

Stabilization of the Nyköping's riverbank with micropile-walls

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ABSTRACT: Along the Nyköping River (100 km south of Stockholm), the slope of the northern riverbank indicated a potential sliding failure – especially around the area called “Åkroken” which is planned to become a new residential area. The cross section of “Åkroken” shows a steep slope (~ 20%) with heavy surcharge loads on top due to the building plans. The geology consists of approx. 1 m upper filling material “rich” on archaeological findings from medieval times (12th century). Beneath the filling there is approx. 7-9 m silty-clayey layer over the bedrock. This slope is supported with masonry gravity walls founded into the river bed. However, these walls showed clear signs of instability since the wall was tilting towards the river. As a prevention measure, the city council cordoned off the area. ÅF Consult was committed to assess the stability of the slope and design safety measures to both be able to renovate the masonry walls and increase the factor of safety for the entire fringe.

As a remediation measure a micropile-wall was recommended to prevent the effects of a landslide failure in the Nyköping River. The micro-pile wall's main functions was to avoid further displacements during the renovation of the old masonry walls, and later on to work as a permanent structure. The micropile-wall was designed for 100 years life-span according to Swedish Standards. Bored micropiles, Ruukki RD 170/12.5 mm, were installed c/c 1 m and filled with concrete. Tieback anchors, Ischebeck TITAN 73/53, were installed c/c 2.5 m with a 45 degrees inclination and embedded in rock. Numerical analysis (PLAXIS and Geostudio) were utilized to assess the slope stability and estimate the range of displacements during the construction of the micropile walls. Geotechnical investigations estimated the material properties for the calculations.

INTRODUCTION

This paper is prepared as part of the 13th International Workshop on Micropiles. The topic of this work focuses on the slope stabilization of a riverbank applying micropile-walls and tieback anchors.

The site was located along the Nyköping River (100 km south of Stockholm, Sweden) where the slope of the northern riverbank indicated a potential sliding failure – especially around the area called “Åkroken” which is planned to become a new residential area. The cross section of “Åkroken” shows a steep slope (~ 20%) with heavy surcharge loads on top due to the building plans. The geology consists of approx. 1 m upper filling material “rich” on archaeological findings from medieval times (12th century). Beneath the filling there is approx. 7-9 m of silt and silty-clayey layers over the bedrock. This slope is supported with masonry gravity walls founded into the river bed. However, these walls showed clear signs of instability since the wall was tilting towards the river. As a prevention measure, the city council cordoned off the area (See Figure 1). ÅF Consult was committed to assess the stability of the slope and design safety measures to both be able to renovate the masonry walls and increase the factor of safety on the entire fringe.

In general, methods to prevent slides on slopes can vary from case to case. Commonly known methods are: soil reinforcement, retaining structures, geometric improvements, re-vegetation, drainage or counterweight masses. In this particular case, apart from the common geotechnical uncertainties e.g., spatial variability [1] the design was limited by other factors, such as: archaeological findings, urban planning, existing buildings and the presence of a river regulated by a hydropower plant. Furthermore, it was necessary to repair the existing masonry wall and remove the trees that were slowly falling down. With these circumstances a soil reinforcement with micropile-walls seemed to fit the best to cope with these limitations. In this paper are described the analyses of the information for the instability failure mode, the design method for the retaining structure and the details of the final design of the remediation measures.



Figure 1 Slope instability signs on the masonry walls (Source: Nyköping City Council)

ANALYSIS OF THE INFORMATION FOR THE INSTABILITY FAILURE MODE

When ÅF Consult was committed to assess the slope stability the first task was to analyse the geotechnical conditions of the soils. Thus, based on the field test investigations (CPT, samples, piezometers, lab results) it was created a limit equilibrium model with the software Slope/W. The model showed critical safety factors slightly higher than 1, see Figure 2. Another aspect was the unfavorable inclination ($\sim 20\%$) of the soil layers to slide into the river, this was considered with the grid and radius method in Slope/W inclining also the radius lines of the slip surfaces [3]. Some of the characteristics of the methodology are included in Table 1.

