Ground improvement methods for the construction of the federal road B 176 on a new elevated dump in the brown coal region of MIBRAG

Méthodes d’amélioration de sols pour la construction de la route nationale B 176 traversant un remblai récent d’une mine de lignite de MIBRAG

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ABSTRACT: The MIBRAG Company operates two surface mines in the region south of Leipzig in Germany. This is the reason why the existing B176 road needed to be relocated up to 1 km on a length of more than 5 km. This move will place the new road on almost 60 m recently placed landfill area. Different ground improvement techniques such as Controlled Modulus Columns (CMC), Dynamic compaction and Dynamic Replacement were used for the foundation of the bridge and the road depending on the soil conditions and settlement tolerance of the structure. Because of significant stability problems, 15 m deep “floating” stone columns are installed in the landfill. The design and the settlements were significantly optimized by the combination of the different soil improvement techniques. The settlement forecast based on DIN EN 4094-5 Ménard pressuremeter results and finite elements calculations are validated with the results of inclinometer measurements under the largest 15-m-high and 70-m-wide embankment.

RÉSUMÉ: La société minière MIBRAG exploite deux bassins de lignite dans le sud de Leipzig en Allemagne. Pour continuer l’extraction de lignite, la route nationale B 176 doit être déplacée sur une longueur de 5 km à une distance de 1 km sur un remblai récent d’environ 60 m d’épaisseur. Le renforcement du sol de fondation de la route et des ouvrages d’art a nécessité la mise en œuvre des techniques d’amélioration de sol CMC, consolidation dynamique et colonnes ballastées. Grâce à la combinaison de ces méthodes, des solutions d’exécution sûres et économiques ont été proposées et réalisées aussi bien pour la fondation principalement flottante de la route et des ouvrages d’art que pour la zone de transition au terrain naturel. Les déformations sous un remblai de 15 m de haut et 70 m de large ont été estimées grâce au pressiomètre Ménard et aux calculs aux éléments finis ; elles sont validées par les mesures inclinométriques.

KEYWORDS: Embankment, brown coal mining, Controlled Modulus Columns (CMC), stone columns, Ménard pressuremeter.
MOTS-CLÉS: remblai, mine de lignite, Colonne Module Contrôlé (CMC), colonnes ballastées, Pressiomètre Ménard

1 INTRODUCTION

The area south of Leipzig is characterized by brown coal mining, and with an area of 500 square kilometer it is one of the largest landscape construction sites in Europe. The existing federal road B 176 between Pödelwitz and Neukieritzsch will be relocated by the MIBRAG for brown coal mining. The first construction section has an overall length of 8.3 km. The federal road B 176 will be rebuilt by MIBRAG 5.5 km on the young elevated dump of the Vereinigtes Schleenhain mine and will be handed over to the State Agency for Road and Transport.

The young mixed dump fill areas are deep, from at least 60 m and partially up to 105 m depth down to the natural soil. Because of the large thickness of this fill deposit, these areas are usually founded with shallow techniques to remain cost-effective. The connection to the existing B176 takes place on the so-called mainland area.

The future road will vary in elevations from existing ground level to about 15m above the current elevation resulting in varying settlements profiles across the length of the road.

Without the use of ground improvement methods, differential settlements of up to one meter across the road would have to be expected. For areas with more than 3 m of additional fill, ground improvement was performed using mainly the intensive dynamic compaction (Dyniv), while for the areas with embankment of up to 15 m in height and 70 m in width, stone columns were used. In the transition zones between Dyniv and stone columns, Dyniv columns were executed as dynamic replacement. At the bridge abutment, Controlled Modulus Columns (CMC), full-displacement-columns were used. in which the soil will be replaced by non-reinforced concrete.

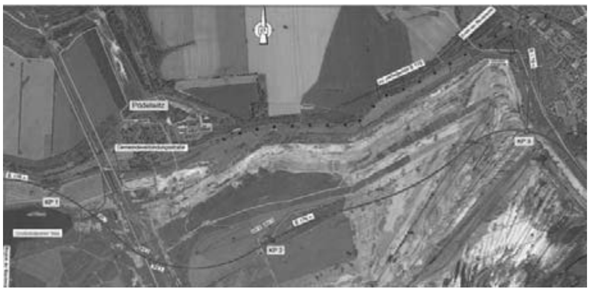


Figure 1. Development of the new B176 (G.U.B. Ingenieur AG 2010).

