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Redevelopment of spoil heap for construction of the homogenization coal deposit

Réaménagement du terril pour la construction de gisement de charbon d'homogénéisation

P. Cernoch
CEZ Energeticke produkty, s.r.o. Prague, Czech Republic

J. Kostal
INSET s.r.o. & Czech Technical University in Prague, Faculty od Civil Engineering, Department of Geotechnics, Prague, Czech Republic

ABSTRACT: Currently the brownfields are frequently used for the construction of industrial units. A designed homogenization coal deposit (HCD) has determined very strict limits for the deformation of the foundation. Since there is heterogeneous unconsolidated spoil heap with huge depths in the area, the implementation of the foundation using classic technologies will be very complicated. We have done geological investigation and field testing. We have determined several methods of feasible foundation. Individual options have been reviewed by numerical modeling using finite element method. Furthermore, the monitoring system was projected and constructed along with foundation of the HCD. Nowadays, we have more than 15 years of experience with service the HCD – thanks to continuous data from the monitoring. At this time, we are still observing this area also with numerical modeling and field tests. The field tests are repeated every 5 years, with the aim to measure the bearing capacity of bedrock vs. the stacker (loader machine). A lot of output data over a long time period, carried out field tests including numerical modeling are unique.

RÉSUMÉ: Actuellement, les friches industrielles sont fréquemment utilisées pour la construction d'unités industrielles. Un gisement de charbon d'homogénéisation conçu (HCD) a déterminé des limites très strictes pour la déformation de la fondation. Étant donné que la zone de déblais hétérogène non consolidée avec de grandes profondeurs se trouve dans la zone, la mise en œuvre de la fondation à l'aide de technologies classiques sera très compliquée. Les analyses ont notamment validé la possibilité de règlement de tas de déblais. Nous avons déterminé plusieurs méthodes de la fondation réalisable. Les éventualités individuelles ont été examinées par modélisation numérique à l'aide de la méthode des éléments finis. En outre, le système de surveillance a été projeté et construit avec la fondation du HCD. De nos jours, nous avons plus de 15 ans d'expérience dans le travail avec HCD – grâce aux données continues de la surveillance. En ce moment, nous observons toujours ce domaine également avec la modélisation numérique et les tests sur le terrain. Les essais sur le terrain ont été répétés tous les 5 ans. La capacité portante du substratum rocheux par rapport au chargeur (empileur) a été mesurée dans ces limites. Un grand nombre de données de sortie couvrant une longue période de temps, les tests sur le terrain, y compris la modélisation numérique sont uniques.

Keywords: brownfields; settlement; monitoring; numerical modeling.

1 INTRODUCTION

Geotechnics includes a wide range of activities. From the basic requirements of this discipline (such as slope stability calculations, bearing capacity determinations of bedrock for foundations or defining a specific material composition of a road) geotechnics today also deals with exceptional and unusual tasks. These include, for example, the treatment of a former sludge lagoon, modeling of transport of contaminants or the operation and monitoring of a homogenization coal deposit. To keep emission limits in coal-fired power stations, the quality of the combustion coal must be respected.

For this purpose, homogenization coal dumps (HCD) are being built. In many cases, the HCDs are located on the spoil heap bodies of former surface coal quarries. The homogenization of coal is carried out by loader machines (stackers), which are sensitive to the different settling of the tracks (see Figure 1).

If the HCD is built on a heterogeneous unconsolidated spoil heap with huge depths, there is a risk of large soil settlement in the beginning of the construction and its operation. This is, of course, unacceptable, and it is therefore necessary to eliminate uneven settlement. One example of possible solutions is to stabilize (improve) the subsoil (bed). In order to assess the effect of reinforcement and subsequently ensure safe operation of the HCD, it is appropriate to carry out field tests. The purpose is to estimate the weight distribution of the stacker to the spoil heap body through the base layer of the improved soil (so-called "trunk"). The comparison of the achieved values from the individual field load-bearing tests makes it possible to determine the degradation of the trunk and the underlying soil, including the evaluation of the deformation and stability characteristics of the structure.

Figure 1. Stacker on the HCD site.

