modulus of reaction

Modulus of subsoil reaction is computed by method Schmitt.

Basic soil parameters

No.	Name	Pattern	φ_{ef} [°]	c_{ef} [kPa]	γ [kN/m³]	γ_{su} [kN/m³]	δ [°]
1	Glina		14,00	0,00	19,00	9,00	14,00
2	Preperina		30,00	10,00	21,00	11,00	30,00
3	Hribina		32,00	40,00	23,00	13,00	32,00
4	AB konzola		45,00	100,00	23,00	13,00	45,00

Soil parameters to compute pressure at rest

No.	Name	Pattern	Type calculation	φ_{ef} [°]	ν [–]	OCR [–]	K_r [–]
1	Glina		cohesionless	14,00	-	-	-
2	Preperina		cohesive	-	0,25	-	-
3	Hribina		cohesive	-	0,20	-	-
4	AB konzola		cohesive	-	0,16	-	-

Parameters of soils to compute modulus of subsoil reaction (Schmitt)

No.	Name	Pattern	ν [–]	E_{oed} [MPa]	E_{def} [MPa]
1	Glina		0,40	3,00	-
2	Preperina		0,25	15,00	-
3	Hribina		0,20	50,00	-
4	AB konzola		0,16	80,00	-

Soil parameters

Glina
Unit weight : γ = 19,00 kN/m³
Stress-state : effective
Angle of internal friction : φ_{ef} = 14,00 °

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Cohesion of soil :	c_{ef}	=	0,00 kPa
Angle of friction struc.-soil :	δ	=	14,00 °
Soil :	cohesionless		
Oedometric modulus :	E_{oed}	=	3,00 MPa
Saturated unit weight :	γ_{sat}	=	19,00 kN/m^3

Preperina

Unit weight :	γ	=	21,00 kN/m^3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	30,00 °
Cohesion of soil :	c_{ef}	=	10,00 kPa
Angle of friction struc.-soil :	δ	=	30,00 °
Soil :	cohesive		
Poisson's ratio :	ν	=	0,25
Oedometric modulus :	E_{oed}	=	15,00 MPa
Saturated unit weight :	γ_{sat}	=	21,00 kN/m^3

Hribina

Unit weight :	γ	=	23,00 kN/m^3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	32,00 °
Cohesion of soil :	c_{ef}	=	40,00 kPa
Angle of friction struc.-soil :	δ	=	32,00 °
Soil :	cohesive		
Poisson's ratio :	ν	=	0,20
Oedometric modulus :	E_{oed}	=	50,00 MPa
Saturated unit weight :	γ_{sat}	=	23,00 kN/m^3

AB konzola

Unit weight :	γ	=	23,00 kN/m^3
Stress-state :	effective		
Angle of internal friction :	φ_{ef}	=	45,00 °
Cohesion of soil :	c_{ef}	=	100,00 kPa
Angle of friction struc.-soil :	δ	=	45,00 °
Soil :	cohesive		
Poisson's ratio :	ν	=	0,16
Oedometric modulus :	E_{oed}	=	80,00 MPa
Saturated unit weight :	γ_{sat}	=	23,00 kN/m^3

Pile fixed into the rock

Length of wall in the rock l = 3,50 m
Bearing capacity of rock R = 3000,00 kPa

Geological profile and assigned soils

Position information
Terrain elevation = 16,90 m
Geological profile and assigned soils

No.	Thickness of layer t [m]	Depth z [m]	Altitude [m]	Assigned soil	Pattern
1	0,60	0,00 .. 0,60	16,90 .. 16,30	AB konzola	
2	2,40	0,60 .. 3,00	16,30 .. 13,90	Glina	

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No.	Thickness of layer t [m]	Depth z [m]	Altitude [m]	Assigned soil	Pattern
3	1,80	3,00 .. 4,80	13,90 .. 12,10	Preperina	
4	-	4,80 .. ∞	12,10 .. -	Hribina	

Excavation

Soil in front of wall is excavated to a depth of 0,00 m.

