Interactive geotechnical design with geosynthetics for the covering of sludge lagoons and tailings ponds

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Abstract

Today industrial tailings ponds originating from the processing of ores, refining of coal and from the chemical industry present a great source of environmental problems world wide. The coverage of industrial sludge deposits and tailings ponds requires increased attention to the geotechnical design and proofs due to the complex geotechnical boundary conditions. The authors give detailed information on the characteristics of the tasks and present the coherences of an interactive geotechnical design approach. A case study finally documents the different installation phases of the covering system together with the geosynthetic components involved.

1 Introduction

In various fields of industrial production processes a large number of production residues of varying consistency are obtained. Firm materials are usually reused or deposited. Fluid to pulpy waste which for example result from the mining industry but also from dredging works or from waste water treatment plants are often brought to large basins for sedimentation or consolidation purposes or in order to be treated otherwise or to be finally deposited. In order to accelerate the consolidation process and to reduce the infiltration of rain water, it is often necessary to cover the lagoons quickly with soil or to install a capping sealing system in order to reduce emissions.

For the geotechnical design the planning engineer is confronted with the task to develop a concept which ensures the accessibility of the soft soil, which exhibits extremely high water contents together with coexistent low shear strength. In order to find an economic technical solution, experiences and knowledge about the load-deformation behaviour of weak, cohesive soils as well as a preferably representative knowledge about soil models regarding the behaviour of the soil under consideration of typical construction loads.

Considering all these special soil mechanic properties and requirements which are exemplified in the following, it is essential to optimise the planned procedures for the covering regarding the available parameters. Finally the feasibility respectively the stability of the chosen cover concept has to be proven for all relevant loads by means of suitable geotechnical methods.

2 Geosynthetic solutions

For the remediation of tailings ponds it is necessary to assure first of all an accessible surface on top of the weak sludge material. This is in a first stage important to enable an accessible area from which in-situ soil investigation, as e.g. vane shear testing and sampling for laboratory testing, can be carried out, as basis for a geotechnical design to define a temporary or final cover system. In a second stage geosynthetic load bearing systems can allow light weight construction equipment to drive on the weak sludge material for the installation of the cover system.

Geosynthetics can make a substantial contribution for this challenge as they provide the capability to spread point loadings homogeneously through e.g. a geogrid to a larger surface area. This load distribution results in a reduction of local deformation and improves the bearing capacity of soft soils.

This special load bearing behaviour, also referred to as "snow shoe effect", is assured by the rigidity of the used geogrid. Decisive is the torsional stiffness in load direction, which acts perpendicular to the level of the geogrid and not, as often shown, the so called junction strength at the intersections of the longitudinal and transverse grid elements. The junction strength in fact causes good load distribution behaviour. Due to the fact that the section modulus changes with the rib thickness by cubing, contractions like they can be found in the centre of a single rib of extruded geogrids can lead to a weakening of the rigidity in the level of the geogrid at the same time.

The flexural rigidity of a single geogrid rib is defined as product of moment of inertia (I) and coefficient of elasticity (E). To achieve preferably high product stiffness it is recommendable to manufacture a geogrid with ribs of constant cross-section geometry based on a raw material basis, which leads to a preferably high coefficient of elasticity.

Based on gained site experiences a needle-punched nonwoven geotextile filter- and separation geotextile with an area weight of at least 300 g/m^2 should be placed underneath the geogrid. With this as usually named Combigrid® composite product the accessibility on extremely weak sludge material with c_u-values < 5 kN/m^2 can be assured.

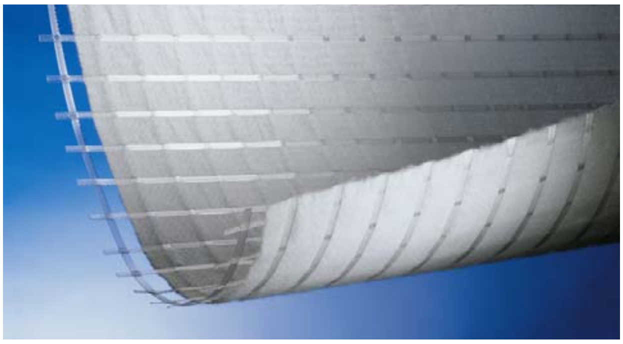

Figure 1 Combigrid® geogrid/nonwoven composite

2.1 Geosynthetic cover system

A complete coverage is carried out in those cases where future maintenance investments shall be kept on a low level, the necessity for the decrease of emission and immission is given and / or extraordinary loads have to be expected.