For the safety of the HCD, it is also absolutely necessary to carry out monitoring of the construction, both of the underground tracks and of the surrounding environment (especially the condition of the spoil heap body and its saturation). The monitoring is used in the first phase of field load-bearing test as well. Results from tests and monitoring are also often used to verify numerical modeling. During monitoring, the warning states (limit values) are, of course, determined and evaluated.

2 MONITORING

INSET Company carries out a comprehensive long-term geotechnical monitoring of the HCD built up on the spoil heap. Prior to construction, a monitoring system was set up in 1998 at the earliest. This consisted of particular probes and sensors that were linked to the readout base stations (see Figure 2).

Figure 2. Readout base station (monitoring).

Also, bar extensometers were installed for measuring horizontal deformations in the longitudinal axis of the base track. To monitor the settlement of the spoil heap and the trunk, altimeter gauges were installed at different depths, working on the principle of measuring the pressure of the liquid. At the same time, the altimeter gauges were fitted with a thermistor for temperature measurement. The values of the contact tension, on the subsoil and at various height levels of the trunk, were measured by contact stress sensors. The above measurements were supplemented by geodetic stabilized points, which monitored the deformation of the surface areas of the spoil heap. In order to observe the depth of the horizontal deformations of the subsoil, the inclinometer boreholes were implemented. The saturation of the environment (spoil heap) was documented using hydrogeological boreholes and piezometers (dynamic penetration probes fitted with a plastic, perforated casing). At the same time, pore pressure gauges were installed into different depth levels of the subsoil.

The complete monitoring system was complemented by groundwater quality observation. It was based on laboratory chemical analysis of collected underground water samples and on the valorization of climatic data of the area of interest. At the same time, regular field inspection was carried out. The evaluation of measured data during monitoring included the determination of limit values (warning states) that contained assessment of groundwater level and chemical composition development during time. The most important was the determination of critical values of measured deformations. Deformation measurements were divided into three areas: the area of the spoil heap slope, the second part was the subsoil of coal depots and the third one the tracks of the stackers supplemented with temperature sensors.

3 FIELD LOAD-BEARING TEST

Before operating the HCD a field load-bearing test of the stacker tracks was performed and initial numerical calculations were carried out.

The test section of the track was loaded with a steel grid (6 x 3 meters), to which concrete panels were gradually laid (weight 2.3 tons). All values were measured before and during each loading of the track. At the same time, the geodetic measurements of altitude of the test track section were made. The loading of the track took place after five loading steps, with a maximum load of 60 panels. Unloading was carried out subsequently at the same stages as the loading, including the reading of the monitored values and geodetic measurement. Before the loading begun, the settlement of the bed (subsoil beneath the tracks) decreased by 12 to 23 mm due to the soil weight of the stabilized trunk. At 2 m depth, 6 mm decrease was measured and a value near zero was documented at 5 m below the bed. The maximum deformation of the tracks at maximum load was no more than 16 mm.

Geodetic measurement before loading						
označení bodu		.	10.15. Hod.			15.30.hod.
	date	heioght	date	heioght	**def.(mm)**	date
	07.07.1998		13.07.1998			13.07.1998
1	678	701	731	702	**1**	657
2	674	705	734	699	**-6**	658
3	673	706	743	690	**-16**	662
4	673	706	742	691	**-15**	662
5	675	704	742	691	**-13**	663
6	678	701	672	685	**-16**	662
7	685	694	**739**	694	**0**	664
8	685	694	672	695	**1**	665
9	681	698	676	691	**-7**	666
10	678	701	681	686	**-15**	665

Table 1. Geodetic measurement.

The largest settlement of the track after completion of the unloading phase (of the field load-bearing test) was 10 mm. This value was used in following approximate numerical calculations.

The stretch value due to the maximum track load was only 0.07% and therefore was not included in the further calculations. Equal increase/decrease in tension, corresponding to the increase/decrease of the load/unload applied, has been registered.

Five steps of loading and unloading were measured corresponding to 20%, 40%, 60%, 80% and 100% of the maximum load which was 60 panels of 2 383 kg, i.e. 143 t plus steel support grid. The measured maximum contact stress on the surface of the trunk was 106 kPa and the maximum contact stress on the trunk base was 46 kPa.

