Special Aspects for Building a Motorway on a 185 m Deep Dump

Aspects particuliers pour construire une autoroute sur un remblai de comblement de 185 m

Vogt N., Heyer D., Birle E., Vogt S.
Zentrum Geotechnik, Technische Universität München, Munich

Dahmen D., Karcher C., Vinzelberg G., Eidam F.
RWE Power AG, Cologne

ABSTRACT: The major part of the new motorway A 44 will be constructed on a deep dump of the Garzweiler open cast mine, reaching a maximum depth of 185 m. The soils are placed by large scale spreaders in a bulk flow. Thus, the uncompacted dump possesses a pronounced compressibility and can exhibit long-term time-dependent deformations, mainly as a result of particle redistribution in the dump. The magnitude and rate of the deformations depend on numerous parameters, of which the soil type is the most important. With this background, the RWE Power AG has developed a concept for dumping the pit with selected soil-types on which the autobahn will be constructed. This concept only allows the dumping of mainly coarse- and mixed-grained soils beneath the future motorway. Extensive laboratory and field tests have confirmed that the settlements along the A 44 route, compared to similar dumps in the area of the Rhenish lignite mines, can be clearly reduced. Based on the laboratory and field tests a model that allows the calculation of the time- and stress-dependent deformations within the dump, as well as on the surface along the planned autobahn, has been developed.

RÉSUMÉ: La nouvelle autoroute A 44 sera construite sur la zone remblayé de la mine à ciel ouvert Garzweiler, zone qui atteint une profondeur maximale de 185 m. La terre du remblai est déversée par des gros tombereaux rigides en grande masse. Les sols présentent dès lors une densité relativement faible ce qui se traduit par une compressibilité prononcée lors du processus de remplissage et peut conduire à des déformations à long terme, principalement en raison de la redistribution des particules dans le corps de remplissage. L'ampleur et le rythme des déformations dépendent de nombreux paramètres. Le type de sol est le plus important. Dans ce contexte, la société RWE Power AG a développé un concept de remplissage de la fosse sur laquelle l'autoroute sera construite qui utilise une sélection des granules et sables lors du déversement. Des essais à grande échelle, en laboratoire et en place, ont confirmé que les déformations à la surface du remblai peuvent être nettement réduites par le choix ciblé des matériaux. Un modèle de mécanique des sols permettant de représenter les déformations à la surface du sol a été développé à partir des expériences en laboratoire et sur le terrain.

KEYWORDS: dump, mining, settlements, time-dependent deformation, creep, sand

MOTS-CLES: mine, comblement, tassement, déformation, fluage, sable

1 INTRODUCTION

The Rhenish lignite mining area covers the flat plains of the Cologne Lowland between the cities of Aachen, Monchengladbach and Cologne. With a total annual output of some 100 million tons of lignite the 3 currently active large-scale open cast mines contribute to 12 % of the electricity production in Germany. The area under consideration is part of the Garzweiler open cast mine, presently covering an area of 48 km^2. In order to exploit the annual 35-40 million tons of lignite, a fivefold magnitude of overburden (150 million cubic meters) must be excavated and dumped. The current mining permit stipulates the year 2045 by which the exploitation will have to end east of the city of Erkelenz.

Because of the westwards progressing exploitation, the motorway A 44 has been closed since November 2005 over a stretch of about 10 km. Since then traffic has been redirected along the almost parallel running autobahn A 61. The area of the former autobahn is currently used for mining purposes. According to the planning schedule, the open cast mine will reach the autobahn A 61 right-of-way by the year 2017. Before the A 61 can be closed and dismantled, the A 44 that has been closed must be reopened to traffic. The major part of the new autobahn comprising 6 lanes within a cross section of 42.6 m in width will be constructed on dumped soils of the Garzweiler open cast mine, which have a maximum depth of 185 m (Köther and Reeh 2011). Figure 1 on the right gives an overview of the opencast mine Garzweiler situated within the Rhenish lignite mining area as well as the autobahn A 44 and A 61.

