Uranium ore treatment tailings pond remediation – A case study

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Abstract

In the past, the eastern part of Germany (the former GDR) had been the world's third largest producer of uranium. After 1990uranium excavation was no longer permitted in Germany, however the existing uranium ore open-pit sites and tailings remained as old-polluted sites. Pond 4 tailings impoundment in Freital, was built in 1957 as a settling basin for residues produced from the uranium ore treatment facility of the Wismut company. In 2006, the authority of water management declared Pond 4 as contaminated site to be rehabilitated. The main aim was to reduce the contamination risk and to lead the concentration values to minimum acceptable for the public health.

The solution proposed for the rehabilitation consisted of an impermeable capping which mainly aimed at: 1) isolating the residues and therefore reducing the exposure of uranium radiation and; 2) 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 remediation concept consists 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.

Introduction

After 1990, mining of uranium ore was no longer permitted in Germany. Taking into consideration, previously the eastern part of Germany (the former GDR) together with the Czech Republic exported around 231,000 tonnes of uranium annually.

In particular, the Soviet-German stock company "Wismut" carried out an intensive uranium mining operation resulting in large amounts of polluted tailings that were released into the so-called industrial sediment ponds. Pond 4 was built in 1957 as a settling basin for residues produced from the uranium ore treatment facility. Residues from the processing factory were released into the basin from January 1958 to December 1960, but due to its particular morphology the pond also acted as rainwater retention dam. In 2006, the authority of water management declared Pond 4 a contaminated site which had 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 concerns is due to the rainfall infiltration, the material inside the impoundment never reached a completely solid state, so with the lining system, a dam failure always can cause the uncontrolled release of toxic sludge (Syllwasschy & Wilke, 2014). For the IAA Pond 4 in Freital the remediation concept consisted of an impermeable capping to isolate the residues and to reduce the exposure of nuclear radiation.

Nevertheless, the construction of a cover system on top of a weak and heterogeneous tailings can be a challenge. Generally speaking the placement of the cap on soft tailings can be done mainly mechanically or hydraulically. According to the site specific conditions, the solution may include the combination of the two methods and/or the use of complementary materials and technologies (Langseth et al. 2015). For example, Wells et al. (2010) and Abusaid et al. (2011) described the conception, the design and the final construction of cover system on very soft oil sand tailings pond by using a 2 m thick layer of low density fill (coke), geosynthetics (geotextile and geogrids) placed on the frozen tailings during winter time and vertical strip drains to accelerate the consolidation process.

The mechanical placement of the cover system uses light earthwork equipment working from the edges of the tailings basin pushing a lift of fill material over the tailings. The use of geosynthetics plays a key role in such systems to enable a safe access surface for the machineries.

In this paper, the remediation work for Pond 4 in Freital from its initial concept to the design and execution is fully described.

Capping system with geosynthetics

General Background

The design of the cover system of a tailings pond normally depends on the requirements of the customer or the appropriate authority and the intended use after capping. In the design of such systems, the use of geosynthetics stabilize the soft subsoil and therefore enable workers and construction machinery to work carefully on the tailings pond without treating the tailings further.

Generally speaking, the cover system may consist of a simple geosynthetic layer for reinforcement and fill material or a multi-layer system with geosynthetics, soils and qualified liner system with gas and water drainage.

According to the tailing's characteristics, the regulations in force in the specific lands and the final use of the site after remediation, the thickness of the different layers may vary but in general it is not less than 1.5 m – 2 m. The main challenge designing such a structure is the construction of the system on top of a very soft and extremely heterogeneous soil. In fact, 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 this case, geosynthetics for reinforcement, for example geogrids or woven geotextiles with adapted design strength might be used.

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

Settlement estimation of the tailings

Settlement due to consolidation may be significant in these subgrade conditions. Therefore, they should be assessed and they should be consistent with the allowable deformation of the sealing system of the capping.

Soil investigation should contain consolidation tests to specify settlement during and after construction period. In case no data is available, a settlement assumption has to be done based on experience in comparison with similar soils and the prediction should be verified during the construction phase for example by means of measuring points on the surface.

Geosynthetic reinforcement design

Typically in the capping systems design, woven fabric or geogrids or combinations thereof like woven/geogrid or geogrid/non-woven are selected. The main function of woven fabrics and geogrids is to transfer tensile stresses resulting from the construction of the cover system i.e., soil and traffic load, into the anchor trench. In addition, non-wovens can also work as separator and filter to keep sludge in place below the geotextile. As tailings can have different origins like mining, heap leaching, harbour or river sediments and 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), polyester (PET, PES), polyethylene (PE) and polyvinyl alcohol (PVA) can be used in a normal pH-range from 4 to 9.5. In areas with pH of 2-4 or 10-13, PP and PVA is recommended to be used if long term stability has to be considered in the design.