Ditch bottom shape

No.	Coordinate x [m]	Depth z [m]
1	0,00	0,01
2	-0,25	0,01
3	-8,75	0,01
4	-17,15	3,40
5	-18,15	3,40

Origin [0,0] is located at the ditch bottom.
Positive coordinate +z has downward direction.

Terrain profile

No.	Coordinate x [m]	Depth z [m]
1	0,00	0,00
2	0,10	0,00
3	3,25	0,00
4	7,35	-3,10
5	14,65	-3,10
6	21,75	-6,50
7	36,75	-9,30
8	37,75	-9,30

Origin [0,0] is located in upper right edge of construction.
Positive coordinate +z has downward direction.

Water influence

Ground water table is located below the structure.

Global settings

Number of FEs to discretize wall = 100
Analysis of depending pressures : reduce according to analysis settings
Minimum dimensioning pressure is considered as $\sigma_{a,min} = 0{,}20\sigma_z$

Settings of the stage of construction

Design situation : permanent

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Analysis results

Pressure above the slip surface

Depth [m]	Passive pressure [kPa]	Active pressure [kPa]
0	0,00	0,00
0,00	0,00	0,00
0,00	0,00	0,00
2,75	109,70	114,47

Distribution of pressures acting on the structure (in front and behind the wall) - above slip surface

Depth [m]	Ta,p [kPa]	Tk,p [kPa]	Tp,p [kPa]	Ta,z [kPa]	Tk,z [kPa]	Tp,z [kPa]
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.00	0.00	0.00	0.02	0.02	0.02
0.60	0.00	0.00	0.00	1.04	1.04	1.04
2.46	0.00	0.00	0.00	4.26	4.26	4.26
2.75	0.00	0.00	0.00	4.77	4.77	4.77

Distribution of pressures acting on the structure (in front and behind the wall) - below the slip surface

Depth [m]	Ta,p [kPa]	Tk,p [kPa]	Tp,p [kPa]	Ta,z [kPa]	Tk,z [kPa]	Tp,z [kPa]
2.75	-15.31	-15.31	-15.31	38.56	41.43	78.79
3.00	-15.85	-15.85	-15.85	41.91	45.03	85.63
3.00	-9.71	-19.72	-266.33	11.88	19.80	267.24
3.29	-11.81	-21.74	-290.36	13.18	21.82	291.27
3.39	-12.55	-22.45	-294.29	13.64	22.53	299.77
3.75	-15.20	-25.00	-308.31	15.28	25.07	330.07
3.92	-16.38	-26.13	-314.56	20.19	26.21	343.60
4.30	-19.19	-28.82	-329.40	31.84	34.81	375.66
4.54	-20.94	-30.50	-338.63	39.09	40.17	395.62
4.68	-21.93	-31.46	-343.91	43.23	43.23	423.86
4.80	-22.84	-32.32	-348.69	46.99	46.99	449.46
4.80	0.00	-24.24	-499.19	19.44	24.30	676.91
5.10	0.00	0.00	-514.89	0.00	0.00	755.97
5.11	Rock	Rock	Rock	Rock	Rock	Rock
6.70	Rock	Rock	Rock	Rock	Rock	Rock
7.23	Rock	Rock	Rock	Rock	Rock	Rock
7.73	Rock	Rock	Rock	Rock	Rock	Rock
8.60	Rock	Rock	Rock	Rock	Rock	Rock

Distributions of the modulus of subsoil reaction and internal forces on the structure

Depth [m]	kh,p [MN/m^3]	kh,z [MN/m^3]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
0.00	0.00	0.00	-1.79	0.00	0.00	0.00
0.01	0.00	0.00	-1.79	0.02	-0.00	0.00
0.43	0.00	0.00	-1.61	0.75	-0.16	0.02
0.86	0.00	0.00	-1.43	1.49	-0.64	0.18
1.29	0.00	0.00	-1.25	2.24	-1.44	0.62
1.72	0.00	0.00	-1.07	2.99	-2.57	1.47
2.15	0.00	0.00	-0.90	3.73	-4.01	2.87

