Research results of geotechnical properties of soils at the Podkrušnohorská výsypka dump in Sokolov brown coal field

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Open pit brown coal mining in the Sokolov coal field has been suffering with the lack of a space for overburden rocks dumping from its very beginning.

The Podkrušnohorská výsypka dump is situated in a geomorphologically highly broken landscape at the Krušné Hory Mountains foot and northern part of Sokolov Basin divide.

Dump rock consists of tuffaceous clays vith minimal specific resistance values QST = 0.5 - 1.0 MPa and cypric clays with minimal specific resistance values QST = 1.0 - 2.0 MPa.

Large scale research works took place on the dump in various periods of time. The mining solutions of the methods on the dump were subjects of stability expert's statements. 23 statements were produced sequentially from 1966 which were aimed to both general slopes of whole the dump and partial issues on the dump during its foundation.

The dump was the scene of the series of landslides, most important of them were in the years 1986/1987 and 1990. Hydro-geological and geotechnical research was the base for stability reports and it concentrated in the dump bed quality, dump water bearing, bed water bearing, and to obtaining geotechnical parameters dump bed and dump rock fill. Basic physical and descriptive strength, transformation and technological parameters were established by in situ and laboratory tests.

A long term geotechnical monitoring has been taking place on the dump – ground water level measurement, penetration measurement, dump body pore pressure measurement, inclinometric measurements in the drills, and geodetic observation of surface points of the dump.

Key words: *geotechnical properties, dump, soil, brown coal, Sokolov*

Area characteristics

Podkrušnohorská Výsypka Dump is situated in a highly geo-morphologically broken landscape at the boundary between the Krušné Hory Mountains foot and northern part of the Sokolov Basin. The area of interest was originally created with forest landscape with varying representation of beech, oak, and significant share of confers, mainly fir and pine. The landscape was originally very broken and the segmentation was kept by mining activity – building of the Podkrušnohorská Výsypka Dump.

Total area affected by mining activities is 1957.1 ha. The dump length is 8.3 km west – east and width 2.3 km. Ca 886 000 000 m^3 overburden rock was deposited in the dump.

An original configuration of the terrain under the dump was ca 460 – 480 m above sea level in the south and 460 – 530 m above sea level in the north, the terrain was declined from north to south and south west under a general declination not more than 2 degrees. The Boučský and Hluboký Potok Streams ran a western par of the area in a widely opened valley which got narrow to a deep gorge. The Lomnický Potok Stream ran between the western and eastern part of the dump in a shallow valley and the area had a character of an elevation which made good conditions for precipitation runoff. The Lipnický Potok Stream ran between the central and eastern part of the dump in a N – S oriented valley which created depressions with surface and underground water overflow in its central part. The Vintířovský Potok Stream ran in the eastern part of the area in a NW – SE oriented valley. The eastern part of the original terrain was relatively flat with a plain at 480 m above sea level. The Lipnice quarry was mined out and its mining space cancelled. Former Lipnice pit bottom and W and N parts declines generally in longitudinal N – S direction and in general N - N declination in south and eastern part. The Erika quarry was mined out in the south western part of nowadays dump. The bottom of the pit decreases from north and west to south to the deepest point of 429 m a. s. l., which was in the central part of the pit. Both mined out pits were filled with older dumps. Dumping in all the dump was finished according to valid projects.

The configuration of a new terrain after finishing all dump body is created by a new body with a oblong shape in W – E direction with a 8.3 km total length and 2.3 km average width with two peaks 600 m a. m. s. l. high between which a shallow gap originated in S – N direction. The surface of the dump decreases from the peaks under a general declination 1 : 15 to 1 : 17 to south and south west, under a declination 1 : 13 to 1 : 15 to south east, and under a declination 1 : 7 to 1 : 8 to north. Single dump levels are sloped and shaped to a required body form (Stanek, 1991).