Table 1 Characteristics of slope instability limit models

Limit equilibrium method	Soil failure mode	Pore-water pressure	Search slips method	Failure surface
Morgenstern-Price	Mohr-Coulomb Undrained and Combined	Manual piezometric line with automatic correction	Grid and radius considering 20% slope	Circular slip

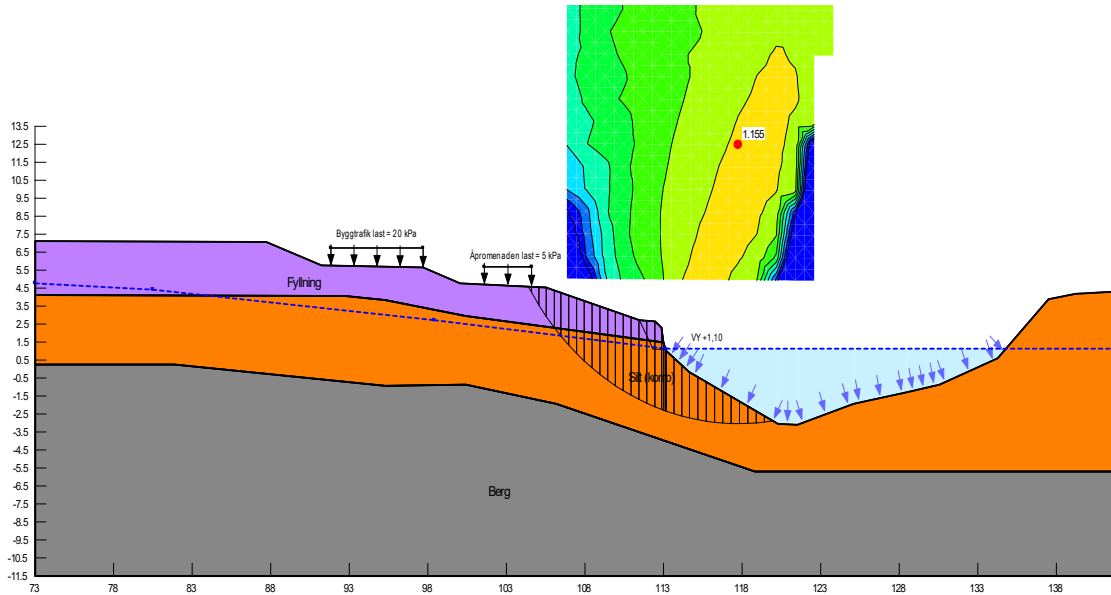


Figure 2 Critical slope stability 1.15. It was required a $SF_{combined} > 1.45$

Introduction of remediation measures in the model

As a remediation measure for the unstable condition of the slope we recommended to build micropile-walls and tieback anchors embedded into the rock. These structural elements were included in the Slope/W model increasing the resisting forces of the anchors and micropile-wall until the required SF was fulfilled in each case.

DESIGN OF MICROPILE-WALLS AND TIEBACK ANCHORS

The retaining system was designed according to Swedish standards [8], [9], [10], [11] and [12] for a 100 years lifespan. The design considered two approaches. At first, an Ultimate Limit State (ULS) design was performed considering multiple variables, such as: construction plans, heavy spread loads, water and groundwater levels and reduction of effective steel sections due to oxidation. This approach was applied analytically including partial safety factors in the calculations. The other design approach consisted of a Serviceability Limit State (SLS) to analyse the stability and deformations during construction. There were considered 5 construction stages: 1) Installation of micropiles, 2) Excavation up to wale beam and tieback level, 3) Pre-stressing of the anchors at 220 kN, 4) Excavation and renovation of masonry walls, 5) Filling up the excavation to the original ground level. The soil and structural properties are included in Table 2 and Table 3 according to the soil investigations and [6] and [7].

Table 2 Soil properties, characteristic values

Material	Unit weight	Friction angle	Undrained Shear strength	Effectiv. cohesion	E-modulus	Poisson ratio
Symbol	γ	ϕ'	C_u	c'	E	$\nu (nu)$
Units	[kN/m ³]	[°]	[kPa]	[kPa]	[MPa]	-
Filling	18	34	---	---	15	0.2
Silt/Silty Clay	16	27	30	3	10 (Undr 7.5)	0.2
Bedrock	26	-	-	-	50000	0.2

Table 3 Structural properties, micropiles and tieback anchors

Material	EA	EI	Unit weight	Diameter	c/c
Units	[kN/m]	[kN m ² /m]	[kN/m ³]	[m]	[m]
Micropile RD 170/12,5	912067 ⁽¹⁾	2672 ⁽¹⁾	78.4	0.16	1
Grouted rock anchor	55528	35	24	0.10	2.5
Soil anchor Titan 73/53	299000	143	51.2	0.073	2.5

⁽¹⁾Reduction of 3 mm corrosion.

