Uranium ore treatment tailings ponds remediation: A German case

Laura Carbone, Ole Syllwasschy & Oliver Detert
Huesker Synthetic GmbH, Germany

Pierpaolo Fantini
Huesker SRL, Italy

ABSTRACT: In the past, the eastern part of Germany (the former GDR) had been the world's third largest producer of uranium. Although, uranium excavation is no more allowed in Germany since 1990 the uranium ore, pits, open-pit sites and tailings remain as old-polluted sites. The "Pond 4" is a tailings pond in Freital built in 1957 as a settling basin for residues of the uranium ore treatment of the Wismut company. In 2006 the authority of water management declared the Pond 4 as contaminated site to be remediated. The remediation concept consisted of an impermeable capping with the dual purpose of long-term reduction of contaminant release and of providing the basis for subsequent landscaping. The construction of a cover system can be challenging due to the very soft subgrade. The use of geosynthetics provides the most economic and feasible solution and can be easily combined with other methods as for example in this project with vertical drains. In this paper the case study of Pond 4 in Freital is presented. Particular attention is given to the use of geosynthetics in the system. The stability analysis, the selection of the materials and the installation phases are fully described and can be used as reference for alternative solutions in similar projects.

Keywords: tailings ponds, remediation site, alternative capping, geosynthetic bearing layer

1 INTRODUCTION

Mining excavation of uranium is no more allowed in Germany since 1990. Nevertheless, in the past the eastern part of Germany (the former GDR) under the former Soviet Union leadership exported together with Czech Republic around 231.000 ton of uranium. In particular, in Saxony in 1954 was established the Soviet-German stock company (SDAG) "Wismut" that until 1990 had been the world's third largest producer of uranium (Koß, 1997). The recovered and recycled uranium was delivered to the Soviet Union. Such an intensive uranium mining operation, as operated by Wismut (SDGA), is unique in such a densely populated area around the world.
In the past the uranium ore contained up to 80% of uranium dioxide (UO_2) while today worldwide the uranium ore usually contains no more than 1% of UO_2.

During the mining of the uranium ore, pits, open-pit sites and tailings remain as old-polluted sites. The ore has been grounded and usually leached with sulphuric acid H_2SO_4. The resulting sludge contains the daughter nuclides of uranium and thus about 85% of the radioactivity of the ore (Koß, 1997). The tailings were then usually released into tailings ponds the so-called industrial sediment ponds (named IAA). For example the industrial tailings ponds in Freital (Germany) were filled up with 400.000 m^3 of sludge between 1949 and 1960. In particular, the tailings "Pond 4" was built in 1957 as a settling basin for residues of the uranium ore treatment. Residues from the processing factory were released into the basin from January 1958 to December 1960 but due to its particular morphology the pond acted also as rainwater retention basin. In 2006 the authority of water management declared the Pond 4 to be a contaminated site and to be remediated.

Generally, the management of tailings ponds consists of three main steps: solid-liquid separation, sludge dewatering and disposal (Zinck, 2005). One of the main concern is that due to the rainfall infiltration the material inside the impoundment never reaches a completely solid state so that the lining system or a dam failure always can cause the uncontrolled release of toxic sludge (Syllwasschy and Wilke, 2014).

For the IAA Pond 4 in Freital the remediation concept consisted of an impermeable capping. The main aim is to isolate the residues and therefore to reduce the exposure of nuclear radiation. In 2015 the remediation works started.

Nevertheless, the construction of a cover system on top of a weak and heterogeneous tailings can be a challenge and the use of geosynthetics in such systems provides the most economic and feasible solution. In this paper, the remediation work for Pond 4 in Freital from its initial concept to the design and execution is fully described.

2 “POND 4” REMEDIATION CONCEPT

The remediation concept consisted of an impermeable capping which mainly aimed at:

- isolating the residues and therefore reducing the exposure of nuclear radiation;
- preventing new leakage formation by limiting the infiltration of water into the pond.

The restoration included also the geotechnical stabilization of the entire area and the management of the rainfall water. The site remediation consisted firstly in the removal of the surface water (~ 2 m) from the pond and then the installation of the multi-layer cover system. Afterwards a new water retention basin can be built without direct contact with radioactive sediments.

