Influence of the rate of construction and of rock mass strength reduction on the stability of deep cuts in marl

Influence de taux de construction et de reduction de resistance de roche sur la stabilite des deblais profonds dans la marne

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ABSTRACT

During geotechnical monitoring of anchored retaining structure and marl rock mass in conditions where marl is sensitive to variations in water content, the question appeared if design investigations in such cases generally overestimate strength and stiffness parameters. Another question is concerned with the extent and amount of changes in rock mass properties and with the influence of the construction rate and sequence. It was found out that the process of secondary humidification of the slope is directly related to the progress of works. The recorded increase of marl water content was on average 1.2% and the average decrease of uniaxial compressive strength was 28 %.

RÉSUMÉ

Au suivi des conditions de sols de fondation et des ouvrages ancres dans les marnes sensibles a l'humidite de la partie nord-est de la Slovenie, des questions sont posees de savoir si les parametres de resistance de la roche, suffisants et de qualite, obtenus a partir des recherches, sont surestimes, dans quelle mesure a l'arriere-pays les conditions suite a l'excavation sont egales aux conditions en phase de recherches, et de quelle maniere le taux de construction ou de l'excavation de la roche agissent sur la condition entiere et la modification des parametres de resistance. Il a ete constate que le processus de l'humidification secondaire de la roche est lie directement a l'avancement des travaux. Il est enregistre une augmentation en moyenne de 1.2% d'humidite de marne et une chute moyenne de 28% de resistance a la compression uniaxe.

Keywords: failure surface, earth pressure, stability analysis, water content

1 INTRODUCTION

In Slovenia, at a junction of traffic ways from Austria and Hungary towards Croatia and Italy, the motorway split is designed in a deep cut. Regarding the composition of the ground and the design strength parameters of the rock, supporting measures were adopted, consisting of prefabricated concrete columns arranged on steep cut slopes and of prestressed geotechnical anchors. The columns, anchors, binding beams and the fill between columns are constructed in a tight sequence immediately following the excavation. The direction and the height of excavation were designed according to the individual working phases and the final layout of the cutting slopes. Geotechnical monitoring during the construction showed movements behind the 520 m long and 30 m high retaining structure. The control geotechnical investigations showed essentially lower strength parameters (q_u) and higher natural water content (w) of the marl rock mass if compared to the data obtained during the design investigation phase. The rock mass is formed by rhythmic sequence of marl layers and layers of saturated fine sand. This was clearly observed on the slope after the excavation. With additional investigations also the retention curve, swelling potential and the residual shear angle were determined. These are the parameters that can help us understand the impacts of relaxation of the rock mass behind the cut on its strength and deformability. With further construction the stability and the progress of works are regulated by additional supporting measures taking into account the results of monitoring and reduced strength and stiffness parameters.

Figure 1. Bedding of the excavation with visible sandstone aquifer layers.

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-2020

Figure 2. View to retaining wall OZ-05 during construction

2 GEOLOGICAL AND HYDROLOGICAL CONDITIONS

The basic rock mass of the area in question is formed by miocene sediments, sandy marls, sandstones and siltstones. They alternate, with prevailing marl layers. According to the mineralogical petrographical data the rock mass is carbonate clayey siltstone and calcite muscovite quartz marly claystone. Sheet minerals of claystones and siltstones are predominantly oriented along the bedding, which results in strong hygroscopicity of the rock mass. Between the marl and sandstone layers there are layers of fine grained mica quartz sandstone and grey sandy siltstone of different thicknesses.

From the hydrogeological aspect the area belongs to areas with poor permeability. The first type of water is represented by water in the weathered cover layer and appears locally. The second type is water in the rock mass. It appears in sandstone with double porosity. It flows in from open cracks, and partially also from intergranual porosity, and it leaches in the form of dripping. The water in the cracks is located in hydrologically closed system under hydrostatic pressure of 5 bars.

