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Risk assessment of deep-seated slope failures in the Czech Republic

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ABSTRACT: This article deals with examples of deep-seated slope failures situated in regions with various geological, morphological and tectonic conditions in the territory of the Czech Republic. The selected examples are situated in the outer western Carpathian flysh zone, Bohemian Cretaceous basin, and Tertiary neovolcanic area. All these regions are characterized by high susceptibility to deep failures. Results of monitoring of recent movement activity and models of slope failures are demonstrated.

1 INTRODUCTION

Slope deformations are a significant geodynamic phenomenon for the Czech Republic territory. They are responsible for considerable damage to technical objects, as well as on the property of the population. Slope deformation studies, as well as practical measures to solve unfavorable effects are of an old tradition.

As early as around 1920 professor Quido Záruba, a founder of the Czechoslovak engineering-geological school, published his first study about landslides. It was the occurrence of landslides destroying a part of the mining town of Handlová in Central Slovakia between 1960 and 1961 that invoked nation-wide systematic registration of dangerous landslide phenomena in economically important regions of former Czechoslovakia between 1962 and 1963. The data were collected and deposited in Central geological archives Geofond in Prague and Bratislava, and they are accessible electronically. Organized updating of Geofond in the Czech Republic was carried out after 1997, in the year of an avalanche-like occurrence of landslides and earth flows in flysh rocks of Western Carpathians (Rybář & Stemberk 2000) of the eastern part of the republic. In the most suffering parts of the republic a detailed mapping of stability conditions at a scale of 1 : 10 000 was carried out. Then, prognostic maps of susceptibility to landsliding were derived and gradually handed over to public administration officials dealing with land use planning (Rybář 2003).

After completing the nation-wide registration of all the dangerous landslide phenomena during the 60's of the last century, a coordinated research into slope movements was organized in Prague and Bratislava. Increased attention has been paid since to deep-seated slope deformations. The majority of cases were considered permanently dormant. Old relict forms of deformations not respected during construction or mining activities may cause a situation when even a minor improper disturbance (e.g. unloading of slope toe, loading of the upper part of the slope, leakage of water from a water supply or sewage line, etc.) may trigger uncontrolled movements and an emergency state.

2 REGIONAL DISTRIBUTION OF DEEP-SEATED SLOPE DEFORMATIONS IN THE CZECH REPUBLIC

The territory of the Czech Republic belongs to two different geological units of quite uneven geotectonic evolution. A major portion of the territory of the Czech Republic is a part of an old Hercynian mountain range, the so-called Variscan province, the geotectonic evolution of which finished at the end of early Paleozoic. This territory is indicated as Bohemian Massif which reaches to Austria in the south, to Bavaria in the west, and to Saxony and Poland in the north. The eastern part of the Czech Republic, considerably smaller, belongs to a younger unit, to a so-called Alpine province. A young mountainous system with a complex nappe de charriage structure originated by the end of the Secondary era and in Tertiary. Engineering-geological conditions between Bohemian Massif and Western Carpathians are substantially different, which results in a serious dissimilarity in slope movement evolution.

Deep-seated slope deformations in Bohemian Massif can be found mainly in the Bohemian Cretaceous Basin, and also in the highland areas of Tertiary volcanites. In Western Carpathians it is mainly flysh rocks of the mountainous relief of the Moravskoslezské Beskydy Mts. that are affected by deep deformations.

