STATIC CALCULATION OF STABILIZATION OF THE LANDSLIDE IN CUT 4 FROM km 878+650 TO km 879+050

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Summary: *The paper presents retaining structure to stabilize the landslide in the middle section from 878+775 to km 878+825, and slope protection on both left and right sides in order to provide vertical cutting and excavation to the level of highway platform. Retaining structure was designed as micro-pile wall with three different types of walls depending on the pile position. Micro-pile is made from steel pipe dia. Ø139.6 mm and 8.8mm thick wall, which is filled with cement mortar of minimum strength 30 MPa. In a constructive view, the designed retaining structure is a plate that is resting on the continual tie beams, which are supported in discrete points by geotechnical anchors. Calculation of stability and bearing capacity of protective structure was carried out in several phases. Phases are modeled according to the technology of execution of works. The calculation was performed in FEM program called Plaxis 2D. This calculation is based on the finite element method, using an incremental, iterative process. Based on the performed analysis, calculation of stability and bearing capacity, it can beconcluded that designed support structure satisfies all the necessary conditions of stability and bearing capacity.*

Keywords: *Retaining structure, micro-piles, Plaxis 2D*

1. INTRODUCTION

The design for building permit for landslide stabilization in the area of cut 4 was created by Faculty of Civil Engineering, University of Belgrade [1]. Input data used in calculations were the soil parameters from geotechnical study based on investigation works and additional investigation works. This study was developed by Institute of Transportation CIP [2]. Since the soil layers consist of degraded rock, the parameters for layers were obtained by analogy using Mohr-Coulomb and Hoek-Brown model. After above mentioned study, Faculty of Civil Engineering University of Belgrade made

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additional analyzes and interpretations of existing investigation works previously done by Institute of Transportation CIP [3]. These analyzes were performed as control verification for adopted values of the deformability parameters for purpose of making design for building permit.
During the execution of the works, significant differences between designed and real geotechnical conditions on site were noticed. As a result of these significant differences from the previous Design for Civil Permit, further Design for Execution was developed.

2. PROTECTIVE STRUCTURE

This design analyses retaining structure to stabilize the landslide in the middle section from 878+775 to km 878+825, and slope protection on both left and right sides in order to provide vertical cutting and excavation to the level of highway platform. Retaining structure was designed as micro-pile wall with three different types of walls depending on the pile position, anchors and tie beam.
Micro-pile is made from steel pipe dia. Ø139.6 mm and 8.8 mm thick wall, which is filled with cement mortar of minimum strength 30 MPa. On the top of the piles there is a pile cap beam which connects the piles and provides overall structure to work as a whole. Micro-pile front facing is designed to be covered in two layers of 5 cm of shotcrete with polypropylene fibers.
Horizontal tie beams are designed in longitudinal direction on equal vertical spacing. There are two types of tie beams. The first type is made from two steel UPN240 profiles which are concreted after installation with concrete grade C25/30. In this way, a continuous beam with composite cross-section is formed. The second type is classical RC beam. During the execution and drilling of micro-piles, deviation of micro-pile may occur and cause problems to installation of the horizontal tie beams. It is very important to perform continuing of reinforcement by welding UPN profiles or by overlapping the reinforcement bars. As the result, the design proposes two types of horizontal beams so that the Contractor can use the one more adequate to the real situation on site. Figure 1 presents plan and longitudinad section of tie beam.

