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### Design of a cantilever wall

Program: Cantilever wall

File: Demo\_manual\_02.guz

This engineering manual describes how to design and analyze a cantilever wall.

### Assignment:

Design a cantilever wall with a height of 4,0 m and analyze it according to EN 1997-1 (EC 7-1, Design approach 1). The terrain behind the structure is horizontal. The ground water table is 2,0 m deep under the surface. Behind the wall acts a strip surcharge with a length of 5,0 meters and a magnitude of 10  $kN/m^2$ . The foundation soil consists of MS – Sandy silt, the allowable bearing capacity is 175 kPa. The soil behind the wall will consist of S-F – Sand with trace of fines. The cantilever wall will be made of reinforced concrete of class C 20/25.



Scheme of the cantilever wall - Assignment

The parameters of the soils are defined as follows:

Soil	Profile [ <i>m</i> ]	Unit weight $\gamma \left[ k N / m^3  ight]$	Angle of internal friction $\varphi_{e\!f} \left[ \circ  ight]$	Cohesion of soil $c_{ef} [kPa]$	Angle of friction structure – soil $\delta = \begin{bmatrix} \circ \end{bmatrix}$	Saturated unit weight $\gamma_{sat} \left[ kN/m^3 \right]$
S-F	0,0-4,0	17,5	28,0	0,0	18,5	18,0
MS	from 4,0	18,0	26,5	30,0	17,5	18,5



#### Solution

To solve this problem, we will use the GEO5 "Cantilever wall" program. In the following text, we will explain the solution step by step.

Firstly, in the frame "Settings" click on "Select settings" and choose analysis setting No. 3 - "Standard – EN 1997 – DA1".

NumberNameValid for1Standard - safety factorsAll2Standard - limit statesAll3Standard - EN 1997 - DA1All4Standard - EN 1997 - DA2All5Standard - EN 1997 - DA3All8Czech republic - old standards CSN (73 1001, 73 1002, 73 0037)All25United Kingdom - EN 1997All26United Kingdom - EN 1997, gamma water = 1.0All32USA - LRFD 2003All33USA - LRFDAll36NCMA - SRW Design ManualAll41LRFD - StandardAll69Switzerland - SIA 260 (267) - STR, GEO - standardAll70Ewitzerland - SIA 260 (267) - STR, FDU - standardAll	Settings lis	t			×
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Dialog window "Settings list"

In the frame "Geometry" choose the 4<sup>th</sup> shape and enter its dimensions as shown in the picture.



Frame "Geometry"



The structure now looks like this:



Frame "Geometry" – scheme of the cantilever wall

In the frame "Material" enter the material of the wall. The wall will have a unit weight of  $\gamma = 25 \text{ kN/m}^3$  and it will be made from concrete of class C 20/25 and steel of class B500.

Unit weight of wall : $\gamma = 25,00$ [kN/m <sup>3</sup> ]							
- Concrete	- Longitudinal reinforcement						
<u>C</u> atalog <u>U</u> ser def.	C <u>a</u> talog	U <u>s</u> er def.					
C 20/25 f <sub>ck</sub> = 20,00 MPa f <sub>ctm</sub> = 2,20 MPa	<b>B500</b> f <sub>yk</sub> = 500,00 MPa						

Frame "Material" – Input of material characteristics of the structure



In the frame "Profile", we define the soil interference at a depth of 4 m using the "Add" button.

Interf. #	Depth [m]		<b>+</b> E	Add 🗄	Terrain elevation	:	[m]
> 1		0,00					
				New in	terface	×	
				Coord	nate : Z =	4,00 [m]	
					🕂 Add	X Cancel	
				L			



Then, we will move to the frame "Soils". Here, we will define the parameters of the soils, as shown in the following pictures, by clicking the button "Add". Firstly, we will add the S-F soil, which will be behind the wall. Next, we will add the MS soil, which will form the foundation.