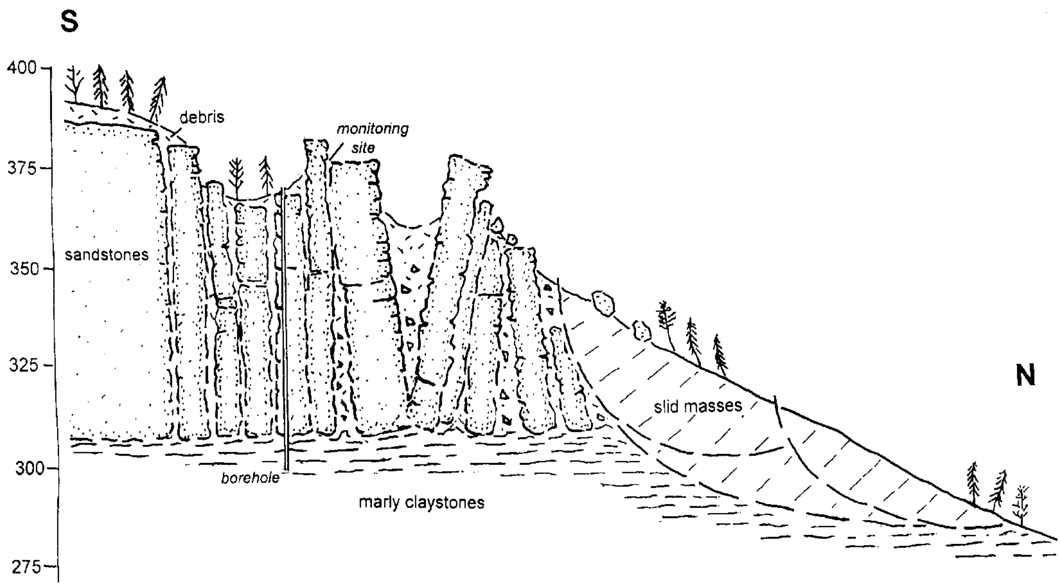

Figure 1. Cross-section through the slope deformation near Olšina Village with position of exploratory borehole and monitoring site.

3 SELECTED TYPES OF DEEP-SEATED SLOPE DEFORMATIONS IN BOHEMIAN MASSIF

Ideal conditions for deep slope failure appear in a situation when the upper part of slopes is built by rigid, brittle and permeable rocks, while the lower part by plastic rocks with low permeability. Then, in the upper parts rigid blocks creep on the plastic bedrock (after classification of Nemčok et al. 1972). After Varnes (1978) it is a "lateral spread". Research into this type of slow and long-range slope movements is of a long tradition in the Czech, as well as in the Slovak Republics (Záruba 1956, Pašek & Košťák 1977, Malgot 1977, Nemčok & Baliak 1977).

3.1 *Highland region of Bohemian Cretaceous*

Classical examples come from the margins of sandstone tabular rock-benches in the region of the Bohemian Cretaceous Plateau (Fencl 1966, Kyrianová 2004). Příhrazy Highland in the watershed of the Jizera River is a typical area. The landslides have been monitored there since 1926 when an extensive landslide originated destroying a substantial part of the village of Dneboh (Záruba 1927; Záruba et al. 1966). The landslide originated in claystones and marlstones overlain by quartzitic thick-bedded sandstones up to 106 m thick. The upper part of the slope built by sandstones was disturbed by intensive gravitational loosening.

As the studies show, these large and complex forms of block-type slope deformations (Fig. 1) resulted from an intensive destruction of the plateau edge under climatic-morphogenic conditions of the Pleistocene and early periods of Holocene. However, under present conditions these forms of block-type deformations have been considered almost constantly inactive or fossil. A long-term stability was, among other considerations, evidenced by the absence of failure of Drábské Světničky Castle ruins, the castle built by the end of the 14th century just above the Dneboh Village.

Since 1989, morphologic signs of a sharp acceleration in slope processes have been observed in the northern slopes of Příhrazy Highland. There appeared subsurface erosion and fresh sinking of ground into fissures without any obvious intervention into the slope. At the beginning of summer 1989 an intensive failure process in a small rock tower at the plateau edge above Olšina Village was found. Considering the geodynamical phenomena indicated above, systematic monitoring of movements in the sandstone massif has started.

Monitoring has confirmed a steady creep process with an average rate of about 2 mm/year. Active block movements can be evidenced with the observation that new fresh sinks in superficial sediments appear up to several tens of meters from the upper edge of the slope (Stemberk & Zvelebil 1999, Stemberk 2003). In an exploratory borehole situated directly into the zone where active block movements had been observed, about 1 m thick layer of marlstones with plastic consistency was detected at the contact sandstones-marlstones. A direct relation between movements at the monitoring place and variations of groundwater level was evidenced by groundwater level monitoring. A sudden block movement by 3 mm occurred at the end 2002, and gradual uplift of groundwater level by about 1,7 m followed. Groundwater level stabilized then by the end of August 2004.