The first soils under the planned route of the A 44 were dumped close to the proposed autobahn interchange Jackerath in the south in 1999. From this time on the dump has continuously progressed to restore the original topography. The dumping taking place in area close to the A 44 should be completed by the year 2016. An aerial photograph in figure 1 shows the Garzweiler open cast mine in the background as well as the extent of the area that has been reused for agricultural purposes in the foreground. The A 44 route can easily be seen between the farmland.

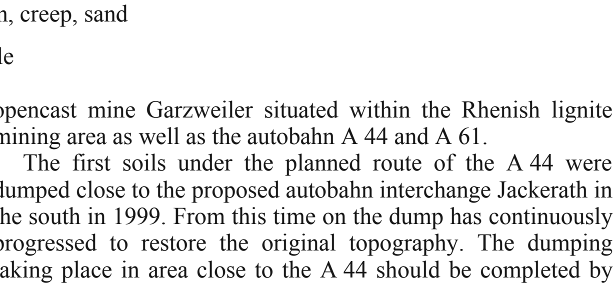

Figure 1. Mining area of Garzweiler (left) and an aerial photograph of the planned A 44 route (right)

2 DUMPING CONCEPT

In order to reduce the deleterious effects on the future use of the mining area that may arise from dumped soils, the RWE Power AG developed a concept introducing restrictions regarding the content of fine particles (d < 0,06 mm) of the soils dumped below the future motorway. Figure 2 illustrates the cross section of the dump with requirements on the soils.

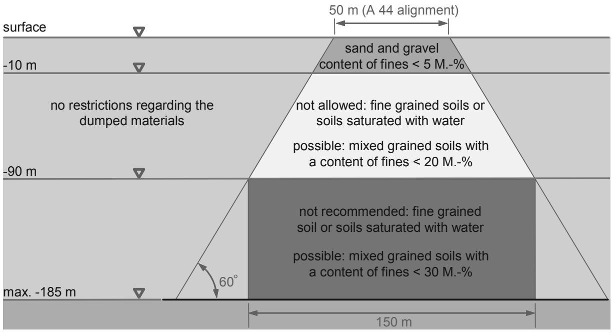

Figure 2. Dumping concept

At depths below - 90 m under the planned surface on which the motorway will be constructed it is not recommended to dump fine-grained or saturated soils. In this bottommost part of the dump only soils with fines contents < 30 mass-% should be deposited. The width of this lower region is 3 times the width of the planned motorway. Between -90 m and - 10 m more stringent restrictions are set. Only soils with a fines content < 20 mass-% may be used to construct this part of the dump. The top part of the dump from - 10 m to the ground surface is made up of sand and gravel with a fines content < 5 mass-%.

To verify the described concept, soil samples were taken at different depths and positions from the dump along the A 44 route since the year 2008. A total of 716 samples were classified by the year 2011. Considering the total soil masses dumped into the areas described in figure 2 and the capacity of about 240 000 m^3 per day and per large scale spreader, sampling may be considered as a random test method. Despite this, the evaluated data provides essential information about the adherence to the defined dumping concept.

The evaluation is based on a macroscopic classification scheme of every single soil sample. The classification divides the grain-size fractions gravel, sand and fines. This gives a quick classification without conducting laboratory-based tests such as sieving. The macroscopic classification was verified by calibration phases at different points between 2008 and 2011. In this calibration the outcome of the macroscopic classification was compared and finally adjusted to the results of the grain size distribution gained from laboratory sieving. During the calibration phases a total of 106 grain size distributions shown in figure 3 were investigated.

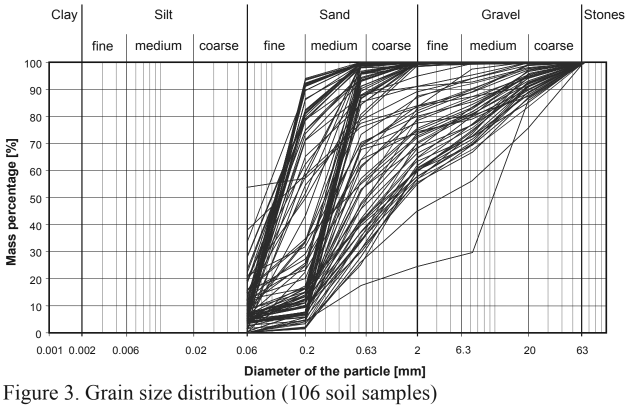

Figure 3. Grain size distribution (106 soil samples)

The results show that for 91 % of the soil samples the sand fraction is dominant. 92 % of the soil samples have a content of fines < 15 mass-%. Only 2.5 % of the samples are classified as fine-grained soils with a fines content > 40 mass-%. In the top layer of the dump sand and gravel is dominant.