Add new soils		×
Identification		Color
Basic data     Unit weight :     Stress-state :     Angle of internal friction :     Cohesion of soil :     Angle of friction strucsoil :	$\gamma = 17,50 \ [kN/m^3]$ effective $\bullet$ $\phi_{ef} = 28,00 \ [°]$ $c_{ef} = 0,00 \ [kPa]$ $\delta = 18.50 \ [°]$	Pattern category GEO  Pattern Sandy silt
Pressure at rest	?	-
Soil :	cohesionless	
- Uplift pressure Calc. mode of uplift : Saturated unit weight :	standard     ▼       γ <sub>sat</sub> =     18,00     [kN/m³]	Classification Classify Clear Clear Add X Cancel

Dialog window "Add new soils" - adding soil S-F



Dialog window "Add new soils" – adding soil MS

Note: The magnitude of the active pressure also depends on the friction between the structure and the soil. The friction angle depends on the material of the structure and the angle of internal soil friction – normally entered in the interval  $\delta \approx \left(\frac{1}{3} \div \frac{2}{3}\right) \cdot \varphi_{ef}$ 



We assign the soils to the geological layers in the frame "Assignment".



Frame "Assignment"

In the frame "Terrain" choose the horizontal terrain shape.

β=0	Depth of terrain below the top of wall : h =	0,00 [m]	

Frame "Terrain"

The ground water table is in a depth of 2,0 meters. Therefore, we will move on to the frame "Water" and select the type of water close to the structure and its parameters, as shown in the picture below.

	i i i			
h <sub>4</sub>	<ul> <li>Ground water table (GWT) par</li> </ul>	ameters —		
	GWT behind construction :	h1 =	2,00	[m]
	GWT in front of construction :	h <sub>2</sub> =		[m]
	Uplift at footing bottom due to d	iff. GWTs :	not considered	•
	Tensile crack			
	Depth of tensile crack :	h <sub>t</sub> =		[m]

Frame "Water"

Then, move on to the frame "Surcharge". Here, select permanent strip surcharge with a magnitude of 10  $kN/m^3$  acting as a dead load on the terrain.

New surcharge				>	<
Name: L1					
- Surcharge proper	rties				_
Type :		Strip			
Type of action :		permanent		•	
Location :		on terrain			
Origin :	x =	0,00	[m]		
Length :	=	5,00	[m]		
— Surcharge magnit	tude				_
Magnitude :	q =	10,00	[kN/m²]		
				🕂 Add 🗙 Cancel	

Dialog window "New surcharge"

In the frame "FF resistance" select the terrain shape in front of the wall and then define other parameters of the resistance on the front face.

1	× -	Parameters of resistance	on front face
		Resistance type : Soil :	not considered  MS
FF resistance	<del>,,,,,,,</del> ,	Thickness :	h = 1,00 [m]

Frame "FF resistance"

Note: In this case, we do not consider the resistance on the front face, so the results will be conservative. The FF resistance depends on the quality of the soil and the allowable displacement of the structure. We can consider the pressure at rest for the original soil, or well compacted soil. It is only possible to consider passive pressure if displacement of the structure is allowed. (for more information, see HELP – F1)

Then, in the frame "Stage settings" choose the type of the design situation. In this case, it will be permanent. Also choose the pressure acting on the wall. In our case, we will choose active pressure because the wall can move.

1	Design situation :	permanent 💌
	Pressure acting on the wall :	the wall can deflect (active pressure)
	Pressure acting on the stem :	pressure at rest
Stage settings		

Frame "Stage settings"

Note: A wall stem is usually dimensioned on earth pressure at rest, i.e., the wall can't be moved. The possibility of evaluating the stem and the wall for active pressure is considered only in exceptional circumstances - such as the effects of an earthquake (seismic design situation with partial coefficient equal to 1.0).



Now our task looks as follows:



#### Analyzed structure

Now, open the frame "Verification", where you can analyze the results for overturning and slip of the cantilever wall.