The required tensile strength of the geosynthetic reinforcement should verify the stability of the system. 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 where the mud waving at the edge of the geosynthetic during the filling process can be considered. It is worth to point out that the stability of the system, the stratification of the cover layers and their soil parameters have to be checked carefully during each stage of the filling process. The first soil layers of 0.3 m up to 1.0 m may be the most critical, due to the shear resistance of the weak sludge as well as the counter pressure activated by the surcharge which is negligibly small to prevent ground failure.

Another key aspect during the design, is the installation of the geosynthetic layers. This depends on the size of the pond and on the tailings characteristics. It can be done by sewing together a large panel which can be pulled by winches from the edge into the pond (Figure 1a) or by unrolling and overlapping them (Figure 1b).

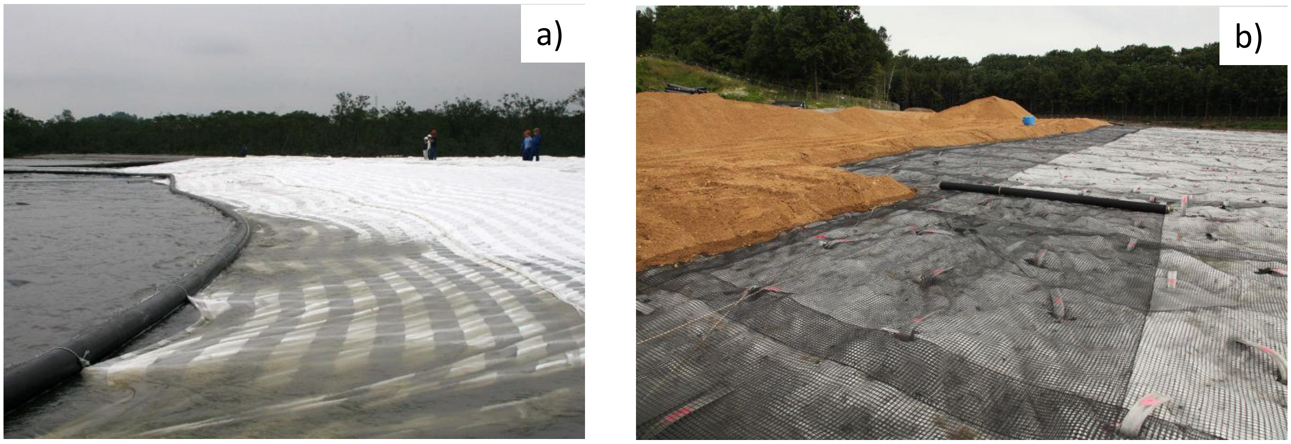

Figure 1. Examples of installation methods of geosynthetics in tailings ponds: a) assembling of large panels; b) unroll and overlap of geosynthetic reinforcement elements

IAA "Pond 4" case study

The cover system of the IAA Pond 4 is aimed at isolating the residues and therefore reducing the exposure of nuclear radiation and preventing new leakage formation by limiting the infiltration of water into the pond. The remediation of the site included also the geotechnical stabilization of the entire area and the management of the rainfall water.

In the case study of Pond 4, three main different areas could be identified depending on the tailings characteristics (Figure 2). Tailings deposited in the outer edge and middle region could be considered as partially dewatered and partially consolidated while the tailings located in the central area under the free water level could be considered in saturated and unconsolidated state.