3.2 *Highland regions of neovolcanites*

Engineering-geological region of neovolcanites belongs to the regions in Bohemian Massif that suffered most from deep-seated slope movements. The basic condition for such deep-seated deformations stems from the fact that, as a rule, at least two different rock complexes of uneven strength characteristics are found together. More rigid and more resistant rocks to weathering always represent reinforcement for the slopes. They are found either in subhorizontal positions or cutting less resistant beds through. Slopes in less resistant rocks keep inclinations higher than the critical one, which leads to permanent instability. Deformations reach often even a depth of several tens of meters, in some cases a depth of 100 m and more. Three cases studied in more detail were selected as examples.

The locality of Stadice Village (Fig. 2) is situated on the left bank of the Bílina River in the České Středohoří Highlands. The studies took place within a layout project for Prague-Dresden motorway D-8. The blocks broken off the edge of a basalt lava sheet about 60 m thick, were found sunk into underlying tuffs and tuffites. Numerous undrained depressions and platforms dipping back against the slope were surveyed. Here, in the western part of the separation zone, is the largest compact block 350 m long and 150 m wide is laying. Its surface is inclined about 18 deg against the slope. The lower part of the slope displays landslides with faces reaching the fluvial plain of the Bílina River (Pašek & Demek 1969). The stretch of the motorway D-8 put already into operation is not threatened by slope movements.

Deep-seated deformation of slopes built by a series of lava flows and sheets in alternation with intercalations of clay sediments can be exemplified in the locality of Čeřeniště Village laying on the right bank slope in the valley of the Labe River (Fig. 3). Basanite lavas are often altered here. The upper part of a considerably large landslide area is found here disrupted by creep lateral movements reaching a depth of 100 m, at least. It is separated from the central part of the slope deformation by a conspicuous platform about 500 m long dipping moderately against the slope. Relatively fast sliding movements take place in the central and lower parts of the slope where rocks of the weathered coat are found. Investigations confirmed at least six lava flows up to 30 m thick in the volcanic complex affected by deep

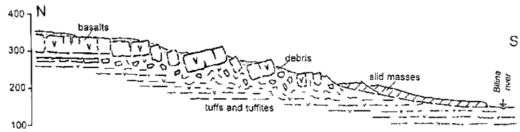

Figure 2. Cross-section through Stadice Village locality in the region of České Středohoří Highlands neovolcanites.

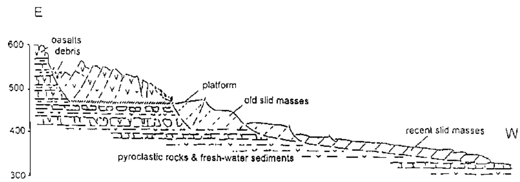

Figure 3. Geological cross-section through the slope deformation of Čeřeniště Village.

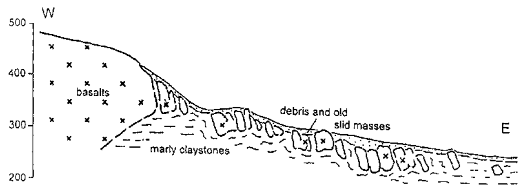

Figure 4. Cross-section through a large landslide area of Prackovice Village on the Labe River left bank.

slope deformations. The lava flows are separated by sedimentary, mainly clayey intercalations. X-ray analysis indicated smectite as the prevailing mineral of all the clayey intercalations. Smectite is very unstable in volume, and brings about weakening of planes and zones characterized of depressed shear strength. These predisposed zones result in gravitational failure of volcanic bodies that can be classified mechanically as lateral-type slides. There was an interdisciplinary research applied here with methods of engineering-geology, Quaternary geology, geomorphology, geomechanics and applied geophysics (Rybář et al. 2000). Monitoring and physical models (Rybář & Košt'ák 2003) contributed to a closer clarification of the mechanism that produced such complex gravitational slope failure.