3 DEEP CUTS AND SUPPORTING MEASURES

Slopes of a 520 m long and 30 m deep cut are protected by retaining structures. On the left side there is structure OZ-05 along the whole length of the cut, while on the right side there are two shorter separated structures. The supporting measures are designed using unified system of anchored prefabricated structures, distributed long the slopes with intermediate berms. The protection of slopes is foreseen at all sections of the cut, where the cut height reaches the height of the lower 9.0 m high level. The concrete columns, geotechnical anchors, binding beams and fills between columns are installed gradually, adapted to the final heights of individual levels. From the aspect of time and logistics, such construction is slow and time consuming.

If the retaining structure is an object that provides permanent stability of the cut, the excavated marl represents an indispensable source of material for the slopes. The need for this material dictated rapid excavation to achieve the fastest possible construction of high embankments.

4 MONITORING DURING CONSTRUCTION

The construction started in June 2006 with intensive excavation and construction of individual structures from several locations. The excavation in front of the structure was ahead of time for the prescribed phase construction of the structure, with the deepening of the excavation in the layout axis. The rock mass in front of the structure did not ensure adequate resistance, nor was it stable in the locally performed excavation, which resulted in a minor local failure of marl at the middle berm.

Immediately after this event there were also larger horizontal displacements noticed in inclinometers in the hinterland and in the upper berm. In individual inclinometers larger translatory displacements appeared at several heights with the magnitude up to 40 mm. The events intensified also the activity related to monitoring other by that time installed measuring points. The measurements of displacements in rare geodetic points at the beams and columns confirmed the displacements, while the anchoring forces were constantly increasing.

All the above stated observations required immediate action to prevent further deformations. The first measures related to the interruption of the excavation works, convey of ballast material in front of the failed slope, immediate anchoring of all the constructed columns and installing additional anchors at the foreseen points.

Figure 3. Slide in marl at the medium berm

To establish permanent stability of the structure, additional geotechnical investigations and boreholes IN were performed (Štern 2007, Petkovšek 2007), forming together with the data of technical monitoring (Štern 2008) the base for determining additional supporting measures and reasons of the emerged conditions.

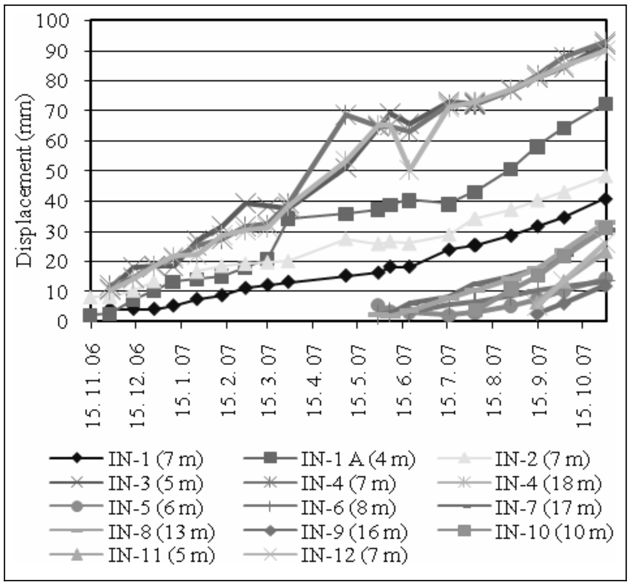

Figure 4. Time history of displacements in inclinometers at critical depths.

The last anchors in the structures were prestressed in December 2008, and the whole construction took two and half years. The displacements were increasing at a rate of 4 mm/month up to the end of construction. After the construction the OZ-05 structure included 717 permanent geotechnical anchors in the total length of 18 545 m, of those 417 anchors were designed in the total length of 8 336 m (Korpar 2004) and additional 300 anchors of the total length of 10 209 m (Korpar 2008).

5 ADDITIONAL GEOTECHNICAL INVESTIGATIONS

Additional geotechnical investigations were carried out on marls, acquired by core drilling of holes, drilled for the needs of installing additional inclinometers. The purpose of additional investigations was also to find answers to the following questions.

Were the input strength parameters for the rock, given and used in the project, overrated?

Are the conditions in the foundation ground after the excavation the same as in the design investigation phase?

Can we expect that with further construction and excavation the conditions in the foundation ground will deteriorate?

Will the displacements continue or subside?

