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Two examples of clay slope stability in areas affected by previous man-made activity – open pit mines, landfills

Deux exemples de stabilité de pentes argileuses dans une zone affectée par des activités humaines précédentes – mines à ciel ouvert, dépôts

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ABSTRACT
North part of the Czech Republic was strongly affected by previous industrial activity, mostly connected with excavation and utilization of brown coal from tertiary area. Huge amount of tertiary clays which overlays this brown coal was removed from the original place and deposited on the other one. Slope stability problems are connected with side slopes of the large pits and with stability of spoil heaps, very often when additionally loaded.
The first case is describing slope instability of the remediated old chemical landfill, subgrade of which is composed either by natural or deposited tertiary clays. Instability with relatively low deformation affected vertical cement-bentonite slurry sealing wall and the most attention is devoted to the counteractive measures to stabilize this movement.
The second case also with complicated geological profile was selected to study different methods of slow slope movement monitoring as indication of displacement area by geodesy and radar interferometry, indication of slip surface in sliding mass, determination of displacement along slip surface supplemented by pore pressure measurement.

RESUMÉ
La partie Nord de la République Tchèque est fortement affectée par l´exploitation industrielle précédente, liée à l´exploitation du lignite de l´aire tertiaire et à son utilisation. De grandes quantités de l´argile du toit du lignite furent cachées et stockées dans les trémies. Ces dernières, souvent chargées ultérieurement, et les pentes latérales des minières sont concernées par des troubles de stabilité.
Le premier exemple porte la description de l´instabilité d'un vieux dépôt de déchets chimiques assaini dont le sous-sol consiste en argiles tertiaires qui s'y trouvaient de manière naturelle et de celles qui y furent amenées. L´instabilité ayant une déformation relativement inférieure affecta le mur de ciment-bentonite d´étanchement. L´importance est accordée avant tout aux mesures qu'il faut prendre pour stabiliser les mouvements mentionnés.
Le second exemple, portant sur un profile géologique compliqué, fut choisi pour étudier de différentes méthodes examinant des mouvements de pentes en tant que l´indication de l´aire de mouvement à l´aide de méthodes de géodésie et de l´interférométrie radar, la caractérisation de la surface de glissement dans des zones de croulement, la détermination de vecteurs de glissements suivi des mesures de pressions de vides dans des milieux extrêmement hétérogènes.

1 INTRODUCTION – CHARACTER OF TERTIARY CLAY IN NATURAL AND EXCAVATED STATE

The thickness of the tertiary sediments reaches 150 m in average in the region of Northwest Bohemia. Besides of brown coal this layer is composed mainly of clays and of claystones. But sand, underclay, slate coal, sand clay and sandy claystone are also present. The overlaying clays have a character of overconsolidated soils with stiff to hard consistency. The portion of clay particles is ranging from 10 to 40% and silt particles from 20 to 60%. Basic clay minerals are kaolinite and illite. Index plasticity I_p is roughly between 30 and 60% with liquid limit w_L reaching the maximum value 100%.

From the place of excavation to the place of spoil heap the clayey material is transported mainly by belt. Before the belt transport starts the great clods are crushed down. During this transport the individual clods are round-off and during wet weather their moisture content is increased. At the end of transport the individual clods are partly compacted by free fall (for overburden conveyer bridge it is up to 20 m). Bulk density is after that approximately 1500 - 1600 $kg{\cdot}m^{-3}$ and macroporosity is around 30%. The individual macropores between individual clods are interconnected and air is in continuous form and so permeability of soil for air is relatively high, Vanicek (1986). Character of fill is close to rock fill. Under this condition an air pore pressure is relatively quickly equalized to the atmospheric pressure. On the contrary the pore water pressure inside of individual clods is negative due to great unloading. Under this condition such soil will easily absorb water – free water or water from saturated air – even from air inside of the spoil heap's body. The properties of the deposited clayey soils are changing with time due to two basic contradiction aspects:

- Process of softening as a result of weathering, moisture content increase and kneading – when free water can fulfil the macropores, final result can be soft clay,
- process of hardening as a result of surcharge by new deposited layers – when the process is very quick and no access of free water the final result can be close to the original natural clay.