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Depth [m]	kh,p [MN/m3]	kh,z [MN/m3]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
2.58	0.00	0.00	-0.73	4.48	-5.78	4.97
2.75	0.00	0.00	-0.66	4.77	-6.54	5.99
2.75	0.00	1.95	-0.66	24.88	-6.68	6.04
3.01	16.67	0.00	-0.57	-17.31	-11.51	8.55
3.44	16.67	16.67	-0.42	-13.96	-4.61	11.96
3.87	16.67	16.67	-0.30	-9.82	0.47	12.78
4.30	16.67	0.00	-0.20	-0.25	2.78	11.93
4.73	16.67	0.00	-0.12	11.09	0.43	11.07
5.16	83.00	0.00	-0.06	-4.77	3.46	10.27
5.59	83.00	0.00	-0.02	-1.41	4.73	8.46
6.02	0.00	83.00	0.01	0.67	4.85	6.36
6.45	0.00	83.00	0.02	1.78	4.29	4.38
6.88	0.00	83.00	0.03	2.23	3.41	2.72
7.31	0.00	83.00	0.03	2.25	2.44	1.46
7.74	0.00	83.00	0.02	2.05	1.51	0.61
8.17	0.00	83.00	0.02	1.76	0.69	0.14
8.60	0.00	83.00	0.02	1.44	-0.00	0.00

Maximum shear force = 11,51 kN/m
Maximum moment = 12,79 kNm/m
Maximum displacement = 1,8 mm
Displacement in the depth of slip surface = 0,7 mm

Verification of rock bearing capacity

Bearing capacity of rock R = 3000,00 kPa
Partial factor on rock bearing capacity γ_{Rr} = 1,40
Max. stress σ = 9,53 kPa
Design bearing capacity of rock R_d = 2142,86 kPa

Bearing capacity of rock is SATISFACTORY

Terrain settlement behind the structure

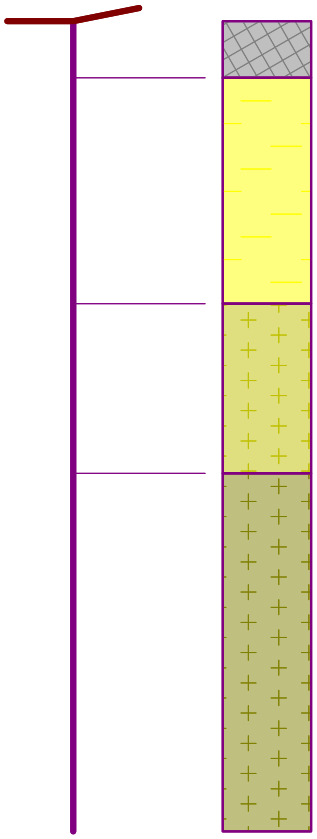
Terrain settlement δ_{max} = 0,7 mm

	Coordinate x [m]	Settlement z [mm]
1	0,00	0,9
2	0,67	1,1
3	1,34	1,2
4	2,01	1,2
5	2,68	1,2
6	3,35	1,1
7	4,02	1,0
8	4,69	0,9
9	5,36	0,6
10	6,03	0,3
11	6,70	0,0
12	6,70	0,0

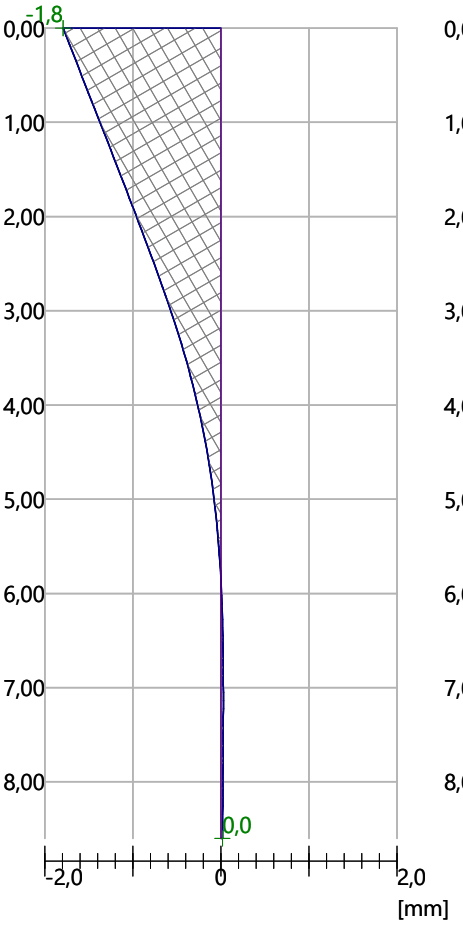
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Name : Analysis	Stage - analysis : 1 - -1

