ROAD CONSTRUCTION ON A LANDFILL WITH VIBRO CONCRETE COLUMNS AND GEOGRIDS

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ABSTRACT: An area near Hanover / Germany, in which an old landfill is situated, shall be used as a site for industrial buildings. A new road has to cross the landfill area. The landfill mainly consists of household waste, local workshops and rubbish, which has been placed into a gravel pit some decades ago with a thickness of several metres. Then the site was only covered by a soil layer of about one metre. Settlements of the fill still have to be expected in an unknown amount due to long-term processes of disintegration of the waste materials. Furthermore latent risks of environmental contamination due to leaching of the waste by rain water etc have to be faced. To solve the problem a special design was developed for the construction of the road on the fill. All loads resulting from the road structure and the traffic shall be brought into the ground below the fill by columns of coarse gravel and concrete installed at the site by heavy vibrator rigs. The diameter of a column is 0.8 m and the distance of the column axes about 2 m. On top of the columns a layer of coarse slag reinforced with geogrids was placed. Then a water impermeable cover and the road structure was built with a geosynthetic liner, several layers of soil and asphalt concrete. In the paper the different aspects of this design will be explained. Results of calculations according to British Standard BS 8006 and to other models are given and discussed. Some data are presented of plate loading tests on and between the columns and of measurements with an inclinometer in a horizontal pipe placed near to the layer with the geogrids.

1 INTRODUCTION

An area some kilometres to the south of the city of Hanover shall be developed for the settlement of industrial companies with a total size of approximately 2.4 square kilometres. The main road leading into this industrial park has to cross an area in a length of approximately 300 m, which has been filled with waste in the past (Fig. 1).

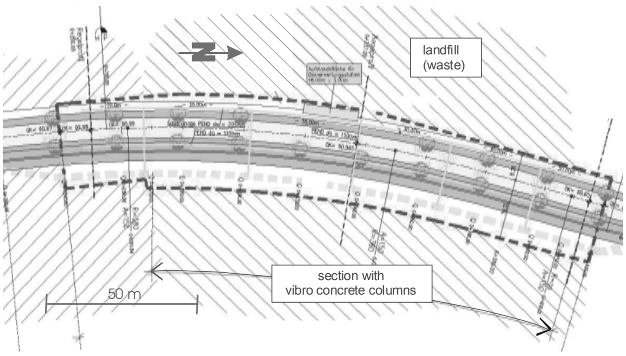

Figure 1 Plan of site

This old waste deposit consists of heterogeneous and partly unknown materials from households and industry as well as soils filled into a former gravel-pit. Disintegration and settlement of the fill material in an unknown amount have to be expected in the future and furthermore the bearing capacity of this fill was found to be completely insufficient to serve as subsoil for the road without special measures of improvement.

For the road on the waste deposit it was necessary to design and build a geotechnical substructure, in order to minimise the deformation and other effects on the road caused by waste disintegration and long-term settlements. Additionally this substructure had to be combined with a cover for the whole area of the waste deposit according to the German regulations for contaminated landfill areas.

Generally other solutions of the problem, e.g. another location of this road or a complete removal of the waste material and replacement by densified, non cohesive soils have been found to be impossible in this case due to further boundary conditions, shortage of time and extremely higher costs. Furthermore possible emission of gas and liquids of the waste had to be taken into consideration.

2 BOUNDARY CONDITIONS

As mentioned in the introduction the waste materials, mainly domestic waste and in addition some commercial waste, were deposited in a former excavation for gravel mining. The gravel-pit has been excavated up to a depth of about ten metres below ground surface until 1970. After abandonment of the gravel mining the pit was filled at its base with a layer between 1.5 m to 4 m in thickness, mainly consisting of soils, which have been removed during the gravel mining process. Then the southern part of the pit was filled with waste from building destruction and the northern part was mainly filled with domestic and industrial waste. Finally the fill area was only covered by a one metre thick soil layer. This cover soil, also gained during the gravel mining, is consisting of sandy silt with organic matter and has a soft consistency.