But also upper part of the exposed natural clay can change its properties due to unloading and negative pore pressure suction. Therefore these tertiary clays can be found in very different conditions in this area, where parts with extremely low strength can be preferable place for landslides or for extremely high deformations.

2 SLOPE INSTABILITY OF CHABAROVICE LANDFILL

Landfill is situated to the town Usti nad Labem along the road to small town Chabarovice. Total area is roughly 40.8 ha but the remediated area (surrounded by vertical sealing wall is about 26.8 ha. Top of the landfill is the highest place with slopes all around – see fig. 1. –Vanicek et al (2003). Area belongs to the North Bohemian brown coal basin. In the close vicinity were open pit mines and even elder deep mines, in some cases below the landfill area. Subsoil is mostly composed from tertiary clay material, which was in history partly excavated and material used in brick factory. Storing of the waste material started roughly 100 years ago, mostly on this excavated pit.

Fig. 1 Aerial view on the Chabarovice landfill

Body of the landfill was not stable, different movement were observed in history, very often connected with small – creep – movement, very sensitive to the rainfall. Therefore the steps of ensuring slope stability were incorporated among the other steps of the landfill remediation which started in 2000. Basic principle of remediation process is encapsulation with the help of vertical sealing cement bentonite slurry wall and sealing capping system.

Landfill shaping have to guarantee not only that the surface sealing system will be gravitationally drained but also that the lower general slope inclination will increase slope stability. Additionally the loading berm was proposed and constructed in the north-east part of landfill, where previous instability was observed. But in fact first problems started during the excavation for loading berm when local slips occurred. In summer 2001 sealing wall was finished as well as the capping system in the central part of the landfill. After heavy rainfalls in September 2001 first cracks were observed in the north-east part of the landfill, roughly in middle of slope, where ground shaping was not fully finished yet.

The reason why the cracks were observed in the middle of slope was not so difficult to explain due to an injection of the upper part where barrels with liquid waste material were expected and also due to higher infiltration of the surface water from the upper part, where capping system was finished. Visual and geodetic observation proved lower speed of deformation in the autumn and winter time, but after another speed increase 7 inclinometers were installed in March 2002. They proved shear movement in depth about 20 m in inclinometers just below observed cracks, about 5-7 m just front of the sealing wall and no deformation behind sealing wall. Cross section is shown on Fig. 2.

From the beginning the main discussion was associated with character of slope instability, because especially in IJ 5 shear deformation was only in the order of mm per month. Results from inclinometers IJ4 and IJ5 (and similar ones in the second cross section) were indicating slip surface, but on the other hand in the lower part no indication of surface uplift was observed to balance the mass lost in the upper part. To check the influence of creep deformation on the slurry wall, the surface was cleaned (protected during winter time) and only small cracks (1-3 mm) were observed, perpendicular to the longitudinal axis of the wall and guiding concrete strips. Shearing along these cracks reached max. 10 mm. Therefore the outer face of the vertical sealing wall was exposed and cracks were observed there, partly filled by clay. Width of these cracks was higher than on the surface, therefore the discussion of the width of the pit to allow bending loading of the exposed wall started. After that the discussion if the slope deformations are due to slip shearing or as the results of continuous deformation of the deposited clay, or as the result of collapse of spaces after old deep mining activity (roughly 20 m under surface of tertiary clays) was not so important.

At this stage it was doubtless that some additional steps should be done and that the price of the remediation will go up. The problem was that so many members started with some initiative – designer, investor, contractor, supervisor etc. Field investigation included another inclinometers (result of which was that the slip surface can be even deeper in the lower part, but shear deformations were again very low there), and pore pressure measurement. Pore water pressure was very high, exceptionally even higher than the surface at this time, probably as result of the additional loading in this part, indicating that the pore pressure parameter B is close to 1.