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Geological characteristics of Podkrušnohorská Výsypka Dump bed layer

This part of the area of interest belongs to southern block of Svatava crystalline complex which is a part of the Krušné Hory Mountains crystalline complex.

Crystalline complex

Crystalline rock massif is created by binary micaceous muscovitic schist, silicificated a lot, locally by phyllitic rock. The crystalline surface was weathered kaolinitically to a remarkable depth. Weathered material was often redeponed by water erosion and it creates positions of coarse sandy micaceous kaolinitic clays to fine grain sands.

Tertiary

Early tertiary is represented by sediments of Staré Sedlo strata lying on denuded crystalline surface. Sandstones, quartzites, and conglomerates of those strata have been preserved only at the relicts near south and south east margin of the area of interest

Quaternary

Quaternary sediments are developed in irregular mostly small depths in the area of the dump. They are slope loams with low content of the chips of quartz, sandstones, and mica schists. There are peat stones and small depth peat in local depressions. An immediate dump bed is created by a small layer of loams, sandy clays with mica schist or quartz chips under which positions of totally or partly decomposed mica schists are. It implies from the analysis of all research works in the territory that base is not an unsuitable geo-mechanical environment with occurrence of unbearable stratigraphic strata.

Hydro-geologic situation in the base and body of the dump

It implies from engineering geological exploration results that the contact of a dump with the base is not aquiferous continuously at all the area of the dump but aquiferous areas are quit large.

Exploration profiles

Characteristic profiles where slopes stability was explored were selected to evaluate the stability of dump slopes.

The stability of slopes was solved, exploring and surveying works were concentrated, hydro-geological regime of water in the dump, and field observations were carried out in the profiles which go through sensitive parts of the slopes of the Podkrušnohorská Výsypka Dump.

Strength parameters of dumped rocks

Strength parameters of dumped rocks were found out in more stages.

<u>**Strength parameters of rocks used in final review of dump slopes stability** (For the plan of opening, preparation, and mining)</u>

Calculation parameters of shear strengths were determined from the analyses of previous development of stability in the dump.

a, Shear strength of mushy earths from lower parts of filled Erika pit. It is lower than a measured minimum. The mushy earths were not able to undergo shear tests owing to their odd consistency:

$$\boldsymbol{c} = 5\ \text{kPa},\ \boldsymbol{\varphi} = 2.6^{\circ}$$

b, Shears strengths of earth which are in the area of lowest measured residual strengths. They characterise shear strength of the contact of a dump and a base with various aquiferosity and disturbance:

$$\boldsymbol{c} = 5\ \text{kPa},\quad \boldsymbol{\varphi} = 2.6^{\circ}$$
$$\boldsymbol{c} = 6\ \text{kPa},\quad \boldsymbol{\varphi} = 2.9^{\circ},\ \text{enlarged by 20 \%}$$
$$\boldsymbol{c} = 7.5\ \text{kPa},\ \boldsymbol{\varphi} = 3.9^{\circ},\ \text{enlarged by 50 \%}$$

Strength which is a calculation value for current dump levels in Erika quarry area. The strength is approximately in the middle of the residual values range:

$$\boldsymbol{c} = 10\ \text{kPa},\ \boldsymbol{\varphi} = 6^{\circ}$$

Strengths which characterise shear strength of new dump. i.e. planned levels. They are approximately in the middle of top values range:

c = 10 kPa, φ = 12°, lower value is applied at calculation of Erika quarry area

c = 20 kPa, φ = 14°

Safety of final dump shape in all the dump space is explored at eight characteristic profiles (Dykast, 1992). The found out stability coefficient $\mathbf{k_s} \geq 1,5$ suits mining regulations

Stability solution

Three independent methodologies were used for dump stability solution:

- (MON) octaedric tension methodology,
- (MRS) force balance methodology,
- (MS) S. K. Sarma methodology.

