Design of the Eldorado Gold Efemçukuru Filtered Tailings Facility

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Abstract

Eldorado’s Efemçukuru Project incorporates the design of a filtered tailings facility to store 1 million cubic metres of dry stack filtered tailings in a high seismicity region of Western Turkey. Compared to conventional tailings technologies, dry stack filtered tailings have many advantages in terms of lowering long-term environmental liability/impacts (for example through decreased potential seepage, minimized storage footprints, and ease of progressive reclamation). An important design feature of this project is the incorporation of a fully-lined base (HDPE/GCL double-liner) coupled with an underdrain system for seepage control at the base of the facility, as the tailings are potentially acid-generating. Increased structural integrity is achieved through compaction of tailings filter cake material in lifts, the construction of rock toe berms on the downstream side of the pile, and selection of a double-liner system that will provide sufficient frictional strength in this high seismic zone. The use of a filtered tailings and liner system in the Eldorado Gold Efemçukuru project provides added protection of groundwater resources and represents another step in tailings waste management and environmental stewardship in the industry.

1.0 Introduction

The Efemçukuru gold mine is located in western Turkey, approximately 20 kilometres southwest of the port city of Izmir on the Aegean coast (Figure 1). The mine consists of an underground operation centred around high grade epithermal gold vein deposits. The operations will require the disposal of development rock and filtered tailings within a small valley upstream of Kokarpinar Creek.

In 2006, the project received an Environmental Positive Certificate from the Turkish Ministry of the Environment and Forestry upon its review of the project Environmental Impact Assessment report. Remaining permitting and engineering required to commence construction followed; with site preparation construction activities beginning in the summer of 2008; and plant commissioning and tailings placement beginning in the summer of 2011.

The design and construction of the filtered tailings facility will be the focus of this paper. Key design considerations for the project include seismic resistant design and a double liner system for environmental protection.
2.0 Site Conditions

The Efemçukuru mine is located in a semi-arid, high-seismicity, mountainous area at altitudes between 550 metres and 770 metres above sea level. General topography in the area is characterized by steep hills and narrow valleys. Nearby land uses include the growth of vineyards by small rural communities, or are forested.

2.1 Geology

Valley slopes are typically comprised of a thin layer of dry, granular colluvium (less than 1 metre thick) underlain by approximately 2 to 3 metres of weathered bedrock. Thicker alluvial surficial cover materials (3 to 5 metres) may be present at the valley bottom near the toe of the tailings or development rock pile.

2.2 Climate

The climate of the area is characterized by distinct wet and dry seasons (hot/dry summers and warm/rainy winters) with the majority of the precipitation occurring from October to April. The average annual precipitation is 740 millimetres. Temperatures at the site generally range between 30 degrees Celsius in the summer and 0 degrees in the winter, with a mean annual temperature of approximately 15 degrees Celsius.

2.3 Seismicity

Turkey lies within the Mediterranean sector of the Alpine-Himalayan orogenic system, which runs west to east from the Mediterranean to Asia. Turkey is surrounded by three major plates: African, Eurasian, and Arabian (see Figure 2). Two smaller plates underlie most of Turkey; the Aegean Plate (west) and the Anatolian Plate (east).
Western Turkey is considered to be an active earthquake area, and Izmir is in one of the seismically active parts of the Aegean Plate. Several large earthquakes with magnitudes greater than 6 have been recorded in the area.

Table 1 shows the design seismic parameters for the project site derived from the USGS Geologic Hazards Science Center.

Table 1: Seismic Design Parameters for the Project Site

<table>
<thead>
<tr>
<th>Return Period</th>
<th>PGA</th>
<th>Sa(0.2s)</th>
<th>Sa(1.0s)</th>
<th>Design Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:475</td>
<td>0.5</td>
<td>1.215</td>
<td>0.485</td>
<td>Operational</td>
</tr>
<tr>
<td>1:2475</td>
<td>1.0</td>
<td>2.43</td>
<td>0.97</td>
<td>Closure</td>
</tr>
</tbody>
</table>

Figure 2: Tectonic Map of Turkey. From USGS Circular 1193, Implications for Earthquake Risk Reduction in the United States from the Kocaeli, Turkey, Earthquake of August 17, 1999, modified from Barka (1992) and Rockwell and others.

2.4 Groundwater Conditions

The groundwater table is reported to be greater than 7 metres below grade beneath the tailings area. There are also localized seeps observed down valley from the tailings area.

3.0 Design Overview

The current Efemçukuru waste storage facilities include a development rock pile, and a compacted filtered tailings facility located in a small valley upstream from the Kokarpinar Creek. The Efemçukuru filtered tailings facility is located at the head of the valley, while the development rock pile is located directly to the east, and near the foot of the valley. The main water management feature
within the valley is a shared concrete dyke and sedimentation pond located at the toe of the development rock pile.

