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ENGINEERING-GEOLOGICAL CONDITIONS OF THE EFFECT OF A LANDSLIDE FROM MINING ACTIVITY

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ABSTRACT

The paper deals with a slope deformation in Řepiště (Paskov), which is located between the towns of Ostrava and Frýdek Místek; Řepiště is situated in the Ostrava-Karviná District within the reach of the effects of mining activity. The deformation involves the Paskov Mine, which is the only active mine in the Ostrava section of the district. The study included mapping complemented with a geophysical survey using resistance tomography; along with the information obtained from the inspection, it provided an overview of the engineering-geological conditions of the slope deformation. The interpretation of the data obtained identified a very complicated structure, including several levels of slip surfaces. The landslide is thus a textbook example of slope movements with a very complicated geological structure occupying an extensive spatial area in the mining landscape and affecting the stability of a road running directly through its body.

KEY WORDS

- Engineering geology,
- slope deformations,
- mining,
- undermine.

1. INTRODUCTION

The Řepiště slope deformation is found between the municipalities of Paskov and Řepiště, about 5 km south of the city of Ostrava in the Moravia-Silesian region (Fig. 1) and in an area affected by the mining of a black coal deposit in the allotment of the Paskov Mine. It is on map sheet 15-43 of the Ostrava basic map on a scale of 1 : 50, 000 and map sheet 15-434 of the Vratimov map on a scale of 1 : 25, 000. At the same time, it is in a zone stretching a length of about 10 km in the N - S direction, which is morphologically (the steepness of the degree slope caused by the side cutting activity of the Ostravice River) and geologically predisposed towards the formation and development of slope deformations. According to the geomorphological classification of ČÚZK (1996),

the area of interest belongs to the Alps-Himalayan system, the Carpathian subsystem, the Western Carpathians province, the Outer Depression subprovince, the area of the Northern Outer Carpathian Depression, and the Ostrava Basin complex.

The locality is situated on the border of the subcomplexes of the Ostrava Bottomland and Havířov Plateau, which may be morphologically characterized by a degree of slope with an inclination oriented towards the west, which divides the bottomland and the first terrace of the Ostravice River. The mean altitude fluctuates around 244 m above sea level (the Ostrava Basin). Geographically, it is a case of the margin of a flat upland with an erosion-accumulation surface, while the terrain's configuration is conditioned by the geological structure of the bedrock affected by fluvio-glacial, fluvial and eolic modelling activity, as well as

Fig. 1 Localization of the Řepiště slope deformation

periglacial and humid destruction processes. As for the climate, it is a mildly warm, dry area with a mildly warm winter. From a regionally geological point of view, the locality belongs to the north-eastern part of the Bohemian Massif, the so-called Moravia-Silesian Region (Misař, et. al., 1983). The bedrock in the deepest parts of the structure is built up of metamorphic crystalline complexes. The Palaeozoic is represented by the flysch sediments of the upper Devonian and related deposits of the Lower Carboniferous, which gradually transit into the cyclic coal-bearing sedimentation of the Upper Carboniferous. The Upper Carboniferous deposits in the Upper Silesian Basin are stratigraphically divided into the Ostrava (paralic coal-bearing molasse) and early Karviná Formation (continental coal-bearing molasse). The articulated Carboniferous paleorelief oversteps the Miocene sediments of the Carpathian Fore-deep, which represent the autochthonous coat of the eastern slopes of the Moravia-Silesian section of the Bohemian Massif. As for the lithology, it is a case of claystone and clays with abundant silty and sandy components, whose thickness ranges to hundreds of metres in the territory in question. The Miocene sediments are overstepped by the Outer Carpathian nappes formed by the Silesian and Sub-Silesian units. Lithologically, there is claystone in the Silesian unit with positions of lime sandstone; there is sandy-silty lime claystone and clayey limestone in the Sub-Silesian unit. The Sub-Silesian unit of the Outer Carpathian nappes and parts of the Těšín-Hradiště Formation of the Silesian Nappe form the bedrock and lower positions of the slope deformation. The superincumbent Quaternary formations of

the Pleistocene age are made up of the unevenly spread glacialigenous Elster and especially Salic glacial rocks, character of glacialfluvial sands, sandy gravels and glaciallacustrine clays. In certain places, there are recent deluvial, deluviofluvial and mainly fluvial deposits of different lithological types.

Fig. 2 Location of the Řepiště landslide on a schematic geological map (modified from Cháb, et al., 2007)

The most significant aquifers are fluvial sands and gravels, especially in the valley flats and glacial sandy gravels of the Quaternary age; the isolators are fine-grained glacial, fluvial and eolic sediments. The locality of interest is directly drained by the Ostravice River (the erosive base of the area), which is the right tributary of the Odra River's main course of Order I. No. 2-00-00.