4 MATHEMATICAL SIMULATION

First, the field load-bearing test was mathematically simulated and then further calculations were performed, in particular the effect of soil improvement (stabilization) on the total settlement of the trunk.

The documented values of contact voltages during the load test were used to deduce the load scheme. Although the software used the finite element method, it did not allow to model the details of the subsoil structure. Load diagram was derived using approximation method under which the tension at the locations of the sensors corresponded to the monitored contact stress. The correspondence of the contact stress was checked in three places: in the middle of the load where 46 kPa strain at full load was measured; at a distance of 4.5 m from the center of the load where the average readings from the sensors were 11 kPa; and at a distance of 13.5 m from the center of the load where the low negative tension occurred. The settlement obtained by the altimeter gauges was used to correct the values of the deformation modules of the underlying soil materials. The deformation module of the subsoil varied between 15 and 20 MPa and was derived by matching the deformations at the locations of the altimeter gauges.

5 MODELING REAL SITUATION

In the second phase of the numerical calculation a real situation was modeled, when the load on the track was solved by a stacker (mass 642.3 tons). The legitimacy of the use of the planar modeling method was ensured by appropriate modification of the applied load, ensuring its final length was respected. In both cases, the trunk was simulated in a longitudinal section as a beam on a flexible substrate and was transversally cut as a planar problem with a beam of infinite length. To verify the transfer of the weight of the stacker to the subsoil of the trunk in a cross section a mathematical model was constructed using the finite element method with triangular elements and a modified set of input data.

The model was a plane symmetrical with the axis of symmetry passing through the center of the track. It showed a space of 12 x 12 m, in which three different levels of the spoil heap were simulated: consolidated; unconsolidated and the compacted soil. At the same time, the trunk was implemented into the model. The load of the model corresponded to the maximum field load-bearing test and was provided with an unequal load of 100 kPa in the symmetry axis, 100 kPa in the adjacent node and 20 kPa in the next node.

The initial stress was derived from the geostatic strain at the value of the side pressure coefficient of 0.67. After tuning the load transfer (based on the comparison of the contact tension at the points of the model of the corresponding position of the sensors in the field load-bearing test), the approximate calculation continued to determine the deformation properties of the model soils. In particular, it was the influence of the input parameters of the unconsolidated spoil heap body whose influence on the final settlement values was professionally estimated to be the largest (compared to similar tasks previously solved). Different variants for different input values of the lambda and kappa parameters were modeled. By modeling, the absolute magnitude of the displacements and strains in the monitored test locations were determined.

6 COMPARISON

At the same time, the model values were compared with the results of the monitoring, respectively with the results obtained during the field load-bearing test.

Several mathematical approaches have been used to evaluate or compare. The 100% load phase in the field test was compared to the 72% load phase on the model. This results from the fact that we are modeling the final load of the final path using the planar method and thus the infinite load of the infinitely long path. From the recorded tension values, the initial strain (geostatic stress from the weight of the modeled materials under the influence of the side pressure coefficient) was subtracted.

From a comparison of monitored values and model results we can state that very good agreement was reached. In terms of displacements, the differences were minimal. From a tension point of view, it was found that where there was no match for some sensors, there was a match for other sensors. This phenomenon can be explained as a consequence of the reduction of the stress to respect its final length, which cannot be ensured at the same time for both levels. In order to compare the efficiency of the stabilization (improvement) of the subsoil (trunk) calculations were only made for the spoil heap body. This calculation has shown that the impact of coal depots on settlement of the soil below track of stackers can be up to a depth of 60 mm. The settlement of the spoil heap caused by the weight of the stacker machine was an unacceptable value of 250 mm (without stabilizatoin). As expected, building an improved soil trunk has had a decisive influence on the deformation values achieved. The values of deformations from the weight of stacker ranged from 42 to 47 mm. During filling a coal dump, it is not only the settlement of the spoil heap beneath the dumps that appears, but also the further displacement of the subsoil below the stacker tracks. The calculation was carried out assuming that the filling of the coal dump was spread equally over the entire length with a maximum height of 16 m. The documented settlement reached 40 mm. It should be noted that the effect of creep underlying soil may increase about 50% in settlement in the course of a constant load (lasting about 3 months).