The southern area of the deposit, which is mainly filled with coarse and stiff waste was used during the last years for different commercial purposes, mainly to recycle and to store construction material and to park trucks and cars. The northern area with a quite soft fill of domestic and industrial waste lied idle for most of the time.

In the past settlements of the waste body, resulting from a reduction of the waste material and caused by the decomposition and disintegration of the waste material, have been compensated by refilling.

For the road, which shall carry heavy traffic up to the construction class II/III as defined by German regulations a stiff subsoil with a modulus of deformation of E_{v2} higher than 45 MN/m^2 is required (vide section 5).

In the northern part of the landfill, where it contains mainly domestic and commercial waste, vertical settlements of several decimetres and in addition horizontal displacements have to be expected due to further consolidation of the waste and due to traffic loads after construction of the road. The rate of these settlements and deformations and their amount cannot be calculated or estimated with sufficient reliability. Furthermore, these ground movements would also affect the planned lines for dewatering and for the supply of the industrial park with water and gas, which have to be placed beside the road.

The ground below the road in the southern part of the landfill has a bearing capacity, which is sufficient for the embankment and traffic loads. This was approved by geotechnical site investigations. The preloading of this area during its use as a storage yard has contributed to these conditions.

Within the frame of the geotechnical site investigations, which have been carried out for the whole area, observations and measurements of the concentration of gas components in the air above and in the ground have been performed. It was found that rotting processes of organic constituents in the waste lead to marsh gas, mainly of methane. Furthermore, a benzene content of up to 17 mg/m^3 was measured in pores of the ground.

The existing soil cover of silt and fine sand on the waste cannot prevent gas emission into the biosphere. Therefore a cover system with different layers containing a geosynthetic liner of HDPE had to be designed and integrated into the structure required to carry the loads caused by the weight of the road embankment and of the traffic.

Figure 2 Area of organic waste with dark colour after removal of the soil cover

3 GEOTECHNICAL DESIGN

To improve the bearing capacity of the ground a geotechnical structure has been designed, which shall carry the road embankment and traffic loads without remarkable deformations and transmit them into the firm stratum below the fill. This supporting system is formed by vibro concrete columns with extended caps and an embankment of coarse slag reinforced by geosynthetic grids. In the road embankment different layers for sealing and drainage have been implemented together with a system of tubes to collect gas emissions from the waste and to prevent ingression of water. Figure 3 shows a cross section of the main supporting structure with concrete columns, of the reinforced embankment and of the liner system below the road. The basic design was mainly developed by engineers of Ingenieurbüro Richter GmbH in Hildesheim / Germany and improved by geotechnical consulting.

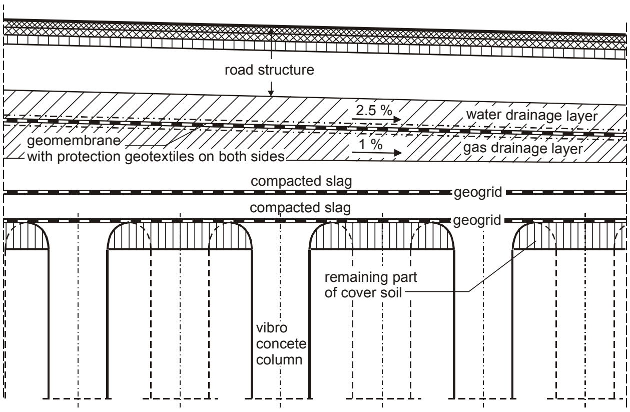

Figure 3 Cross section of the main supporting system (without scale)

With a special geotechnical method, developed by Keller Ground Engineering, Offenbach / Germany, columns made out of concrete with coarse gravel have been vibrated into the ground for the transfer of mainly vertical loads into the deeper subsoil. The procedure is as follows: A very heavy vibrator with eccentric concurrent rotary motors is carried by a rig and penetrates into the subsoil. During the pulling-process concrete with coarse material is inserted into the subsoil by the vibrator and compacted in a permanent re-pack process.