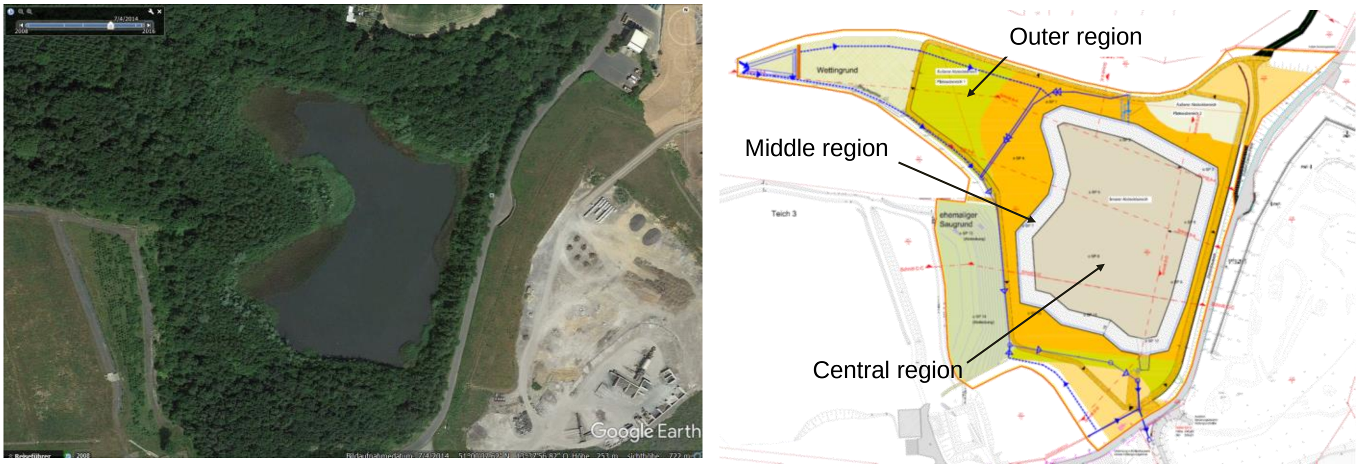

Figure 2. Pond 4: a) aerial view (Google Earth - April 2014); b) top view – characterization according to the tailings properties.

The cover system consisted of the succession of mineral soils and geosynthetics designed according to the storage and evaporation principle with a total thickness of about 2.0 m and it is composed of the following layers (from the bottom to the top):

- 0.5 m drainage layer and base course
- 0.5m mineral sealing layer ensuring hydraulic conductivity k ≤ 1·10-9 m/s,
- 1.0 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 was used as separation and filtration layer and two perpendicular placed geogrids were introduced into the system as reinforcement element.

Therefore, the final cover contained the following layers (from the bottom to the top):

- tailings
- non-woven geotextile
- 2 layers of geogrid (installed perpendicularly to each other – T-shape)
- vertical drains (middle and central region)
- woven geotextile (central region)
- mineral drainage and bearing layer
- mineral sealing layer ensuring hydraulic conductivity $k \leq 1\cdot10^{-9}$ m/s
- soil cover

As first step, the removal of the surficial water was carried out. The area was prepared by extracting the existing free water (~2.0 m i.e. around 15,600 m^3) from the central part of the Pond 4 (Figure 3).

Figure 3. a) Preparation of the area (~50,000 m² – Google Earth - April 2016)

It is worth noting that the water generated as part of the clean-up of former uranium mining and processing had to be treated prior to being discharged into receiving streams. For filtration purposes, as alternative to the lamella separator, a geotextile dewatering tube was used. In this case, flocculants were added into the water-tailings mixture and the fine sediments could be retained in the geotextile tube and afterwards easily transported to the treatment plant. The woven fabric of the geotextile tube served as filtration and was designed to withstand the forces acting during the operational filling.

Afterwards, the construction of the cover system proceeded with the installation of the materials in the outer regions. Here, subsoil material outside the water profile in the bank zone could be considered as dry. In this area, favorable conditions with regard to load bearing capacity could be assumed. Therefore, in this area the trenches to anchor the geogrid were constructed as follows. First, the non-woven fabric (E 250 K4) was rolled out as a filter and separation layer. Subsequently, the first geogrid layer (Base 40) was rotated through 90° to the non-woven direction. The overlap between the different geogrid panels was minimum 0.50 m. The next step was 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 bottom nonwoven layer (Figure 4). This method enabled that the forces from construction equipment are transferred in the longitudinal and transversal direction in an excavated area so that the overlap between the panels are not overstressed.

Figure 4. Geogrid T-shape installation

The installation was carried out by placing the layers of soil with a thickness of approximately 0.3 m which acted as load-distributing working surface and the use of light machinery was recommended for this purpose.

The middle cover area was free of the surface water. This means that the same installation procedure as for the outer cover area could be used, but in addition vertical drains in the triangular grid of 1.5 m were introduced into the system to enhance the consolidation process and expel pore water followed by the placement of the drainage mineral layer. The vertical drains were installed through the first geogrid and the nonwoven geotextile and then the second layer of geogrid was installed on top (Figure 5).