2. GEOLOGICAL CONDITIONS OF THE STUDY AREA

Within our study of the archival materials in the area of the slope deformation, we identified several exploratory projects carried out for various purposes. Among the most significant was a survey to calculate the reserves of black coal within the Paskov allotment, a survey to assess the return on investment for the extraction of brick-making materials (loess loams and glacialacustrine clays) behind the

south-eastern limit of the slope deformation and, last but not least, mapping work on broader scales and more detailed surveys in order to evaluate the stability of parts of the south-eastern section of the slope deformation. The stability was assessed with regard to the waste disposal site, which was established in a depression formed by the liquidation of a return airway of the Paskov Mine behind the edge scar in the south-eastern part of the slope, and secondly, in connection with the failure of a road running across the landslide's body and a road bridge over the Ostravice River in the toe part on the south-western border of the slope deformation. A systematic survey of the overall sliding area around Paskov was carried out in 1975, but no topical assessment of the locality to a similar extent has been implemented thus far.

Our own field research, which made use of the results of the bore-hole archive surveys, produced a functional map of the slope deformation (Fig.3); it depicts the morphological elements, partial landslides, selected wells implemented during previous exploration work, the lines of newly carried-out geophysical profiles, geological cross-sections and points on which the terrain deformation parameters were determined.

The specific and direct exploratory work carried out at the locality of interest included the implementation of engineering-geological and hydrogeological wells, namely in the periods around 1975, when the first survey of the locality took place. Certain engineering-geological boreholes (V26, V31 and V40) were fitted and later used to measure the precise inclinometry of the failure of the casings (in the order of the initial years); others provided basic information on the rock composition of the slope deformation. The HV101 hydrogeological borehole situated in the south-eastern part of the landslide provided samples for the laboratory determination of the basic physical-mechanical parameters. The next twenty hydrogeological boreholes carried out served to monitor the hydrogeological conditions of the landslide. Lastly, a network of geodetic points was established, with the use of which movements of the slope surface were observed.

Fig. 3 Map of the Řepiště slope deformation with positions of the sections marked

Fig. 4 Geological cross-section of the WE part of the Řepiště slope deformation

Fig. 5 Geological cross-section of the NWW-SEE part of the Řepišť slope deformation

Based on the geological profiles of the borehole archives and field research on the slope deformation, two geological cross-sections were fitted that reflect the rock composition in the south-eastern (Fig. 4) and south-western (Fig. 5) parts of the slope deformation. The following engineering-geological types of soils were determined within the geological structure of the slope deformation in the location of the first cross-section:

Deluviums unevenly cover partial sections of the slope deformation; they especially build the terrain's elevation and show a very irregular and locally variable structure. The initial materials for their formation are all types of rock from the bedrock. They are made up of various granulometric types of loam and clay with dragged positions of sandy and gravelly rocks of the Řepišť Plateau and with shreds to blocks of Pre-Quaternary bedrock rocks.

The *loess loams* represent the earliest member of the natural Quaternary sequence and are a case of silty and clayey loams of an eolic origin of a stiff-to-solid consistency.

The *sediments of the Řepišť Plateau* reach a thickness of over 20 m, but drop towards the north. It is a case of salic glacial sediments that, in an ideal sequence, are represented by gradual boulder loams, glacialustrine clays and glacialustrine gravels. This complex of lithogenetic types, of which ochre, yellow-brown and grey-brown colourings are typical, are not usually completely developed and often do not agree with the above-mentioned model.

Clayey eluviums, which represent a product of the weathering of the Pre-Quaternary rocks of the Sub-Silesian and Silesian Nappe. Lithologically, they are a type of variously tinted clayey soils of different consistencies and grain size distributions with the remains of a non-decomposed parent rock of changeable colours. In certain places the eluviums are linked to the Pre-Quaternary bedrock and can be distinguished from the diluviums only with difficulty.

Pre-Quaternary bedrock is represented by the rocks of the Sub-Silesian and Silesian Nappe, while the course of the then mutual

border is complicated with respect to the occurrence of frequent outliers and slices in the place of the nappe front (the edge of the thrust). In particular, there are various types of claystone, less sandstone and rare, but also relatively varied, rocks associated with teschenite.

At the location of the second geological cross-section, the occurrence of slightly different super incumbent deposits was discovered; they rest on Pre-Quaternary bedrock similar to the site of the first cross-section.