On the left bank of the Labe River one finds locality of Prackovice Village where rigid blocks move on plastic beds (Fig. 4). Margins of a volcanic body built partially by basalt, partially by trachytic rocks, that are heavily altered at places, are disrupted. Blocks separated from the mother volcanic body sit on calcareous claystones and marlstones of Upper Cretaceous. Marginal volcanic rocks are displaced and rotated down the slope and form a typical dominant of the local morphology. Their surface often shows a backward tilting, against the slope. It is so even in the case of the largest of the blocks which is about 450 m long and 50 to 60 m wide. Here, crossing this area of Prackovice Village, the route of motorway D-8 was designed. Therefore, engineering-geological, geotechnical and geophysical survey was effected here in several steps.

The layout and size of individual buried basalt blocks was successfully verified with the use of geomagnetic methods. Two blocks were drilled through by core boreholes. At one case the basalt block was found 38,7 m thick and clearly separated from the bedrock of Cretaceous marlstones that were in a zone 1,40 m thick intensively deformed. In the central and lower parts of the slope prospecting verified thickness of the slid material of up to 15 m. All the studies proved that the motorway construction will be demanding but realizable (Pašek & Kudrna 1996).

4 SELECTED TYPES OF DEEP-SEATED SLOPE DEFORMATIONS IN WESTERN CARPATHIANS

Extensive slope deformations in the eastern section of the Czech Republic reached by Western Carpathians developed on the crests and on the slopes of Moravskoslezské Beskydy Mts. Under mountainous conditions of flysh where sandstones alternate with claystones, it is mainly translational slope movements along moderately inclined predisposed planes and zones that occur. They can involve very slow creep at rates of mm per year but also can accelerate and develop into dangerous fast moving character of rock slides.

A long tradition has been the investigation of a mountainous slope under the crest of Mt Lukšinec, a north-western spur of Mt Lysá Hora (1323 m a.s.l.). A group of thick-bedded sandstones, 30 to 70 m thick, is disturbed by block gulches up to several meters wide (Novosad 1966). In one of them covered by debris, a dilatometric instrument TM 71 was installed, and monitoring has proved quasi-continuous rate of about 0, 5 mm per year in block separation (Novosad & Košt'ák 2002). In the bedrock of sandstones one finds a sandstone group of beds intercalated with claystones. Beds are tilted from 10 to 15 deg and the tilt coincides with the slope inclination (Heiland 1998).

Another locality in the Moravskoslezské Beskydy Mts., being monitored for a long time, is a translatory landslide on the right bank of the water reservoir Šance on the Ostravice River. The slide is old and was activated in 1969 by water rise in the reservoir backwater zone. Displacements in total have reached up to 4 m since. Movements were monitored from the very beginning of the reservoir construction and small deceleration of movements was indicated. Monitoring methods were improved radically during the last decade. The data are registered automatically with remote satellite transmission. Continual monitoring of the rock slide made it possible to handle an emergency situation here when slope movements started to accelerate rapidly during a flood period of July 6, 1997. There was a danger that the reservoir could be partially filled and the dam crown spilled over. An emergency plan allowed for evacuation of the population from the valley under the dam and the notice was bound to monitoring data. Luckily, extreme precipitation stopped after July 9, and landslide movements slowed down rapidly and returned to the original non-catastrophic level (Novosad 2002).

Since 2000 data about gravitational movements have been monitored in the crest area of Moravskoslezské Beskydy Mts. Blocks of rigid sandstones and conglomerates with intercalations of claystones are moving along predisposed planes and zones that are usually bound to bedding and tectonic fault lines (Stemberk & Jánoš 2003). Plan areas of slope deformations reach hundreds of square meters to kilometers. Relief in the crest parts of slopes is usually step-like, and the so-called double crests are frequent. Mapping registered systems of pseudokarst fissure caves in separation zones. These reach considerable depths, e.g. in Kněhyně Cave had a measured depth of 72,5 m.

First results from monitoring in Cyrilka Cave reflect present tectonic movements in the evolution of the cave system (Stemberk 2002). Cyrilka Cave originated on a NNE-SSW fault crossing the main ridge of the Moravskoslezské Beskydy Mts. which is generally oriented to E-W. Sinistral horizontal movements were registered, corresponding to the geologically proven youngest Upper Tertiary movements in the area (Krejčí et al. 2004).

