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Geogrids on vibro-concrete-columns for a road crossing a landfill

Géogrilles et colonnes ballastées crépies pour une route traversée une décharge

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ABSTRACT
Near Hanover / Germany a new industrial estate is planned. A new road leading into this industrial estate has to cross an old landfill area. To improve the bearing capacity of the ground for the road construction a geotechnical structure has been designed, which carries the road embankment and traffic loads. This structure is formed by vibro concrete columns and an embankment reinforced by geogrids. 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.

RÉSUMÉ
Près de Hanovre / Allemagne une région industrielle est projetée. La nouvelle voie d'accès menant dans cette région industrielle se faut traverser une ancienne décharge. Pour améliorer la résistance du sous-sol pour la route une construction géotechnique a été crée qui porte les charges de la chaussée pavé et les charges du traffic. Cette construction se compose des colonnes ballastées crépies et d'un digue armé avec des géogrilles. Dans cette contribution les aspects differents de ce projet sont expliqués. Des résultats de calculs conformes au British Standard BS 8006 et d'autres modèles sont présentés et débattus. De plus quelques résultats des essais de charge à plaque sur et entre les colonnes ballastées et de la menstruation avec un clinomètre dans un tube horizontal qui est placé près des géogrilles sont présentés.

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).

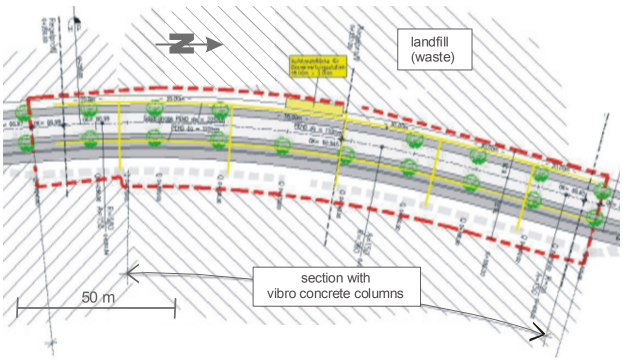

Figure 1. Plan of site

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 settlements of the fill material in an unknown amount have to be expected in the future. 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 much higher costs. Furthermore possible emission of gas and liquids of the waste had to be taken into consideration.

2 BOUNDARY CONDITIONS

The waste was deposited in a former excavation for gravel mining. The gravel-pit has been excavated until 1970. After abandonment of the gravel mining the southern part of the pit was refilled with waste from building destruction; the northern part was mainly refilled with domestic and industrial waste. Finally the fill area was covered by a one metre thick soil layer. This cover soil is consisting of sandy silt with organic matter and has a soft consistency.

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

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 deformation modulus of E_{v2} higher than 45 MN/m^2 is required (vide section 5).

In the northern part of the landfill 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. Further, these ground movements would also affect the planned lines for dewatering and for the supply of the industrial estate 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.

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 geogrids. 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 2 shows a cross section of the main supporting system with the concrete columns, the reinforced embankment and the liner system below the road structure.

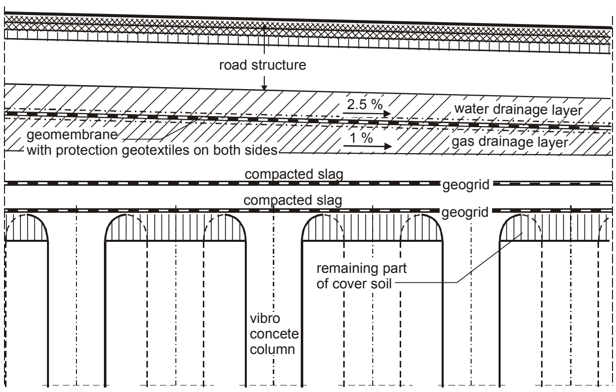

Figure 2. Cross section of the main supporting system (without scale)

With a special geotechnical method, developed by Keller Grundbau, 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. Certain compaction of the soil or fill surrounding these concrete columns can be expected additionally due to the dynamic action of the vibrator.