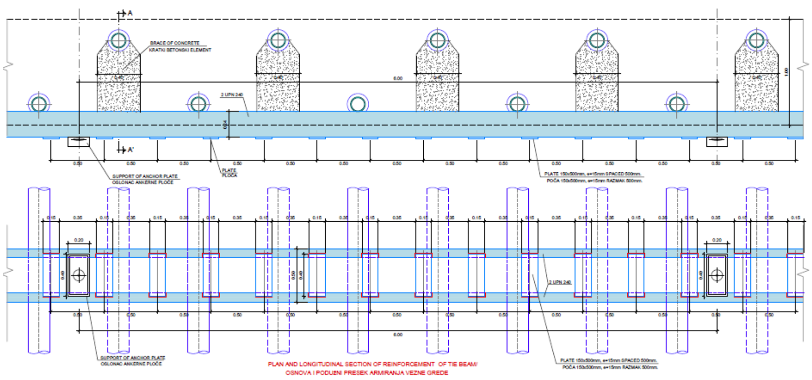

Figure 1. Plan and longitudinad section of tie beam

Pile cap beam and tie beams are supported by long pre-stressed anchors which are anchored into the rock formation. One anchor consists of 5 steel cables Ø15.2 mm with total bearing capacity of 1200 kN on the yield strength. Anchor length is 20 to 40 m depending on geological conditions where they are performed. The bulb length is 6 m for the first anchor row and 10 m for the other rows. Grouting of the bulb is performed with minimum pressure of 5 bar. During the execution of works the Contractor is obligated to make an anchor passport for each anchor. These passports have to be submitted to the responsible designer for inspection and approval. Before starting the works, the contractor is obliged to prepare and submit detailed technology for execution of works for geotechnical anchors and submit it for approval to the responsible designers. Special attention should be paid to the testing and pre-stressing of the anchors. First row of anchors in the head beam is pre-stressed and locked with a smaller force of around 300 kN, and the rest of the anchors in the lower rows are pre-stressed depending on the anchor spacing. In a spacing with 3.0 m the pre-stressing force should not exceed 450 kN, and where the designed anchor spacing is 6 m the pre- stressing force should be around 600 kN. Figure 2 presents detail steel beams and plates for anchors.

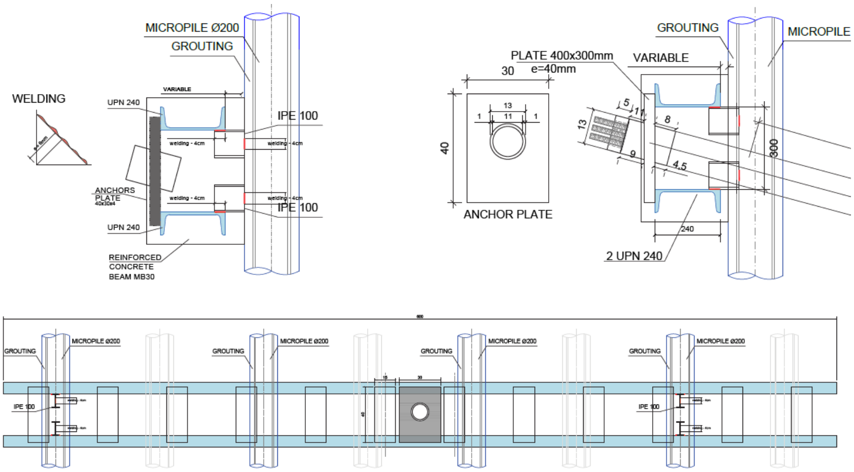

Figure 2. Detail steel beams and plates for anchors

In a constructive view, the designed retaining structure is a plate that is resting on the continual tie beams, which are supported in discrete points by geotechnical anchors.
In the middle part of the cut, in front of the micro-pile wall, there are permanent berms. These berms are stabilized with shotcrete and self-drilling anchors. These anchors have a nominal bearing capacity of minimum 280 kN. The diameter of the steel anchor bar is Ø32 mm and the diameter of the hole is minimum Ø76 mm. The grouting of these anchors is performed in full length. At the top of the anchor, a concrete cap is provided to prevent the steel plate from punching through shotcrete. Similar as for geotechnical anchors, it is necessary to engage an accredited laboratory that will perform quality control and testing during the execution of the anchors.

3. PROTECTIVE STRUCTURE CALCULATION OF STABILITY AND BEARING CAPACITY

Calculation of stability and bearing capacity of protective structure was carried out in several phases. Phases are modeled according to the technology of execution of works. The calculation was performed in FEM program Plaxis 2D [4]. This calculation is based on the finite element method, using an incremental, iterative process. The stability factor in Plaxis 2D program is obtained according to a process called Phi-C Reduction, which is adopted as a very good method for this type of calculation. For this purpose of this design, two characteristic cross sections were modeled in Plaxis 2D. It is justified to use analysis in 2D plane - strain state. The cross section on km 878 + 800 and on 878+950 were adopted as critical. The values of parameters which are used in the calculation are given in Table 1, and these values are taken from above mentioned geotechnical reports.

Table 1. Parameters used in the calculations

Layer	γ [kN/m3]	φ [°]	c [kPa]	E [kPa]
dl,pr, Sde	19	27-28	3-10	4000-8300
S*	26	33-47	33-141	198000-1415000
S**	22	20-27	10-15	4000-8300
S	27	44-55	87-466	693000-5309000
Ka	22	19	1	4000-8300

The structure of micro-piles is modeled as a beam element with equivalent bending rigidity and axial rigidity. The anchor bearing capacity is modeled as an elastic-plastic simple rod with a real bearing capacity of anchor. The anchor filling is modeled as infinitely rigid. The initial stress-strain state is modeled as a kind of "gravitational load" taking into account that the terrain is not flat but is in inclination. The protective structure and the excavation were modeled in several stages according to the methodology of work execution for this type of structures.

4. CALCULATION RESULTS

-km 878+800
Since landslide occurred during the execution of works in the area from km878+775 to km 878+825, it was necessary to include the existing sliding plane into the calculation. Figure 3 presents the deformed mesh for typical cross section.