The dry filtered tailings facility is proposed to be constructed in five major phases (Phase I through V); with the ultimate configuration rising to an elevation of 743 metres. Two main benches/terraces of 5-metre-width are present, each incorporating side-slopes of 3 horizontal to 1 vertical (3H:1V). This results in an overall slope of 3.5H:1V for the tailings pile. Ultimate capacity is currently planned at 1 million cubic metres.

The filtered tailings design layout is shown in Figure 3, along with the approximate development rock facility footprint, and the downstream concrete dyke and sedimentation pond. Figure 4 shows a cross-sectional view of the tailings facility along the valley drainage centreline.

Figure 3: Design Layout

Figure 4: Cross-section along drainage centreline.
3.1 Tailings Facility Liner and Underdrain System

The key components of the seepage control system for the filtered tailings storage facility consists of:

- A geosynthetic double liner system installed over the footprint of the tailings storage area. This consists of an upper textured HDPE layer, a leak detection system and a lower GCL layer.
- A 10-metre-wide primary rock drain that runs along the central base of the valley for controlling drainage within the filter tailings pile.
- A piping system (“primary pipe system”) that directs collected seepage through the tailings toe berms, to a down-valley collection system.

The double-liner system consists of a double-sided textured high-density polyethylene (HDPE) liner underlain by a 0.3-metre-thick sand separation layer, followed by a geosynthetic clay liner (GCL). This textured HDPE-GCL system was selected based on results of a laboratory liner testing program that was completed to support the detailed design phase of the project. The liner screening tests included:

- Hydraulic Puncture Testing (ASTM D5514, at 1100 kPa)
- Interface Direct Shear Testing (ASTM D5321, at 200, 600, 1100 kPa)

The original liner testing program consisted of the evaluation of a HDPE-GCL system and a HDPE-bituminous liner system.

Under normal loads of 1200 kPa, the HDPE-GCL system had better performance in the liner interface direct shear tests. The bituminous liner (manufactured with a root film) failed internally in the liner interface direct shear tests (~9º), after approximately 600 kPa and was therefore not selected for the tailings design.

Hydraulic puncture testing was also completed with the granular site foundation soils and the HDPE-GCL and HDPE-bituminous liner systems. In both cases, localized deformations were noted in the base liners (either GCL or bituminous), but no localized deformations or puncture was reported in the overlying HDPE layer.

Based on the liner testing results, the HDPE-GCL system was selected in the final design. A sand layer between the two barriers provides shearing resistance between the two interfaces and drainage for leak detection control.

3.2 Tailings Properties

The design tailings properties are summarized in Table 2. The filtered tailings material is classified as a low-plasticity silt (ML), with a P80 (i.e. 80% passing particle size) of 67 microns.

<table>
<thead>
<tr>
<th>Characteristic Index Properties of the Efemçukuru Filtered Tailings</th>
<th>Average Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids Specific Gravity</td>
<td>2.9</td>
</tr>
<tr>
<td>USCS Group Symbol</td>
<td>ML</td>
</tr>
<tr>
<td>Atterberg Limits (LL=Liquid Limit, PL=Plastic Limit)</td>
<td>LL=24%, PL=21%</td>
</tr>
<tr>
<td>Grainsize Distribution:</td>
<td></td>
</tr>
</tbody>
</table>
80% Passing (microns) & 67 \\
\hline Standard Proctor Maximum Dry Density (kg/m³) & ≈1850 \\
Standard Proctor Optimum Moisture Content (by dry weight) & ≈15.8% \\

3.3 Stability

3.3.1 Compact Filtered Tailings Design Concept

The tailings storage facility design has been completed based on the development of the facility as a dry stack tailings system. The dry stack tailings system produces a mechanically dewatered tailings product at relatively low moisture content which can be handled as a “dry” material (i.e. truck haulage and dozer spreading).

Because the filtration process produces a “dry” tailings material that can be compacted, a retention dam (as required for conventional tailings) is not needed in the current design system. The filtered tailings will be placed in controlled lifts and compacted to create a stable engineered structure. There is a rock berm at the toe of the structure that provides additional stability.

The stability of the facility is dominated by sliding along the liner system during a large seismic event.

3.3.2 Seismic Evaluations

Under seismic conditions, liner integrity is controlled by the potential for damaging displacements as the filter tailings pile slips across the underlying liner during an earthquake. These displacements were evaluated using a simplified semi-empirical predictive model developed by Bray and Travasarou (2007). It is a Newmark type model based on the results of nonlinear fully coupled stick-slip sliding using a large database of recorded ground motion signatures. The slopes of the tailings facility are designed so that the yield acceleration (from 2D limit equilibrium analyses) conforms with a seismic displacement value less than 15 centimetres as calculated from the Bray and Travasarou method. This 15-centimetre “Newmark based” threshold displacement value is consistent with engineering practice (Kavazanjian, 1999).