Hydrologic situation

A large body of Podkrušnohorská Výsypka Dump with its 1957, 1 ha area is a significant hydrologic element in the landscape, too. There are more water outflows in the foot of the dump. All the outflows are long term monitored.

As the outflow monitoring shows, the Podkrušnohorská Výsypka Dump is a rich permanent water source. All watercourses which were in the area of future dump (streams from the Krušné Hory Mountains, Boučský Potok Stream) were relocated outside the dump area before starting the dump. Most original watercourse channels were used as suitable places for drainage building. Right there and at some of the places waters flowing out of the dump are measured.

Monitoring of dump hydrologic situation

Monitoring of out flowing water was changed step by step according to dumping continuation. Basic changes were carried out when single part of the dump (Týn, Boučí, Smolnice, Vintířov dumps) unified to one complex unit – the Podkrušnohorská Výsypka Dump. The monitoring measures all out flowing waters from the Podkrušnohorská Výsypka Dump only after 2000 (Dykast, 1996).

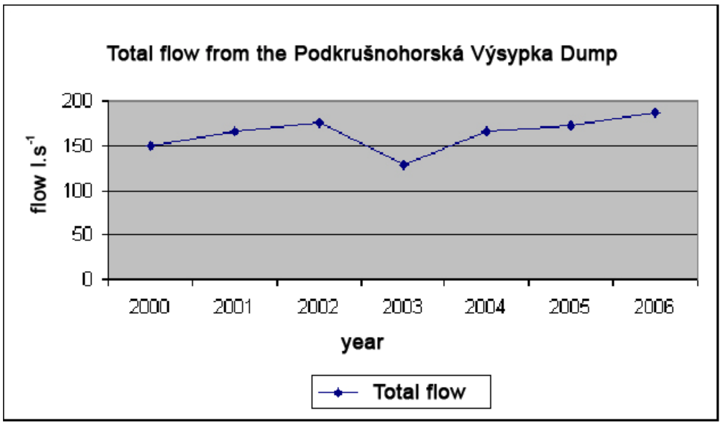

Fig. 1. Total flow from the Podkrušnohorská Výsypka Dump.

Results evaluation of BP 46 and BP 47 penetration probes measurement definition of shear strength properties of examined rocks in an effective and total value set

The strength evaluation of a set of 10 penetration probes which were realised on two identical places of the dump is the object of interest. The probes were carried out on the Boučí external dump which is a part of a large Podkrušnohorská Výsypka Dump. Clays from deposited mined claystones of cypris upper strata complex of the Antonín seam were dumped at the places of BP 46 and BP 47 probes (VÚHU a.s. Most et al., 1997-2007).

Both probes are located at the report profile. Repeated examination of Boučí dump stability in this profile line was the reason why penetration measurements were repeatedly realised at the BP 46 and BP 47 probe place from 1992 to 1998 (Mikoláš 2009). Results of the measurement were used as input data to stability calculations.

Comparison of dump body changes 1992 - 2008

Tens tables with hundreds shear strength values were obtained by measurement. Tables "Total parameters of the probe for evaluating by a weighted average" were used to compare the changes. Values for dump body were obtained by the means of a weighted average where depths of single dump layers were the weight (Tables). It is an overall strength average of dump body in a given place and an observation time, except the contact dump base area which was evaluated separately.

The separation of a dump to dump body and contact area with base implies from long term experience in dump observation. A contact of a dump with a base is usually created at the bottom of a dump where some decrease of strength parameter occurs. The existence of the contact can be put in direct context with a water horizon at dump base. This horizon at the base of a dump is practically under all body of the dump, depending on the morphology of original terrain. Its yield is depending on the amount of water input to the dump body and an efficiency of drainage system. It is practically a single water horizon hydrological continuity of which can be proved by a large area observation.