The cover system is composed of (from the bottom to the top):

- 50 cm drainage layer and base course,
- 50 cm mineral sealing layer ensuring hydraulic conductivity $k \leq 1 \cdot 10^{-9}$ m/s,
- 1 m vegetative cover soil.

In order to be able to build the mineral layer on a very soft subgrade (i.e. saturated tailings) vertical drains have been included in the system, a non-woven geotextile as separation and filtration layer and two crosswise geogrids as bearing layer.

Depending on the position, the stored tailings differ in their physical behaviour. According to the tailings characteristics, three main different areas can be identified (Figure 1). While the tailings in the outer edge and middle region can be considered as partially dewatered and partially consolidated, the tailings located in the central area under the free water level is mainly very fine-grained material that can be considered in saturated and unconsolidated state.

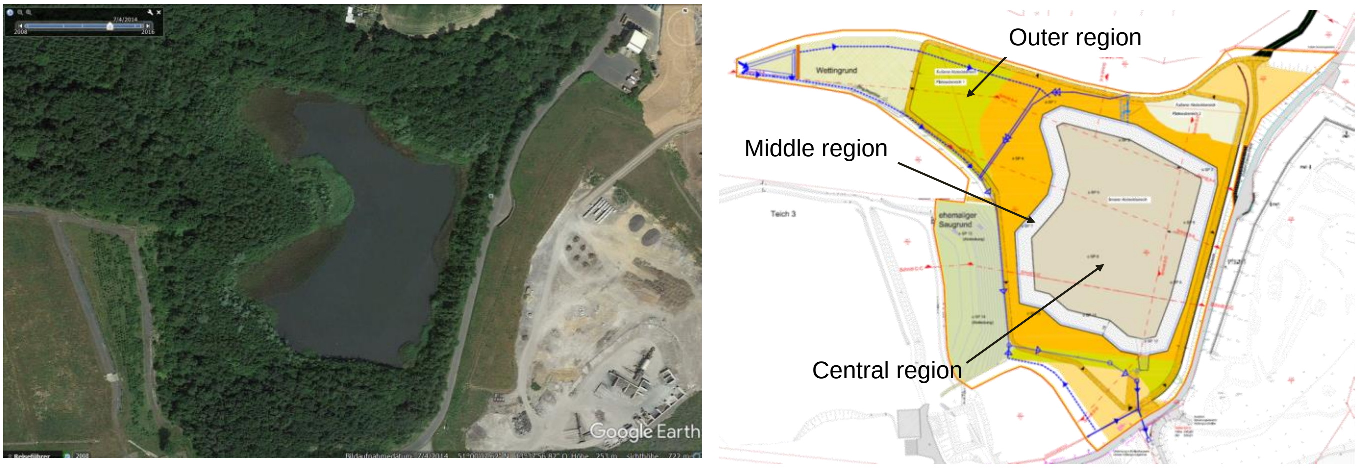

Figure 1. Pond 4: a) aerial view (Google Earth - April 2014); b) top view – characterization according to the tailings properties.

As first step the removal of the surficial water was carried out. Afterwards, the vertical drains will enhance the consolidation process and expel pore waters together with the placement of the drainage mineral layer that will serve both as a working platform and as surcharge load to enhance consolidation. The installation of this layer is possible thanks to the nonwoven layer acting as separation and the two layers of geogrids to enhance the load-bearing capacity and improve load distribution. The schematization of the remediation concept for the Pond 4 is shown in Figure 2.

