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Stabilization of railway landslide with bored pile retaining wall

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ABSTRACT

On the RAILWAY ZAGREB-RIJEKA, instability (landslide) has been noticed from km 571+270 to 571+700 (line is in the cut), but since 1958 mentioned part of railway was never fully repaired. For improvement was chosen 140 m long bored pile retaining wall, 10 m deep, with horizontally dug drains. Plaxis 2D and GeoStudio-Slope/W software were used for simulation of the current situation and for designing stabilization elements. The solution is implemented and there are several measurements of pile retaining wall displacements that will be presented.

Piles has diameter of Φ 88 cm on the axial spacing of 140 cm. Piles were performed by drilling using casing. The length of the piles are 6 m and 10 m. Carrying beam of pile retaining wall has cross section B x H = 100 x 60 cm. Dug drains are carried out with concrete drainage pipes ϕ 20 cm and set at the appropriate depth in the trenches. In total, 10 drains were performed, with length of 12 m dug maximum 3 m from ground surface, and are connected in the existing concrete channels along the railway line.

Keywords: landslide, bored piles, retaining wall

1. INTRODUCTION

The Zagreb-Rijeka railway, Moravice - Skrad section (built 140 years ago) at the Lokvice location passes through cut up to 15 m high, approximately from km 571+270 to km 571+700 of railway line. According to the existing documents, the stability of the cut and the slopes above were considered in 1958. The first solution was a concrete trench and stone facing. Over time, cracking and deformation of the concrete trench and stone facing were noticed. Also, on the slope below the right side of the cut, was still active an old landslide that was at the creeping stage. Landslide constantly causes lifting of the railway track, damaging drainage channel along the track and stone facing in the cut.

Because of slope instability, in 1992, geotechnical investigation and conceptual design were conducted. Later, during 1995, detail design was finished. According to detail design, slope stability was solved with retaining wall along the existing concrete trench on the right side of the railway track.

During 2012 was decided to rehabilitate the landslide in cut "Lokvice". Because of that, engineering geological mapping was performed. All geotechnical data obtained by previous studies was used to create complete picture of stability and geological conditions.

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Figure 1. Previous solution – drainage channel and stone facing

2. PREVIOUS STUDIES

Written records about stability problems of Lokvice cut goes back in 1958. During mentioned year geological map of the wider area (Marić and Crnković, 1958) was made. In that map material, softening and sliding on the location was mentioned. In the same year, another author (Sarajlić, 1958) has writing about the problems of rehabilitation of Lokvice cut. Also, location was mentioned as an example, where any of technical intervention did not solve problem completely. After each intervention (many of them were performed) there was still caution for slow driving through section of Lokvice cut. Authors (Marić and Crnković, 1968), after field investigation, found that with performance of the longitudinal drainage channel, partly solved drainage system, although they proposed building lateral drains connected to the longitudinal channel. In 1992, for the solution of landslide reconstruction, detailed geotechnical investigation was performed and preparation of conceptual design of slope mitigation was made. Later on, in 1995 detailed design was made for the landslides mitigation proposing reinforced concrete retaining wall.

3. GEOTECHNICAL SOIL CHARACTERISTICS

To determine the geotechnical soil characteristics, all previously performed geotechnical investigation were analysed. Investigation was mainly based on boreholes with average depth of 8-10 m. In boreholes, disturbed and undisturbed samples were extracted, after which samples were tested in laboratory. In each layer SPT tests was also performed.

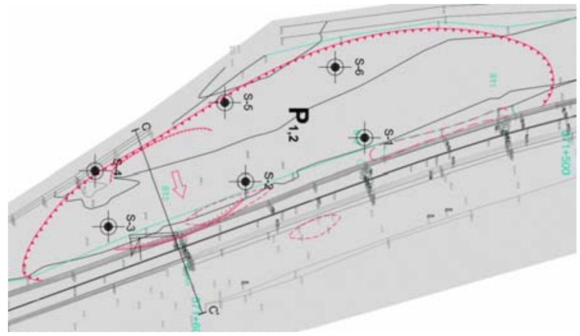

Figure 2. Sliding body contours and borehole locations

According to the performed testing following can be conclude; natural moisture content of the samples is between 9.2 to 21.1%. Liquid limit range is between 25.5 to 53.2% but most of the samples have medium plasticity (35-50%). Plastic limit range is between 12.1 to 16.5% (with two exceptions 20.5 and 34.7%) and calculated plasticity index is between 13.4 and 33.5%, which together with liquid limit classified material as a clay with mainly medium plasticity.