During the HCD operation, further numerical calculations were carried out to solve the effect of groundwater in the spoil heap body on the deformation changes in the trunk and in the subsoil of tracks. The effect of groundwater was to increase vertical deformations by 30% on average and to triple increase of horizontal displacements of the stacker tracks. At the same time, the effects of the groundwater level increase (to reduce the stability of the monitored structure) were simulated. The model showed that upon raising the groundwater level by 1.5 m, the degree of stability dropped to 0.1 in the assessed profile.

7 *FIELD LOAD-BEARING TEST*

The above results allowed the next step to be taken to carry out – the first filed load-bearing test with the stacker on tracks. The purpose of this test was to survey the weight distribution of the machine to the spoil heap over the underlying layer of the improved soil (trunk) under real conditions.

As with the previous test, load transmission was observed by the construction's monitoring system. The stress and deformation values obtained were then used as the target values of the approximate numerical calculations (verification of the previously solved models). The main objective of the field load-bearing test was to check the effect and in situ quality of the improvement of the base of the tracks for the stacker. Concurrently, we can compare the results between each field load-bearing test (the period of repetition is about once every 5 years) and determine whether there is a decrease in the settlement of the tracks over time.

The field load-bearing test of the tracks was executed by moving the stacker from the initial assembly site of the stacker machines along the tested part of the track within the area of the monitoring elements. Before the passage of the stacker readings of all monitoring elements were made and at the same time the initial geodetic leveling measurements of the surface of the tracks was carried out (Figure 3).

In order to also detect immediate changes in contact stress during the approach of the stacker and its movement over the sensors, some of them were connected in the measuring station to the data logger for continuous data readout.

Figure 3. Geodetic measurements.

The timetable of the field load-bearing test included the locomotion of the stacker, the load of the stacker at rest phase, the first partial departure, the resting state, and the second departure of the stacker outside the monitored area and full relief (a total of two days of field testing). During the monitoring of the HCD a total of four field load-bearing tests were carried out. From the measured deformations after the loading and unloading of the track by the stacker machine, the settlement of the tracks decreases considerably. In 2000, the value of settlement was 16 mm, in 2005 it reached 4 mm and in 2011 it dropped to only 0.1 mm. The last measurement (July 2017) showed settlement only 0.05 mm. The contact stress decreased by 2011 and subsequently stabilized.

The development of documented values of contact stresses is indicative of the fact that further improvement of the spoil heap body is unlikely to occur and the soil has come close to its peak optimum.

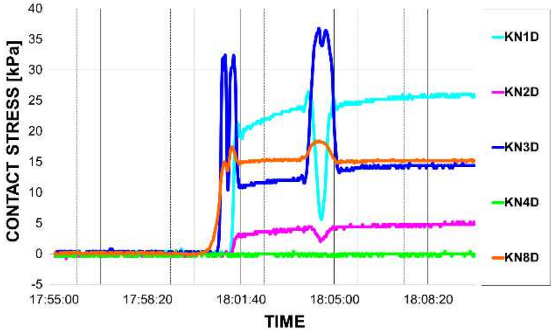

Figure 4. The contact stress during the field test.

On the basis of the results obtained, we can say that there has been an improvement in deformation properties of the subsoil during time – deformation modules E_{def} have increased, the settlement has been reduced (see Figure 4).

8 CONCLUSIONS

Today, the homogenization coal deposit has been operational for 20 years. The results of the field load-bearing tests, the numerical calculations and data evaluation of the monitoring system have always been compared with the previous measurement phases. From the results achieved we can declare that during the existence of the construction there has been a significant improvement of the subsoil under the tracks. At the same time, the contact stress values decreased and the documented total settlement of the track surface (max. 20 mm) was considerably reduced.

Comprehensive monitoring of the HCD notably contributes to the safe operation of the structure. The contact stress sensors are still functional today however some measuring elements have already been removed from the monitoring system – altimeter gauges (lifetime of about 15 years) in particular, and also there was a breakdown of some extensometers.

During the HCD operation, therefore, the monitoring system was complemented by additional probes and measuring components. Thanks to past experience with the HCD it can be advised that it was very useful to use the observation approach to the solution. Based on the results of the monitoring system, field tests and numerical calculations the appropriate construction and technical precautions were implemented in time.

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