THE USE OF GEOSYNTHETICS LINING SYSTEMS FOR MINE TAILINGS FACILITIES AT MINE SITES IN CHINA

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Abstract: This paper provides a summary of our experience over the past 10 years with the legislated environmental protection requirements for tailings storage facilities for a number of mine sites in China. The paper provides details of a number of projects where geosynthetic liners and other geosynthetics have been installed. The sites vary from steep mountainous terrain sites subject to torrential rain to cold high altitude desert sites. The geosynthetics have been used for bedding layers, cushioning, drainage and lining systems. Some of the facilities are deep valley fills, 100 m plus high embankments, with groundwater and surface water extraction occurring around the sites for human consumption.

The paper also describes the issues related to the lining systems, and the geosynthetics solution adopted to raise a storage embankment to final height.

Keywords: Geomembrane, GCL, installation damage, tailings, embankment.

INTRODUCTION

The growth of the Chinese economy and changes in the country's economic policies have resulted in a number of new mines being developed in China as joint venture operations with foreign mining companies. Golder has been involved in the design and review of a number of tailings storage facilities at some of these mines. Environmental legislation in China classifies tailings in terms of a waste classification system, and sets limiting concentration criteria for discharge water from the tailings facility.

Environmental legislation requires that tailings storage facilities must be lined when the concentration of any chemical species exceeds the limiting criteria. The required lining systems vary from single compacted clay liners to dual composite liners incorporating geosynthetic systems. The main perceived risk is the potential for contamination of surface water or groundwater at the site. Liners have also been used at facilities where the tailings satisfies the discharge criteria, but where potential seepage of tailings water into the storage embankment must be reduced.

This paper describes the experiences of the authors related to the lining challenges encountered at a number of the tailings storage facilities.

CHINESE DISCHARGE REGULATIONS

Various Chinese Standards regulate the potential for contamination by tailings in a storage facility. Chinese environmental standards classify wastes according to the concentration of metals in "percolates" (leachate). The assessment process commences with a review of the geochemistry of the tailings to determine whether the material would be classified as a solid waste or as a hazardous waste in terms of the regulations. Standard GB 18599-2001 "Standard for Pollution Control for the Storage and Deposition Sites for General Industrial Solid Wastes" identifies requirements for solid waste materials and considers two classes of solid waste storage sites: Type I and Type II.

Leachate from tailings to be stored at a Type I site should have pH values of between 6 to 9 and concentrations of potential pollutants below limiting criteria given the relevant discharge standard. Most of the criteria are similar to those used in western countries but some, including notably arsenic and total cyanide, are set at lower concentrations than are typically applied elsewhere. Tailings storages at Type I sites do not require a liner. Type II sites are required if one or more potential pollutants have leachate concentrations in excess of the limiting criteria, but less than threshold concentrations for hazardous wastes, as defined by Standard GB 5085 "Distinguishing Standards for Hazardous Waste" Tailings storages at Type II sites require a liner and the floor of the storage basin should be at least 1.5 m above the groundwater table. Liners may be either compacted clay liners having specified minimum hydraulic conductivities or geosynthetic liners. The Standard also stipulates the thickness of a clay liner in terms of the hydraulic conductivity and thickness of the foundation soils.

EXPERIENCES RELATED TO APPLICATION OF THE REGULATION REQUIREMENTS

The regulations apply to all new projects, so the geosynthetics details described in this paper are related to the requirements of the regulations. Two projects are described in detail and general experiences on these and other projects are summarised towards the end of the paper.

SITE 1

A new underground gold mine was developed in mountainous terrain in a river valley in Shaanxi Province. A tributary creek and valley, 1 km to the east of the plant, contained an abandoned asbestos mine and tailings from the mine was apparently discharged into a tailings storage in the tributary valley. The tailings also covered a large area of prime farm land alongside the river. The topography is typically very steep thin soil covered rock slopes with limited access.

Designs for the tailings storage were prepared by Golder Associates and the Xian Design Institute in China. Tests showed the tailings to be a Type 1 waste so no liner was required in the basin of the storage. A valley tailings storage was designed and the storage embankment was constructed in 5 stages using waste rock. A clay core was constructed in the Stage 1 embankment and the core was keyed into weathered rock below the embankment. The low permeability component of the embankment for the remaining stages was provided by a 1.5mm thick HDPE geomembrane liner. The geomembrane liner was keyed into the top of the clay core of Stage 1 and buried into a compacted clay key trench at the junction to the abutments of the facility. The Stage 1 to 2 embankments were constructed using the downstream method of construction. Tailings were deposited from the embankment into a series of paddocks beaching towards the head of the valley. Cyclones were used to place the coarse fraction of the tailings near the embankment. The purpose of the paddocks was to provide a limited area and thereby higher paddock structures for the limited coarser fraction of tailings. The paddocks formed part of the tailings dam embankment. The tailings prior to the cyclone split is fine grained with 80% by weight smaller than 40 µm, which results in a very slow draining material.