' Ve	erificati	on : 🛨 📄 [1]									🕵 In detail
	No.	Force	Fx	Fz	Applicati	on point	Minor		- Verification -		
0	of force		[kN/m]	[kN/m]	x [m]	z [m]	load		OVERTURNING :	SATISFACTORY	(52,7%)
	1	Weight - wall	0,00	61,00	0,87	-1,38			SLIP:	NOT OK.	(124,5%)
	2	Weight - earth wedge	0,00	23,55	1,31	-1,54					
	3	Active pressure	-42,28	60,25	1,80	-1,46					
e 🗌	4	Water pressure	-20,00	0,00	0,80	-0,67					
atio	5	Uplift pressure	0,00	0,00	0,80	-4,00					
rifi 🗌	6	L1	-7,99	8,67	1,61	-2,08		_			
s –											

#### Frame "Verification"

Note: The "In detail" button in the right section of the screen opens a dialog window with detailed information about the analysis results.



#### Analysis results:

The verification of the slip is not satisfactory. The utilization of the structure is:

_	Overturning: 52,7 %	$M_{res} = 208,17 > M_{ovr} = 109,75$	[kNm/m]	SATISFACTORY
_	Slip: 124,5 %	$H_{res} = 65,74 < H_{act} = 81,83$	[kN/m]	ΝΟΤΟΚ

Now we have several possibilities how to improve the design. For example, we can:

- Use a soil with better characteristics behind the wall
- Anchor the base
- Increase the friction by bowing the footing bottom
- Anchor the stem

These changes would be economically and technologically demanding, so we will instead choose the easiest alternative. The most efficient way to deal with this in the design phase is to change the shape of the wall and introduce a wall jump.

Changing the design: change the shape and the geometry of the wall

Return to the frame "Geometry" and change the shape of the cantilever wall. To increase the resistance against a slip, we will introduce a base jump. Change the shape of the wall and the values of  $x_1$  and  $x_2$  as shown in the picture.

'	L L .	<b>_</b>		-	Ŀ	Д	$\square$	, _	ļ	<u>]</u> >
	. <b>k</b> .	— Wall geon	netry							
		k =	0,40	[m]	v <sub>1</sub> =	0,40	[m]	s <sub>1</sub> = [		[-]
	s <sub>2</sub> :1	h =	3,60	[m]	v <sub>2</sub> =	1,70	[m]	s <sub>2</sub> = [	0,00	[-]
	" v <sub>1</sub> v <sub>2</sub>	h1 =		[m]	v3 =		[m]	Shank	0,40	[m]
	xxi i	h2 =		[m]	x <sub>1</sub> =	0,80	[m]	x3 = [	0,00	[m]
	x2  x3	xx =	0,40	[m]	x <sub>2</sub> =	0,40	[m]			
		z <sub>1</sub> =		[m]	k1 =		[m]			
Geometry		z <sub>2</sub> =		[m]						

Frame "Geometry" (Changing the dimensions of the cantilever wall)

Note: A base jump is usually analyzed as an inclined footing bottom. If the influence of the base jump is evaluated as front face resistance, the program analyzes it with a straight footing bottom, but FF resistance of the construction is analyzed to the depth of the bottom part of the base jump (More info in HELP – F1)



### New shape of the structure

Then analyze the newly designed structure for overturning and slip.

Verification : 🛨 📄 [1]										
No.	Force	Fx	Fz	Applicati	on point	Minor		— Verification —		
of for	e	[kN/m]	[kN/m]	x [m]	z [m]	load		OVERTURNING :	SATISFACTORY	(49,4%)
	Weight - wall	0,00	65,00	0,95	-1,28			SLIP:	SATISFACTORY	(64,9%)
2	Weight - earth wedge	0,00	23,55	1,31	-1,54					
3	Active pressure	-42,28	60,25	1,80	-1,46					
4	Water pressure	-28,80	0,00	0,80	-0,40					
5	Uplift pressure	0,00	0,00	0,80	-4,00					
6	L1	-7,99	9,06	1,65	-2,08					

Frame "Verification"

Now, the overturning and slip of the wall are both satisfactory (Utilization: 49.4 % and 64.9%)



Then, in the frame "Bearing capacity", perform an analysis for design bearing capacity of the foundation soil - 175 kPa.