Made-up ground. In the near-surface parts there are coarse gravels with a loamy-sandy filling. Lower, as deep as 3 m, they pass into clayey-sandy and sandy loams of a mainly stiff consistency with abundant dark and reddish brown fragments of 1 - 5 cm. In terms of the classification according to ČSN 73 1001, these are soils of the Y group.

Deluvial sandy clays form the approximate 1.1 m thick bedrock of the made-up ground. Brown sandy clays, reddish, beige and black stains and a content of 1 cm fragments, a natural water content of $w_n = 25.59\%$, a degree of consistency of $I_c = 0.82$ (stiff) and a plasticity of $I_p = 27.04\%$, were identified by the laboratory. According to ČSN 73 1001, these are F7 (CS) class soils.

Deluvio-fluvial clays are brown to black, predominantly stiff, silty-sandy clays; in certain places they have a soft consistency with an admixture of organic material. According to ČSN 73 1001, the soil can be characterized as clay with the low to medium plasticity of the F6 (CL, CI) class.

Pre-Quaternary bedrock. In this partial section of the landslide there is mainly lime claystone; certain places have decomposed into grey to greenish-grey varied sandy clays. The solid rocks according to ČSN 73 1001 may be characterized as the R6 class and the decomposed soils as the F4 (CS) and F8 (CH) classes.

Table 1 below provides an overview of the laboratory and standard determined geotechnical characteristics of the rocks described in the location of the second geological profile.

3. FIELD MAPPING

Our own field mapping of the area identified and documented a whole number of natural sliding manifestations. These include a scar edge hidden by vegetation cover, the bending of trees (Fig.6), waterlogging in the slope crest above is the scar edge (Fig.7), and morphological elements in the landslide's body, such as the terrain elevation and depression of locally larger dimensions (Fig.8), an erosion gully with a bare wall and stretched root system in places, draining water in periods of heavier rainfall and waterlogging, especially in the toe part of the slope (Fig.9). In terms of impacts on the engineering structures, we identified cracks in the bituminous

Tab. 1 Overview of the geotechnical characteristics

Rock, soil	Bulk density γ_n (kN/m ³)	Total angle of internal friction φ_u (°)	Total cohesion c_u (kPa)	Effective angle of internal friction φ_{ef} (°)	Effective cohesion c_{ef} (kPa)	Poisson number ν	Deformation module E_{def}
Deluvial sandy clay (F7)	19.2	0	50	24-27	14-17	0.35	4-6
Deluvio-fluvial clay - stiff (F6)	21	0	50	18	12	0.4	3
Deluvio-fluvial clay - soft (F6)	21	0	25	17	8	0.4	1.5
Pre-Quaternary bedrock Limey claystone to clay (R6(F4))	21	0-4	60-70	24-25	14-20	0.35	5-7
Pre-Quaternary bedrock Limey claystone to clay (R6(F8))	20.5	0	50-80	14-16	7-12	0.42	3-5

Fig. 6 Scar edge hidden by vegetation cover (left, centre) and typical bending of trees (right)

Fig. 7 Waterlogging (left) and flooded depression (right) in the slope crest above the scar edge

carpet of the road (Fig.10) crossing the slope deformation. In the toe part of the slope (the south-western border of the slide), this road connects to the bridge over the Ostravice River, whose supporting members on the right bank of the river have also been affected by

sliding manifestations and later reconstructed (Fig.11). On the slope deformation itself and in its vicinity, there are several houses and fences (Fig.12) with apparent manifestations of sliding movements (cracks in the perimeter walls).

Fig. 8 Elevation (left) and depression (right) in the landslide's body, to a larger extent in certain places

Fig. 9 Erosion gullies (left, centre) with bare walls; in places they drain water off the slope, which leads to the formation of swamps on its toe (right)

Fig. 10 Cracks in the bituminous carpet (marked) with frequently repaired parts of the road, running through the side scar edges

Fig. 11 Failure of supporting members of a road (left) and its reconstruction (right)

Fig. 12 Failure of supporting perimeter walls of a dwelling house (left) and fence (right)

4. GEOPHYSICAL MEASUREMENTS

Resistance tomography of the slope deformation in Řepišť was carried out on two profiles (p1 and unclear p2) in its southern part. The *first profile p1* was situated on the south-eastern part of the slope deformation with a length of 128 m, while its top point was about 44 m above the scar edge (Fig.13, Fig. 3 –situation in the locality).