Geotechnical soil model is:

- To a depth of 3-5 meters appears clay layer (low and high plasticity, medium to hard consistency). Clays contain sharp-edged fragments of Triassic and Palaeozoic rocks and rare dolomite blocks. Tested soil samples have cohesion $c = 6\text{-}30\ kN/m^2$ and friction angle $\varphi = 13.6\text{-}34.3\ °$.
- Below the clay layer, clay schist is present, which is in the upper part of layer weathered. With increasing depth, shear strength of clay schist is also increasing. Weathered sandstones and siltstones are also appearing with significantly higher parameters of shear resistance than schist.

It was concluded, that sliding is occurring up to a depth of weathered clay shale appearance. The level of ground water according to the measurements in boreholes is near the ground surface. It can be approximated for stability analysis at 1 m from the ground surface.

4. DESCRIPTION OF LANDSLIDE

With detailed engineering and geological terrain mapping, all visible damage to stone facing is registered along the tracks as well as reinforced concrete channel in the slope bottom. The basic contour of the sliding body in the left and right sides and the top is assumed, and nowhere is clearly visible due to a small displacement in the bottom (a maximum of about 1 m displacement of reinforced concrete channel in the bottom of the slope). According to the established lithological sequence and geological characteristics, it is logical that the lower contour of the possible formation of sliding surface is placed on the bottom of the clay layer. The impact of groundwater can be approximated with line of groundwater level at 1 m from the ground surface.

Figure 3. Sliding body with implemented solution

5. LANDSLIDE STABILIZATION METHOD

Implementation of pile retaining wall and dug drains is planned in the instable slope of the railway line from km 517+498,914 to km 517+637,673 section; length of the section is 139 m. The pile retaining wall is planned to be built over the stone facing on the right side of the cut. Dug drains are planning to be built on both sides of the cut. The total length of all drains is 120 m.

Pile wall is retaining structure which takes lateral loads and permanently prevents excessive horizontal displacements or the possible instability of the existing slope. Dug drains are placed perpendicular to the pile retaining wall, to lower ground water level in the slope. Surface waters are gathered with concrete gutter near the pile retaining wall.

Console pile retaining wall structure consists:

- Piles with nominal diameter of Φ 88 cm on the axial spacing of 140 cm. Piles are performed by bored drilling using casing. Concrete piles, C 30/37, reinforcement bars B 500B. The lengths of the piles are 6 and 10 m.
- Piles were capped by a concrete beam (dimensions B x H = 100 x 60 cm), concrete strength class C 30/37, reinforcement bars B 500B.

Dug drains are build out from a concrete drainage pipe (Φ 20 cm) and set in the trenches at the appropriate depth. In total, 10 drains will be provided, length 12 m. Depth of a dug drains is maximum up to 3 m at the beginning (the highest point), and the outlet is in the existing concrete channels along the railway line.

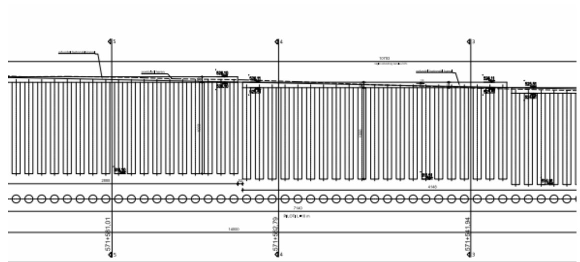

Figure 4. Implemented pile retaining wall

6. GEOTECHNICAL CALCULATIONS

6.1. INPUT DATA AND CALCULATION DESCRIPTION

Calculations were performed for the slope stability of the existing instable slope and for the improved slope with pile retaining wall and drainage system. For the calculation was used computer program "GeoStudio-Slope/W", in which the sliding body is divided into segments and is calculated the ratio of shear resistance in the ground and actions on the sliding mass that is displayed as a safety factor.