In addition certain compaction of the soil or fill surrounding these concrete columns can be expected due to the dynamic action of the vibrator. During the vibration procedure the velocity of penetration and pulling, the penetration resistance, the amount of concrete filled into the ground and further parameters are observed for quality control.

For this project a distance between two adjacent columns of 2.1 m, arranged within a triangular screen, a column diameter of 0.6 m and an extended cap with a diameter of 0.8 m was chosen. In total 920 columns had to be manufactured. Due to the different thicknesses of the landfill the length of the columns was varying. The maximum length was about 8.5 m. The columns are embedded with a depth of 0.5 m to 1.0 m into the firm stratum.

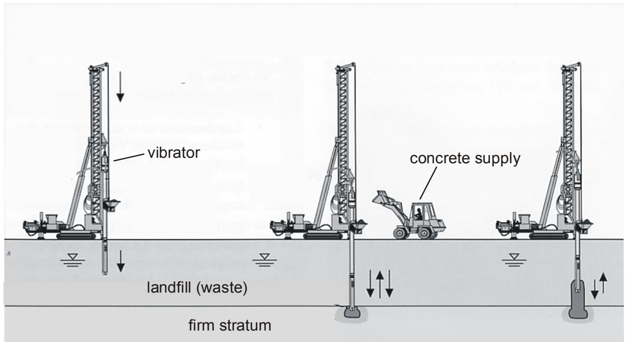

Figure 4 Steps to install vibro concrete columns (method of Keller Ground Engineering, Offenbach / Germany)

On the caps of the concrete columns an embankment formed by layers of non cohesive material and geogrids for reinforcement was designed to carry and distribute the loads from the road. The total thickness of the embankment layers, which can be related to load distribution, is about 2 m. Slag and coarse grained ash resulting from the incineration of domestic waste with a grain size between 2 and 32 mm instead of crushed gravel are accepted as fill material, if this material is matching the technical specifications and environmental quality requirements.

To obtain a quite horizontal level on the column caps a thin compensation layer has to be placed. The embankment above is formed by the following components:

- a geogrid of the type Secugrid® 400/40 R6,
- a compacted layer of slag material with a thickness of about 0.3 m,
- a second geogrid of the type Secugrid® 400/40 R6 crosswise to the first one,
- a layer of gravel (2/32 mm) for gas drainage,
- a 2.5 mm thick geomembrane of HDPE with geotextiles (each with a weight of 800 g/m², mechanically bonded, non woven) on both sides for protection,
- another layer of gravel (2/32 mm) for water drainage purposes below the road structure.

The layers of the road structure above this embankment system have a total thickness of about 0.75 m and are designed in accordance with German regulations for road construction for heavy traffic.

4 GEOSYNTHETIC REINFORCEMENT

For the reinforced embankment structure the selected slag and Secugrid® 400/40 R6 have been proposed by the contractor Hastrabau-Wegener, Hanover. Secugrid® is a product of NAUE FASERTECHNIK GmbH & Co KG, Lübbecke, with grid elements of prestrained flat bars made of polyester. The dimensions of the flat bars can be varied in relation to the tensile forces. The bars are placed crosswise to form a grid when the knots are welded. Secugrid® 400/40 R6 has a tensile strength of 400 kN/m in the main direction and of 40 kN/m in the perpendicular direction. A good contact between geogrid and coarse grains of adjacent material is reached due the gaps between the flat bars.

Tensile forces are expected to act in the geogrid reinforcement placed in the lower part of the embankment near to the caps of the stiff concrete columns. In the compacted embankment material arching effects between adjacent columns shall lead to load concentration on the concrete column. On the soft landfill material and soil between the concrete columns nearly no load should be transferred. If the material of the embankment fill is showing some dilatation in the space below the “arches” this is limited due to the geogrid reinforcement, which keeps the fill material in its position and prevents destabilisation of the “arches“.