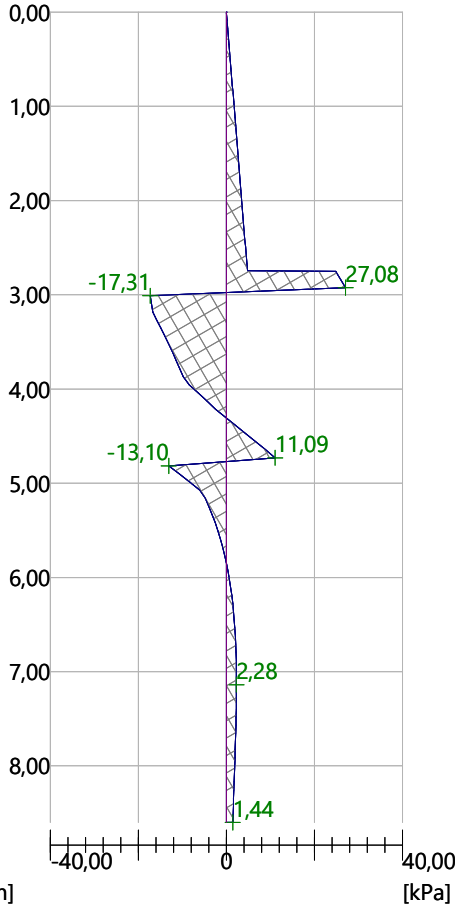
Geometry of structure
Length of structure = 8,60m