The bearing behaviour of geosynthetic load distribution systems, which are used as stabilisation layer for the coverage of weak sludge material, is mainly determined by the soil-geogrid interaction behaviour as it is also considered for the reinforcement of base courses in road construction. To assure an optimum shear resistance of the soil, a loosening of the grain structure in the tension zone has to be avoided. The interlocking of soil and geogrid ensures the absorption of tensile forces already at low elongations.

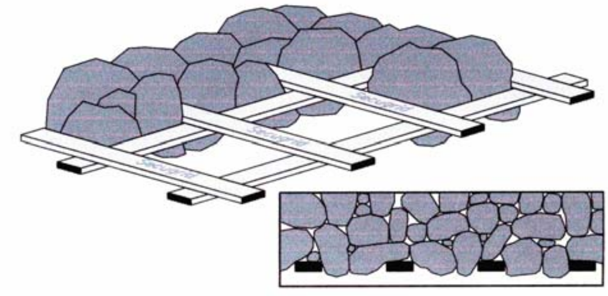

Figure 2 Soil-geogrid interaction

Depending on the subsoil conditions, especially if very high water contents are present, a combination of the load bearing system together with mineral or geosynthetic horizontal or vertical drainage systems are necessary to control the pore water pressures respectively to allow drainage.

Pre-load ballasting together with installed geosynthetic vertical drains release excess pore water and improve consolidation processes. In Praxis the methodical discharge of pore water with a gradient of 3%, as commonly used in landfill engineering, is often difficult to achieve, as the surfaces do not exhibit an adequate inclination. As a rule, lower inclinations of up to 1% can be accepted from a stability point of view.

3. Geotechnical Design

To be able to professionally estimate influencing parameters such as structure, installation procedure and construction progress, the construction of test sections is recommendable. The adjustment of the final cover system has to be verified by analytical and numerical calculation methods, as a failure of the test section would automatically mean a considerable exposure of personal injury. For the test section an area has to be chosen, which can be assumed to provide representative conditions. If applicable, a second test section has to be constructed for areas with unfavourable characteristics.

3.1 Analytical Design Method

The analytical calculation methods are based on the modelling of mostly circular failure plains, which are penetrating the subsoil. The loads from the soil coverage are distributed over a large area, whereas an additional horizontal force component develops with ongoing forward movement of the construction vehicle. In reality tilting and rotation at the fill edge will occur in the case of a failure.

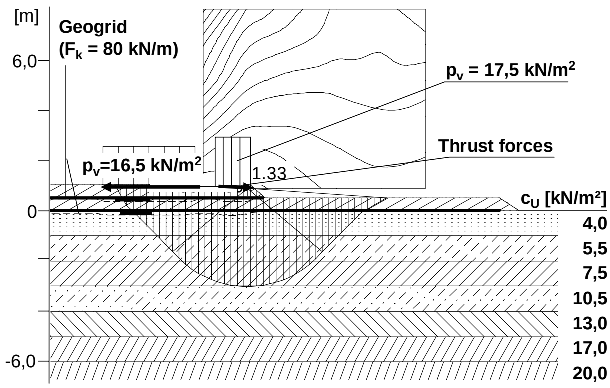

Figure 3 Analytical design method of geosynthetic load bearing system with live loads

3.1 Numerical Design Method

Contrary to the analytical approach, numerical methods can also consider deformations. Especially with very soft systems a significant conclusion about effective stresses can be expected.