The shear or friction behaviour of the embankment fill, characterised mainly by the shear or friction parameter, and the stress-strain-relationship, especially the stiffness of the geosynthetic reinforcement, are important for the behaviour of the whole structure. Shear strength and friction of fill and stiffness of geogrids should be high to keep deformations within acceptable limits. It can be assumed that there is nearly no relative displacement in the contact areas of fill material and geosynthetic reinforcement.

Design calculations have been performed by BBG Bauberatung Geokunststoffe GmbH & Co. KG, Lemförde / Germany according to British Standard BS 8006 (1995), section 8.3.3.6. The external surcharge load w_s and the weight of the embankment fill have to be transferred mainly onto the caps of the concrete columns. Soil arching between adjacent column caps has to be taken into consideration.

In BS 8006 (1995) an arching coefficient C_c as shown below is defined to cover these effects.

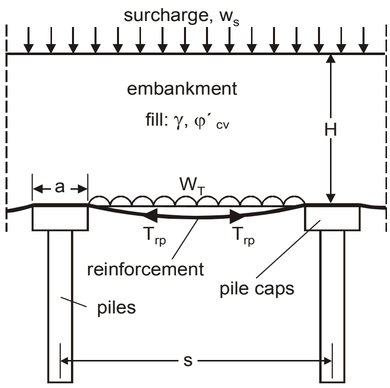

Figure 5 System and variables used in determination of T_{rp} according to BS 8006 (1995)

According to BS 8006 (1995) the distributed load W_T carried by the reinforcement between two adjacent concrete columns can be determined for H > 1,4 · (s - a) from equation (1) :

$$W_T = \frac{1{,}4 \cdot s \cdot f_{fs} \cdot \gamma \cdot (s-a)}{s^2 - a^2} \cdot \left[s^2 - a^2 \; (p'_c / \sigma'_v)\right] \qquad (1)$$

with

- s = spacing between adjacent concrete columns
- a = diameter of pile caps
- γ = unit weight of embankment fill
- f_{fs} = partial safety factor for soil unit weight
- H = height of embankment
- p'_c = vertical stress on the caps of concrete columns
- σ'_v = factored average vertical stress at the base of the embankment ($f_{fs} \cdot \gamma \cdot H + f_q \cdot w_s$)

with the following relation of vertical stresses

$$\frac{p'_c}{\sigma'_v} = \left[\frac{C_c \cdot a}{H}\right]^2 \qquad (2)$$

and with the arching coefficient

$$C_c = \left[\frac{1.5 \cdot H}{a} - 0{,}07\right] \quad \text{for ductile concrete columns} \qquad (3)$$

the tensile load T_{rp} per metre ‘run’ generated in the extensible reinforcement resulting from the distributed load W_T is given in equation (4):

$$T_{rp} = \frac{W_T \cdot (s-a)}{2a} \sqrt{1 + \frac{1}{6 \cdot \varepsilon}} \qquad (4)$$

with

- ε = strain in the reinforcement.

Based on direct shear tests an angle of internal friction of 45° for the non cohesive embankment fill was taken for the calculations. At the edges of the embankment there are slopes and therefore sliding and slope stability have to be taken into consideration. The lateral sliding stability and the tensile load T_{ds} in a reinforcement placed at the base of the fill can be calculated in accordance with BS 8006 by the following equation (5):

$$T_{ds} = 0.5 \cdot k_a \cdot (f_{fs} \cdot \gamma \cdot H + 2 \cdot f_q \cdot p) \cdot H \qquad (5)$$

with

k_a = active earth pressure coefficient
f_{fs} = partial factor for fill unit weight
f_q = partial load factor for external applied load
p = external applied load
γ = unit weight of embankment fill
H = height of embankment fill

In the case studied in this paper the tensile forces T_{ds} are small as the embankment is not more than about two metres thick.