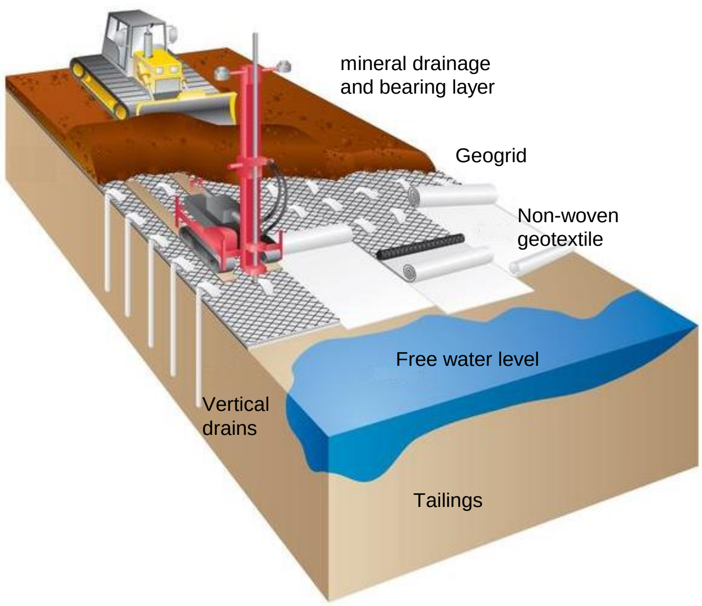

Figure 2. Schematization of the Pond 4 remediation work concept (adapted from Wismut GmbH website).

The resulting contaminated water is then collected and treated. On top of the drainage layer a properly compacted mineral sealing layer will be installed and afterwards the cover soil layer is foreseen to allow the construction of the new water retention basin.

3 TECHNICAL DESIGN

For the technical design of the capping system an intensive investigation of in situ soils is required. The following data are requested:

- Geotechnical parameters of tailings / fill material
- Stratification of the subsoil
- Tailings pond size
- Free water level
- Live load of construction machinery

According to the deposition history, dewatering and weather conditions, the hydraulic and mechanical characteristics of the tailings may differ in depth and across the area.

In large lagoons with heterogeneous tailings parameters the reinforcement with adapted design strength might 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 pond (Syllwasschy et al., 2007).

3.1 *Geosynthetic reinforcement design*

Currently there is no established method available to design the geosynthetic reinforcement according to the membrane-like loading effects. Edil and Aydilek (2001) described a design procedure and Espinoza et al. (2012) presented a case history and a more sophisticated design method. These designs are based on bearing capacity analyses in combination with membrane contribution of the reinforcement. Additionally Bishop's method can be used for the stability analysis in order to assess the behavior of the soft tailings during the filling progress at the edge of the geosynthetic.

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 contribution 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 as well as by the length of the lever arm. This can lead to inadequate consideration of the horizontal forces of the geotextile (Syllwasschy et al., 2007).

Regarding the stability of the system, typical values of undrained shear strength of the tailings about $c_u = 0.5 - 5$ kPa can be used and the factor of safety has to be checked for each stage of filling. 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 0.6 - 1.0 m may be critical. At this stage the shear resistance of the weak sludge as well as the counter pressure activated by surcharge is negligible. Therefore, ground failure is likely to occur. To overcome this problem, the use of light machinery with very small live load and additionally the installation of thin soil layers up to a maximum of 30 cm can be used.

Another aspect that has been considered in the design when geotextiles are used in the system (both woven and non-woven) is their long term filtration behaviour with respect to clogging effects. Filter stability analysis have been carried out and in general, geocomposites or woven materials having apparent opening sizes in the range of O_{90} = 0.08 – 0.2 mm showed good dewatering effects and settlement effects. Both effects increase stability during and after construction period (Syllwasschy and Wilke, 2014).

3.2 *Settlement estimation*

Settlement due to consolidation may be significant and they should be assessed and consistent with the allowable deformation of the sealing system.
Soil investigation should contain consolidation tests to specify settlement during and after construction period. If there are no data available a settlement assumption has to be done based on experience in comparison with similar soils. 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.

3.3 *Geosynthetic selection and installation methods*

Typically woven fabric or geogrids or composite materials 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.

Depending on the chemical characteristics of the tailings different raw materials should be selected. Normally polypropylene (PP), polyesther (PET, PES) and polyvinylalcohol (PVA) can be used in a normal pH-range from 2 to 9.5. In areas with pH 10-13 only PP and PVA may be used, if long term stability has to be considered in the design.
The installation of the geosynthetics depends on the size of the pond and on the tailings characteristics (Figure 3). It can be done by unrolling and overlapping them (Figure 3a) or by sewing a large panel pulled by external edges into the pond (Figure 3b).