The paddocks were formed using geosynthetic bags that were filled with excavated moist tailings from the beach area. The paddock walls were formed by vertical stacking up to 4 rows of bags at a time, prior to the paddocks being filled with cycloned tailings. The bags were of woven manufacture and allowed the enclosed tailings to consolidate quickly under the self weight of the tailings and overlying bags used to form the paddock bunds. The bags were placed by hand with labourers walking on the geosynthetic bag paddock walls.

Figure 1 shows a cyclone located on the crest of the embankment and the upstream paddocks, with the geosynthetics bags visible in three rows from the embankment. The paddocks included cross walls to facilitate staging of the construction of the paddocks.

Figure 1. Thickened tailings paddock and cyclone

The tailings embankment was due for the next raise and the issue of construction time and cost, materials source and land being covered by a downstream raise of the embankment, were considered. An alternative method of raising the embankment was investigated by Golder Associates. It was considered that a modified centreline raise may be an option, if the tailings strength can be improved by rapid drainage and possibly reinforcement.

Field trials were undertaken to identify measures to accelerate consolidation of the cycloned tailings in the paddock. Paddocks were constructed on the surface of the tailings storage. Various underdrainage systems were tested including a low cost locally manufactured geocomposite drain (Figure 2). The geocomposite drain comprised a void former with a composite woven and non-woven knitted geotextile wrapped around the void former. The void former was a series of rings with the composite geotextile spanning between the rings to form a tube. The combination of a woven geotextile and a non-woven geotextile provided a product that had a significant tensile strength and a filter ability to keep tailings particles out of the drain. The drains were installed at approximately 1.5m centres to provide a high rate of consolidation of the tailings.

A layer of the geocomposite drains was installed across the paddock for every 3 m in elevation in the paddocks. The drains were connected to a PVC collector pipe and a sump to facilitate the removal of collected consolidation water from the paddocks. The reinforcement capacity of the geocomposite material provided tensile capacity to the paddock system to reduce the risk of foundation failure through the unconsolidated tailings below the paddocks, and allowed the paddock walls to be constructed significantly higher than the rest of the tailings upstream of the paddock system, improving the freeboard for the facility. Test on the paddock tailings showed tailings dry density in excess of 1.4 t/m^3 could be achieved within 1 month of deposition.

Figure 2. Underdrainage trials

The consolidated tailings in the paddocks improved the stability of the embankment and allowed the Stage 3 and 4 raises to be carried out using the centreline method of construction. This construction method reduced the foundation area covered by the final embankment and the volume of construction materials used, thereby realising significant cost savings. The centreline raise incorporated a gabion wall constructed on the upstream part of the embankment. A geocomposite liner, comprising a 1 mm thick medium density polyethylene geomembrane liner and approximately 150 gsm nonwoven geotextiles bonded to both sides of the geomembrane was placed in the centre of the gabion wall. The purpose of the geocomposite liner was to limit seepage of tailings water through the gabion wall, with the geotextile layers providing cushion protection to the geomembrane. Figure 1 shows the gabion wall and Figure 3 shows placement of the geocomposite liner in the gabion wall. The geocomposite drain was surrounded with sand to further protect the geomembrane from the steel mesh of the gabion structure.

The geocomposite liner was installed in stages equal to the roll width to facilitate the welding of seams between rolls. The upstream gabion provided support to the geocomposite liner and also provided drainage on the upstream side to reduce the hydraulic head on the liner.

The geocomposite drain was joined to the geomembrane liner of the earlier raises by a horizontal fusion weld on the crest of the lower raise embankment.

Figure 3. Geocomposite liner installed in gabion wall, filling sand on either side of the liner

Stage 5 was raised using the upstream method of construction using cycloned tailings mixed with 5% cement. This final raise brought the embankment height to over 100 m high above the downstream toe. The inclusion of cement was to improve the erosion resistance of the material to result in a more robust design.

The cemented tailings raise was constructed in top of the area that had previously been constructed using the geocomposite drains, which provided a competent foundation to the raise embankment. The inclusion of the geocomposite drains accelerated the consolidation settlement of the tailings, which resulted in less settlement of the final raise of the embankment and thereby reduced the risk of differential settlement strains in the embankment. Figure 4 presents the final raise of the embankment with the final layers of tailings being placed on the facility in preparation for final shaping. The exposed geotextile bags can be seen along the upstream side of the paddocks, together with the freeboard that was achieved by the geotextile bag system.