In BS 8006 (1995), section 8.3.2.11, it is stated generally that the maximum strain in a basal reinforcement should not exceed 5 % for short term applications and 5 % to 10 % for long-term conditions. For the calculations a maximum permissible strain of 4 % was assumed for the serviceability limit state. The diagram in Figure 6 shows that about 60 % of the maximum tensile load is related to this strain for Secugrid®. If deformations of the embankment would cause a strain of 4 % in the geosynthetic reinforcement, (in our case with a diameter a = 0.8 m of the caps of the concrete columns and with a column distance s = 2.1 m) the following tensile loads are obtained by the equations given above:

- in the direction of the embankment axis:
  $T \approx 100$ kN/m
- traversal to the embankment axis:
  $T + T_{ds} \approx 120$ kN/m

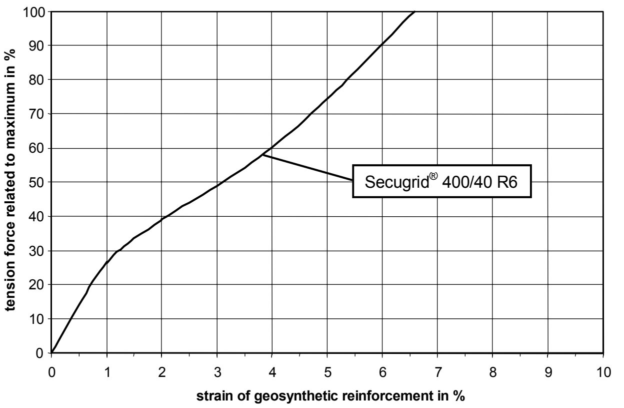

Figure 6 Tension force related to maximum tension force vs. strain of geogrids installed above soilcrete columns

As the maximum tensile strength of Secugrid® 400/40 R6 is 400 kN/m in the main direction and two layers of grids are placed crosswise, there is a high factor of safety in the design.

Further investigations by the authors of the University of Hanover have been concentrating on the question of modelling the structure and estimating the possible tensile load if a reinforcement is installed in the embankment near to the caps of the concrete columns. Calculations based on structure models proposed by KEMPFERT et al (1997) and ZAESKE (2001) deliver results of the tensile loads in the reinforcement between 40 and 80 kN/m for our boundary conditions, if the soil parameters are varied within certain limits. If a simple framework structure is used to model the arching effects in the embankment a tensile load of only about 15 kN/m is acting in the reinforcement near to the slopes.

It is our opinion that tensile loads in the reinforcement of constructions comparable to the one discussed in this study are overestimated by calculations according to BS 8006 (1995). Field tests as performed e.g. by GOURC and VILLARD (2000), PAUL and SCHWERDT (2001) clearly document that arching effects in the embankment soil and the membrane effect of the geosynthetic reinforcement have to be regarded. For the serviceability limit state these effects lead to low strains and tensile forces in the geosynthetic reinforcement. To verify this deformation measurements have been started after completion of the embankment construction. First results of these measurements and some results of load plate tests on the embankment during construction will be shown in the following chapter.

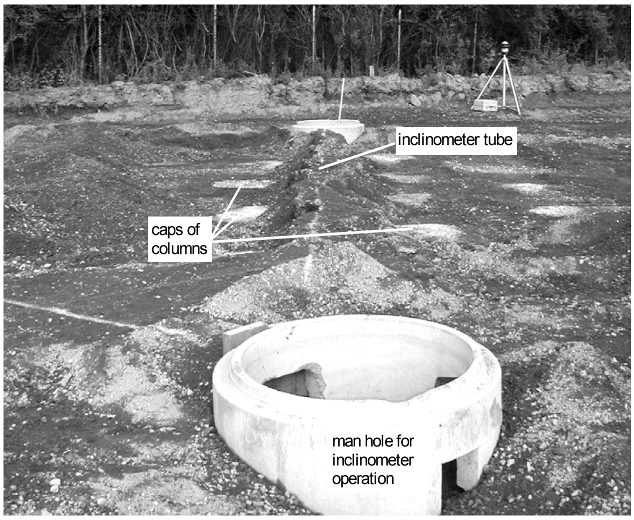

Figure 7 Test field under construction with caps of vibro concrete columns and tube between man holes for inclinometer operation