3 TIME-DEPENDENT DEFORMATION OF THE DUMP

3.1 *Geodetic measurements along the autobahn alignment*

It is well known that large dumps within the Rhenish lignite mining area exhibit significant time-dependent deformations (Nehring 1968, Kothen and Knufinke 1990). This is mainly due to the comparably low densities resulting from the dumping method without compacting of the soil masses. As noticed in Section 2 the soil type and the water content mainly influence the magnitude of the time dependent deformations. Typically the rate of deformation decreases strongly according to the elapsed time since the end of the dumping process. Nevertheless, due to the large dump depths of by far more than 100 m settlement rates of the surface in a magnitude of several centimetres per year may be observed even a decade after completing the dump (Lange 1986).

For providing detailed information about the time-dependent deformation of the Garzweiler dump along the planned A 44 route a series of measurements were undertaken and analyzed. The survey department operated by RWE POWER AG provides a main database for surface deformations. The changing geometry of the dump resulting from the advancing dumping progress is monitored continuously throughout the entire dump. Additionally along the A 44 route discrete survey points are installed every 50 m to get as precise data as possible. In two sections (at station 4 900 m and station 5 900 m) the intervals of the survey points were reduced to 10 m apart in order to examine differential deformations over short distances.

Figure 4 plots calculated strains of the dump at the survey points against time. The diagram shows data collected from survey points near station 4 900. Zero time is set at the end of the dumping process. The first measurement was taken on day 1 and then on day 7 day after the completion of the dump.

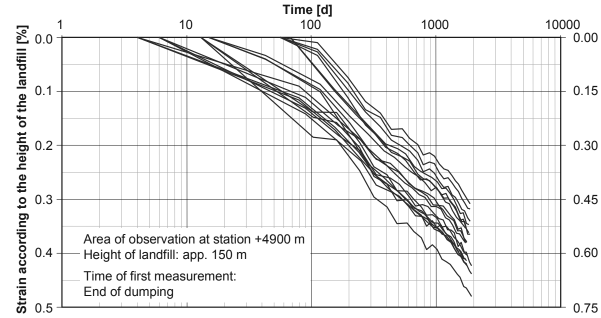

Figure 4. Time-dependent strain and deformation of the dump body

In the logarithmic time scale used in figure 4 the relationship between strain and time show a nonlinear behaviour during the first 100 day period. This shape as given in figure 4 is strongly dependent on the method by which the data is evaluated. The longer the interval between the end of dumping process and the first measurement, the stronger the curvature is of the data line. To ensure a uniform evaluation, the onset of the time dependent deformation is set by the end of dumping process for each survey point. In reality time dependent deformations already occur during dumping process. So start of the time-dependent deformation is a function of the speed of the dumping progress itself. Furthermore, the deformation rates decrease rapidly shortly after completion of the dump. This means that even once the dumping process is completed within a period of 1 day a significant curvature appears at the beginning of the time dependent deformation curve.

For the serviceability of the autobahn, deformations that occur once the superstructure of the roadways is built are of interest. As the construction of the motorway takes some month it is not necessary to describe the curvature of the time-dependent deformation, which is observed during the first period.

According to figure 4, the deformation characteristics after approximately 100 days may be described by a creep law given by Buisman 1939. This law was originally developed to describe the creep following consolidation of clays after a stepwise increase in effective stresses. In addition it is suitable to describe the deformation characteristic of the dump mainly made up of unsaturated coarse-grained sandy soils. The creep law demands two model parameters, a reference time (defined as the time when the deformation starts) and the magnitude of creep deformation. The deformation rate characterized by the slope in a semi-logarithmic time vs. deformation plot as given in figure 4 is described by the parameter C_K in analogy to the parameter C_B given in the original work of Buisman 1936 ("K" represents the German word "Kippe" meaning "dump").