Above the scar edge of the first slip's surface at a distance of 42 m from the beginning of the profile, an area of high resistance was measured, which may be interpreted as a probable pocket of gravels

or sands. At a stationing of 45 m it is possible to interpret the beginning of the first slip's surface on the border of relatively high and low values of resistance, which in the whole length (83 m) is situated at a depth of 5 (in the lower part of the profile) - 10 m (in the central part of the profile) below the surface, and it approximately copies its relief. In the near-surface zone the slope is made up of loams of various characters below which there are very dry gravels. In the central part of the profile, a relative resistance minimum (approx. below 16 Ω m) was identified at a depth of about 10 - 20 m, which may be interpreted as an area with significant saturation by ground water, e.g., a rock body formed by much washed claystone.

Fig. 13 Profile p1 – results of resistance tomography of the Řepiště slope deformation and its interpretation

The forming of the second slip surface was interpreted at the stationing of 80 - 98 m, again on the border of relatively higher and lower values of resistance of about 2 m below the surface. Below this slip surface, at a depth of 10 - 18 m, an area with relatively high values of resistance was discovered (300 - 900 Ω m); it may be characterized as a position of gravelly or sandy soils. A relatively sharp border between the area of relatively lower resistance in the central part of the measured profile and the areas with relatively higher resistance may indicate a tectonic dislocation with an identical inclination to the slope deformation's inclination. The local maximum again passes (on the stationing of 100 m in the direction of the profile measured) into the local minimum, which is a very

Fig. 14 Profile p2 – results of resistance tomography and its interpretation of the Řepiště slope deformation

probable response to the significant waterlogging in the toe part of the slope deformation.

The second geophysical profile p2 of 158 m (80 electrodes, spacing that measures 2 m) was conducted in an EW direction approximately along the slope's thalweg (Fig. 3 –situation in the locality), while the top point of the profile is located below the road connecting the municipalities of Paskov and Řepiště.

In this profile (Fig. 14) three slip surfaces were interpreted by making use of the information from the shallow engineering-geological wells. The profile involved only the lower part of the first expected slip surface, which outcrops on the 24 m stationing. It is located in low resistance values (below 16 Ω m); probably it is a case of a deeper slip surface running to depths of 15 - 20 m. The second slip surface, which is as far as 22 to 60 m from the beginning of the profile, joins onto the first one and runs as deep as 7 m below the surface. On the stationing of 60 m it is possible to observe its gradual deepening down to 25 m (a stationing of 104 m), while in the overall length, it ranges in low resistance values (below 16 Ω m). The third expected slip surface was interpreted as deep as 25 m on the 40 m stationing at the site of the local resistance minimum (about 5 Ω m). Its further course may be characterized by gradual shallowing to the 136 m stationing where it outcrops. At the stationing of 104 m there is an apparent crossing of the second and third slip surfaces, which manifests a relatively complicated case of massif failure. It is located approximately as far as 122 m from the beginning of the profile in an area with a relatively low value of resistance compared with the surroundings (below 16 Ω m). In the area of the outcrop it runs through locally minimal resistance values (about 140 Ω m), which are surrounded by local resistance maximums of about 700 - 1300 Ω m. According to the profile curves of the apparent resistance that are, when compared with the 2D resistance model, a different type of representation of the values taken, outcropping snags all the way to the surface were also determined in connection with the second slip surface according to the local minimums on the stationings of 57 and 96 m.

5. CONCLUSION

Concerning its geology and geomorphology, the locality of Řepiště is significantly predisposed to the formation and development of slope movements. The structure of the degree of the slope between the Havířov Plateau and Ostrava Bottomland, which falls into the Ostravice River flat, is characteristic of deluvio-fluvial deposits, i.e., the alternation of gravelly and sandy soils with fine-grained soils on the clayey bedrock of the Silesian and Sub-Silesian units of the Carpathian nappes.

The benefits of the archival work are the identification of borehole reconnaissance. The field mapping carried out led to the documentation of sliding manifestations, such as a scar edge, stretched root systems in open cracks, the bending of trees, waterlogging above the scar edge, and terrain elevation, depressions, erosion gullies, cracks on the road, etc., in the toe part of the slope.

The main contribution of this study in terms of the reconnaissance of the locality is the implementation of geophysical measurements using the resistance tomography method on two profiles. Two levels of mutually connecting slip surfaces were identified in the profiles. Based on the facts discovered using resistance tomography,

the situation in the slope deformation may be labelled as very complicated from the point of view of slip surfaces.

The manifestations of landslides damage the road running across the slope, the road bridge situated in the south-western part of the toe section of the slope, the houses and the fence. Therefore, it would be suitable to carry out complementary exploratory work and monitor the slope movements in the locality.

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