Displacement of structure
Max. disp. = 1,8 mm



Pressure acting on structure
Max. pressure = 27,08 kPa



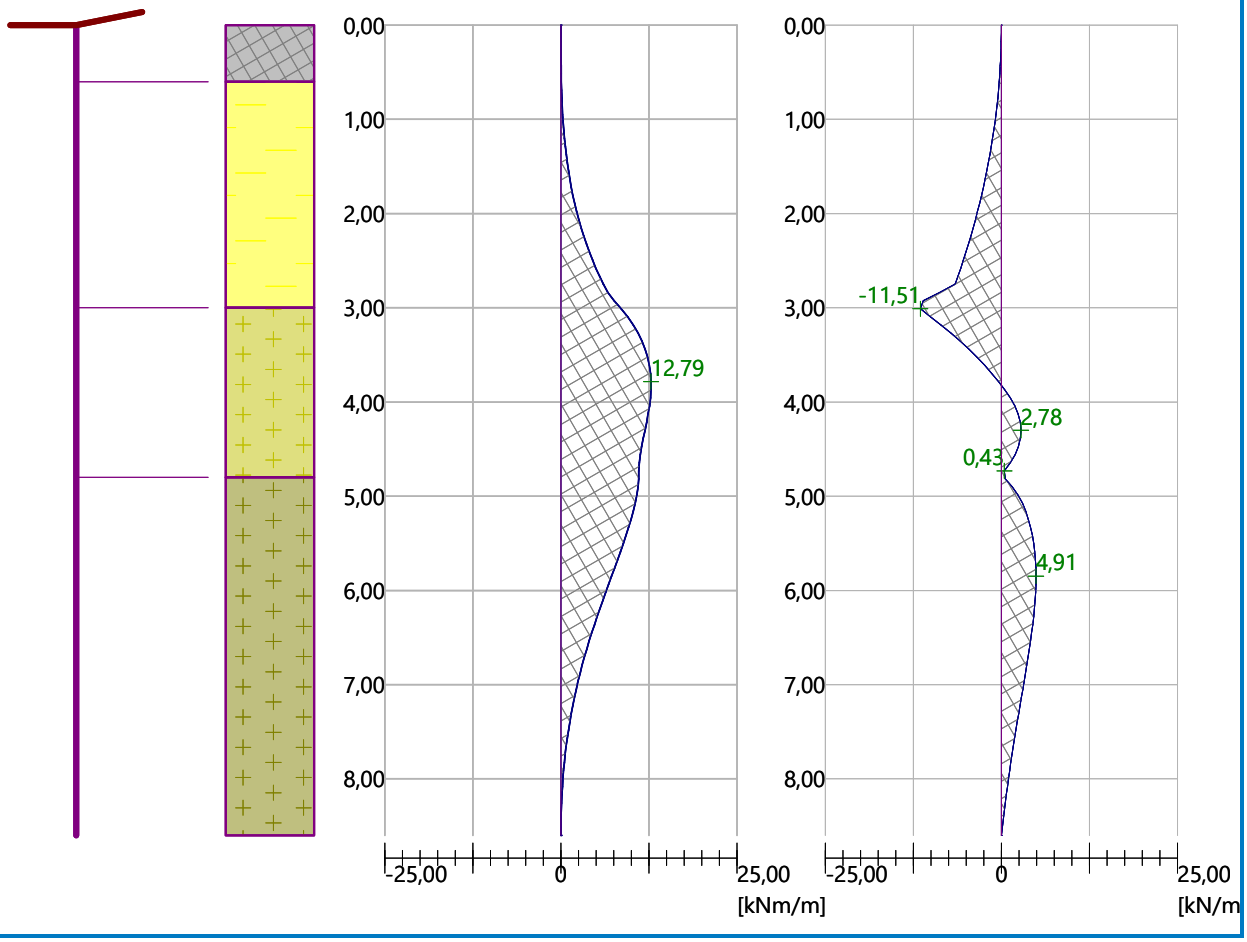
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Name : Analysis	Stage - analysis : 1 - -1