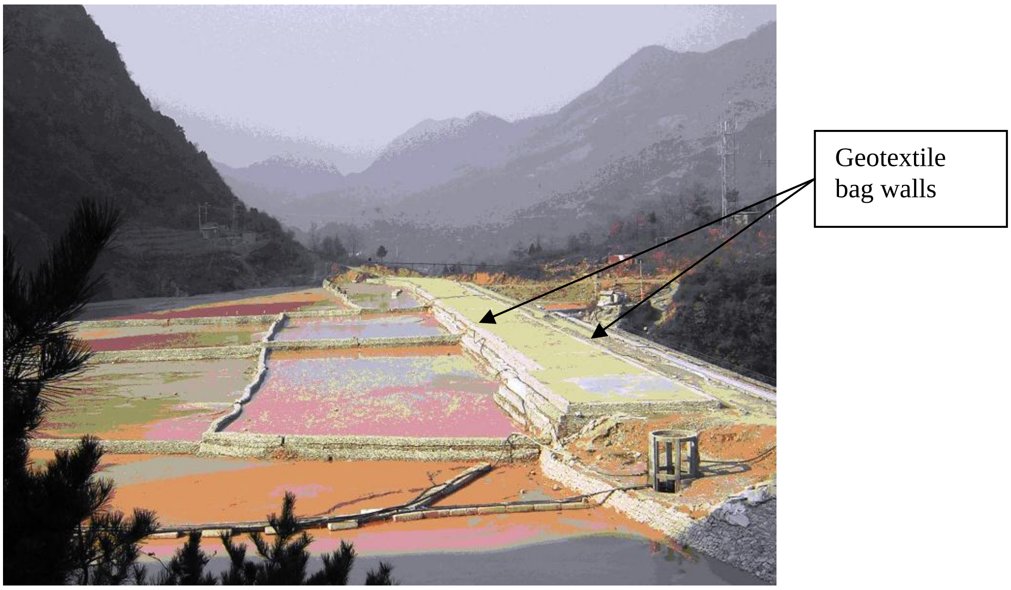

Figure 4. Stage 5 embankment raise

Building on the success of this project this technique has been adopted at other projects in China, and is also being considered for projects in other south East Asia countries.

SITE 2

A gold mine was established in the Gobi desert in Qinghai Province. A valley tailings storage was designed by Golder Associates and BGRIMM, a Beijing based Design Institute. The site has an average elevation of about 3,700 m above sea level and is subject to very high winds for much of the year. Severe cold weather conditions are experienced during the winter months. A tailings storage site was selected about 1 km from the process plant and about 500 m from an ephemeral river that is located in the valley. A “turkeys nest” tailings storage was constructed using waste rock from the mine and soil and rock obtained from borrow sites to construct the storage embankments. The storage has 3 cells (dams) with Dams 1 and 2 constructed as small cells to contain concentrate and tailings produced during the first year of operation and Dam 3 to contain the run of mine tailings. Testing of the tailings showed that it is a Type 2 waste and a liner was therefore required in the tailings storage.

A geotechnical investigation revealed that the surface soils would not be suitable for constructing an engineered clay liner, and the near surface soils included a high proportion of gravel, pebbles and cobbles. A design was therefore prepared including a geosynthetic liner. Following inspection and laboratory testing of the surface materials a liner design was prepared that involved compaction of the surface in-situ soils and placement of a composite geosynthetic liner comprising a reinforced geosynthetic clay liner (GCL) over the prepared soil surface and a 1.5 mm HDPE geomembrane over the GCL. Figure 5 shows the earthworks in Dam 3.

The construction of the perimeter embankments was designed to facilitate staged lining works to reduce the time that any geomembrane on the slope was exposed to UV radiation from the sun. At the high altitude of the project site the UV radiation is significantly higher than at lower elevations. The staged construction also suited the owner due to delayed cash flow requirements. Staging of the embankments was facilitated by inclusion of benches for anchor trenches and access to future seam construction for the liner.

Once the earthworks were prepared a GCL was placed over the shaped subgrade. The purpose of the GCL was to provide a reliable cushion layer below the geomembrane to protect the geomembrane from damage by the coarse subgrade once the liner was loaded by the tailings. The second function of the GCL was to improve the advective performance of the liner system to reduce the risk of contamination of the nearby water resource. A fairly light grade of GCL was selected to provide a composite action to any defects in the geomembrane, as the tailings contained no organic components, so diffusion through the liner system was not an issue. Figure 6 presents the liner system during construction. It should be noted all the geosynthetic systems were placed by hand, so the exposed GCL area in the figure was trafficked by foot only when placing the geomembrane liner.