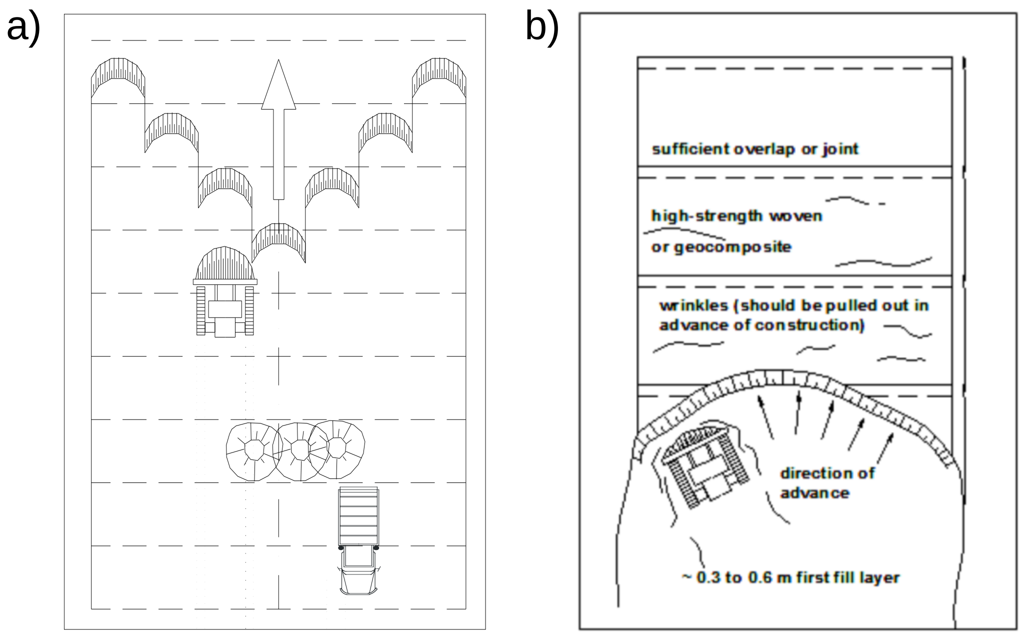

Figure 3. Examples of installation methods of geosynthetics in tailings ponds.

4 CASE STUDY: THE "POND 4"

4.1 *Cover system general description*

Placement of the final cover serves the dual purpose of long-term reduction of contaminant release and of providing the basis for subsequent landscaping. In order to build the cover system, free water has to be extracted from the central part of the Pond 4. This process can be relatively long because it depends on the estimated water volume already existing in place (in this case around 15.600 m^3), on the rainfall (estimated as 25.000 m^3/y) and on the pore water coming from the vertical drains (ca. 5.000 m^3).

Waters generated as part of the clean-up of former uranium mining and processing have to be treated prior to be discharged to receiving streams. According to the local environmental agency, the water should be filtrated prior to the treatment and limit values referred to the outflow are equal to 3,5 l/s, 25 kg/y of uranium and 140 MBq/y Radium -226. The filtrated water should contain a maximum solid content of 30 mg/l.

For filtration purposes, as alternative to the lamella separator, a geotextile tube for dewatering was used. In the solution, the sludge was mixed with flocculants and the fine sediments could be retained into the geotextile tube and afterwards easily transported to the treatment plant. The woven fabric of the geotextile tube acts actually as filtration and at the same time withstand the forces acting during the operational works. A geotextile tube with a circumference of 8 m made of polypropylene was selected for this purpose.

