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Slope failures risk acceptance in the construction of roads on the clayey mine spoil dump, Czech Republic

Prise en compte des risques de rupture des pentes dans la construction de routes sur une décharge minière argileuse en République Tchèque

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ABSTRACT: In this paper, we present a study of a large slope failure, which endangered the construction of a bridge, occurred in 24 m deep cutting with a main scarp upper edge extending over 70 m in length. The stability analysis is discussed, with a critical analysis of safety factors, according to the Eurocode. The important place takes the analysis of slope stability during construction, but also the analysis of long-term conditions, back-analysis, in anthropogenic site, conditions that are not completely covered by geotechnical codes. Lessons learned showed, that a design basis in such an anthropogenic environment should ensure an advanced geotechnical characterizations and parametric engineering assessments. Even in such a case, it will be necessary to acknowledge the risk of slope instability by all stakeholders, mainly due to uncertainties associated with a construction of clayey mine spoil heaps and a subsequent mechanical properties heterogeneity of stockpiled soils. The role of geotechnics is inevitable in such "natural" conditions of mine spoil dumps to provide necessary support throughout entire project life cycle.

RÉSUMÉ: On présente l'analyse des conditions de rupture d'une pente, lors de la construction d'un pont. La rupture s'est produite avec une extension de 70m en amont de la pente, avec un dénivelé de 24m. Les études suivent les règles définies par les Eurocodes, et une analyse critique des facteurs de sécurité est faite. L'analyse est faite en prenant en compte le phasage de construction. Ensuite, des études à long terme, en retro-analyse, avec les particularités d'un site anthropique, montrent que ces conditions ne sont pas prises en compte par les règles de calcul : le site est constitué de dépôts des matériaux argileux stériles provenant des mines de charbon. Les conclusions montrent que, dans des sites anthropiques, une importance considérable devra être portée à la caractérisation avancée des sols en place et qu'il est nécessaire que toutes les parties prenantes du projet prennent connaissance des risques encourus. La complexité du site, provenant de l'origine géologique des argiles à fortes hétérogénéité et remaniées lors de dépôts disparates, implique un comportement difficilement prévisible sur le long terme : le rôle et l'implication du géotechnicien, reste fondamentales tout au long de la vie de l'ouvrage .

Keywords: Slope stability; safety factor; anthropogenic site; clayey mine spoil; long term behaviour.

1 INTRODUCTION

As society develops, human activity has an increasing influence on the change of an environment. Mining activities and a subsequent processing of raw materials represent one of the world's biggest waste management challenges with a definite impact on the surrounding environment.

The north-west part of Czech Republic is characterized by the extensive open cast mining of brown coal for several decades. With the progress of open cast mining, overburden spoil material (clays primarily), covering brown coal reserves, is stockpiled in non-engineered manner into large spoil heaps/dumps, several tens of meters in height. These locations represent potential sites for infrastructure projects thanks to an interesting economical aspect. Even if the economic aspects are favourable, technical, and mainly geotechnical issues regarding possible developments represent significant challenge. One such particularity is the acceptance of the risk arising from the "natural" geotechnical conditions of the mine spoil heaps.

2 SPOIL HEAPS SPECIFICS

Vanicek and Vanicek (2008) and Najser (2010) summarized the uniqueness associated with the construction of clayey spoil dumps. During mining, overburden clays in the form of irregular lumps typically 500 mm in size are stockpiled in large dumps. The total thickness of the layers is generally 20-50 m. The spoil material has a double porosity: the porosity of the clay lumps (primary intragranular) and the pores between the clay lumps (secondary intergranular). The total porosity can reach up to 70%. The clays are stockpiled top-down by free fall from a height of 15-30 m. Although the free fall allows some compaction, the resulting secondary porosity is considerably high, up to 35%. Generally, the loose material has the character of crushed stone material in an embankment with steep slopes of 1:1 (V:H) - 45-degree angle. The properties of the stockpiled material change with time due to increasing height and interaction with water. When the lumpy clays adversely change their mechanical properties due to interaction with water, the original hard clays/claystones change to clays of soft to very soft consistency. Such weakened soils present significant challenges to geotechnical engineering primarily due to significant settlement up to collapse and uneven settlements. Discovering of such altered layers in both vertical and horizontal directions is practically impossible, which greatly inhibits available options for subsoil improvement. Moreover, the progressive transformation from loose to fine-grained matrix with time makes the mechanical modelling of lumpy clays considerably uncertain.

3 CASE STUDY

This construction project including roads construction on the body of an external mine spoil dump was greatly influenced by certain technical challenges that had to be considered in such an anthropogenic environment.

The construction was realized on considerable thicknesses of spoil material, consisting of clayey soils and claystones with the thickness up to 70 m. These are Tertiary lacustrine clays and claystones (Cypress Formation) - kaolin-illite clays with variable minor content of montmorillonite.