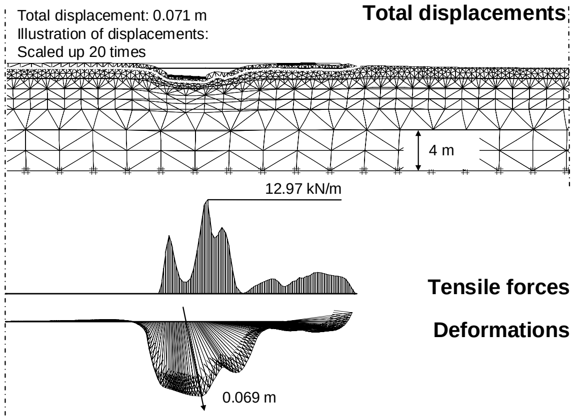

Figure 4 Numerical calculation approach of geosynthetic load bearing system with live loads

3.3 Monitoring Method

To achieve a continuous impression about the behaviour of the covered areas, which can provide data for further verification of the design methods, a continuous metrological monitoring is recommended. Due to missing generally accepted design methods continuous monitoring together with test sections can act as interactive part for the verification of carried out calculations.

The amount of measurement data and measurement procedures has to be adjusted according to the sensitivity of the project. The necessary instrumentation includes the installation of inclinometers and piezometers up to strain and stress sensors to control the long-term behaviour of the reinforcing element.

The initial high costs for instrumentation have to be seen alongside increasing reliability and possibly economisation for further construction stages with an optimised coverage method.

4. Interactive Geotechnical Design

For the evaluation of the results of an analytical design approach it has to be considered that an un-deformed system forms the basis for this calculation (First order theory). However, in the case of very soft subsoil, even at low loads, large deformations of the subsoil have to be expected, without the incidence of a failure of the complete system. Favourable effecting influences thus remain unconsidered. Such a favourable influence is e.g. a reduction of the load differences resulting from the sinking of the fill and a bulge before filling (equalisation of the site surface) as well as a pre-deformation of the reinforcing element in the main shear zone.

The realisation of an analytic calculation method at a pre-deformed system (Second order theory) fails, because of the pre-deformations which can not be described in advance by analytic methods and because of the restrictions of the available calculation programmes, which are usually not designed for such applications.

Carried out parameter studies of REUTER et. al, 2002 concerning the comparison of in-situ measurements with Finite Element Calculations on 2-dimensional and 3-dimensional systems document, that the effectiveness of the geosynthetic-soil load bearing behaviour is significantly underestimated by using solely analytical design methods.