The cover consists of the succession of mineral soils and geosynthetics and is designed according to the storage and evaporation principle with a total thickness of ca. 2 m.
The final cover system results of the following layers (from the bottom to the top):

- tailings
- nonwoven
- 2 layers of geogrids (installed perpendicularly to each other – T-dimension)
- vertical drains
- mineral drainage and bearing layer
- mineral sealing layer
- soil cover

In the outer edge regions, outside the water profile, the subsoil in the bank zone can be considered as dried. In this area, favorable conditions with regard to load bearing capacity can be assumed. Therefore, in this area the trenches to anchor the geogrid will be foreseen. First, the non-woven fabric (E 250 K4) is rolled out as a filter and separation layer. Subsequently, the first geogrid layer (Base 40) is rotated through 90° to the non-woven direction. The overlap between the different geogrid panels is at least 50 cm. The next step, is the installation of the second geogrid layer (Base 40) for the load distribution rotated by 90° to the first geogrid position and parallel to the lowest nonwoven. This method enables that the forces from machineries can be transferred in the longitudinal and transversal direction in an excavated area so that the overlap between the panels will not be overstressed.

Figure 4 illustrates an aerial view of the site before and during the installation of the geosynthetics.

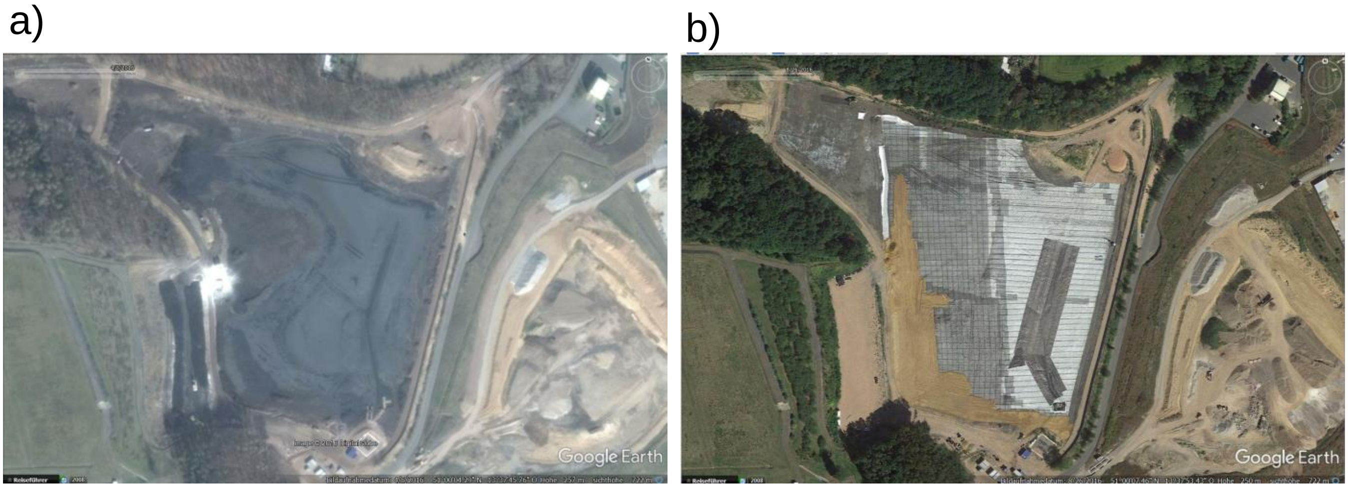

Figure 4. a) Preparation of the area (~50.000 m^2 – April 2016); b) Part of the installation phase (August 2016)

The installation is carried out by laying the thin layers of soil with a thickness of approximately 30 cm acting as load-distributing working surface; for this purpose a light machinery is recommended.

The middle cover area is free of the surface water. This means that the same installation procedure as for the outer cover area can be used but in addition vertical drains in the triangular grid of 1.5 m should be used. The vertical drains can be installed through the first geogrid and the nonwoven geotextile and then the second layer of geogrid can be installed on top (Figure 5).