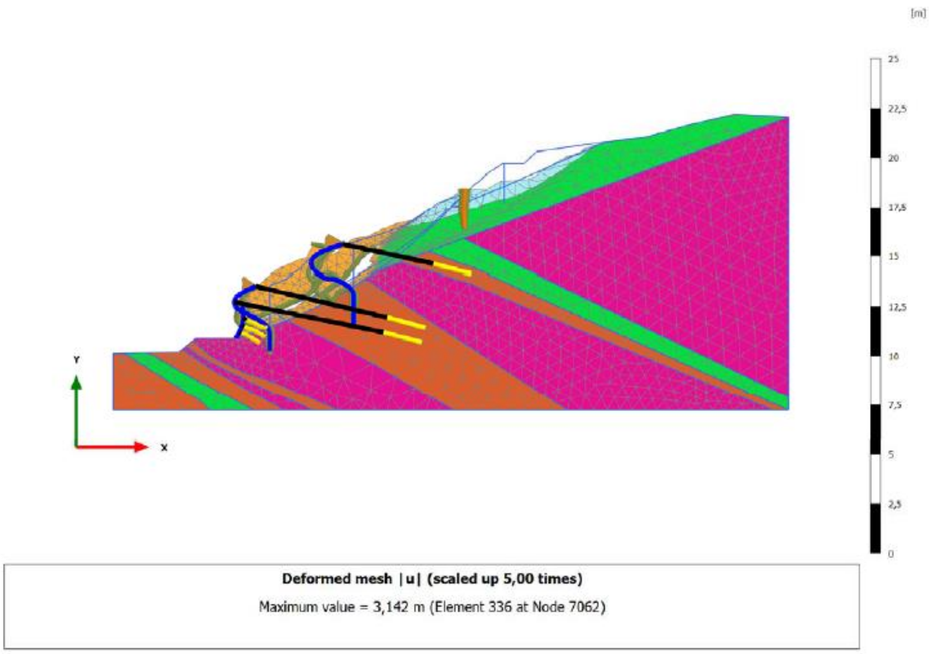

Figure 3. Deformed mesh for the cross section 878+800

Extreme values of force in cross-section:

1) For Micro-piles:
$M_{max} = 0.75 \cdot 72.8 = 54.6\ kNm$
$T_{max} = 0.75 \cdot 128.6 = 96.45\ kN$
$N_{max} = 0.75 \cdot 267.8 = 200.85\ kN$

2) For pre-stressed geotechnical anchors:
$N_{max} = 847.97\ kN$

3) For self-drilling anchors:
$N_{max} = 40.00\ kN$(pre tensioning force)

The global safety factor for this part in the existing state without the protective structureis about Fs=1.0. After the construction of the support structure, the global safety factor will be about Fs=1.44.

-km 878+950
In this zone, a small landslide also occurred during the execution of the works in the area from km 878+870 to km 879+050. The position of the highway platform is such that in any case the sliding material has to be excavated. Therefore, it is not necessary to stabilize the activated landslide, as it is the case on km 878+800. Figure 4 presents the deformed mesh for typical cross section.

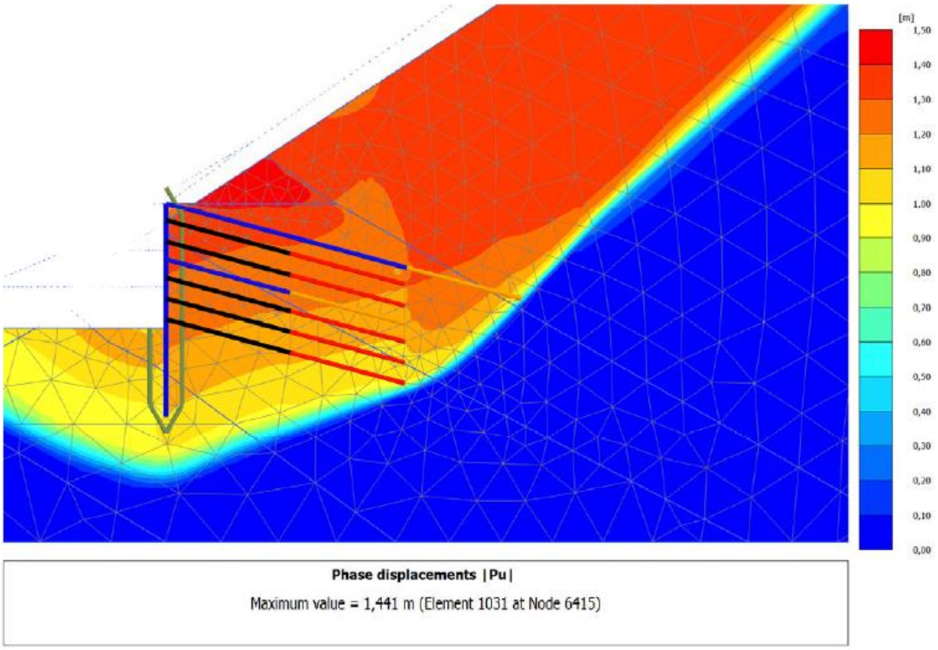

Figure 4. Deformed mesh for the cross section 878+950

Extreme values of force in cross-section:
1) For micro-piles:
$M_{max} = 1.5 \cdot 25.79 = 38.68\ kNm$
$T_{max} = 1.5 \cdot 90.89 = 136.3\ kN$
$N_{max} = 1.5 \cdot 529.60 = 789.90\ kN$