With the help of various ground improvement methods, the embankment stability verifications were performed by using the results of Ménard pressuremeter with enhanced factor of safety. By adjusting the ground improvement methods to the various sections and ground conditions, a technical and economical optimization could be achieved. The improvement of the soil characteristics as well as the latest results of settlement measurements confirmed the success of the method.

2 SITE INVESTIGATION, GEOLOGICAL FEATURES

In central Germany, there are mainly landfill sites with mixed soils with varying silt contents. Due to the technique used for filling, dumped from a great height, the fill is deposited in poorly compacted heterogeneous horizontal thin layers (varved). These mixed soil man-made deposits are much more compressible than natural soils. Particularly in the upper soil layers down to a depth of 10 m, the soils are often arranged in a very loose state. A reliable assessment of the interaction between the structure and the subsoil is very difficult on mixed dump soil.

Figure 2. The dump of Schleenhain

As a result of loose deposition or rather the heterogeneity of the material and its density, the soil behavior is different from natural deposits. Experiences and methods used with the development of soft natural soil are not transferable to these types of man-made deposits (Lausitzer und Mitteldeutscher Bergbau – Verwaltungsgesellschaft 1999). The process of conveying, transporting and dumping is the reason that the deposit is locally marked by extreme material and density heterogeneity in a very confined space. Due to the mixture of cohesive fines and loose grain, these deposits consistently characterized by a very strong sensitivity and the risk of loss of strength due to plastification by water ingress.

The soil investigation results from the fill show a large variation in grain size.

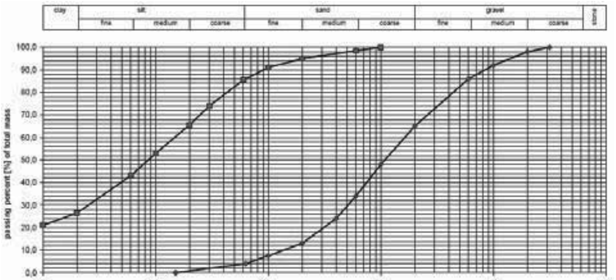


Figure 3. Spread of grading curves of the dump soil (G.U.B. Ingenieur AG 2010)

The following fractions have been used for the design of the ground improvement for the new road, according to the geotechnical report (G.U.B. Ingenieur AG 2010):

- 20% boulder clay
- 20% sands and gravels
- 25% tertiary clay
- 30% fine and medium sand
- 5% brown coal

This mixed-grain fill material represents almost the entire typical soil in the mining area. Details on the natural soil with boulder-clay and silt layers of the quaternary will not be presented here.

Currently, the groundwater level has been lowered to at least 35 – 40 m below ground-level by the ongoing dewatering operations of the daylight mining, whereupon the relatively steeply running saturation lines of the depression cone have all developed in tilted, grown border slopes. By the year 2100, a static groundwater level should be reached after turning off the pumps at an altitude of 125 m of about 15 m significantly below the gradient and at least slightly below the lowest level of the foundation of new embankments.

With w_n = 10%...14%, the calculated current water content under the influence of dewatering is in the normal range of natural humidity. Laboratory tests showed a proctor density about ρ_{Pr} = 1.846 g/cm^3, and a proctor water content about w_{Pr} = 9.9% and thus good compression options.

Cone penetration tests from the landfill at up to ca. 20 m depth vary mainly in the range of qc ~ 1.0 MN/m^2...3.5 MN/m^2, which lead to the estimation of a stiffness modules Es ~ 2 MN/m²...9 MN/m², with average = 5.5 MN/m², as described in the geotechnical report.

It is a mixed-grain fill material (fine particle fraction > 20%...25%) in the earth-moist state. With water saturation a plastification is possible, because of the fine particle fraction and the storage of loose grains and mixed pseudo-cohesive soil. In the event of plastification, the shear strength drops to about 50% of the baseline values.