Obtained values of strength parameters of dump rocks and determined dependencies of resistance on depth were plotted to the graph by the means of lines. With allowed implification it can be stated that a declination of the trend line corresponds with an angle of inner friction and a length from the origin of coordinate system corresponds with consistency. At this interpretation, the parallelism of trend lines proves equality of inner friction angle, equal distance from horizontal (axis with a level above sea) or equal intersection point on the Penetration resistance axis prove equal consistence value. Improvement of the strength parameters of dump caused by the primary consolidation enlarges the declination of a trend line (Not typical for a dump) or the distance from the origin of coordinate system. Or by both, but improvement of the two strength parameters at once is not typical for dump rocks. Fill of a dump has a high piece rate and behaves as a false gravel after its dumping i. e. high angle of inner friction and low consistency. Values of the angle of inner friction should decrease by time which should be compensate by increase of consistency i.e. the trend lines should decrease their declination and increase their distance from the origin of the coordinate system. Such a time depended run of changes in strength parameters distribution correspond theoretical presumptions on dump body behaviour. Measurements results of BP 47 (1992) and BP 471 (1998) probes correspond exactly to the presumptions and prove that dump rocks have a tendency change the distribution of strength parameters (Fig. 3).

A course of strength changes of the dump body in the place of probes from the BP 46-462 measurement set can be seen in Fig. 2. It must be stated in the very beginning that measurement results from 1995 (BP430) are not in an accord with a characteristic behaviour of the dump (it is interesting that the same is with BP 440 probe in the place of BP 47 probes) and it is why the BP 430 and 440 probes were put out of the penetration measurement interpretation.

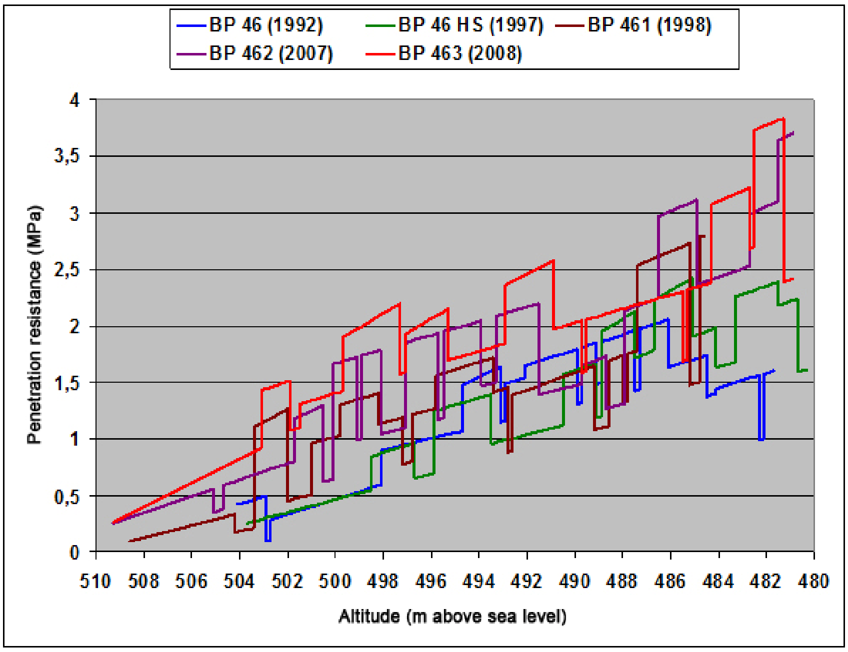

Fig. 2. Penetration probes from the BP 46 set (1992 – 2007) .