In the eastern part of Hostýnské Vrchy Hills, on SE slope of Křížoý Hill one finds an extensive landslide area up to 800 m long and 375 m wide. Limits of the disrupted area in ground plan show correlation with tectonic fault lines. A separation wall in arcose sandstones is up to 45 m high with fissure caves at its toe that are accessible to a depth of 12 m. A total sink in the upper trench can be estimated up to 65 m. In the uncovered bedrock of sandstones one will find alternating flysh layers of claystones and sandstones. The upper part of the slope deformation displays block-type character while in the lower part passes into a complex of active and temporary stabilized landslides (Fig. 5). Baroň (2004) presents results of dilatometric measurements in pseudokarst of Zbojnická Cave from a period December 2001 – September 2004 and comes to wall separation by about 1,7 mm and to subsidence of cave bottom by about 2,6 mm. Movement reactivation is generally parallel with precipitation, however delayed by 15 to 25 days. Reaction to temperature is considerably smaller.

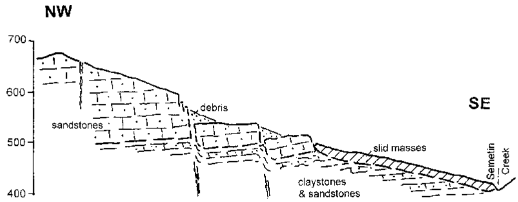

Figure 5. A schematic cross-section through the Křížový Hill slope deformation.

5 CONCLUSIONS

The Czech Republic pays an increased attention to deep-seated deformations of creep character. To recognize them in the terrain is often not easy and requires a long experience. In the relief, forms of such deformations are usually most obvious in the upper tensile zone while at the slope toe they are often completely wiped out by denudation processes. In the past such deep slope deformations were considered permanently stabilized. Monitoring with the use of high resolution instruments brought important data showing instability in a series of investigated deformations. Old relict deep-seated deformations not recognized in time may be activated or their low rate movement accelerated in case of an anthropogeneous intervention. A number of examples from Czech Cretaceous Plateau can be named where instability originated during construction of motorways in regions with relict forms of deep-seated slope deformations.

Let us give the example of old deep slope deformations that were underestimated during investigations for dam construction near Žermanice Village in the region of the Carpathian flysh in NE Bohemia in the 50's of the last century. Only after the construction of the concrete gravity dam were the slopes of the valley found to be affected by old deep deformations (Záruba 1956). It was about 30 m thick bedded vein of rigid volcanic rock of Těšinit group of beds that was broken in the Pleistocene into huge blocks sinking in soft Lower Cretaceous marlstones of bedrock. Excavations during dam foundation caused dangerous reactivation of old movements, and a series of measures had to be applied to complete the reservoir. Safe operation called for a monitoring system, and present results give evidence of permanent movements and inclinations of dam blocks at low rates that, however, cannot cause any damage during operation of the water reservoir.

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REFERENCES

Baroň, J. 2004. Structure, dynamics and history of deep-seated slope failures. Ph.D. Thesis, Masaryk University, 1–98. Brno.

Fencl, J. 1966. Types of landslides in the Cretaceous Basin of Bohemia (in Czech). *Sbor. geol. Věd, Ř. HIG* 5: 23–36.

Heiland, J. 1998. Translational block-type slope movements-mechanism and examples. *Acta Montana IRSM AS CR*, AB 6 (109): 81–137.

Krejčí, O., Hubatka, F. & Švancara, J. 2004. Gravitational spreading of the elevated mountain ridges in the Moravian-Silesian Beskids. *Acta Geodyn. Geomater*. 1,3(135): 97–109.

Kyrianová, I. 2004. Mapping of geodynamic phenomena in NE parts of the Příhrazy Plateau (in Czech). *Zpr. Geol. Výzk. V r.* 2003: 69–71. Praha.

Malgot, J. 1977. Deep-seated gravitational slope deformations in neovolcanic mountain ranges of Slovakia. *Bull. IAEG* 16: 106–109.

Nemčok, A. & Baliak, F. 1977. Gravitational deformations in Mesozoic rocks of the Carpathian mountain range. *Bull. IAEG* 16: 109–111.