2) For pre-stressed geotechnical anchors:
$N_{max} = 478.76\ kN$

The global safety factor for this part in the natural state without the protective structure is about Fs=1.15. After the construction of the support structure, the global safety factor will be about Fs=1.49.

5. MONITORING OF THE STRUCTURE

During the execution of the works it is necessary to perform permanent monitoring of the movement of the structure. Measurements of the movements should be performed by geodetic observation of benchmarks placed on the support structure. These points should be placed on the tie beams as well as on the top of the structure. In the longitudinal direction, the measuring points are positioned on each 25.0 m, in line with the highway cross sections.

Behind the designed supporting structure, it is necessary to install inclinometers. Inclinometers measure horizontal displacements of the soil from surface to the required depth. These measurements are very important because based on them, a conclusion about the stability of the structure and the entire terrain behind support structure can be made.
All measurements should be performed in a specific time period with a certain frequency. During the execution of the work, measurements should be carried out at least once a week. After the end of works, in the first two years, measurements should be carried out at least once amonth. When the period of two years expires, measurements in inclinometers should be carried out once in three months, and measurement of movement and force in the anchors once in two months.

6. TECHNOLOGY OF WORK EXECUTION

In order to satisfy all the necessary criteria for quality of works, safety and health at work during the work execution, it is necessary to divide and execute works in several phases.

I PHASE
Execution of works on designed protective structure begins with drilling micro-piles from the surface of terrain to the projected level. Drilling is performed with casing diameter of 200 mm. After completion of the drilling, a steel tube Ø139.6 mm thickness 8.8 mm from high quality steel is placed inside a borehole. Then, injection of the interior of borehole with a cement filler is performed, after this the casing is pulled out. Connection of micro-piles on top is performed with head beams which have different dimension according to the wall type.

II PHASE
When the execution and connection of micro-piles with head beam is completed, excavation in front of micro-piles is performed. The excavation is performed by height of 2.0-3.0 m, or about 1/2 height between the head beam and tie beam. Parallel to curtain of piles, excavation is performed gradually in sectionsof about 20.0 m long. Then, shotcreting along vertical surfaces on the face of curtain of piles is performed. After shotcreting, execution of the first tie beam and first row of anchors through head beam can be done. When the injection grout in anchors reaches the required strength, the pre-stressing of the anchors is carried out by corresponding force, in accordance with the designer instructions. The same technique is applied in all length of protective wall.

III-VII PHASE
The works within these phase are similar to works performed in phase II. A gradual excavation is performed from a level above to half the height between the two tie beams. These works are then followed by successive shotcreting, the construction of new tie beams and the execution and pre-stressing of the anchors at the level above follow. This procedure is repeated until construction reaches to the bottom of the excavation.

7. CONCLUSION

Based on the performed analysis, calculation of stability and bearing capacity, it can be concluded that designed support structure satisfies all the necessary conditions of stability and bearing capacity.

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ПРОРАЧУН СТАБИЛИЗАЦИЈЕ КЛИЗИШТА У ЗОНИ УСЕКА БР. 4 ОД км 878+650 ДО км 879+050

Резиме: *У раду је приказан прорачун потпорне конструкције која има улогу да стабилизује клизиште у средишњем делу од км 878+775 до км 878+825, док са леве и десне стране треба да омогући вертикално засецање терена и ископ материјала до платформе будућег ауто пута. Потпорна конструкција пројектована је као завеса од микро шипова са три различита типа завесе, у зависности од распореда шипова. Микро шипови се састоје од челичне цеви пречника Ø139.6 мм дебљине 8.8 мм која је испуњена цементном испуном минималне чврстоће 30 MPa. У конструктивном смислу пројектована потпорна конструкција представља плочу која је ослоњена на континуалне греде у виду везних греда, а које су ослоњене у дискретним тачкама помоћу геотехничких сидара. Статички прорачун стабилности и носивости заштитне конструкције извршен је у рачунарском програму Plaxis 2D 2018. Прорачун је заснован на методи коначних елемената са инкрементално итеративним поступком. На основу извршених анализа, прорачуна стабилности и носивости, може се закључити да пројектована потпорна конструкција задовољава потребне услове стабилности и носивости.*

Кључне речи: *Потпорна конструкција, микро шипови, Plaxis 2D*