Many different slope stability calculations were executed, as methods of limit equilibrium so FEM. For average inclination between inclinometers IJ5 and IJ4 roughly 8^0 and residual angle of the internal friction roughly 11.5^0 it is obvious that pore pressure is playing most significant role. Potential slip surface is situated close to the boundary of origin tertiary clays with new deposited clays, where lowest shear strength can be expected as the result of water inflow and kneading in newly deposited clay and due to upheaval and swelling at the surface of origin tertiary clay. When using wedge method of calculation it was concluded, that the potential slip surface will go up in the lower part close to the axis of the sealing wall. Therefore when discussion what method of stabilization of slope deformation have to be used the method of lowering pore pressure by vertical drains

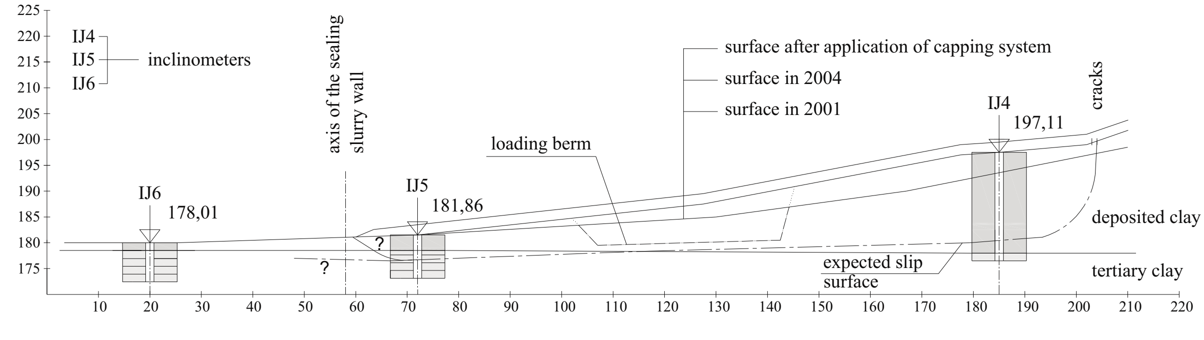

Figure 2. Section through reclaimed Chabarovice landfill

supplemented with small additional loading berm was preferred front of the methods proposing retaining wall from deep piles.

Still the investor preferred to prove the proposed method on limited area. Therefore at the end of 2003 vertical geodrains were installed on selected area – roughly 30 000 m with average depth about12 m (between 7-17 m). Proposed depth 17 m was reached only in the exceptional case because the resistance was bigger than expected from the penetration tests. Results of the pore pressure measurement proved quick pore pressure dissipation and the same result was obtained when additional loading berm was applied above area with vertical drains.

Final recommendation therefore include the following steps:

- to realize another vertical drains in strip above sealing wall (roughly 80 000 m with average depth 15 m),
- to add loading berm above this part,
- to add additional thin vertical sealing wall below existing one,
- to substitute proposed compacted clay liner (CCL) on the surface by bentonite mattress (GCL) to decrease additional loading and to improve the flexibility of the surface sealing.

3 UNSTABLE SIDE SLOPE OF OPEN CAST MINE

Based on previous activities in the region a three-year project “Research and Verification of Methods of Slope Movement Monitoring” was executed. Test site has an area of more than 20 ha and is located on side slope of open cast mine Chabařovice in North Bohemia (Fig. 3). The area was selected because of complicated geologic section which consists of excavated mine partly covered by internal spoil heap in lower part of the site. Upper part was not directly affected by mining activity.

The second reason for site selection is instability of both parts. The problem of slope instability will be important in near future because of reclamation forming lake in excavated area.

Research was designed to characterise slope stability conditions and to meet different categories of requirements:

- Indication of stable and or unstable area by geodesy and radar interferometry,
- determination of displacement range and velocity,
- indication of slip surface in sliding mass,
- determination of displacement along slip surface, spatial mass deformation and pore-water pressure distribution and
- link to slope stability computational methods for stability assessment.

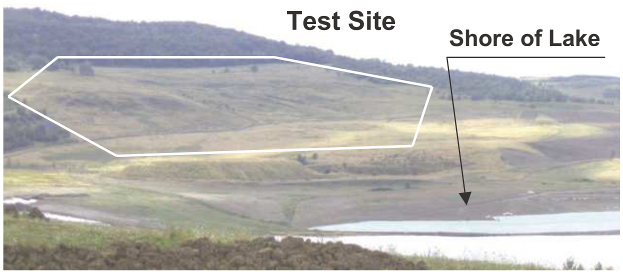

Figure 3. Unstable slope of open cast mine Chabarovice

3.1 *Test site instrumentation*

Test site offers slides with various rates of sliding with different kinematics and slip zones located in variable depth in areas with different inclination (Zalesky et al., 2003). Wide range of monitoring methods is used there:

- Geodetic measurement using set of Leica TC 1800 and re-installable measuring points installed by dynamic penetration equipment,
- combined casing for sliding micrometer and high accuracy inclinometer for reference points establishment, using special insert tool to link geodetical and geotechnical measurements (RAB VB 01÷03),
- combined casing for sliding deformeter (displacement range 100 mm/m) and inclinometer for measurement of 3-D displacements in unstable areas. (MPD 01÷04),
- standard inclinometer casing and magnetic settlement marks,
- pore-water pressure measurement using standard sensor with filter installed in boreholes and or BAT intelligent sensor with different filters installed by penetration.