The central area of the pond is characterized by fine-graded sludge with low bearing capacity that cannot be considered as working area. In fact, because of the extremely soft sludge, great deformations can occur when the mineral layers are installed. In this case, it is then necessary to use an additional reinforcement layer. For this purpose, woven geotextile (Sefitec PP 80) which has a longitudinal and transversal tensile strength of 80 kN/m, on top of the other geosynthetic layers was used as additional support to the bearing capacity. Here, the woven geotextile is installed as one single large panel sewed in situ and then pulled in the defined area to the outer region where is then fixed.

a) b)

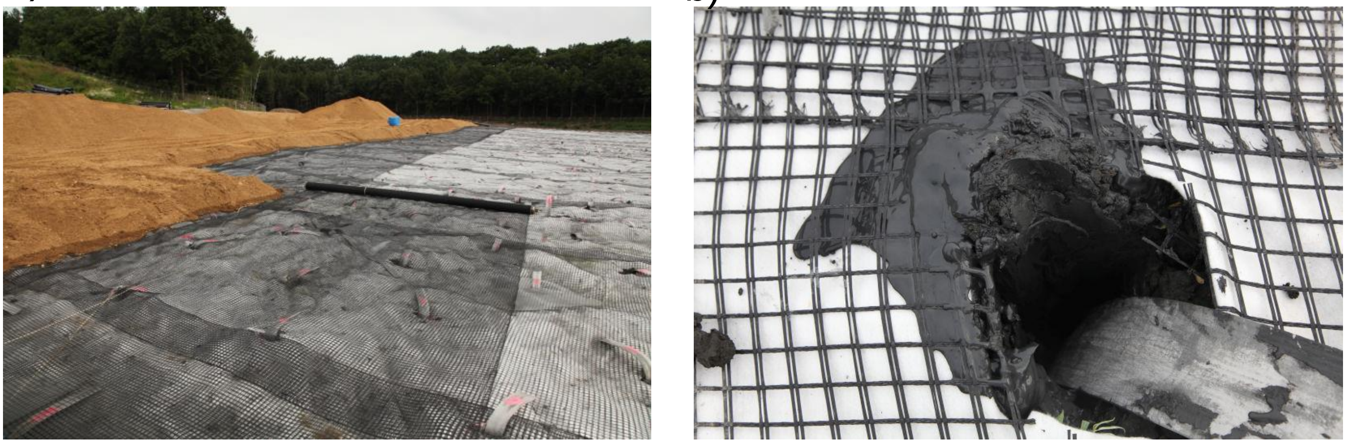

Figure 5. a) Installation of the cover system in the middle region: strip drain installed between the the geogrid layers; b) Zoom on the strip drain area after installation

4.1.1 *Dimensioning of the geosynthetic reinforcement*

In the determination of the tensile strength of the geosynthetic reinforcement the stability analysis should be carried out. The design takes into account the verification of the bearing capacity of the combined system (soft subgrade and geosynthetics). This analysis enables to determine the design tensile strength of the bearing layers while the actual tensile strength of the reinforcement (i.e., geogrids or woven geotextile) will be determined by applying reduction factors that takes into account creep, installation damage, joints and connections, environmental chemical impacts and dynamic effects if present. The service life of the geosynthetics was set to 25 years since their use is supposed to be limited to the construction period.

The static calculation was performed by using GGU-stability program applying Bishop method (Figure 6). The stability took into account seven main construction steps corresponding to different loading conditions.

The traffic loads were set to $p = 8$ kN/m² and the soil thickness varied from 0.3 m in the first to 2 m in the last design phase. The design was performed according the Eurocode 7 for the temporary load case.

Since the tailings varied significantly according to the region of the pond, a very low undrained shear strength equal to $c_u = 3$ kN/m^2 was chosen to characterize the tailings behaviour in the whole pond.

The results according to Bishop show that even with a very low undrained shear strength of $c_u = 3$ kN/m^2, the stability analysis is verified. Furthermore, the safety margin is large enough that even though the undrained shear strength of the tailing would decrease to $c_u = 2$ kN/m² the stability verification is still satisfied.

