SLUDGE LAGOON COVERS WITH GEOSYNTHETICS: DESIGN AND SPECIAL PROCESS TECHNIQUES

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ABSTRACT. The construction of a capping system on top of a sludge lagoon is a technically hard task. The weak sediments and their low shear strength afford highly sophisticated and plant optimized solutions. The use of geosynthetics can massively reduce the potential risk of failures and catastrophes for the environment caused by sludge impoundments.
In the past the use of plant specified fabricated geosynthetics and a detailed planned construction work results in cost and time effective solutions. Based on one topical project the main characteristics for choosing the reinforcement, the design and the work schedule will be presented in this paper.

1. Introduction

If sludge storage areas, the so called tailings ponds, lagoons or old quarries, have to be remediated the most economic and feasible solution normally consists of a capping system including geosynthetics. The design of the cover respectively the liner system normally depends on the requirements of the customer or the appropriate authority and the intended use after capping. This might be simple covering for isolating the sludge in combination with an impervious lining system to prevent infiltration of rain water and generation of leachate or it can then be used as traffic area (i.e., container storage areas) or even for industrial or housing purposes.
The capping system may consist of a simple reinforcing geotextile and fill material or a multi-layer combination of geotextiles, high quality soils and a qualified liner system with gas and water drainage.

Geotextile reinforcement stabilizes the soft subsoil and enables workers and construction machinery working carefully on the sludge lagoon. Therefore the sludge maintains its geotechnical characteristics and no other chemically stabilisation process or other treatments are required.

2. Technical design

The design is based on an intensive soil investigation. The following data are necessary for design:

- Geotechnical parameters of sludge and fill material
- Stratification of the subsoil
- Dimensions of the sludge lagoon
- Water level
- Live load of construction machinery

According to the deposition history, dewatering and weather conditions the hydraulic and mechanical characteristics of the sludge may be subjected to larger differences in depth and across the area.

In large lagoons with non-homogenous sludge parameters geosynthetic reinforcement with the proper design strength can be used. In smaller lagoons or lagoons where areas with different sludge characteristics are not well known it is advisable to use the most conservative design parameters for the whole lagoon.

Dimensioning

Currently there is no established method available to design the geosynthetic reinforcement according to these membrane-like loading effects. Edil and Aydilek (2001) described a design procedure or

Espinoza et al. (2012) presented a case history and a more sophisticated design method. These designs are based on bearing capacity (rutting) analyses, the latter in combination with membrane contribution of the reinforcement. Additionally Bishop's method can be used for the stability analysis to enabling to consider mud waving in front of the filling progress at the edge of the geosynthetic. (Figure 1).

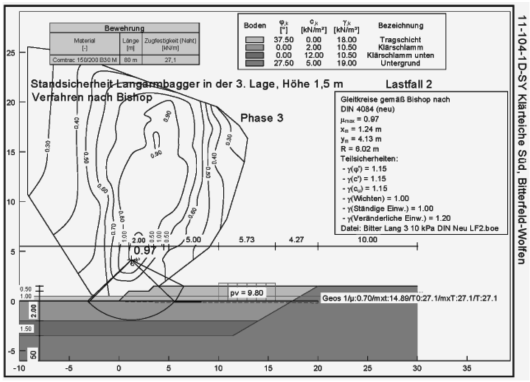

Figure 1. Typical Bishop slip circle for sludge lagoons.

Sometimes analysis based on wedge or slice methods (e.g. Janbu) may be advantageous compared to circle methods (e.g. Bishop, Krey) because of the better considerations of the forces of the geotextile reinforcement. Within the circle design methods the reinforcement is taken into account as a moment that is strongly influenced by the choice of the midpoint and so by the length of the lever arm. This can lead to inadequate consideration of the horizontal forces of the geotextile.
Regarding the stability of the system, the stratification of the cover layers and their soil parameters have to be checked carefully in each stage of filling. Especially the first soil layers up to 0.3 to 1.0 m may become critical. At this stage the shear resistance of the weak sludge as well as the counter pressure activated by surcharge is negligible small to prevent ground failure.

Settlement

Usually a standard capping height of at least 1 m is used in the design. Other several projects show a cover soil height up to 3-6 m according to the requirements of the lagoon´s use after capping. Settlement due to consolidation may be very important in case of qualified sealing systems where the drainage of the cover soil is of major importance and specified inclinations are required. Soil investigation should contain consolidation tests to specify settlement during and after construction period.

If no data are available, a settlement assumption has to be done, based on experience in comparison with similar soils. Based on this assumption multiplied by a factor of safety the required gradient of the drainage layer should be constructed sufficiently. It may be useful to install measuring points on the surface of the sludge to allow control of settlement during the filling process and verify the settlement prediction thereby adjusting the gradient if necessary.