In figure 5, the parameter C_K derived from the time dependent deformation curve of the survey points along the alignment of the planned A 44 autobahn is plotted. C_K was evaluated from the slope of the deformation characteristics for a period of 1 year after the completion of dumping until mid 2011.

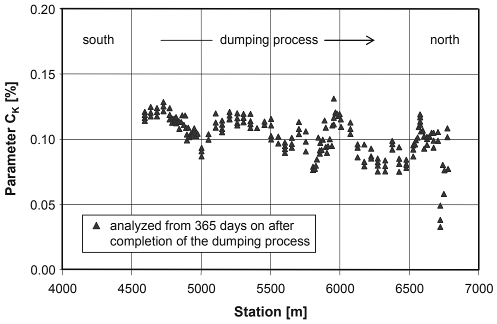

Figure 5. Parameter C_K along the A 44 autobahn route

The plot in figure 5 gives a very uniform distribution of the parameter C_K in between the station 4500 m and 6800 m of the A 44 route. C_K varies in between 0.075 % and 0.125 % with a mean value of roughly 0.1 %. Only some points around 6700 m give smaller values of C_K. Analyses of the data show that the depth of the dump along the observed survey points has no effect on the parameter C_K. Nevertheless the depth of the dump within the area that can be observed until now changes from in the south 135 m to 155 m in the north.

In the future the dumping process will advance another 3 km to the north creating depths of dump up to 185 m. The shown geodetic measurements provide data for determining time dependent deformations. Therefore, special care is required in the evaluation of geodetic data on a continuous basis to verify that the values of C_K will change in the northern region because of an increasing depth of dump. In the event the dumping concept described in chapter 2 is carried out until the dump beneath the A 44 alignment is completed, the measured C_K of 0.1 % will provide valuable information for the prediction of deformations.

3.2 *Effect of initial density on the time-dependent behaviour*

The stress and time-dependent deformation behaviour of the soils was investigated using one-dimensional compression tests. Four different soils representing the majority of the curves plotted in figure 3 were chosen. In different test series the effect of varying initial density and loading rate on the time-dependent compression were examined in detail. Additionally, soaking at different stresses was evaluated.

All tests were carried out by increasing the stress stepwise while observing the axial deformation of the sample. Within the first few seconds after the stress was applied, comparatively large strains were measured. The following strains reduce rapidly with elapsed time. This characteristic can be described by drawing a straight line in a diagram plotting strain versus natural logarithmic time (see figure 6). The slope of the straight line can be expressed by the Buisman constant C_B (Buisman 1936).

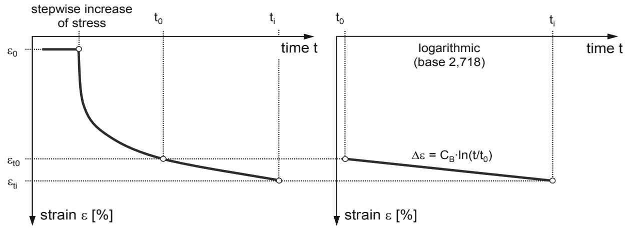

Figure 6. Time-dependent deformation after a stepwise stress increase

Figure 7 illustrates the values of C_B determined for a silty fine sand with a content of fines of 15 mass-%. The samples had heights of 2 cm and 10 cm with respective diameters of 10 cm and 30 cm. Different initial densities with density indices $I_D = 0$ to 0.8 were examined. The initial water content was about 10 % for all tests. The tests show a clear dependence of the Buisman constant on the initial compaction index and governing stress. C_B increases clearly with increasing stress. On comparing the results for different relative densities it can be seen that the C_B value decreases with increasing density. On analysing all tests carried out on 4 soils samples, no significant influence of the soil type was recognized. Only a slightly higher C_B value was determined for the silty sand (see figure 7) having a fines content of 15 mass-% opposed to the other investigated soils for which the fines content varies between 3 and 6 mass-%.