3 PLANING OF THE SOIL IMPROVEMENT METHODS

The connection to the new B176 is located on the so-called mainland area. This is characterized by the transition from natural soil towards the central part of the road to the landfill area. From this point of view it is a very challenging geotechnical transition in the route. Other settlement issues are arising from the different embankment height as a result of the area conditions. Without the use of specially adapted ground improvement methods, settlements of up to one meter could be expected. In order to reduce settlements and to avoid critical differential settlements, a special sequence and quality control of soil improvement techniques was chosen at the transition with the main land and the three structures.

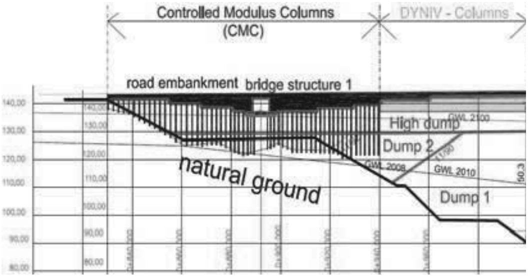


Figure 4. Design section along the road centerline in the transition from the main land (natural ground) to the landfill.

The following figure 5 shows the floating foundation of two building structures on the 50 to 70 m thick fill deposit.

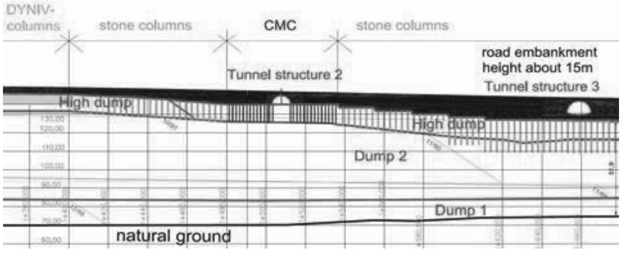


Figure 5. Design section of the tunnel structures crossing the up to 15 m high embankment over the landfill

The tunnel structure 2 above the belt conveyor is founded by the vibration-free CMC method. For the construction of the 15 m tall embankment 70 m wide at its base, the stone columns technology were used.

Figure 6 gives an overview of the different improvement techniques carried out in the area of the belt conveyors structure 2. The longitudinal section elevations showed a height difference of respectively 1.75 m. The shallow stone columns reach 10 m to 15 m deep.

Figure 6. 15m high difference including ripping holes for the two devices RSV, CMC directly on BW2 and pressumeter PMT in front.

4 RESULTS OF THE SOIL IMPROVEMENT

Hereafter, examples of results for the stone columns treatment area are shown. Test areas and boring before and after treatment were performed near the highest embankment section to be able to derive the soil parameters of the calculation model.

The Menard pressuremeter tests were performed within the stone columns and in the center of the grid of installation.

Figure 7. Execution of the Ménard pressuremeter between and centrally in the columns

Due to the compaction at optimum proctor water content corresponding to figure 8 most often an improvement between the columns with the factor of 2 was measured. With the mean stiffness modulus of E_c = 100 MN/m^2 in the columns with at least 70 cm diameter, this results in a 3 times higher design relevant modulus of E_s =30 MN/m^2 for the improved ground.

The Stiffness modulus was doubled after treatment in the center of the grid of installation, in between columns. This fairly remarkable result was made possible by the water content close to the optimum Proctor of the deposits of the mining ground, and also by the powerful V23 vibrator. A transfer of these high values to other constructions projects without these optimal conditions is not possible and it is highly recommended to use a project-specific calibration with test fields and the Ménard pressuremeter for other projects.

The results of the cone penetration tests also showed an improvement factor of 2. It should be noted that the initial values may have been too low. The improvement as shown by CPT`s is similar to the Ménard pressuremeter. The stiffness modulus in cohesive soils can only be measured by pressuremeter and oedometer tests on undisturbed soil samples.