Selected methods of geotechnical instrumentation are used in groups combined with geodetic measurement to ensure cross-comparing (Zalesky et al., 2004).

Special attention will be given to upper part of the site being not directly affected by mining activities and or to lower part located in the mined area, where the clay base is covered by internal spoil heap (Fig. 4).

Figure 5 describes typical section of the side slope of the mine with boundary between lower and upper parts.

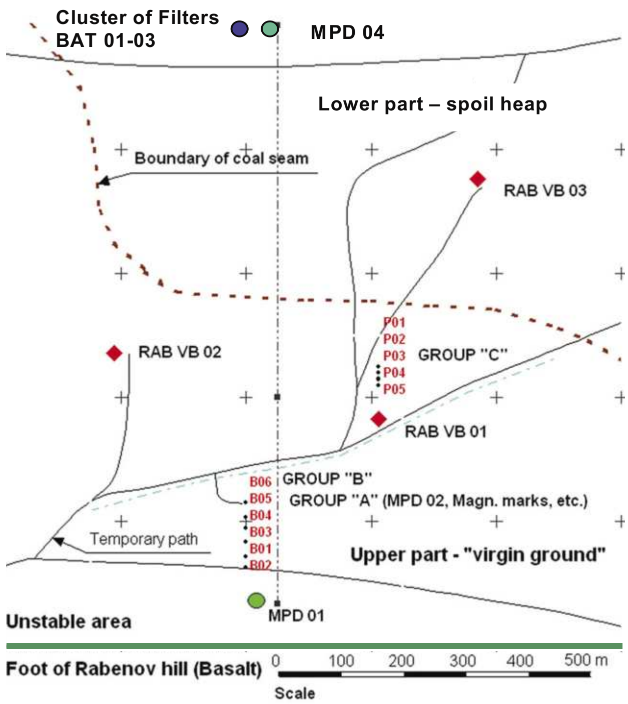

Figure 4. Test site - schematic site plan

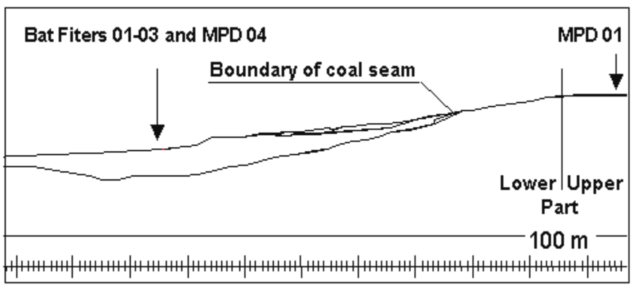

Figure 5. Typical section through unstable part of the open cast mine

In upper part, there were expected slides in shallow zone up to 6 m at the maximum. To be sure to describe the whole sliding activity in this part, the MPD 01 borehole 23 m deep was instrumented with combined casing.

3 clusters of BAT filters for pore pressure monitoring were installed in lower part the spoil heap. Location of the first is presented on Figure 4, other two are placed in shore of lake with rising up water level. Results of pore pressure monitoring will be discussed on example of the cluster BAT 01-03.

40 m deep borehole MPD 04 was bored and instrumented in 2004 after unsuccessful boring in 2003. Combined casing with total depth 40 m crosses 30 m of spoil heap and is embedded 10 m in clay base (Fig. 5). Boring in 2003 did not cross the spoil heap completely and it was used for open standpipe piezometer installation at 27 m depth (in Fig. 6 – MPD 04/2003).