Nemčok, A., Pašek, J. & Rybář, J. 1972. Classification of landslides and other mass movements. *Rock Mech.* 4(2): 71–78.

Novosad, S. 1966. Slope disturbances in the Godula Group of the Moravskoslezské Beskydy Mountains (in Czech). *Sbor. geol. Věd, Ř. HIG* 5: 71–86.

Novosad, S. 2002. Šance dam – "Řečica" landslide. In "*1st ECL Field Trip Guide, Post-Conference Field Trip*", 11–20. Praha, Bratislava.

Novosad, S. & Košt'ák, B. 2002. Lukšinec Hill. In "*1st ECL Field Trip Guide, Post-Conference Field Trip*", 21–23. Prague, Bratislava.

Pašek, J. & Demek, J. 1969. Mass movements near the community of Stadice in north western Bohemia. *Studia Geographica* 3: 1–17.

Pašek, J. & Košt'ák, B. 1977. Block-type slope movements (in Czech). *Rozpr. Čs. Akad. Věd, Ř. mat. přír. Věd* 87(3): 3–58.

Pašek, J. & Kudrna, Z. 1996. Motorway in a landslide area in the České Středohoří Mts. (in Czech). *Zb. 2. Geotechnická konf.*: 97–102. Bratislava.

Rybář, J. 2003. Landslide susceptibility mapping under conditions of the Czech Republic. *Geologisches Jahrbuch*, SC 4: 253–257. Hannover.

Rybář, J. & Kudrna, Z. 2004. Evaluation of dangerous geodynamic phenomena near the town of Mladá Boleslav, Czech Republic. *Zb. ved. konf. "Geológia a životné prostredie"*: 97–101. Bratislava.

Rybář, J. & Košt'ák, B. 2003. Monitoring and physical model simulation of a complex slope deformation in neovolcanics. In Natau, O., Fecker, E., Pimental, E. (eds), *Geotechnical Measurements and Modelling*: 231–237. Lisse, Balkema.

Rybář, J. & Stemberk, J. 2000. Avalanche-like occurrences of slope deformations in the Czech Republic and coping with their consequences. *Landslide News* 13: 28–33.

Rybář, J., Vilímek, V. & Cílek, V. 2000. Process analysis of deep slope failures in České Středohoří neovolcanites. *Acta Montana IRSM AS CR*, AB 8(115): 39–46.

Stemberk, J. 2002. Slope and tectonic movements trial in Moravskoslezské Beskydy Mts. In *1st ECL Field Trip*

Guide, Post Conference Field Trip: 24–27. Praha, Bratislava.
Stemberk, J. 2003. Study of the slope deformations on Příhrazy plateau near Mnichovo Hradiště, map sheet 03-34-01 at a scale of 1:10 000 (in Czech). *Zpr. geol. Výzk. v r. 2002*: 102–103. Praha.
Stemberk, J. & Jánoš, V. 2003. Slope deformations on Radhošť Ridge, Moravskoslezské Beskydy Mts., map sheets 25-23-09 and 25-23-10 at a scale of 1:10 000 (in Czech). *Zpr. geol. Výzk. v r. 2002*: 104–106. Praha.
Stemberk, J. & Zvelebil, J. 1999. Changes of the slope movements activity along the north-western rim of the Příhrazy plateau (in Czech). *Geotechnika*, 2: 15–20.
Varnes, D.J. 1978. Slope movements types and processes. In R.L. Schuster & R.J. Krizek (eds) "*Landslides Analysis and Control*", 11–33, Special Report 176, Washington D.C.
Záruba, Q. 1927. About sliding of soils in Czechoslovakia (in Czech). *Čs. Vlastivěda,1.díl*: 83–90. *Praha.*
Záruba, Q. 1956. Superficial quasi-plastic deformations of rocks (in Czech). *Rozpr. Čs. Akad. Věd. Ř. Mat. přír. Věd* 66(15): 1–34.
Záruba, Q., Fencl, J., Šimek, J. & Eisenstein, Z. 1966. Analysis of the Dneboh landslide (in Czech). *Sb. geol. Věd, Ř. HIG* 5: 141–160.