Ultimate and Serviceability Limit States

This design approach checked that the dimensions of the retaining system in the ULS calculations would not experience excessive deformations neither slope instability during the construction. The results of slope instability and displacements analyses for each construction stage are shown in Table 4. In the first stage, the results showed that the SF of the slope might be lower than 1 due to the heavy loading from the pile driving machines. However, the expected deformations were small. In the second stage, the slope stability raised to 1.14. The horizontal deformations remained small and towards the river until the anchors were pre-stressed in stage 3. At stage 5 the slope stability reached SF=1.3, and the maximum horizontal deformations were expected towards the backfill of the micropile-wall. Thus, the existing masonry walls could be repaired with minimum risk. Furthermore, it was possible to visualise other potential failure modes at each construction stage, e.g., heave at the bottom of the excavation due to unloading conditions, and therefore perform complementary calculations to avoid failure (See Figure 3).

Table 4 Compilation of safety factors and maximum displacements (mm)

Section BB SLS	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Safety Factor	0.89	1.14	1.18	1.18	1.27
Horizontal Displacement:					
(+) To Nyköping river	+3.6	+5.9	(-11.1)	(-11.1)	(-12.1)
(-) To Kv. Åkroken					

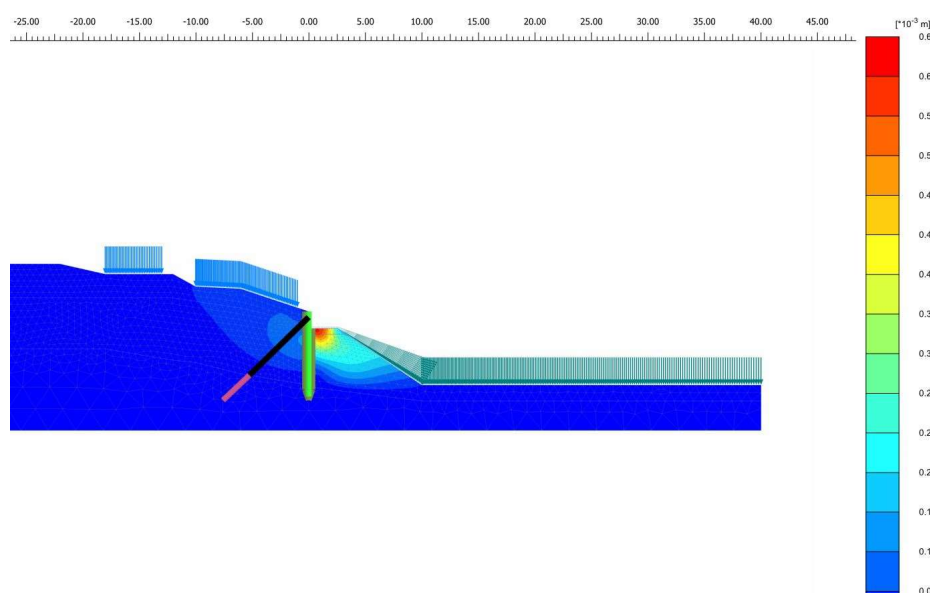


Figure 3 Potential failure mode due to heave at stage 4

FINAL DESIGN OF THE REMEDIATION MEASURES

The dimensioning process provided a retaining system consisting of bored micropiles, Ruukki RD 170/12.5 mm, installed c/c 1 m and filled with concrete and welding steel plates in between micropiles spacing. Tieback anchors, Ischebeck TITAN 73/53 shall be installed c/c 2.5 m with a 45 degrees inclination and embedded in rock. More details of the design can be seen in Figure 4.