During the construction of a bridge structure, a slope failure (landslide) occurred in the cutting with a total depth of approximately 24 m, and length of the main scarp upper edge approximately 70 m (Figure 1). The sliding surface was clearly characterized by a smoothed plane-slip surface with soil displacement of up to 5 m downward at a slope of approximately 45° (Figure 2). The landslide body covered an area of approximately 5000 m2 with a potential soil volume in the landslide of 50000 m3. Observations of the main sliding surface showed an interface of brown and distinctly coloured grey clays, which differentiated largely in consistency. The landslide body negatively affected the construction of the bridge structure and raised many questions about the next steps of the construction due to the geometric constraints of the planned construction. Removal of the landslide body at the bottom was not an option, however works, under increased safety precautions, had to be planned.

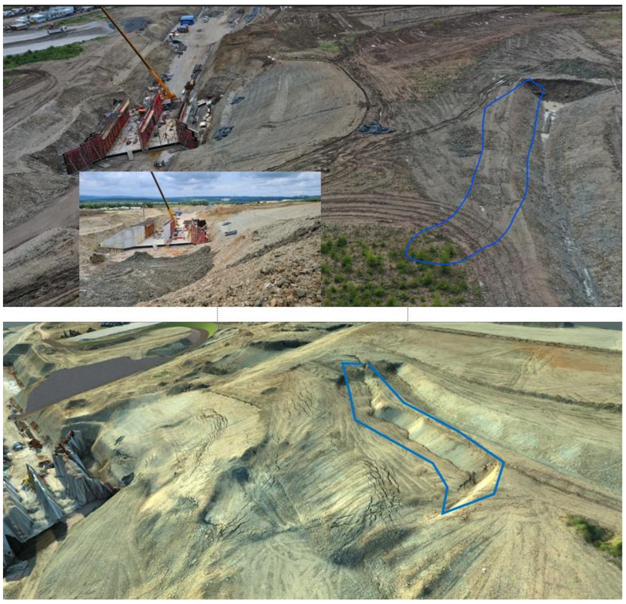

Figure 1. Landslide within 24m deep cutting (upper picture shows a situation before the failure).

Figure 2. Main scarp upper edge of the landslide.

4 BACK-CALCULATION

After the initial measures were taken to minimize the safety risk and based on the results of the daily monitoring, geotechnical assessments of the actual situation as well as back-calculated stability assessments were carried out. It should be paradoxically noted that the slope failure occurred after the construction of the stabilization berm at the toe, following the occurrence of a crack at the crown of the slope cut. Simultaneously, excavation works of soil in the upper part of the cut body were conducted to relief the associated stress just before the slope failure.

The numerical stability analyses results showed that the required theoretical safety factor was achieved in the phase of conducting stabilization measures, after the crack had occurred (Figure 3). Still, the question had arisen as to why the landslide occurred?

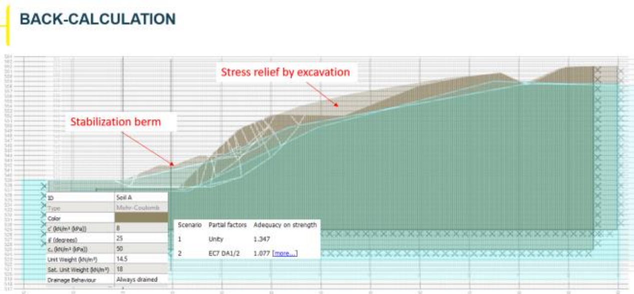

Figure 3. Back-analysis of the failure occurred after the construction of stabilization berm and excavation of upper part material.

The geotechnical back-analysis included parametric studies with different elements of instability. It turned out that a geometric instability element had to be present in the system (model), which was a prerequisite for the occurrence of the slope failure (Figure 4). By including such an instability element in the form of a completely thin layer of soft clay in the body of the landslide, the calculated degree of safety was insufficient, which also confirmed the theoretical possibility of a slope failure. Such calculated representation corresponded well with the site observations.

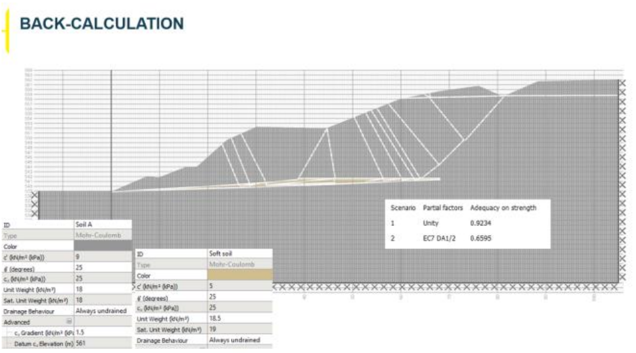

Figure 4. Back-analysis of the failure including an element of instability – 0.5m thick seam of soft soil in the cutting.