5 TEST FIELD AND MEASUREMENTS

The technology and production procedure used to install vibro concrete columns in a fill of waste from household and industry with mainly unknown material composition was tested in a field and optimised. About 30 columns mainly with a length of about 5 to 6 m have been installed in this test field with a pattern as shown in Figure 8. Due to the increased diameter of the column caps the open space between two columns is only about 1.4 m. Stiff concrete with components of coarse material and a strength of about 10 N/mm² was used for the columns. No significant installation problems have been observed during the installation of the test columns, which became part of the final structure.

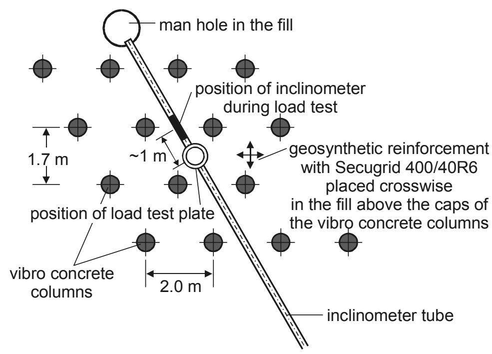

Figure 8 Position of inclinometer and of load test plate (layout plan)

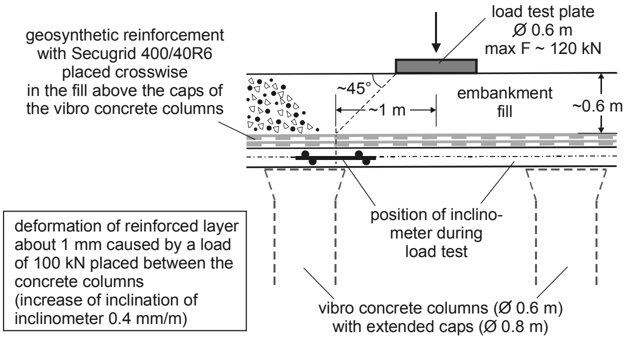

Figure 9 Position of inclinometer and of load test plate (cross section)

In the test field an inclinometer tube was placed horizontally in the level of top of the columns. Then a test embankment with a total thickness of about 0.6 m was built, consisting of two layers of the geogrids in crosswise position and of compacted slag with coarse and sharply edged grains and a high angle of internal friction as explained above.

Common load plate tests as used to investigate the deformation modulus of layers for highway construction have been performed on the test embankment. Figure 8 and 9 show a sketch of the test layout. Some tests have been performed with a load plate position directly above a concrete column and some between concrete columns. Results of these tests are documented in Figure 10.