Choice of raw-materials and type of reinforcement

Typically woven fabric or geogrids or combinations like woven/geogrid or geogrid/non-woven can be selected for the capping system. The main function of woven fabrics and geogrids is to transfer tensile stresses resulting from soil and traffic load across a larger area, into the anchor trench. In addition, non-woven can also work as separator and filter to keep sludge in place below the geotextile. As sludges can have different origins like mining, heap leaching, harbour or river sediments, wastewater treatment sludges, they can have very diversified chemical properties. Depending on the chemical characteristics of the sludge different raw materials should be selected. Normally polypropylene (PP), polyesther (PET, PES), polyethylene (HDPE) and polyvinylalcohol (PVA) can be used in a normal pH-range from 4 to 9.5. In areas with pH 2-4 or 10-13 only PP and PVA may be used, if long term stability has to be considered in the design.

Laying of geotextiles

The installation of geotextiles depends on the lagoon size. Small lagoons have an area up to 20.000-30.000 m² or a maximum width of 150 - 200 m independent of the length. These areas can be covered by one or more large panels, consisting of several geotextiles sewed together. The advantage of a panel against installing single sheets of 500 – 1000 m² (often in two layers) is a very fast covering of the lagoon in one layer and less contact of people to the sludge. Panels need to be prepared in plant and/or on site. Sewing of a 10.000 – 20.000 m² panel from a 5 m width material will take not more than 1-1,5 days. The materials used are woven fabrics or a combination of different products because they can easily be sewn and provide good seam strength. Installation by ropes and electric winches, maybe supported by two excavators at the edge, and it can be done in less than 20 minutes if prepared perfectly. After anchoring the panel at the lagoons edges soil installation can start with light machinery within one or two days after panel installation. During this process workers are not needed to walk on the lagoon or onside the panel, an important aspect for safety at work.

3. Case study "Sewage ponds Bitterfeld south"

The sewage pond of Bitterfeld is a sludge lagoon in Germany used in the beginning as clay open pit mining. Once the clay mine was exhausted, it was used as storage for chemical wastes, often sludges or liquids without fulfilling to specific requirements.

The total area of the site is about 7 ha. It is separated in three ponds, the largest one of about 2.7 ha already in a more or less stable situation, so it could already be covered without using geosynthetics. Pond 2 (P2) and 3 (P3) have sizes of about 1.4 to 1.6 ha and a rectangular shape with a maximum length of about 180 m respectively 200 m.

Mechanical characteristics of the sludge varied over area and depth. Undrained shear strength in P2 was between c_u= 0,5 to 7,8 kPa, respectively in P1 c_u= 0,1 to 4.9 kPa. Water permeability between k_f= $1.1 \cdot 10^{-9}$ to $1.3 \cdot 10^{-6}$ m/s. The chemical stock contained among others chromium, mercury, chlorobenzene, hydrocarbons, dioxins, furans, high amounts of phosphates.

Remediation concept, design and installation of the geosynthetic panel

In this case, due to the sludge characteristics, the solution proposed to cover the ponds was a single geosynthetic used as separation and reinforcing layer. Large single layer panels offer as main advantages shorter sewing and installation periods, no contact between workers and sludge and therefore better working safety, no problems with overlapping of single lanes.

According to the data of ground investigation, undrained shear strength was taken into account distributed over depth. As stability during construction is the most important task when covering sludge lagoons, different steps of covering the ponds with soil using long-bow excavators where investigated. In the state of construction a 30 t excavator was taken into account, working on a 1.5 m bearing layer resulting in a traffic load of about 10 kPa on top of the reinforcement. Different steps of soil layer installation (each layer about 0.5 m) and different positions of the excavator depending on the length of its long-bow were calculated. Consolidation progress due to increasing load has been calculated according to Bjerrum and Berre (1973) but was not taken into account just to be on the safe side.

For Pond 2 and Pond 3 single sheets were produced in length of 200 respectively 220 m and sewn on site. Total size of each panel was 16.000 m² respectively 18.000 m². Sewing took place alongside the lagoon, with each new sheet the sewing side changed, so in the end about 16 to 18 sheets were fixed to each other like an accordion. The geosynthetic used was a semi biaxial composite, i.e. a PVA-Geogrid (with width tensile strength of 150 kN/m in the machine direction-MD, and of 200 kN/m along the cross machine direction-CMD) combined with a 300 g/m² PP non-woven called Comtrac 150/200 B30 M. The higher tensile strength in (CMD) was chosen to have higher seam strength, as needed for the pulling operation of the large panel.