The main geotechnical investigations, boreholes marked by O, for the design of the layout and structure originate from 1999. The time delay to 2006, when the same marls were investigated as potential fill material, brought new knowledge about the behaviour of soils with large swelling potential, which are also these soils.

While the aim of the investigations of natural water content (w) and uniaxial compressive strength (q_u) is direct comparison of absolute values between the design phase and the construction phase, the purpose of additional investigations was to establish also, whether the rock in the cut has swelling potential, and if so, to what extent the natural swelling potential was already mobilised after the excavation. We defined the retention curve, swelling deformations and the swelling potential as well as residual shear angle, i.e. parameters that could help us understand the impacts of rock relaxation in the cut on its strength and stiffness parameters.

5.1 *Uniaxial compressive strength and natural water content*

Additional investigations showed increase of water content in the slope after the excavation: at the critical spots by more than 5%, and on average by 1.2%. Due to changes of the hydrological regime caused by the progressing excavation works that change the drainage boundary conditions for the hanging underground water, caught in sandy layers, the process of further humidification is directly related to the progress of the cut in the depth. Due to terrain unloading the increased pore volume allows the slope to saturate additionally through capillary flow. Owing to the plastic character of the marl the process of secondary humidification is followed by softening of the previously hard ground.

The data analysis of uniaxial compressive strengths shows that material strengths in slopes of active cut are lower than strengths recorded in the time of natural condition. The decrease of average compressive strength, measured for the total depth and for all samples, is on average 28%, from the average value of q_u = 5036 kPa to q_u = 3637 kPa. In individual adjoining boreholes this ratio may even be higher.

5.2 *Investigation of shear strength*

Shear strength characteristics were measured in direct shear apparatus on a sample with water content above the liquid limit. The measured shear parameters were c = 4.3 kPa and φ = 28°, while the shear angle at zero cohesion was φ = 28.5° (Petkovšek 2007).

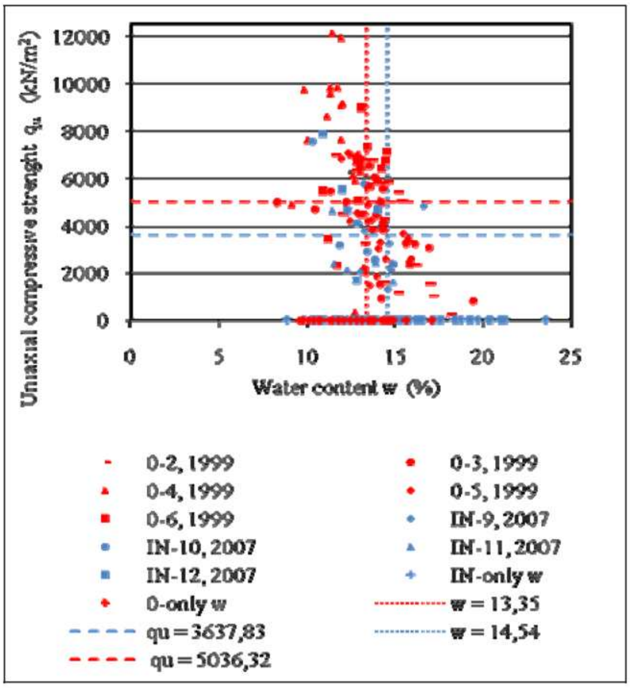

Figure 5. Relationship between natural water content and uniaxial compressive strength from the investigation phase (red) and from the construction phase (blue)

5.3 *Suction measurements*

The soil constantly referred to as marl is clayey in character. According to the Atterberg plasticity limits it belongs to the group of low plasticity (CL) clays. According to its retention curve (Petkovšek 2007) its behaviour in contact with water is very similar to medium plasticity clays. According to some data (Petkovšek 2006), the mentioned marls also show properties of high plasticity clays.