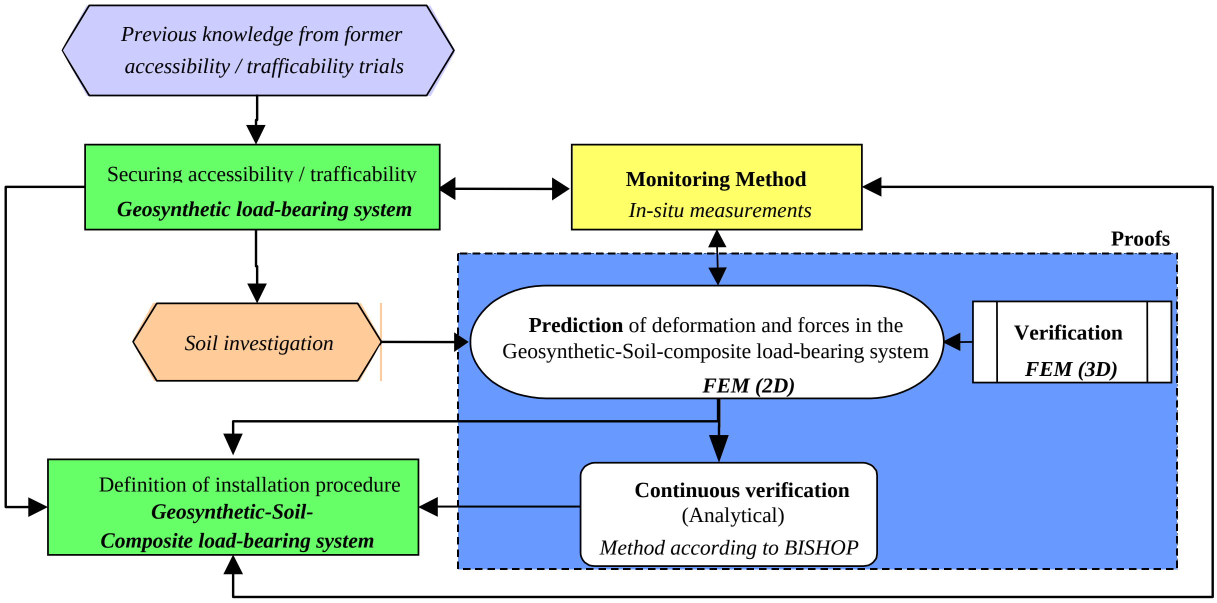

Figure 5 Flow chart of interactive geotechnical design

In order to predict the stability on very soft subsoil with the use of exclusively analytical calculation methods, this can only be classified as conditionally suitable, according to the current state-of-the-art.

Pre-deformations can indeed be forecasted by using finite element calculations at two dimensional systems; however the illustration of the effective bearing behaviour of extremely soft subsoil and the considered tensile elements and friction materials (soil) under a locally restricted loading area can only be realised with the use of a three dimensional calculation model.

As this means a disproportional complexity for smaller and medium projects in practice, the possible field of application of three dimensional calculations is to a large extent restricted to survey.

The remarks concerning test sections as well as to supplementary methods do not have to be considered as geotechnical proofs in the classic sense. In fact they should be used - in the absence of a complete and generally valid design procedure - as interactive part for the verification of the carried out calculations.

5. Case Study

5.1 Stabilization of uranium tailings impoundments ("IAA Helmsdorf) at WISMUT

Wismut GmbH has responsibility for the rehabilitation of tailings management facilities (TMF) Helmsdorf and Dänkritz 1 located at the Crossen site and Culmitzsch and Trünzig at the Seelingstädt site in Eastern Germany.

Together they cover an area of more than 570 hectares and contain about 150 million cubic meters of fine-grained residues or tailings from the processing of uranium ore.

Figure 6 Aerial view of a Tailings Management facility

The tailings were discharged into the tailing impoundments as slurry. This is the reason why the tailing ponds contain in addition to solid residues great volumes of water, which is both radioactively and chemically contaminated.

Uranium mining at Wismut terminated in the beginning nineties. Until then the internal construction of ponds was characterised by the requirement to differentiate between the various methods of depositing the various methods of depositing the varieties of tailings.

The consolidation process is considerably influenced by the spatial distribution of the different tailings materials caused by the history of flushing. The outer parts of the tailings are predominantly sandy. In direction of the centre parts of the tailings ponds follows an intermediate zone, characterized by an increasing silt content of the material or an increasing amount of silty interlayers respectively. In the centre of the ponds fine slime tailings with low contents of sandy grain sizes are predominating. This involves a decisive impact on the geotechnical behaviour of the sediments and thus their treatment during remediation.

The Wismut tailings ponds are remediated in-situ in a dry state. This decision was taken to ensure, that risks in the time following the completion of remediation measures and the environmental impact would be lower.

In order to accelerate the consolidation process and to reduce pollutant emission and the possible admittance of atmospheric water, the pond should be covered as quickly as possible with soil.

The following list shows the various stages of remediation in compliance with existing standards and official approvals:

- Removal of impounded water zones and water treatment.
- Interim cover.
- Contouring.
- Final cover.
- Landscaping.
- Monitoring after site closure.

Simultaneous measures of landscaping and monitoring have to be realised.

The first step of the in-situ dry rehabilitation is the partial dewatering and the application of an interim cover. This layer is a platform with sufficient bearing capacity to provide accessibility for dozers and other live loads, which is essential for further rehabilitation steps including all necessary investigations.

The areas of settled sediments are covered with an initial layer of nonwoven geotextile to separate the interim covering material from the soft tailings and to prevent the deposited mass from rotational failure, or slumping. This step also allows preliminary limited accessibility to the site.