Note. - Had the BP 430 measurement been realised as first it would have suited into the frame of typical behaviour of dumped material –so called "false gravel" short after dumping – high φ, low c, i.e. a steep trend line intersecting the "Penetration resistance" axis near the origin. It can be seen in the Fig. 2 that the 1992 and 1997 measurement results (see BP 46 and BP 46 HS probes) do not differ very much, only the resistance in the contact of the dump with a base increased much (it means improvement of strength parameters). The dump body itself did not practically change. The BP 46 HS was drawn dashed as both trend lines overlaid in some interval

After increasing the height of the dump in the BP 46 probe place by 4.9 m, the strength parameters improved in primary consolidation process in 1998 the BP 461 probe in the Fig. 2. Values of inner friction angle did not change (there were no apparent reasons of their increase) but the values of consistency increased significantly –the translation from the origin of the coordinate system. Remarkable improvement took place in the failure body itself and there were no changes in the contact area of the dump with the base, respective it increased slightly.

The 2008 measurement results (BP 463) show further improvement of strength situation that is consistency values increase in both the dump body and the base contact area. The rocks with higher strength values were even measured in the area of contact with a base than the strength of the dump body itself. The highest resistance values were even measured at the immediate area with the contact with bed see newly separated area at the base of the dump. This improvement was measured by BP 462 probe but it must be said that such a remarkable improvement is not typical for dump bodies – it an exception of strength situation improvement.

An exceptional layer in the depth of h = 22,3 – 26,3 m (487 – 483 m a. m. s. l.) with $\varphi = 5.9^{\circ}$, c = 11.3 kPa parameters was marked at the BP 462 and BP 463 probe on Fig. 2. The occurrence of the layer shows that though the overall situation improved (both dump body and base contact) places can occur in the dump body where local situation deteriorates.

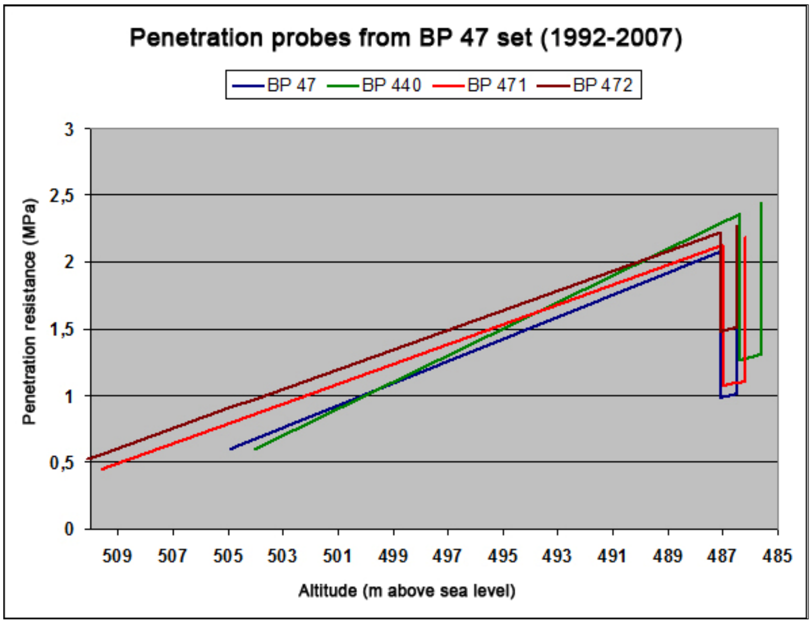

Fig. 3. Penetration probes from the BP 47 set (1992 – 2007).

The measurement results on probes from a BP 47-440-471-472 set show similar behaviour character as the BP 46-430-46HS-461-462-463 probe results. It can be stated that generally they are "better" than the BP 46 results. The measurement results overlay for the area of a dump bed contact at BP 47 set probes so that this area of the dump was measured in a stabile constant depth. It must be further stated that the measurement results for the contact area dump – bed are much more standard at the BP 472 probe (2007) than it was at BP 462 probe (2007) because even if the strength situation improved at the base of a dump at the contact area with bed at the BP 472 probe this part of a dump keeps being its weakest link which corresponds with acquired long term knowledge of the dump behaviour

The 1995 measurement results (BP 440) are not in accord with a typical dump behaviour ant they are hard to interpret so called "false gravel" short after dumping (high φ, low c) which does not correspond with a reality when at first measurement the dumped body did not show such a character of distribution of strength parameters.