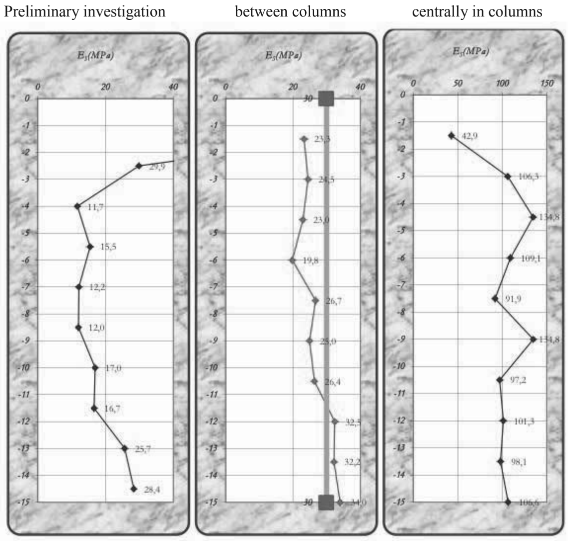


Figure 8. Results from in-between and at the center of the columns

5 NUMERICAL ESTIMATION OF SETTLEMENT

Based on the design soil parameters, the settlement calculation was created in the course of a Diploma thesis (Vogel 2011) with the PLAXIS software.

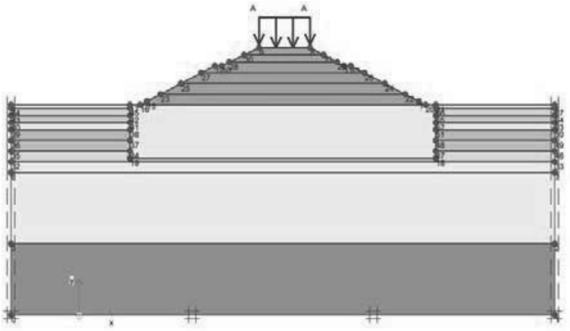


Figure 9. CAD model and PLAXIS model

The layers of the fill deposit from ground level up are divided per figure 9 into different layers. The first 20 meters from the edge of the model to the toe of the embankment are modelled using the thin layered structure of the graded soil charactistics of the dump.

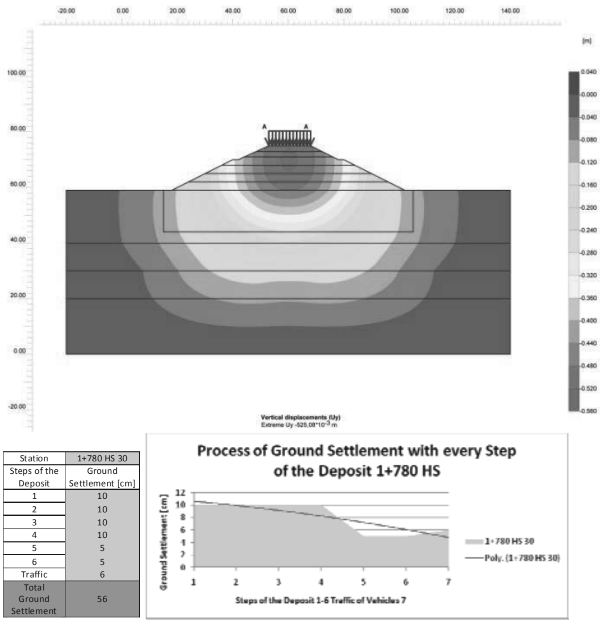
The improvement depth by stone columns below the embankment was 15 m. This improved ground beneath the dam is modelled using a composite layer with a composite average modulus E_s = 30 MN/m^2.

The last two layers of fill are assumed to be each 20 m thick at the lower part of the model domain.

As part of the thesis (Vogel 2011), different behaviour laws for the modelling of the stress-strain relation of the fill material were compared and each corresponding calculations resulted in very variable estimation of the settlements. Between the linear-elastic, perfectly plastic Mohr Coulomb model with one meter expected settlements to the more realistic elastoplastic Hardening Soil model, a difference of half a meter in the estimated long term settlement were calculated using PLAXIS software.

In this paper, we present the results of the Hardening Soil model, where the stiffness modulus for the settlement calculation for the next load level are sequentially recalculated and increased after each load level according to oedometer and pressuremeter test results.

Each of the following six stages corresponds to an embankment height increase of nearly 3 m with corresponding settlements. On the one hand, these settlements decrease with each load step due to a smaller width of loading and with it decrease the loads at depth. On the other hand, additional settlements of the dam itself are calculated for each step.