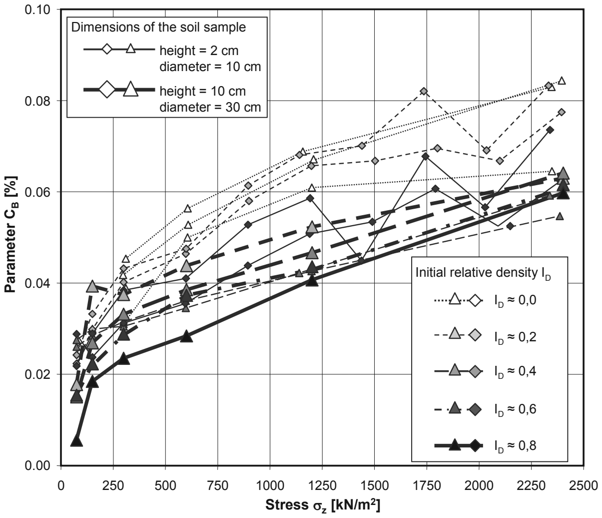

Figure 7. Influence of the initial relative density I_D on the Parameter C_B for a fine sand from the Garzweiler dump (silt and clay = 15 mass-%)

4 PREDICTION OF TIME-DEPENDENT DEFORMATIONS

To predict the future time-dependent deformation of the dump especially regarding the areas along the A 44 route that are not yet filled up, the validation of a model based on a soil mechanic theory was necessary. As a reference date for the model used, the completion of dumping was set to the 1.1.2017. The information seen in figure 8 was calculated using two basic equations describing the stress and time-dependent deformation. This simple model only allows the calculation of a one-dimensional deformation. On expanding the model for predicting more complex dumping processes (e.g. simulating unloading and reloading) within a three-dimensional geometry, a finite element code was used by applying a visco-plastic soil model on the dump body.

The time-dependent deformation is mainly governed by 2 parameters namely the reference time t_0 and a creep parameter defined as C_B or C_K respectively. The magnitude of both parameters was determined using the geodetic measurements at the stations 4 900 m, 5 900 m and 6 600 m where the dumping process was completed several years ago. A favourable outcome between the measurements and the results of the simple model can be found using $C_K = 0.1$ % and setting t_0 at the end of the dumping process. The stress dependent deformation (stiffness) was evaluated using the data of cone penetration tests reaching depths of 72 m below the surface of the dump.

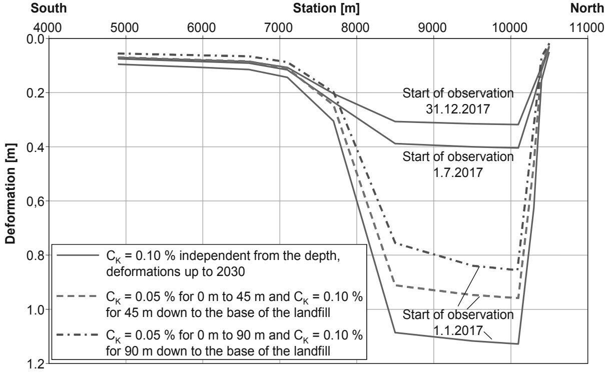

Figure 8. Prediction of the deformation along the planned A 44 for different depths treated by soil compaction methods and the effect of an extended time period after dumping before observing deformations

The continuous lines in the diagram show the predicted settlements of the dump surface considering $C_K = 0.1$ %. Calculations were undertaken until the year 2030 using 11 cross sections between station 4 900 m and 10 500 m. The cross sections were idealized according to a one-dimensional column of soil layers dumped during different periods in time.

For the given case that the soils within the dump do not differ regarding to parameter $C_{K,}$ the calculated deformation is mainly dependent on the depth of the dump and time when dumping is completed or is intended to be completed. According to the used logarithmic creep model the deformations plotted in figure 8, an increase along the route occurs mainly between 8 000 m and 10 500 m. In the case where the dumping process has already been completed since 2 or more years from the start of observation back to the past, the chosen time when the observation starts has a minor impact on the deformations since settlement rates are already small.