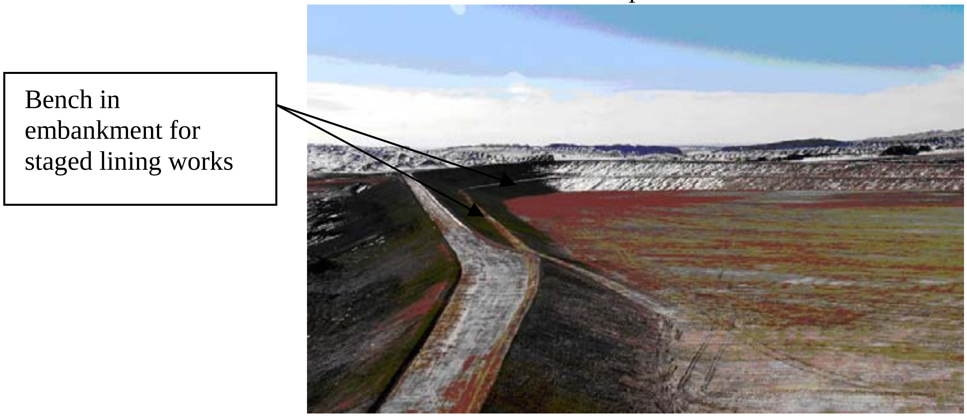

Figure 5. Earthworks for Dam #3

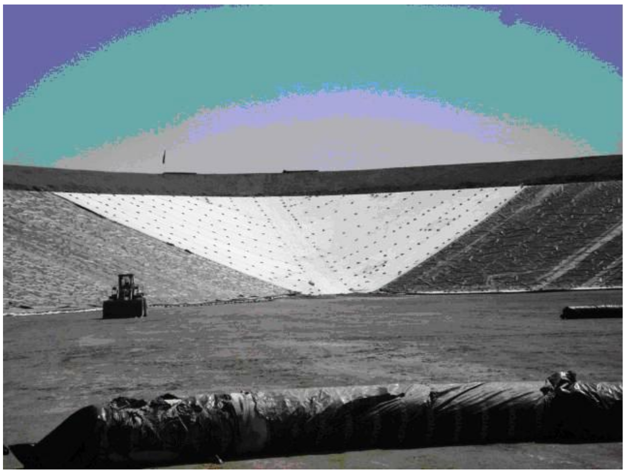

Figure 6. GCL and geomembrane placed in Dam#3.

Due to the very dry conditions at the site, the GCL was expected to take a long time to hydrate from the subgrade, or would hydrate around any defect in the geomembrane. It was therefore considered acceptable to leave the liner exposed and unconfined until the tailings were placed over the liner system.

The geomembrane liner comprised single sided textured geomembrane, which was placed with the textured side down. This allowed a low friction sliding surface to be developed over the top of the geomembrane. The low friction surface was desirable to reduce the loads being taken up by the geomembrane due to the consolidation settlement of the tailings, and to reduce the strain effects on the liner due to freezing of the tailings.

An underdrainage layer was installed inside the tailings storage basin and comprises a drainage layer constructed at the toe of the embankment inside the storage basin, and geocomposite strip drains placed up the slope liner. Figure 7 shows the toe drain comprising selected gravel wrapped in geotextile. Due to access considerations over the liner and to reduce the cost of drainage system in the facility, geocomposite strip drains were also installed across the floor of the storage of the basin, and were held in place by sand bags that also provided temporary ballast against geomembrane liner wind uplift. The construction of the toe gravel drain was considered appropriate as the liner on the slope was anchored at the toe and ballasted along the toe only, which required a significant mass along the toe to provide an appropriate ballast load to resist the high wind at the site. The contractor and the owner accepted the risk of potential elastic uplift of the liner on the slopes during high wind events, and the requirement that some repair of the liner may be required to re-align it after the expected significant deformation. It was considered financially not practical to design ballast for the slope liner for the maximum continuous wind speed at the site that approached 90 km/h. The floor liner was considered lower risk as the floor would be covered with tailings shortly after completion of the liner works.

A perforated HDPE collector pipe was installed in part of the length of the toe drain where the flow rate in the toe drain exceeded the capacity of the gravel layer, with a sump formed in one corner of the tailings dam. A large diameter HDPE pipe was placed up the slope to provide pump access to remove the collected seepage. Figure 8 presents a view of the drain and riser pipe.