Station	1+780 HS 30
Steps of the Deposit	Ground Settlement [cm]
1	10
2	10
3	10
4	10
5	5
6	5
Traffic	6
Total Ground Settlement	56

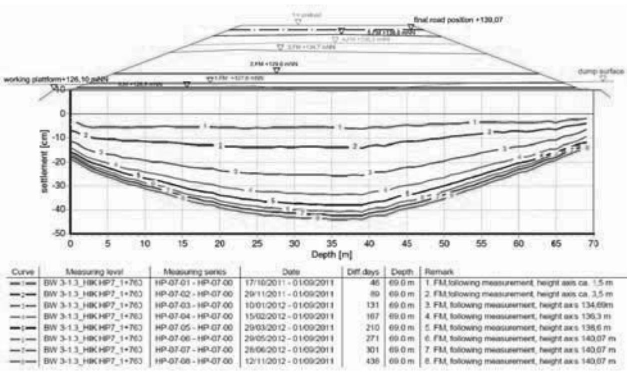
Figure 10. Representation of the predicted total settlements of 56 cm with Plaxis calculation section of 15 m embankment height

6 RESULTS OF THE MONITORING

Seven horizontal inclinometers were installed below the embankment across its section and three vertical inclinometers were also installed at the landfill along the construction road at the location of the highest embankment. The measurements are performed during the embankment construction phase to reach a total height of 15m according to the following sequence:

- every 3 m of fill placement
- immediately after reaching the final height and then every 3 month.

The following figure presents the cross-section measurement at the location of the design cross section.



Curve	Measuring level	Measuring series	Date	Diff days	Depth	Remark
1	BW 3-1.3_HIK HP7_1+763	HP-07-01 - HP-07-00	17/10/2011 - 01/09/2011	46	69.0 m	1. FM,following measurement, height axis ca. 1,5 m
2	BW 3-1.3_HIK HP7_1+763	HP-07-02 - HP-07-00	29/11/2011 - 01/09/2011	89	69.0 m	2. FM,following measurement, height axis ca. 3,5 m
3	BW 3-1.3_HIK HP7_1+763	HP-07-03 - HP-07-00	10/01/2012 - 01/09/2011	131	69.0 m	3. FM, following measurement, height axis 134,69m
4	BW 3-1.3_HIK HP7_1+763	HP-07-04 - HP-07-00	15/02/2012 - 01/09/2011	167	69.0 m	4. FM, following measurement, height axis 136,3 m
5	BW 3-1.3_HIK HP7_1+763	HP-07-05 - HP-07-00	29/03/2012 - 01/09/2011	210	69.0 m	5. FM, following measurement, height axis 138,6 m
6	BW 3-1.3_HIK HP7_1+763	HP-07-06 - HP-07-00	29/05/2012 - 01/09/2011	271	69.0 m	6. FM, following measurement, height axis 140,07 m
7	BW 3-1.3_HIK HP7_1+763	HP-07-07 - HP-07-00	26/06/2012 - 01/09/2011	301	69.0 m	7. FM, following measurement, height axis 140,07 m
8	BW 3-1.3_HIK HP7_1+763	HP-07-08 - HP-07-00	12/11/2012 - 01/09/2011	436	69.0 m	8. FM, following measurement, height axis 140,07 m

Figure 11. measurement results: the settlement curves fit the predictions in the different earthwork steps of the embankment construction

The measured settlement values in all cross sections were similar to the predicted settlement and underline the accuracy of the Ménard pressuremeter and the soil parameters derived from this test which were used for the finite element using the hardening soil model.

7 SUMMARY AND CONCLUSION

The construction of roads on mining areas requires close cooperation between mining engineers, geotechnical engineers and contractors, as the mining technical characteristics, requirements in road construction and geotechnical characteristics must always be brought into line and finished with high-end quality.

A very comprehensive site investigation is essential in dealing with man-made fill deposits. The Ménard pressuremeter brought significant findings throughout the additional preliminary soil investigation.

A technical and economic optimization was achieved by adapting the ground improvement methods to the respective sections. With the help of various ground improvement methods, settlement reduction and improved stability safety factors were successfully obtained.

The high quality of the construction with stone columns, dynamic replacement and CMC was documented not only in foundation with the usual protocols of the manufacturer, but also tested regularly during the construction phase by the Ménard pressuremeter. The settlement calculations and subsequent field measurements confirmed a significant increase of quality.

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