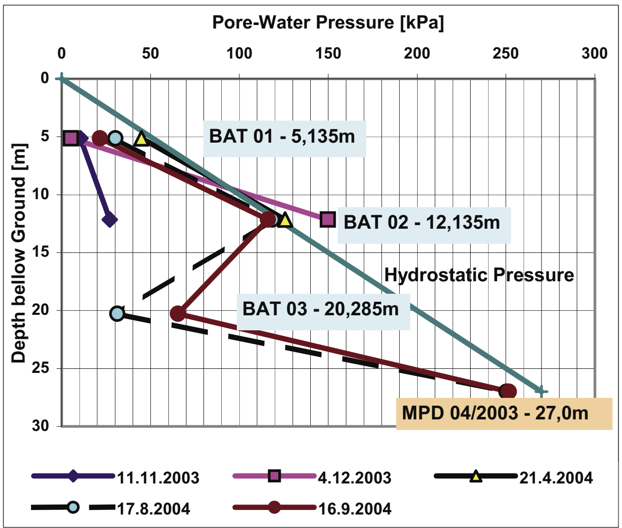

Figure 6. Example of pore-water pressure monitoring in spoil heap

3.2 *Selected results*

Assumptions about behaviour and probable slip zone location in the upper part of test site having inclination close or even less than 5° of horizontal were based on long-term observations and records and on geotechnical site investigation. One system of sliding (shallow slides) meets above assumptions. Instability prior to our instrumentation was with high probability triggered by excess of pore water pressure as a result of long term rainfalls. In time of project execution any excess of pore pressure was not measured because of long precipitation deficiency. Recorded maximum pore pressure was equal to maximum possible hydrostatic state of stress. Displacement measurement with different methods (geotechnical and geodetical) showed in good agreement creep movement of plastic soil several mm/year, only. This is probably connected with previous sliding accompanied by lifts up and drops down of uneven ground. Unfortunately any discrete shear displacement was not recorded in this shallow zone in time of project execution.

In the borehole MPD 01 there was recognized another independent slip zone located in virgin clay base bellow before mentioned zone of plastic soil. The slip is located in firm to hard clay formation at 10 to 11 m depth. Horizontal displacement in discrete shear zone was 10 mm within 1,5 year and the movement is still active. Axial strain measurement by sliding deformeter brings another complementary result connected with above horizontal presented shifts. Due to pretty high accuracy of strain and integrated axial deformation it is possible to evaluate character of soil behaviour with respect to contraction / dilation along slip surface. In this case firm to hard clay was compressed nearly 2 mm within 10 to 11 m depth. This particular case can be probably a result of inclined slip zone.

Monitoring of displacements in MPD 04 in lower part of the site took 2,5 months only and showed creep displacements in order of mm and settlement of 3 mm with zone of increased compression between 18 to 20 m.

Monitoring of pore water pressure in cluster of filters BAT 01-03 and in open standpipe piezometer was carried out 1 year. Selected results of pore pressure are presented in relation to depth with respect to time (Fig. 6). Diagram shows wide ranges of magnitude of pore-water pressure at different depth levels with time. Results are compared with theoretical hydrostatic state of water pressure (thick line). Measurements of pore-water pressure approved occurrence of separated “ground water horizons” in spoil heap body with occurrences of pore-water pressure significantly higher than hydrostatic. This can be due to “artesian water” supply and or caused by contractile behaviour by shear stress especially in soil with double porosity.

4 SUMMARY AND CONCLUSIONS

Authors wanted to show specific problems connected with slope instability, especially on contact with origin tertiary clay with excavated and re-deposited clay, where creep movement is partly due to shear strength decrease on this contact and probably also as the result of creep settlement of clay clods. For the Chabarovice landfill individual steps for stabilization of this creep movement were shown.

In the second case where the experimental tests were performed showed:

- Usefulness of combination of geodetic and geotechnical monitoring methods – especially for surface deformation,
- measured deformations are very low and slow, in the order of mm/year,
- zones, where shear deformations were observed by installed inclinometers, vary with depth indicating not only shallow instability but also a deep one,
- shear deformation in the upper part of testing area indicate deep slip zone (starting at the site slope of the old pit) and a great attention will be given to this result, because proposed flooding of this pit during the phase of area rehabilitation,
- pore-pressure measurement approved occurrence of less and more permeable layers, giving the chance for artesian water development and shoving significant changes with time, in the exceptional case higher than hydrostatic pressure – with negative impact on slope stability.

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