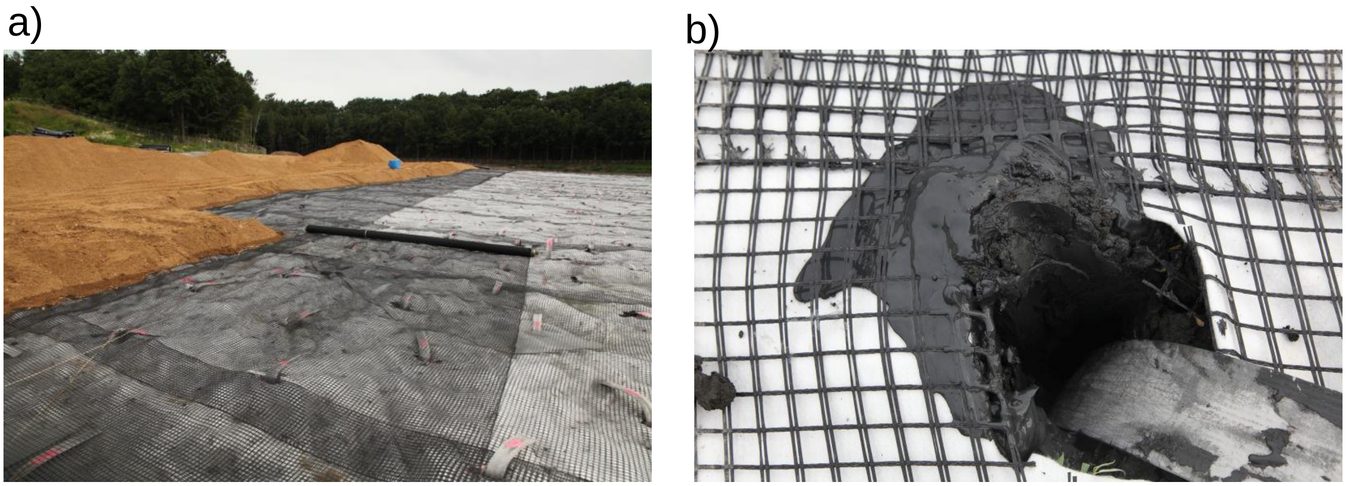

Figure 5. a) Installation of the cover system in the middle region: strip drain installed between the geogrid layers; b) Zoom on the strip drain area after installation

The central area of the pond was characterized by fine-graded sludge with a low bearing capacity. Due to the extremely soft soil conditions, large deformations were expected. In this case it was necessary to use an additional reinforcement layer. For this purpose, a woven geotextile (Sefitec PP 80) which has a longitudinal and transversal tensile strength of 80 kN/m, placed on top of the other geosynthetic layers was used as additional support of the bearing capacity. Here, the woven geotextile was installed as one single large panel sewed in situ and then pulled in the defined area to the outer region where it was fixed.

The construction of the cover system proceeded with the installation of the top soil (Figure 6) on the whole surface and ended in June, 2019.

Figure 6. Installation of the top soil

The remediated area works now as rainwater retention basin as further flood protection.

Dimensioning of the geosynthetic reinforcement in "IAA-Pond 4" cover system

The tensile strength of the geosynthetic reinforcement was determined by carrying out the stability analysis of the system. The design took into account the verification of the bearing capacity of the combined system (soft subgrade and geosynthetics). The analysis enabled us to determine the design tensile strength of the bearing layers while the actual tensile strength of the reinforcement (i.e., geogrids or woven geotextile) is 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 calculated to be 25 years since its use is supposed to be limited to the construction period.

The static calculation was performed by using GGU-stability program, applying the Bishop method. The stability calculations 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, up to 2.0 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 behavior in the whole pond.

Once the stability calculation was carried out, the dimensions of the anchor trench were determined by verifying the analysis against the pull-out and/or sliding of the geosynthetic reinforcement.

Conclusion

As tailings ponds are built as a result of various ore processing facilities, construction of a cover system on top of a weak and heterogeneous subgrade can be challenging. Project-specific solutions are required to remediate the contaminated sites. The use of geosynthetics has proven to be a safe and viable solution for a variety of projects.

In this paper, the remediation case study of “Pond 4” in Freital built in 1957 as a settling basin for residues of the uranium ore treatment of the Wismut company was presented. Here, the remediation concept foresaw the placement of an impermeable cover with the dual purpose of long-term reduction of contaminant release and of providing the basis for subsequent rainwater retention basin for flood protection. The construction of the cover system in a very soft subgrade has been made possible thanks to the introduction of geosynthetics into the system. The selected geosynthetics separated and reinforced the weak subgrade creating a safe and workable surface for the installation of the cover system. In this paper, overviews on the design, the selection of the materials and the installation phases were fully described and can be used as reference for alternative solutions in similar projects.

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