Natural consolidation of the surface through evaporation and desiccation contributes to increased occupational safety since as much of the surplus water as possible is removed beforehand. At the same time, catchment and discharge of surface water is ensured by means of suitable measures.

The nonwoven geotextile is laid down manually in the given direction of the fill. The installation team therefore moves around only on laid out material thereby keeping exposure to harmful substances extremely low. In some cases, installation of the nonwoven geotextile interim covering can take some time, therefore when selecting a nonwoven geotextile, the UV resistance of the material over a medium term (several months) as well as its chemical and mechanical strength is of major importance.

In preparation for the covering work followed by investigation measures over the entire area, it is essential that the fine slime tailings are accessible after the pond water level has been drawn down. Light and inherently rigid structures are advantageous. Provided the material is properly placed, the point loads caused by personnel walking over the area can be spatially distributed and because of the plane load bearing effect, a balance between point load and plane load bearing effect of the geogrid /slime base can be provided.

The geogrid rolls used at the Wismut GmbH site are placed in the direction of fill with 0.5 m overlapping at the edges and are finally linked to one another to ensure a flat connection.

The interim covering of geogrid/nonwoven geotextile and soil guarantees a plane load-bearing effect which absorbs the occurring tensile forces and enables the soil layers to take up the shear force and compressive strength proportionally. The load-bearing behaviour of the sediments to be covered is significantly enhanced and thus provides an element of safety against shear- and ground failure.

Figure 7 Installation of vertical drains

The consolidation process is given practical support by pressing geosynthetic vertical drains (wick drains) into place by so called "stitchers" to provide the necessary accessibility with light-weight earthwork machinery.

A reduction in excess pore water and the resulting stabilisation of the upper tailings layers are further decisive prerequisites for a safe covering of the sediments.

Drains of 0.15m width and 0.01m height are deployed and are normally dimensioned in a 1.5 m triangular grid spacing. The geosynthetic elements are placed at a depth of between 5.0 m and 8.0 m whereby the arrangement of the drains is adjusted to the varying marginal conditions such as consolidation properties and shear strength distribution of the underlying ground.

Machinery driving over the geogrids must be equipped with rubber-tracked chains, or must drive across wooden sleepers to protect the geogrids from damage. Evidence of trafficability for light-weight bulldozers is provided by static calculations.

The material for the interim cover is placed on the prepared surface with a bulldozer. The daily covering rate is 0.5 m to 1.0 m.

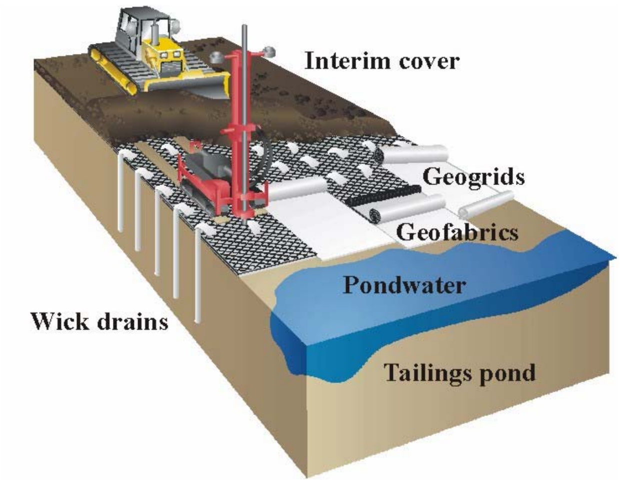

Figure 8 Construction of Interim cover

The soil used for the coverage of the geosynthetic load-bearing system consists of material from waste heaps or other suitable soils from the surroundings.

6. Conclusions

The high complexity of geotechnical design elements demands an interactive examination and evaluation of the strengths and weaknesses of the presently available proof methods. The presented interactive design approach visualises the interaction of the individual geotechnical proof methods among each other as well as the positive feedback from the monitoring method (in situ measurements). The use of a 3-dimensional FEM-model, verified by a 2-dimensional FE-calculation builds the centre point to predict deformations and forces in the reinforcing element. The analytical design method can be judged as being valuable for preliminary design calculations.

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