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 thickness of the landfill the column length was varying up to about 8.5 m. The columns are embedded with a depth of 0.5 m to 1.0 m into the firm stratum.

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 instead of crushed gravel were accepted as fill material, if they are matching the technical specifications and environmental quality requirements. The embankment above the column caps is formed by the following components:

- geogrid of the type Secugrid® 400/40 R6,
- compacted, 0.3 m thick layer of slag material,
- second geogrid of the type Secugrid® 400/40 R6 crosswise to the first one,
- second layer of compacted slag material,
- layer of gravel (2/32 mm) for gas drainage,
- 2.5 mm thick geomembrane of HDPE with non wovens on both sides for protection (each with a weight of 800 g/m²)
- layer of gravel (2/32 mm) for water drainage 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. Secugrid® is a product of NAUE GmbH & Co KG, Lübbecke, with grid elements of prestrained flat bars made of polyester. The bars are placed crosswise to form a grid when the knots are welded. A good contact between geogrid and coarse grains of adjacent material is reached due to 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 columns. 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 embankment 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. The shear strength of the embankment fill and the stiffness of the 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 embankment fill material and geosynthetic reinforcement.

Design calculations have been performed 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 (Fig. 3). Soil arching between adjacent column caps has to be taken into consideration. In BS 8006 (1995) an arching coefficient is defined to cover these effects.

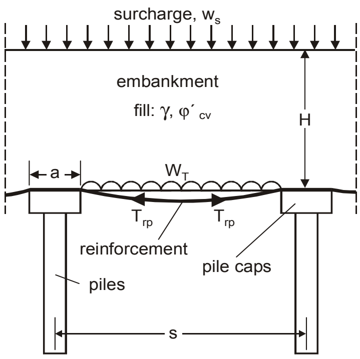

Figure 3. System, variables and symbols used in determination of T_{rp} according to BS 8006 (1995)

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 (1995). 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. About 60 % of the maximum tensile load is related to this strain for Secugrid® 400/40 R6. If deformations of the embankment would cause this strain of 4 % in the geosynthetic reinforcement, in our case the following tensile loads are obtained:

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

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 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.

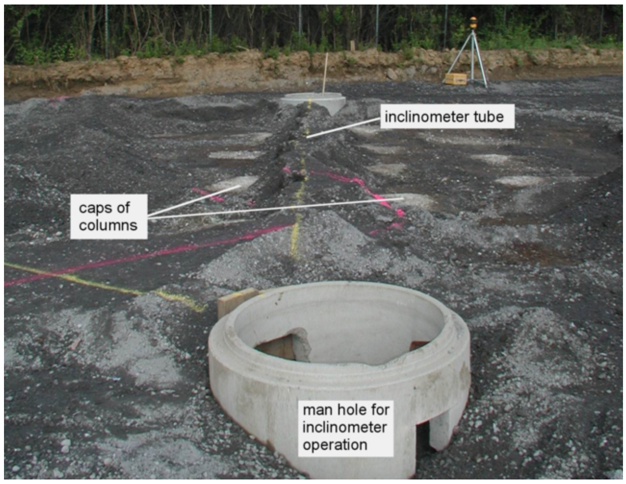

Figure 4. Test field under construction with caps of vibro concrete columns and tube between man holes for inclinometer operation

5 TEST FIELD AND MEASUREMENTS

The technology used to install vibro concrete columns in a fill of waste with mainly unknown material composition was tested in a field and optimised. About 30 columns mainly with a length of about 6 m have been installed in this test field with a pattern as shown in Figure 5. Due to the increased diameter of the column caps the open space between two columns is only about 1.2 m. Stiff concrete with components of coarse material and a strength of about 10 N/mm² was used for the columns.

In the test field an inclinometer tube was placed horizontally at the level of the 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.