The 1998 results (BP 471) or the trend line for a dump body shows a slight decrease of an inner friction angle which is compensated by an increase of consistency values which exactly corresponds with a typical process of a change in the dump strength parameters distribution. An improvement not only for a dump body but for the contact area with a bed was measured in comparison with 1992 (even if moderate) Fig. 3. The same is valid for the 2007 measurement (BP 472) when the consistency values for both the dump body and the contact area with a bed where an increase of the consistency values, or penetration resistance was measured.

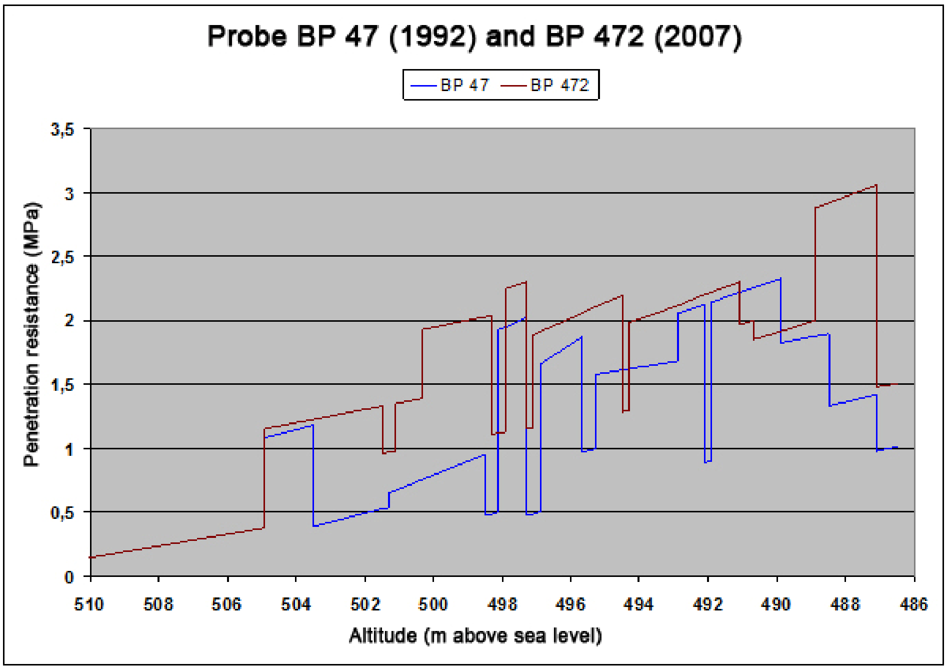

Fig. 4. BP 47 a BP 472 probes comparison.

Trend lines of all geotechnical layers in which the dump was divided at BP 47 (1992) and BP 472 (2007) probes are drawn in Fig. 4. It can be seen that even if strength situation improved generally places occur locally in a dump body where the situation locally deteriorated in the 1992 – 2007 interval (Fig. 4) position in depth h = 15.6 – 15.8 m (494.5 – 494.3 m a. m. s. l.) and h = 19.0 – 20.2 m (491.1 – 489.9 m a. m. s. l.). Water streaming could be disabled and it could accumulate locally after increasing the height of the dump (pores could be clamped). These positions of local value decrease (as a layer in the depth h = 20.6 – 21.4) proved that even if the situation improved in average (both in a dump body and in a bed contact area) places can occur in the dump body where the situation deteriorates permanently.

At the end of analysis acquired shear strength parameters from 1992 – 2008 are summarised to two tables below for an easy comparison of the measurement results (Tab. 1).

Tab. 1. Shear strength parameters from 1992 – 2008.