Geometry of structure
Length of structure = 8,60m

Bending moment
Max. M = 12,79 kNm/m

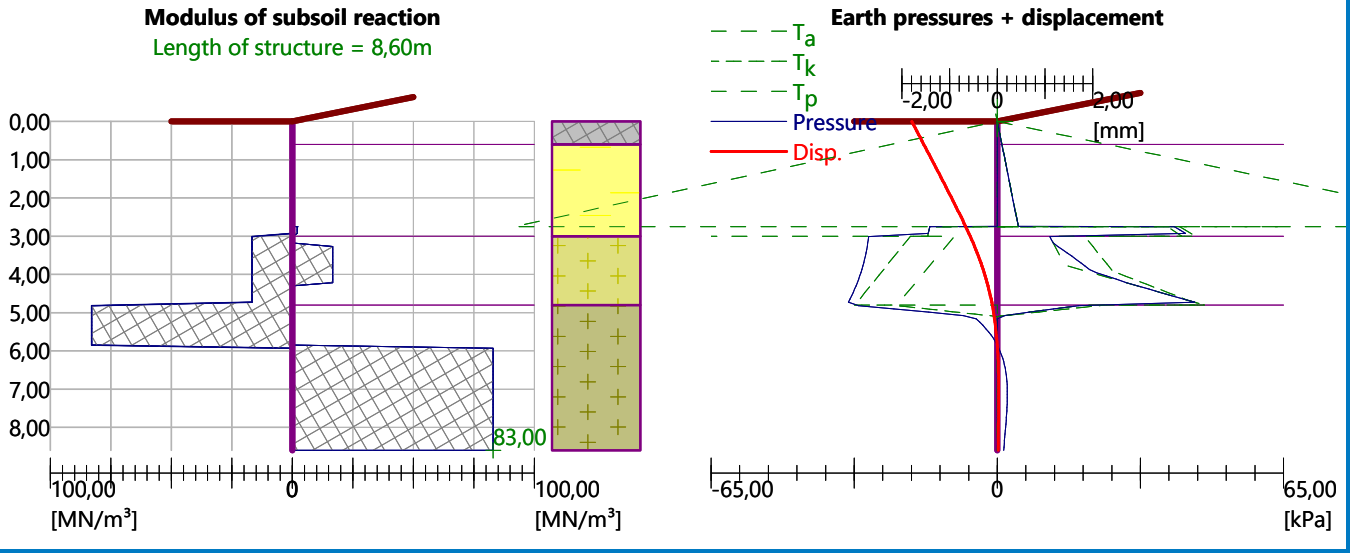
Shear force
Max. Q = 11,51 kN/m



Name : Analysis	Stage - analysis : 1 - -1

Modulus of subsoil reaction
Length of structure = 8,60m

Earth pressures + displacement



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Dimensioning No. 1

	Disp. min [mm]	Disp. max [mm]	Shear force min. [kN/m]	Shear force max [kN/m]	Moment min. [kNm/m]	Moment max. [kNm/m]
0.00	-1.79	-1.79	0.00	0.00	0.00	0.00
0.01	-1.79	-1.79	-0.00	-0.00	0.00	0.00
0.01	-1.79	-1.79	-0.00	-0.00	0.00	0.00
0.43	-1.61	-1.61	-0.16	-0.16	0.02	0.02
0.86	-1.43	-1.43	-0.64	-0.64	0.18	0.18
1.29	-1.25	-1.25	-1.44	-1.44	0.62	0.62
1.72	-1.07	-1.07	-2.57	-2.57	1.47	1.47
2.15	-0.90	-0.90	-4.01	-4.01	2.87	2.87
2.58	-0.73	-0.73	-5.78	-5.78	4.97	4.97
2.75	-0.66	-0.66	-6.54	-6.54	5.99	5.99
2.75	-0.66	-0.66	-6.63	-6.63	6.03	6.03
3.01	-0.57	-0.57	-11.51	-11.51	8.55	8.55
3.44	-0.42	-0.42	-4.61	-4.61	11.96	11.96
3.87	-0.30	-0.30	0.47	0.47	12.78	12.78
4.30	-0.20	-0.20	2.78	2.78	11.93	11.93
4.73	-0.12	-0.12	0.43	0.43	11.07	11.07
5.16	-0.06	-0.06	3.46	3.46	10.27	10.27
5.59	-0.02	-0.02	4.73	4.73	8.46	8.46
6.02	0.01	0.01	4.85	4.85	6.36	6.36
6.45	0.02	0.02	4.29	4.29	4.38	4.38
6.88	0.03	0.03	3.41	3.41	2.72	2.72
7.31	0.03	0.03	2.44	2.44	1.46	1.46
7.74	0.02	0.02	1.51	1.51	0.61	0.61
8.17	0.02	0.02	0.69	0.69	0.14	0.14
8.60	0.02	0.02	-0.00	-0.00	0.00	0.00

Maximum values of internal forces

Maximum displacement = -1,8 mm
Minimum displacement = 0,0 mm
Maximum bending moment = 12,79 kNm/m
Minimum bending moment = 0,00 kNm/m
Maximum shear force = 11,51 kN/m

Verification of RC cross section (Pile curtain d = 0,50 m; a = 1,00 m)

All construction stages are taken into the analysis.
Reduct. coefficient of bearing capacity = 1,00

Verification of cross section in bending:

Reinforcement - 6 pc bars 16,0 mm; cover 50,0 mm
Type of structure (reinforcement ratio) : beam
Reinforcement ratio ρ = 0,307 % > 0,151 % = ρ_{min}
Load : M_{Ed} = 12,79 kNm
Bearing capacity : M_{Rd} = 101,73 kNm
Designed pile reinforcement is SATISFACTORY

Verification of cross section in shear:

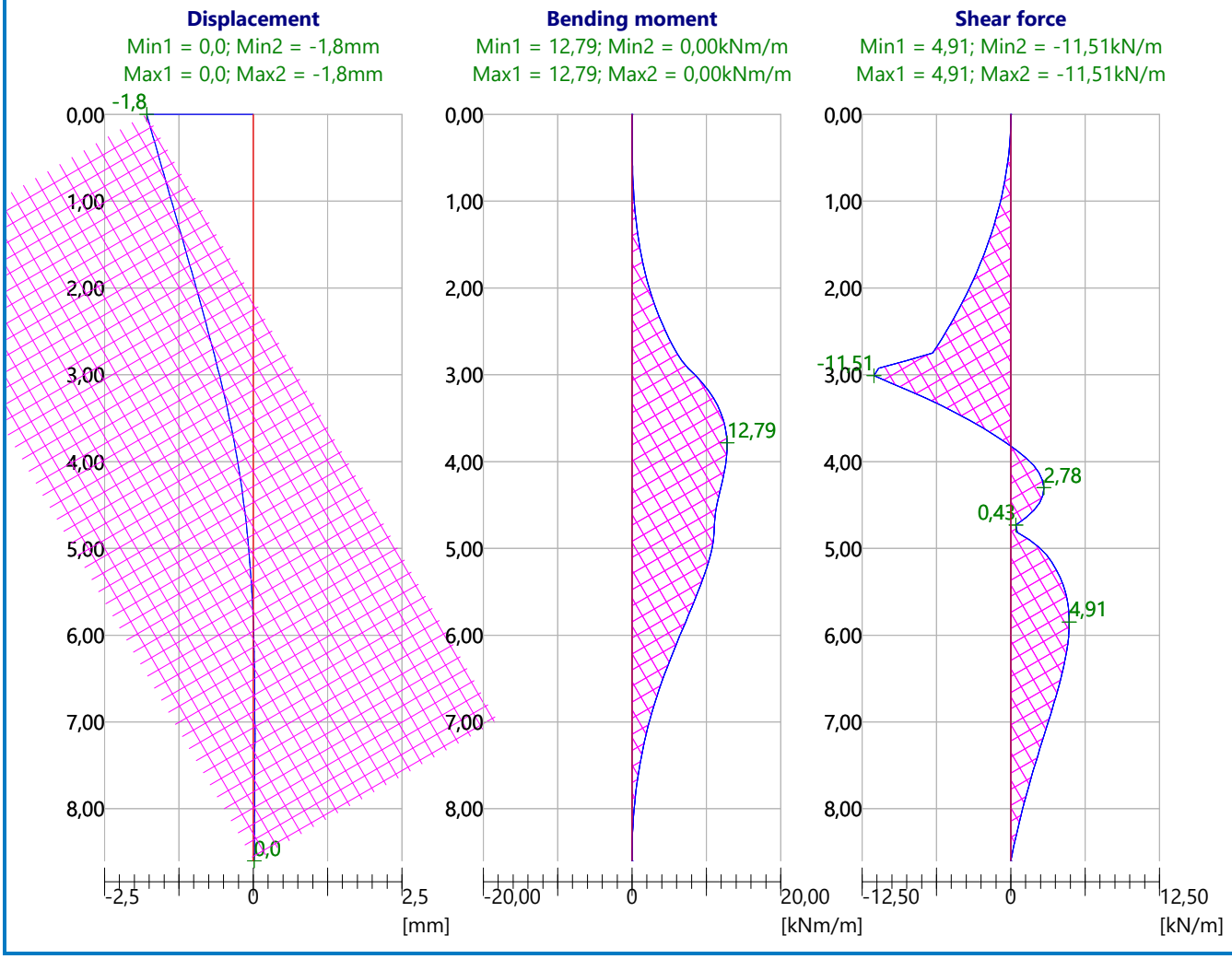
Shear reinf. - 2 profile 10,0 mm; distance 250,0 mm
A_{sw} = 628,3 mm^2
Ultimate shear force: V_{Rd} = 245,86 kN > 11,51 kN = V_{Ed}
Cross-section is SATISFACTORY.

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only minimal shear reinforcement

Overall verification: Cross-section is SATISFACTORY

Name : Dimensioning	Stage - analysis : 1 - 1



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