5 STATIC PENETRATION TESTS

As part of the investigation of the occurred slope failure, an additional geotechnical investigation by means of static penetration tests was carried out. The results provided detailed information regarding the subsoil profile, showing multiple low-peak locations, at different depths, with very low to low shear strength in the body of the landslide as well as in the wider area outside of the landslide body (Figure 5). These locations were local, very thin clay layers of very soft to soft consistency often only a few cm to a few dm thick. Thus, there was a practical confirmation of the hypothesis arising from the back-calculation, and that is a need for the presence of an element of instability in the system in order to model the theoretical failure. With the help of the interpretation of the static penetration results, the potential basal sliding surface was determined, which was necessary for the planning of remediation measures. The static penetration test results also indicated a random occurrence of very soft to soft clay deposits in locations outside the landslide itself. This confirmed the presence of the geotechnical risk arising from the nature of the spoil heap construction, the unpredictable interaction with water and the consequent change in the mechanical properties of the stockpiled clays.

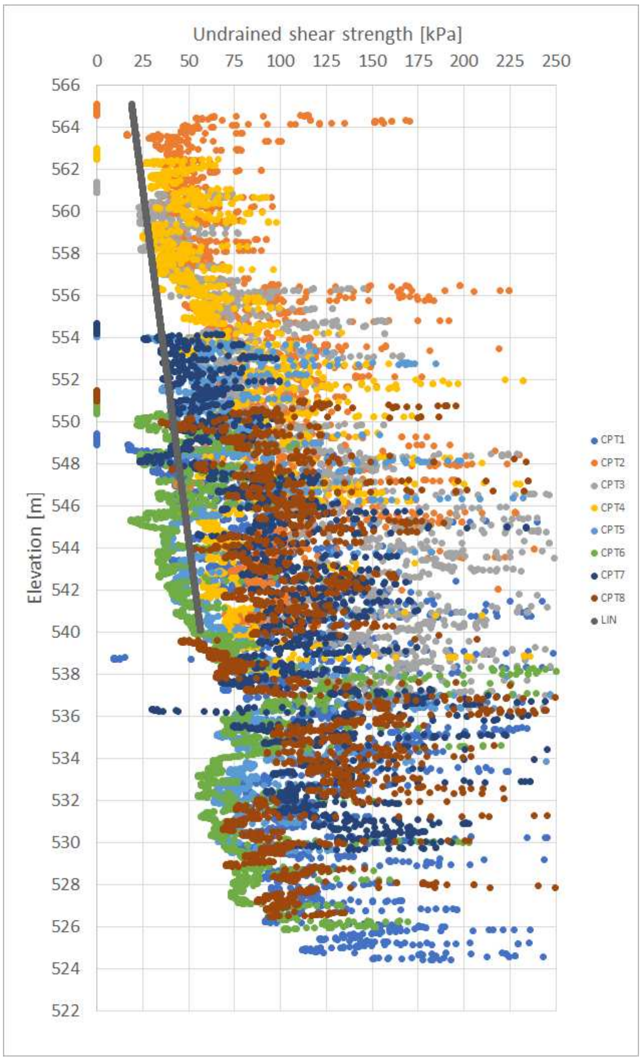

Figure 5. Static penetration test results showing potential basal sliding surface.

6 DISCUSSION

The entire construction site as formed of mine spoil heaps represented geotechnically challenging conditions. The main facts that underlined the geotechnical difficulty were the following:

- Obviously, the geotechnical properties were strongly dependent on the method of the spoil heap construction and in particular, on the interaction of the clay lumps with water long-term
- The construction of the spoil heap was carried out by free-fall of clay-claystone lumps under unknown and time-varying physical and weather conditions, without the classical engineered compaction known from road construction
- Although free-fall during construction allows some compaction, the resulting intergranular - lump porosity reached 35%, which in combination with water interaction varied over the time and created uncertainty to the geotechnical behaviour
- The relocated clay-claystone lumps (excavated and stockpiled) underwent a significant change in stress and depending on the water contact conditions (unknown, highly variable) the expected geotechnical behaviour is between rock type to soft clay type - this represented highly variable geotechnical conditions
- The whole process of stockpiling of clay mine spoil heaps led to an unpredictable alternation/intermixing of softer and stiffer layers/zones that randomly spread across the site
- Despite the site investigation carried out, there had always been uncertainty in the strength parameters and hydrodynamics due to the above facts

7 CONCLUSIONS

The construction site – clayey mine spoil dump represented a critical location predetermined to various forms of instability including slope failures, settlements, irregular groundwater seepage and erosion. Illogically, when the stabilizing measures were conducted, after a tension crack was observed at the crown of the cutting, and with a theoretically increasing factor of safety proved by calculations, a slope failure occurred. Geotechnical design of the 24 m deep cutting in such "natural" environment must ensure an advanced geotechnical characterisation as well as parametric stability assessments including different variables. Nevertheless, in such environments, all stakeholders must acknowledge the acceptance of the geotechnical risk, which would most likely require increased repair and maintenance costs.

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