Year/probe		Shear strength parameters		
1992 BP 46	Dump body	**8,1°**	**17,1 kPa**	**16,9 kN.m^{-3}**
	Contact with bed	4,6°	5,8 kPa	16,9 kN.m^{-3}
1995 BP 430	Dump body	**10,2°**	**19,1 kPa**	**17,7 kN.m^{-3}**
	Contact with bed	6,3°	17,4 kPa	17,6 kN.m^{-3}
1997 BP 46 HS	Dump body	**8,2°**	**16,4 kPa**	**17,5 kN.m^{-3}**
	Contact with bed	6,1°	15,5 kPa	17,5 kN.m^{-3}
1998 BP 461	Dump body	**8,0°**	**24,5 kPa**	**17,5 kN.m^{-3}**
	Contact with bed	6,1°	19,8 kPa	17,5 kN.m^{-3}
2007 BP 462	Dump body	**7,5°**	**35,4 kPa**	**18,6 kN.m^{-3}**
	Contact with bed	8,4°	34,8 kPa	18,6 kN.m^{-3}
2008 BP 463	Dump body	**10,0°**	**23,8 kPa**	**18,4 kN.m^{-3}**
	Contact with bed	7,7°	16,0 kPa	18,6 kN.m^{-3}

Year/probe		Shear strength parameters		
1992 BP 47	Dump body	**10.4°**	**20.5 kPa**	**16.9 kN.m^{-3}**
	Contact with bed	5.8°	4.2 kPa	17.0 kN.m^{-3}
1995 BP 440	Dump body	**12.7°**	**19.5 kPa**	**16.8 kN.m^{-3}**
	Contact with bed	6.5°	10.7 kPa	17.0 kN.m^{-3}
1998 BP 471	Dump body	**9.0°**	**28.5 kPa**	**17.3 kN.m^{-3}**
	Contact with bed	4.7°	14.3 kPa	17.3 kN.m^{-3}
2007 BP 472	Dump body	**8.8°**	**32.5 kPa**	**17.5 kN.m^{-3}**
	Contact with bed	6.3°	19.8 kPa	17.5 kN.m^{-3}

Conclusion

The comparing the results of surveys from various years of penetration measurements showed that it is possible to analyze changes in body dump which take place especially the recovery of better strength This can be obtained especially in the use of graphic forms of evaluation based on a comparison of the trend curve.

In the subsequent evaluation of penetration measurements to external dump Boučí, in the period 1992-2009 was able to demonstrate that the primary consolidation process in this dump are actually causing a time-dependent improvement of strength ratios dump. The prime example are mainly the results of measurements on probes of group BP 46 - see the results of the measurement probes to BP 46 (1992), BP 1946 HS (1997), BP 461 (1998), BP 462 (2007) and BP 463 (2008).

The evaluated numerical data on the internal dump Jiří, first showed that in the years 1995 - 2002 shows a dump high a value of shear strength. But a gradual increase loading dump power creates decreasing strength parameters. When measuring the penetration internal dump in 2008, and in particular the 23/14 probe SPJ in 2009, implemented after the massive landslide internal dump Jiří, was captured at the base of the dump loose material with virtually zero shear strength. The result of probe is unique in the Survey dumps Sokolov brown coal mining district.

At the dump, it is clear that any intervention in the foot dump means deterioration of its stability, which apparently was the cause of a large landslide in 2009.

After consultations with representatives of professional organizations its attention and legal successor, Sokolov and evaluate the results of the solved task is most likely that the landslide occurred raising dumps height above tolerable limits (height reaches 100 m, research has shown that the SU and the dump should be formed with a height of 80 m). Stowing dump masses on silt from the past decade means creating a “floating block” and water when exposed to the latest landslides occurred between 2008 and 2009.

Research has shown that the external spoil improved strength ratios, and it places very strong. This improvement showed virtually all the penetration of the probe in 2008. The results of measurements of penetration compared to the year 2008 with the results of previous surveys allow indirectly confirm that there is no penetration of water from folding into the body of Heather ash dump, which has relationships for the stability of this dump is essential.

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