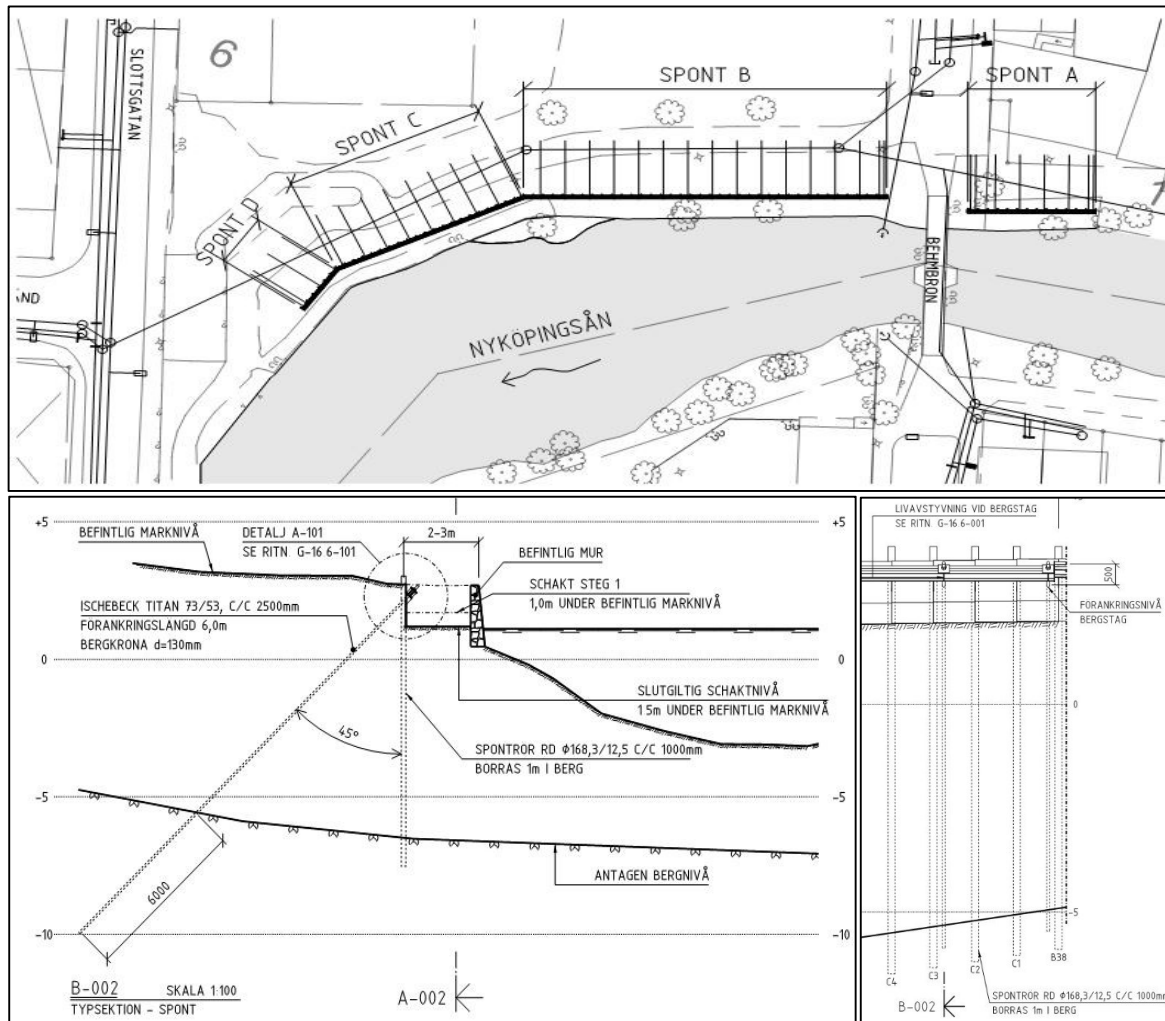


Figure 4 Plan view (top), cross section micropile-wall (bottom-left), profile (bottom-right)

DISCUSSION AND CONCLUSION

Regarding the analyses of the information for instability failure models, the results agreed with other studies performed in the same area. However, if unsaturated conditions were considered the results might have provided higher safety factors, perhaps more realistic [2], [3], [4] and [5]. Although, that assumption would have required further soil investigations [5] and still might overestimate the unsaturated shear strength [3].

The SLS approach using a FE-model provided an estimation of safety factors and deformations for each construction stage. This model assumed 10 kPa surcharge in a bigger extension than in practice. Thus, this 2D model was probably too conservative. However, this assumption remained on the safety side and it followed design standards. Therefore, it was recommended a restriction in surcharge loads adjacent to the masonry wall due to instability/low factor of safety against failure. In order to use the relatively light pile type and installation method, the Contractor could use light machinery or work from a safety distance to the wall. Furthermore, it was recommended to increase the resistance of the micropile-wall by filling each micropile with concrete.

The methodology presented here showed how micropile-walls with tieback anchors were designed to remediate a particular slope instability case. This remediation with micropile-walls fitted the best in “Åkroken” because it allowed access to renovate the masonry walls in safe and dry working conditions with minimum disturbance to the river and existing buildings.

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