The riser pipe was anchored down using concrete collar blocks placed on a layer of textured geomembrane. Experience had shown that the freezing of the tailings resulted in high movement loads on the pipe. The size of the anchor blocks was increased subsequently as the initial size anchor blocks were partially dislodged during the first freeze of the tailings.

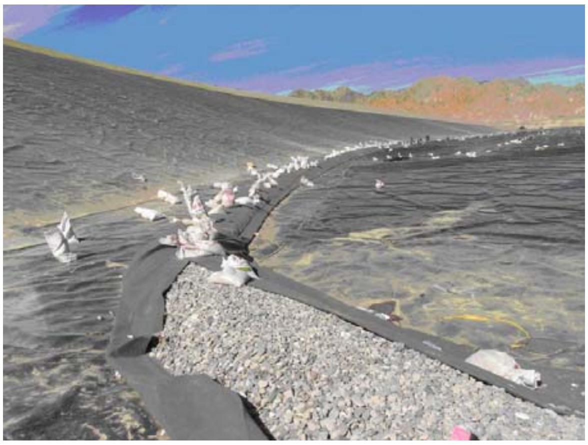

Figure 7. Internal toe drain at Dam # 3.

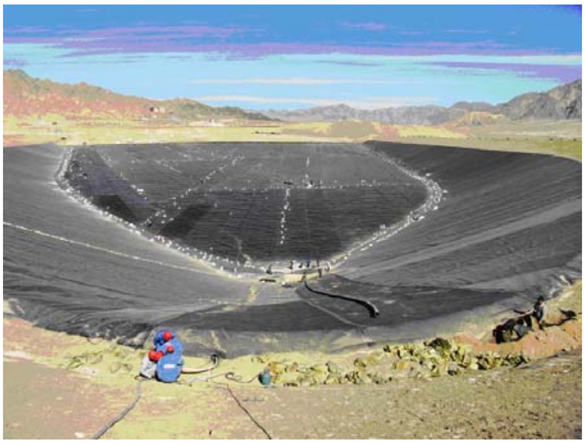

Figure 8. Dam #3 showing HDPE geomembrane liner and sump HDPE riser pipe

CONSTRUCTION

The weather conditions at many of these sites vary from relatively hot and to very cold, with the changes in temperature similar between summer and winter, but with a shift to the slightly warmer in summer and colder in winter. Strong wind occurs over most of the year, and these conditions make geosynthetics installation challenging for both equipment and people.

The large variations in temperature required the contractor to provide significant slack in the liner system to prevent the liner pulling off the slopes in the corners of the embankment and along the toe of the embankment when the liner cooled during the winter freeze. In addition the panels were generally welded during the moderate temperature part of the day, so slack was allowed in the geomembrane panels for when the liner shrunk at night due to the low temperature. Anchor trenches were backfilled during the cool part of the day, to reduce the potential for differential movement between the exposed liner and the buried liner. Due to the usually sunny days the black geomembrane gained enough hear from the sun to facilitate conventional seam welding of the geomembrane, although the wind effect air temperature was generally below 10deg C for large parts of the day. Dust management while welding seams was important and the inclusion of the GCL below the geomembrane provided a low dust environment for the seams, in conjunction with a seam cleaning procedure just ahead of the welder. Dust management using water was not an option due to the lack and value of water in the desert environment.

The tailings delivery pipeline was constructed from HDPE pipes. During the day the temperature of the black pipes increased to above 25 degrees C due to sun exposure. The pipes were joined by full face fusion welding during the day, and on some days large lengths of pipe were joined. Subsequent very low night time temperatures, well below freezing resulted in the rupture of at least one pipe join, as presented in Figure 9.

Figure 9. Rupture of geopipe bend in very cold condition

Close inspection of the rupture did suggest a defect in the pipe bend resulted in a brittle failure of the pipe just outside the weld area of the pipe. Due to the construction timelines with winter looming there was no time to carry out a detailed investigation, so it was recommended to the design institute to include movement compensation loops in the long sections of the pipeline, as it was likely that the delivery system of tailings would be subject to maintenance in the future and the temperature of the pipeline was likely to vary significantly between day and night when no tailings flow occurs in the pipe.

SUMMARY OF LESSONS LEARNED

The experiences from the projects in China are as follows:

- Opportunities exist to develop cost effective solutions for tailings operations due to the need to employ manual labour, which may not be easily achieved using heavy construction equipment. The use of manual labour in

combination with geosynthetics can result in unique engineering solutions, such as the geotextile bag paddock system.
- The extreme weather conditions in the remote parts of China require additional consideration to ensure the desired outcome of the works is achieved.
- Geosynthetic liner systems provide a valuable environmental protection system for remote sites where local materials do not meet engineering requirements.

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