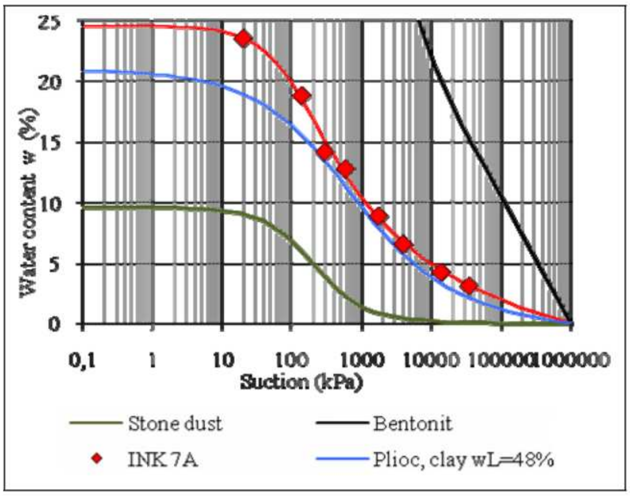

Figure 6. Relationship between suction and water content

Natural water contents of marls from the time of investigations were between w = 8.3 and 19.4%, on average 13.35%, while during construction they reached the values between w = 7.52 and 25.25%, on average 14.46%. The transition of the soil from the zone of residual water content to desaturation zone was at the water content between 8 and 10%.

Based on the above data the investigated marl is outside the critical area of residual water content, where no major volume deformations can be expected.

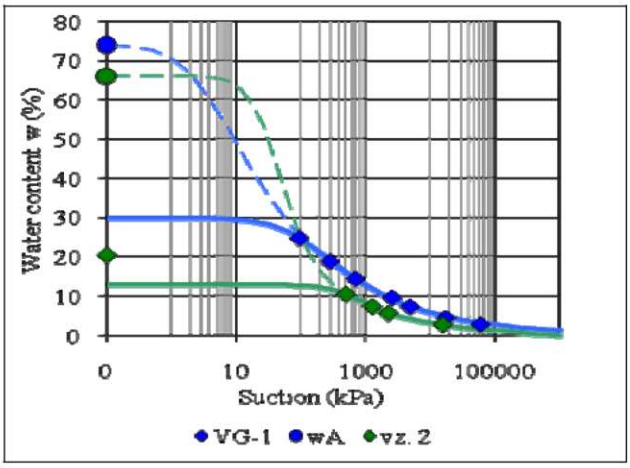

Figure 7. Retention curves defined for marls from the cut

6 BACK ANALYSES

Considering the developed deviations between the designed and actual conditions, additional supporting measures had to be defined. Additional measures were defined on the basis of repeated geostatic analysis (Korpar 2008), performed initially as back analysis and than as design calculation with new geotechnical parameters. The geostatic analysis was made for profile P589. Two analyses were made. In the first one the strength parameters were defined by taking into account the decrease of the marl shear strength, defined iteratively at the value where internal or external capacity is exceeded at least for one anchor according to the project. The volume of soils where considerable decrease of shear strength appeared was defined using displacement measurements in inclinometers with failure line connecting critical depths in individual inclinometer.

According to the results, this condition is fulfilled when using shear angle φ = 27.5º and cohesion c = 5 kPa.

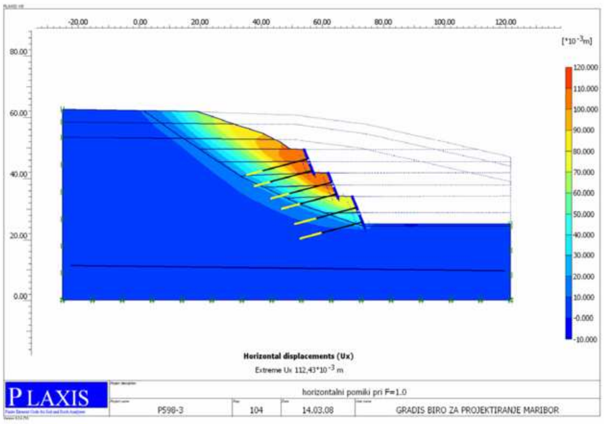

Figure 8. Supporting measures according to the basic project.

Once the limit value of shear angle had been obtained, the analysis with all additional anchors defined, i.e. number, length, load-carrying capacity, is repeated. For parameters defined in this way and for additional anchors the global stability is expressed with the safety factor F = 1.48.