For closure stability (1 in 2475-year event), the reclamation cover will be the primary barrier system that will be used to limit infiltration into the pile and decrease potential seepage through the base of the pile. The cover design has not been finalized at this stage due to the requirement for field trials of potential cover materials. The detailed design of the cover will need to consider threshold seismic displacements, similar to the analysis that was completed for the liner. A target threshold may consider movements on the order of \( \leq 30\text{cm} \) during the closure period. The larger displacement values are consistent with practice (Kavazanjian, 1999) considering the ease of access for repair.

3.4 Integrated Water Management System

Water management of the contact and non-contact water within the tailings valley is integrated with that of the down-valley development rock pile. Downstream of the development rock pile, a concrete sedimentation pond and dyke structure is present, which is used to hold and collect contact water within the valley, prior to treatment.

Within the tailings facility itself, seepage or run-off collected on top of the tailings liner system will flow to the primary rock drain, where two collection pipes will transfer the contact water beneath the tailings rock berm. At the downstream toe of the tailings rock berm, the collected contact water will
then be discharged to the upper interim pond for temporary storage, or be transferred directly to the lower sedimentation pond.

4.0 Site Development and Construction

General site development and construction began in the summer of 2008. Site construction has been completed by JDS Mining, an Engineering, Procurement, and Construction Management (EPCM) contractor.

4.1 Foundation Preparation

For geotechnical stability and reclamation material balance purposes, foundation preparation included the removal and stockpiling of suitable topsoil material from the footprint of waste storage areas. The materials will be used in progressive reclamation of the filtered tailings pile surface.

In addition to the regular pre-stripping activities, the foundation preparation also followed requirements for typical geosynthetic installations. In general, the prepared surface was cleared of large rocks, cobbles, rubbish, roots, sticks, construction debris or other deleterious substances that can damage the liner. Sub-grade surfaces were contoured and rolled to create a firm, smooth and uniform surface that is free of voids and sudden changes in grade.

4.2 Rock Toe Berm Construction

The addition of 10-metre-high rock toe berms is a key design feature required for the geotechnical stability of the tailings pile in a high seismicity environment. Each of the design toe berms will be advanced based on tailings placement phasing, and the timing of required land expropriation plans/negotiations.

The first rock toe berm, completed in 2009, was constructed for the Phase I and II tailings placement. The berm has a top width of 10 metres, and 2.5H:1V outer slopes. The second rock toe berm, planned with a similar configuration, will be constructed for Phase III to V tailings placement (once land negotiations are complete).

The Phase I rock toe berm was constructed with approximately 19,000m³ of development rock. The construction involved preparation of the base and placement of an underdrain system, followed by placement of uneconomic rock. After rock placement, the HDPE-GCL liner system was extended over the top surface of the rock berm, in anticipation of tailings placement over the berm in future expansion phases.
4.3 Liner System Installation

Once foundation preparation was complete, the site contractors were able to prepare the rough sub-base into a smooth surface prior to liner placement. To date, the Phase I and II tailings area liner systems (with associated leak detection piping) have been installed. Future liner expansion phases will be based on the tailings production schedule.

4.4 Filtered Tailings Placement Plan

The site equipment used for the facility currently consists of a low pressure dozer (Komatsu 51PX) and 25-tonne articulated trucks (Cat725) for tailings placement. Triple-axle haul trucks were also temporarily used during the early stages of plant start-up.
In general, the placement plan involves truck placement of tailings material into lifts, followed by dozer compaction to minimum 95% of standard proctor maximum dry density. The initial lift placement over the liner system also required special operating procedures and a minimum 0.5-metre (“protection layer” of tailings) prior to allowing equipment traffic to work over the liner system.

In general, controlled compaction in thin lifts results in earthquake resistance, decreases the potential for the generation of liquefiable zones, and maximizes available storage volumes.


5.0 Conclusions

Dry stack tailings facilities offer an attractive method of tailings disposal for projects containing limited storage areas, sites where concurrent reclamation can be completed, and projects where decreased potential seepage volumes (due to lower tailings moisture contents produced) can be a large environmental benefit.

The dry stack tailings system, coupled with a HDPE-GCL liner incorporated into this project provides another step in mining waste management. The key seismic design features of the Efemçukuru filtered tailings facility are the incorporation of rock berms at the toe of the facility, and a liner system which optimizes the frictional resistance at the base of the pile.

The project itself was challenging due to the permitting requirements, on-going land negotiations, and the completion of engineering designs with the concurrent progression of construction.

On-going work is currently being completed to further characterize the filtered tailings material.

References