<ul> <li>Calculation of bearing capacity of foundation</li> <li>Input bearing capacity of foundation soi</li> <li>Analyze bearing capacity by program Sp</li> </ul>	In detail Verification ECCENTRICITY: SATISFACTORY (67,39)			
<ul> <li>Do not calculate</li> </ul>		FOUNDATION SOIL:	SATISFACTORY	(80,2%)
Stress in the footing bottom : recta	ngle 🔻			
Bearing capacity of found. soil : $R =$	175,00 [kPa]			
Overall length of wall foundation :	[m]			
남 Launch program Spread Footing				

Frame "Bearing capacity"

Note: In this case, we analyze the bearing capacity of the foundation soil as an input value, which we can get from a geological survey, or from some standards. These values are usually highly conservative, so it is generally better to analyze the bearing capacity of the foundation soil in the "Spread footing" program, which takes other influences such as the inclination of the load, the depth of the foundation etc. into account.

Next, in the frame "Dimensioning", we will do a wall stem check. Design the main reinforcement into the stem – 10 pcs.  $\emptyset$  12 mm, which satisfies all the design principles.

- Location of dimensioning							
Wall stem check	•						
— Data for dimensioning —							
Reinforcement cover :	30,0 [mm]	Number of bars :	10,00 [pcs]				
Cross-section width :	1,00 [m]	Bar diameter :	12,0 [mm]				
Required amount of steel area : 958,5 mm <sup>2</sup>							
Required amount of st	eel area :	958,	5 mm <sup>2</sup>				
Required amount of st Inserted steel area :	eel area :	958, 1131,	5 mm <sup>2</sup> 0 mm <sup>2</sup>				
Required amount of st Inserted steel area : — Wall stem check —	eel area :	958, 1131,	5 mm <sup>2</sup> 0 mm <sup>2</sup>				
Required amount of st Inserted steel area : — Wall stem check — SHEAR:	eel area : SATISFACTO	958, 1131,/ RY (80,4%)	5 mm <sup>2</sup> 0 mm <sup>2</sup>				
Required amount of st Inserted steel area : — Wall stem check — SHEAR: FLEXURE :	eel area : SATISFACTO SATISFACTO	958, 1131, RY (80,4%) RY (85,4%)	5 mm <sup>2</sup> 0 mm <sup>2</sup>				

Frame "Dimensioning"



Then, go to frame "Stability", where we will analyze the overall stability of the wall. This will open the "Slope stability" program, where we will move on to frame "Analysis". In our case, we will use the "Bishop" method, which has conservative results. Perform the analysis with **optimization of circular slip surface**, click "Analyze" to perform the calculations and when the calculation is complete, leave the program by clicking "Exit and save". The results will be imported to the analysis report in the "Cantilever wall" program.

Analysis :			
	Slip surface : circular 🔻 🖉 🔗 Re	place graphically	Convert to polygon
	<ul> <li>Parameters of the analysis</li> </ul>	Circular slip surface	Slope stability verification (Bishop)
Analyze	Method : Bishop 💌	Center : x = -0,60 [m] z =	0,76 [m] Sum of active forces : F <sub>a</sub> = 155,02 kN/m Sum of passive forces : F <sub>p</sub> = 393,36 kN/m
	Analysis type : Optimization	Radius : R = 5,66 [m]	Sliding moment : Ma = 877,41 kNm/m
			Resisting moment : Mp = 2226,44 kNm/m
	Restrictions is not input	Angles : $\alpha_1 = -48,37$ [°] $\alpha_2 =$	82,28 [°] Utilization : 39,4 %
			Slope stability ACCEPTABLE

"Slope stability" program – frame "Analysis"

#### Conclusion:

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Result of the analysis:

Overturning: 49,4 %	$M_{res} = 218,35 > M_{ovr} = 107,94$	[kNm/m]	SATISFACTORY
Slip: 64,9 %	$H_{res} = 99,26 > H_{act} = 64,38$	[kN/m]	SATISFACTORY
Bearing capacity: 80,2 %	$R_d = 175 > \sigma = 140,31$	[kPa]	SATISFACTORY
Wall stem check: 85,4 %	$M_{Rd} = 169,92 > M_{Ed} = 145,18$	[kNm] S	ATISFACTORY
Overall stability: 39,4 %	Method – Bishop (optimizatio	n)	SATISFACTORY

This cantilever wall is SATISFACTORY.