7 CONCLUSIONS

When planning deep cuts, it should be considered that unloaded slopes are considerably more unfavourable loading case than their loading by structures. The unloading of slopes means removing natural support and generally also further decrease of mechanical properties of soils and slopes. The data of additional investigations confirmed this assumption. Large and intensive displacements in the hinterland were activated with a time delay of 4 to 5 months after intensive excavations. This was also the time necessary for completing the process of secondary humidification of the slope and the related reduction of strength.

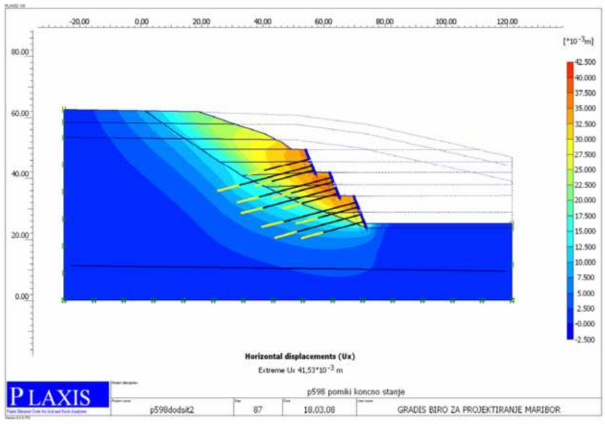

Figure 9: Supporting measures according to the data from additional investigations.

REFERENCES

Korpar, L. 2008. Return geomechanical analysis of stability for retaining wall OZ-05_RC columns from km 14+080 to 14+559 at MW Slivnica – Pesnica, Section Drava-Pesnica. Maribor: GRADIS Biro za projektiranje d.o.o.

Korpar, L. 2004. Retaining wall OZ-05 (RC columns) Plans of building structures. Maribor: GRADIS Biro za projektiranje d.o.o. Project No. 3682.

Ocepek, D. 2001. MW Koper-Lendava, Section Slivnica – Pesnica, Drava – Pesnica, km 14+110 – 14+550, Retaining wall OZ-05, Geological geotechnical report on the conditions of execution – audit-adjusted. Ljubljana: Geoinženiring 50-5/2001.

Ocepek, D. 1999. MW Koper – Lendava, Slivnica – Pesnica, Drava – Pesnica, Cut from km 14+060 to km 14 + 620, Geological geotechnical report, Project for Building Permit, Project for Execution, audit-adjusted. Ljubljana: Geoinženiring d.o.o., 15/474-n.

Petkovšek, A. 2007. Report on additional geomechanical laboratory investigations of a marl sample from additional inclinometer boreholes at the cut Dragučova OZ-05. Ljubljana: University of Ljubljana, Faculty of Civil and Geodetic Engineering No. L-26-07.

Petkovšek, A. 2006. Report on geomechanical laboratory investigations and definition of optimal installation conditions of miocene semi-hard and hard siltstones and clays from the deep cut Dragučova into motorway embankments. Ljubljana: University of Ljubljana, Faculty of Civil and Geodetic Engineering No. L-32.06.

Štern, K. 2008. MW Koper-Lendava, Section Slivnica – Pesnica, Zrkovska cesta – connecting road Pesnica from km 13+520 to km 16+300, Cut OZ-05 km 14+080 to km 14+600, Data from technical monitoring, 10th periodic report. Maribor Geoinženiring d.o.o. GMM 6368_10.

Štern, K. 2007. Report on soil investigations, Additional investigations for the needs of evaluating deep cut stability OZ-05. Maribor: Geoinženiring d.o.o. GMM 6442/07.

Štern, K. 2006. Geological geotechnical conditions and construction technology of MW layout, MW Koper – Lendava with connecting leg, Ptujska - Zrkovska, MW layout km 6+700 to km 10+847. Maribor: Geoinženiring d.o.o. GMM 6271/06.

Štern, K. 2006 Technological report of performed earth works, MW Koper-Lendava, Section Slivnica – Pesnica, Zrkovska cesta – connection Pesnica from km 13+520 to km 16+300, Project for execution. Maribor: Geoinženiring d.o.o. GMM 6260/06.