Besides that, computer program "Plaxis 2D" was used for finite element analysis. Using "Plaxis 2D" additionally, it was calculated safety factor of existing landslides and improved slope with obtaining stress-deformation image of a computational model.

Static system of retaining structure consist console pile retaining wall with piles (Φ 88 cm) on 140 cm axial spacing detained with passive resistance on the buried part of the structure.

With "Plaxis 2D" calculation, next values were obtained: value of stress and displacements in the soil, and also displacements, bending moments, transverse and longitudinal forces in piles, activated passive resistance to the buried part of the pile and factor of global stability with φ-c reduction.

The soil is modelled using nonlinear hardening soil model.

Soil parameters used in calculation:

- Up to the depth of 3-5 meters is present clay layer, low and high plasticity, medium to hard consistency, cohesion c = 8 kN/m^2 and friction angle φ = 17°, Eoed = 4000 kN/m^2.
- Below that, clay schists is present - hard consistency
  - Weathered Schist - cohesion c=20 kN/m^2 and friction angle φ=17°, Eoed = 8000 kN/m^2.
  - Schist - cohesion c=100 kN/m^2 and friction angle φ=20°, Eoed = 20000 kN/m^2.

6.2. RESULTS OF THE CALCULATION

The calculation model in software "GeoStudio-Slope/W" for the existing instable slope

The resulting factor of safety - 1.0, which represents the limit state of equilibrium:

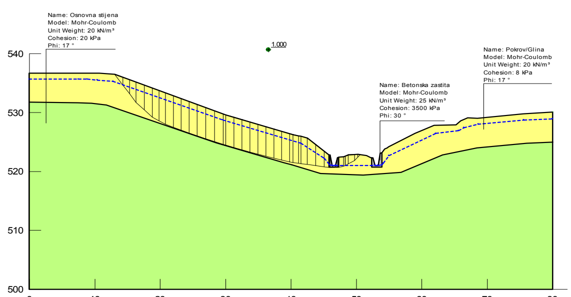

Figure 5. Slope/W calculation result

The calculation model in software "Plaxis 2D" for the existing instable slope

The resulting factor of safety - 1.05, which represents the limit state of equilibrium:

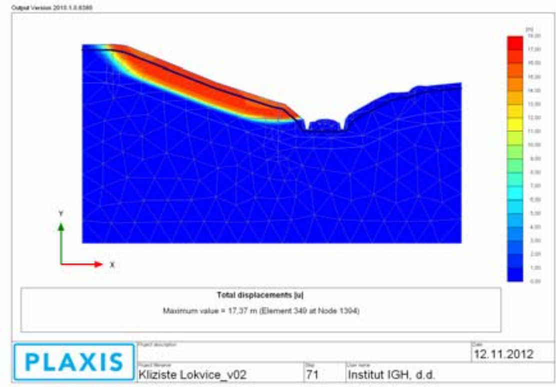

Figure 6. Plaxis 2D calculation result

The calculation model in software "GeoStudio-Slope/W" for the improved slope:

The calculation is conducted according to EC7, part 1, Design Approach 3.

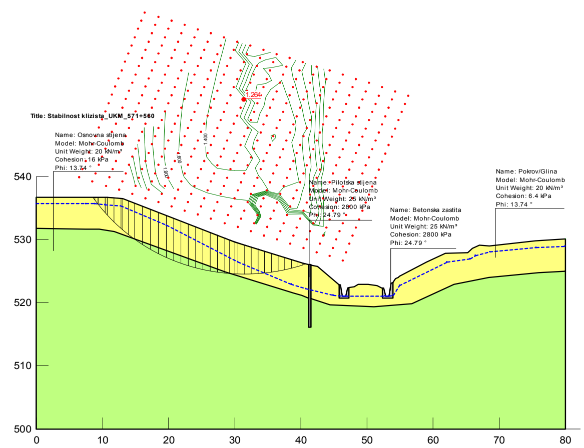

Figure 7. Slope/W calculation result

The calculation model in software "Plaxis 2D" for the improved slope:

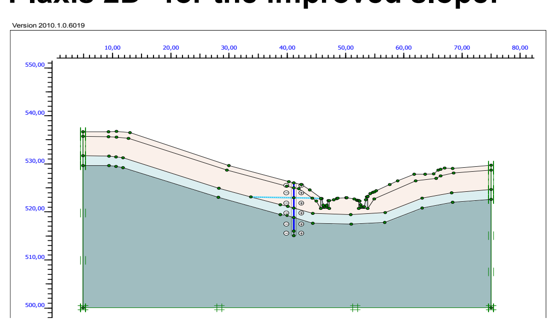

Figure 8. Plaxis 2D calculation model

Maximum horizontal displacements of pile retaining wall are up to 1 cm:

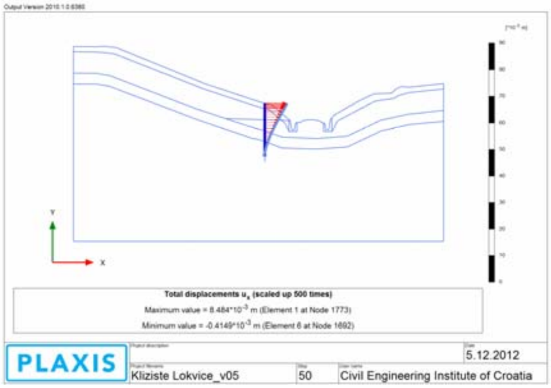

Figure 9. Total displacement of pile

7. CONSTRUCTION OF PILE RETAINING WALL

Reconstruction was made during 2014 and 2015.

Figure 10. Photo of performed piles during drainage installation

Figure 10. Photo of renewed stone facing with pile retaining wall

Figure 11. Photo of performed pile retaining wall

8. DISPLACEMENT MONITORING

Because of the possible landslide activity, the project planned the monitoring program development for retaining structure. The purpose of monitoring is to confirm design assumptions and the possibility of right time intervention in case of larger displacement than anticipated.

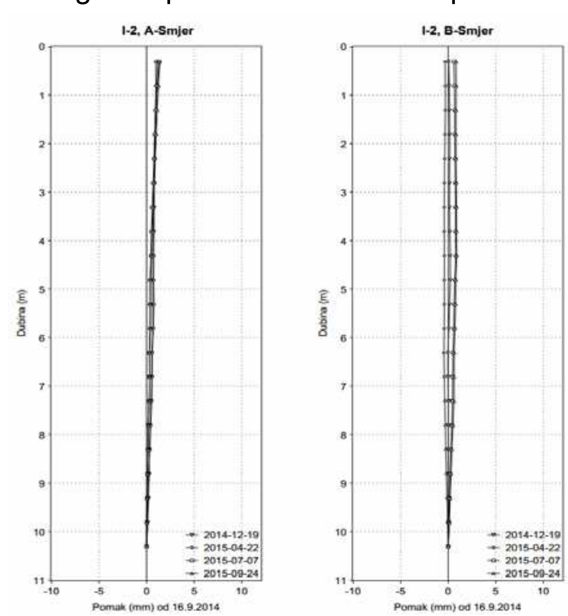

Figure 12. Display of inclinometer measurements

Observation included horizontal displacement monitoring of pile retaining wall, using the built-in inclinometer tube. Inclinometer tube is built into the pile. The measurement shows a peak horizontal displacement of pile for about 2 mm in the period since the end of reconstruction to today.

9. CONCLUSIONS

The slope stability problem of Lokvice cut appears since 1958. Over time were given temporary solutions which proved to be more expensive solution then solving the problem in the end. By analysing previous studies and situation on the site, it was decided to propose a permanent solution. For permanent solution was chosen a pile retaining wall, resulted in minimal measured displacement that approximately coincides with the design solution. The design approach was based on calculation software: GeoSudio-Slope/W (slope global stability) and PLAXIS 2D (stress and strain analysis). First, existing situation on the site (instability) was modelled. Slope/W and Plaxis 2D software showed the same results regarding the global stability (Global Safety Factor – 1,0). Further, modelling in Slope/W and PLAXIS 2D defined were pile retaining wall elements and further monitoring program. According to all above, it is concluded that it is very important to bring the right decision about how to mitigate the landslide, since in this case the previous simple solutions have proved insufficient to prevent further displacement development.

ACKNOWLEDGEMENTS

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