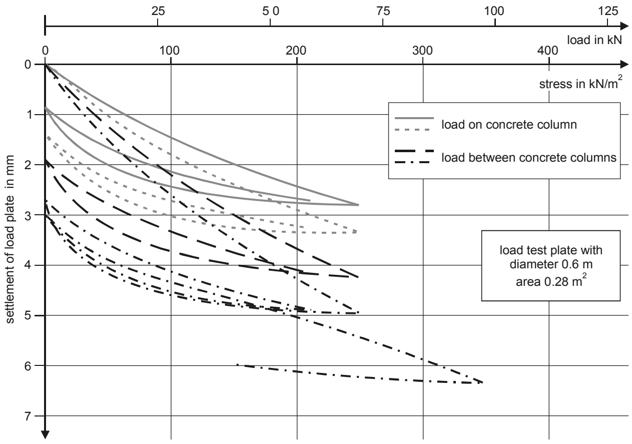

Figure 10 Results of load plate tests

A deformation modulus E_{V2} as defined in German Standard DIN 18134, September 2001, can be derived for the embankment fill of 50 to 55 MN/m^2 for the load plate position
between the columns, and of 60 to 70 MN/m^2 for the load plate position directly on the column. The differences in settlements (vertical deformations) found for the tests on and between the columns are about two millimetres or less under a load of 75 kN. In one test a higher load of about 100 kN was applied on the plate (near to the limit of the load and support system). With the inclinometer in a fixed position in the surrounding of the depressed area (Fig. 8 and 9) it was found that the settlement of the fill in a layer near to the geosynthetic reinforcement is not more than about one millimetre.

The whole construction, which shall support the road crossing the landfill area, was completed at the end of the year 2002. To control the deformation behaviour of the reinforced embankment further inclinometer measurements are performed. First results are presented in Figure 11.

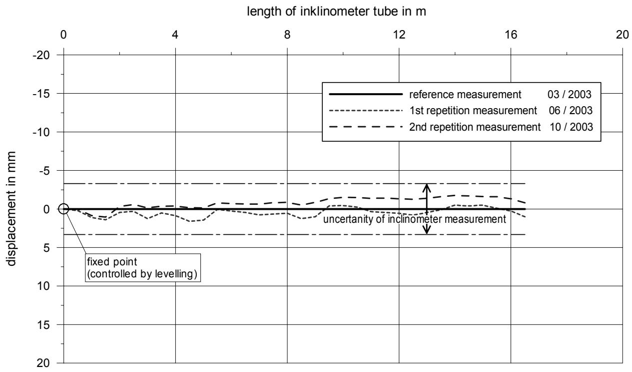

Figure 11 Results of inclinometer measurements after completion of the structure

No significant deformation of the layer reinforced by geogrids has been observed until October 2003. The deformation measurements will be continued as a part of the measures for quality and stability control.

6 REMARKS ON THE CONSTRUCTION

The construction was carried out between July and December 2002. The waste covering soil was partly removed in the construction area. Afterwards the vibro concrete columns were installed.

Figure 12 Equipment and procedure to install vibro concrete columns

After completion of the columns and levelling the area, the first geogrid layer was placed with the higher tensile strength perpendicular to the axis of the embankment and fixed simply by steel pins. Then a layer of slag was placed and compacted before the second geogrid was installed with the main tensile bearing capacity in the direction of the embankment axis. In the case of installation traverse to the embankment axis the grids were overlapping 0.5 m. In the other direction the overlapping was about 0.8 m.

Figure 13 Laying of geogrids

For questions related to the behaviour of the geosynthetics and for quality control - including the material and installation of the welded HDPE-geomembrane - Dr.-Ing. Knipschild, Rosengarten, was acting as expert and consulting engineer.

For the design and the complete construction of the road supporting system in the landfill area approximately one Mio Euros were spent.

Figure 14 Placing of drainage gravel on geotextile protected geomembrane

7 PRELIMINARY CONCLUSIONS

Vibro concrete columns which are supporting an embankment reinforced with geogrids can be used successfully not only to build roads on grounds with soft soils but also in areas filled with waste or similar landfills.

Stiff geogrids have to be used as reinforcement for embankments of compacted coarse grained materials with high shear strength and friction to distribute local loads from roads onto the supporting vibro concrete columns.

Due to arching effects in a compacted embankment fill, which must therefore have a sufficient thickness in relation to the distance between adjacent vibro concrete columns, only small strains have to be expected. By conventional methods to calculate the tensile forces acting in the geogrid reinforcement, for example British Standard BS 8006, too high values are obtained in cases as described in this paper. Our deformation measurements only show small strains of the geogrid to which small tensile stresses are related.

8 ACKNOWLEDGEMENT

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9 REFERENCE

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