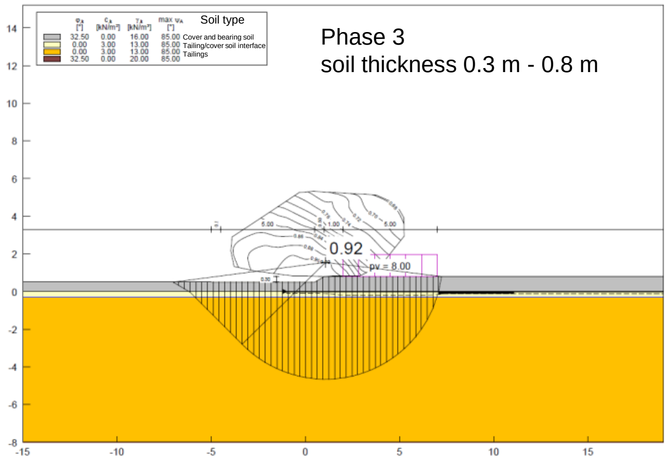

Figure 6. Example of stability analysis during phase 3 according to Bishop method.

Once the stability check is carried out, the dimensioning of the anchor trench was performed by verifying the analysis against the pull-out and/or sliding of the geosynthetic reinforcement. In fact, the load of the cover soil is taken from the reinforcement which in turn transfers it to the anchor trench that then was accordingly designed to withstand the acting forces. Figure 7 shows the anchor trench during construction.

Figure 7. Fixing geosynthetic in the anchor trench.

5 CONCLUSION

In the past, eastern part of Germany (the former GDR) had been the world's third largest producer of uranium. Although, uranium excavation is no more allowed in Germany since 1990 the uranium ore, pits, open-pit sites and tailings remain as old-polluted sites. The "Pond 4" is a tailings pond in Freital built in 1957 as a settling basin for residues of the uranium ore treatment of the Wismut company. In 2006 the authority of water management declared the Pond 4 as contaminated site to be remediated. The remediation concept consisted of an impermeable capping with the dual purpose of long term reduction of contaminant release and of providing the basis for subsequent landscaping. The construction of a cover system in a very soft subgrade with the use of geosynthetics provides the most feasible and economical solution.

In this paper the case study of Pond 4 in Freital is presented. Particular attention is given to the use of geosynthetics in the system. The conceptual design, the selection of the materials and the installation phases are fully described and can be used as reference for alternative solutions in similar projects.

REFERENCES

Edil, T.B., Aydilek, A.H. 2001: Geotechnics of Capping Very Soft Wastes. Proceedings of the Thirteenth International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Turkey, August 2001, Vol. 3, pp. 1903-1906.

Espinoza, R.D., Steier, W.M., Steiner, M. 2012: Construction of cover soil over soft sludge lagoons, Proceeding of geoamericas 2012, the Second panamerican Geosynthetics Conference, 1-4 May 2012, Lima, Peru, pp.

Fiset, J.-F., Zinck, J., and Lafllamme, G. 2003. Mine Sludge Stability/Densification in Cold Climates Sludge Characterization and Sludge Densification. CANMET Mining and Mineral Sciences Laboratories, Report MMSL 03-028 (CR). MERG (Mining Environment Research Group) Report 2003-4.

Hübner, J., Lindner, S., Syllwasschy, O., Schaffranka, E., Koch, L. 2013: Sanierung der „Klärteiche Süd“ in Bitterfeld – Erfahrungen bei der Sicherung einer Schlammablagerung; 9. Leipziger Deponiefachtagung, Leipzig, 2013

Koß, V., (1997). Eine Einführung für Studium und Praxis /Volker Koß. Springer. Pp. 211- 216.

Syllwasschy, O., Detert, O., Brokemper D., Alexiew, D., 2007. Special process techniques with project specified Geosynthetics for sludge lagoon covers. IS Kyushu ´07, 5th International Conference on, Earth Reinforcement, November 14-16 2007 at Fukuoka, Japan

Syllwasschy, O., Wilke, M., 2014 Sludge Treatment and Tailings Pond Cappings by the Use of Geosynthetics, 7th International Congress on Environmental Geotechnics (*7 ICEG*) – Melbourne Australia.

Wismut GmbH website: http://www.wismut.de/en/

Zinck, J. 2005. Review of Disposal, Reprocessing and Reuse Options for Acidic Drainage Treatment Sludge. Canmet Mining and Mineral Sciences Laboratories, Natural Resources Canada, MEND Report 3.42.3.