From stations 8 000 m to 10 500 m the period between the end of the dumping and the start of observation has a strong influence on the calculated deformations that will occur by the year 2030. Even in a period of 6 months between the end of the dumping and the start of observation reduces the calculated settlements significantly. This is of special interest because the planned construction progress of the A 44 is put on hold until the superstructure sensitive to deformations is constructed.

In the simulations the effect of different measures of soil improvement (mainly compaction methods) were examined. The dashed and dash-doted lines in figure 8 show the deformation until the year 2030 for compaction methods reaching a depth of 45 m and 90 m respectively. It is assumed that the compaction of the different soil layers will lead to a lower creep parameter of $C_K = 0.05$ % (see chapter 3.2). The calculation show a 45 m deep treatment of the dump still leads to a comparably high deformation reaching a maximum of 0.95 m. Even a 90 m deep soil improvement will lead to a calculated deformation of 0.85 m.

The results of the simulations show that providing enough time between completing the dumping process and the construction of parts sensitive to settlement is far more efficient than soil improvement or treating deep soil layers in the dump. On waiting at least a 6 month period before the construction of the A 44 autobahn, a major quantity of settlements will already have been developed. By the used models settlements of 0.4 m and 0.3 m are to be expected in between mid 2017 and end 2017 respectively until the year 2030. This magnitude will be covered by the so-called precautionary gradient providing sufficient drainage of water by the planned crossfall of the roadway and the embankment of the motorway (Köther and Reeh 2011).

5 SUMMARY

The paper presents the most important project-specific conditions including the dumping process and the properties of the dumped soils along the future A 44 routing. Furthermore, geodetic measurements have shown to give a good overview on the time-dependent deformation of the Garzweiler dump. By use of one-dimensional compression tests the deformation characteristics of the dump body, consisting mainly of poorly-graded sand were examined. During the test series main influencing parameters such as initial density and loading rate were examined.

Using a simple model for the description of the time-dependent deformation of the dump and its soils the effectiveness of soil compaction methods is discussed and evaluated. The parameters governing the stress- and time-dependent deformations were calibrated by means of field data from the geodetic measurements and cone penetration testing. The simulation results cover the period from the end of the dumping process to the year 2030. Different periods from the end of dumping until the observation of the beginning of surface deformation were considered. It is evident that the period between the end of dumping and the beginning of construction of parts of the motorway sensitive to settlement, has a large impact and can therefore impair the serviceability. By far less impact was predicted in the case that even deep soil layers of the dump would be compacted.

In general it can be concluded that the concept of dumping predominantly coarse-grained soils within the planned route of the A 44 motorway, is suitable for limiting time-dependent settlements. The simulation results and geodetic measurements have shown that by allowing the proposed period of at least 6 months between the end of the dumping process and the start of the construction work the settlements of structures or pavements sensitive to deformations are reduced significantly.

6 REFERENCES

Köther M. and Reeh F. 2011. New autobahn through an active opencast mine. *World of Mining – Surface & Underground* 63 (6), 334-343.

Nehring H. 1968. Markscheiderische Beobachtung von Kippensetzungen im rheinischen Braunkohlenrevier. *Braunkohle, Wärme und Energie* 20 (3), 83-91.

Kothen H. and Knufinke H. 1990. Restsetzungen auf Neulandflächen. *Braunkohle* 1990 (10), 1990, 24-29.

Lange S. 1986. Building on uncompacted dumps in the Rhenish brown coal area of the Federal Republic of Germany. *Building on marginal and derelict land*, Thomas Telford Ltd, London 137-153.

Buisman K. 1936. Results of Long Duration Settlement Tests. *Proc. 1st Int. Conf. of Soil Mechanics and Foundation Engineering*, Cambridge, 103-107.

Vogt, N., Heyer, D., Birle, E., Vogt, S., Dahmen, D., Karcher, C., Vinzelberg, G. 2012. Neubau der A44 auf einer frischen Tagebaukippe, *Beiträge zum 11. Geotechnik-Tag in München Geotechnik und Energie*, Zentrum Geotechnik TU München, Heft 52, 5-17.