The panels for Pond 2 and 3 where fixed to wooden beams and plastic barrels creating uplift forces to prevent the panel front from diving into the water respectively sludge (Figure 2a). The beams were fixed to a steel rope connected to electrical winches fixed on a concrete road close to Pond 3 (Figure 2b).

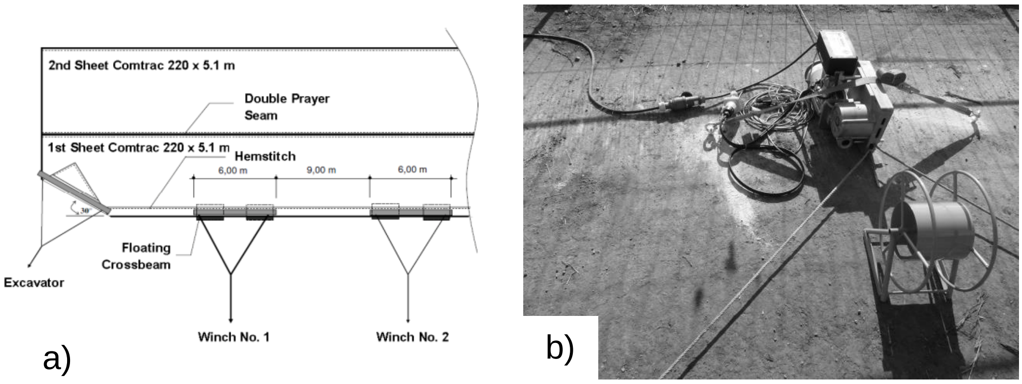

Figure 2. Electric winch of 10 kN tensile force, connetcion of panel to winches.

The panel in Pond 3 (18.000 m²) (Figure 3a) was installed in 7 minutes and the covering phase with soil started two days after.

After six months of the cover phase, the sludge lagoons becomes green and the vegetation starts growing (Figure 3a).

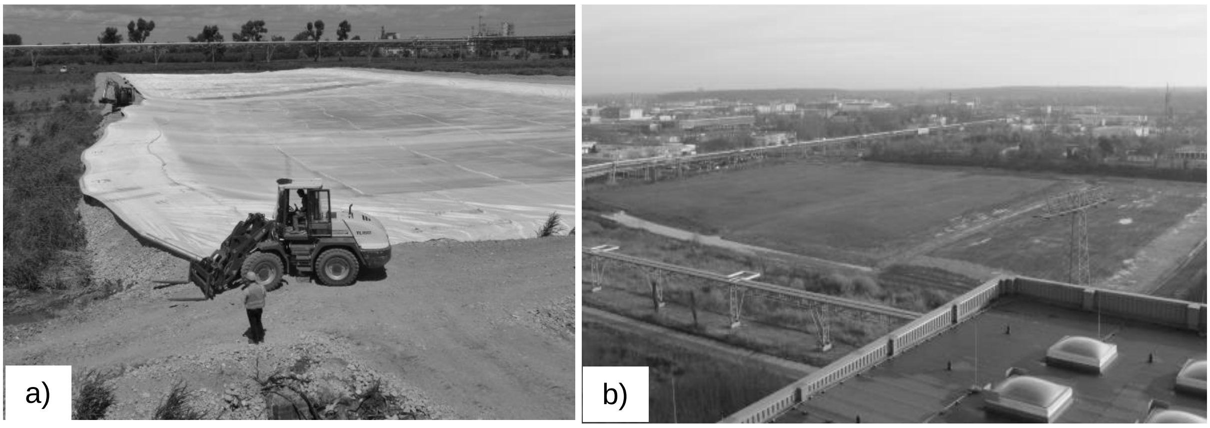

Figure 3: Panel installation and final green area of Bitterfeld sludge lagoon.

4. Conclusion

The use of geosynthetics can massively reduce the potential risk of failures for the environment caused by sludge impoundments.

Different raw materials allow the use of geotextiles in nearly every chemical environment. A lot of projects worldwide show that each sludge lagoon is unique. Each project has its own specifics regarding geology, products and construction. This paper focuses on design and construction phases of sludge lagoon covers considering a specific case of Bitterfeld south sewage ponds.

Geocomposite or wovens have a reinforcing and separating functions and can be sewed in large panels. Woven geotextiles or geocomposites in the form of large prefabricated panels offer a quick and safe way to cover lagoons when the sludge was not stabilized sufficiently before deposition. Low bearing capacity and even an open water table is not a hurdle for this method. Panel sizes of 18.000 m² have been installed successfully. Larger dimensions should be possible using optimized geotextiles, installation process and careful planning.

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