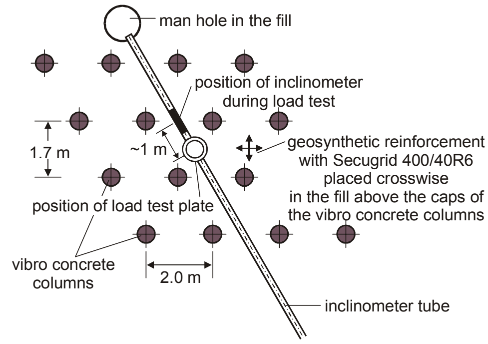

Figure 5. Position of inclinometer and of load test plate (layout plan)

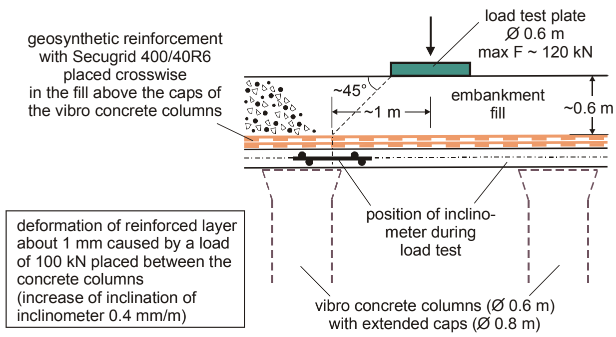

Figure 6. Position of inclinometer and of load test plate (cross section)

Common load plate tests as used to investigate the deformation modulus of layers for road construction have been performed on the test embankment. Figure 5 and 6 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 7.

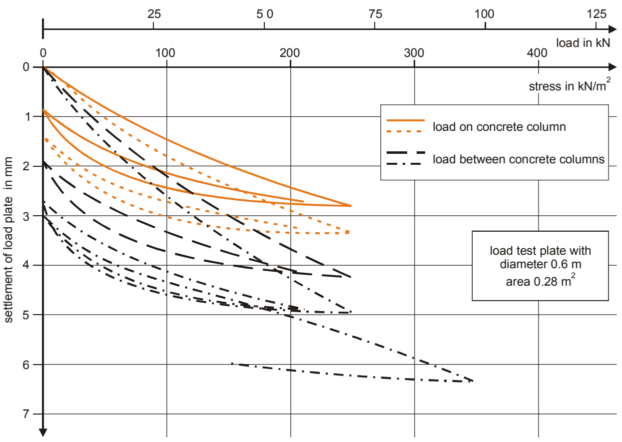

Figure 7. Results of load plate tests

A deformation modulus E_{V2} as defined in the German Standard DIN 18134 (September 2001) can be derived 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 under a load of 75 kN. In one test a higher load of about 100 kN was applied on the plate in a position between the columns. With the inclinometer in a fixed position in the surrounding of the depressed area (Fig. 5 and 6) it was found that the settlement of the fill in a layer near to the geosynthetic reinforcement is not more than 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 8.

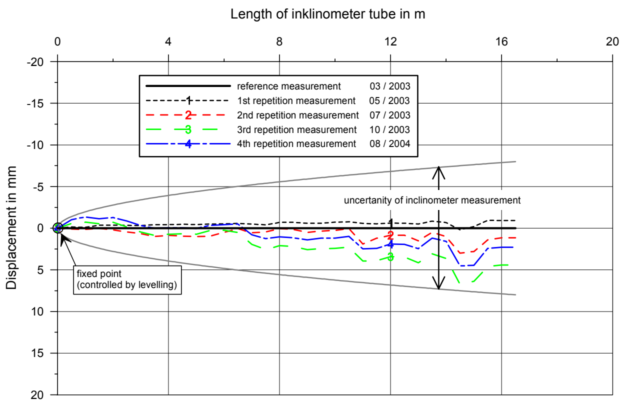

Figure 8. Results of inclinometer measurements after completion of the structure

No significant deformation of the layer reinforced by geogrids has been observed until August 2004. 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.

After completion of the columns and levelling the area, the first geogrid layer was placed with the main 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 strength 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. For the design and the complete construction of the road supporting system in the landfill area approximately one Mio. Euros were spent.

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 other landfills.

Stiff geogrids may 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.

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