Successful tailings dewatering
design using multilinear drainage geocomposites

by Pascal Saunier, Stephan Fourmont, Jacek Mlynarek, Andy Jung and Rob Stafford

The aftermath of the disaster in Brumadinho after the TSF dam collapsed. (Photo by Felipe Werneck/ Ibama, Wikimedia Commons.)

The safe and economical storage of tailings generated by modern-day mining operations is possibly the single largest challenge faced by miners today. By nature, tailings are a waste product that have little to no economic value. Yet, their physical and chemical contents can pose incredible environmental hazards if not stored correctly. The variety of factors that are met when designing tailing storage facilities (TSFs) means that in most cases, a low-cost solution is sought to accomplish storage, meet environmental regulations and adhere to industry best practices. TSFs can be large dam face structures or smaller structures, like retention/ evaporation lined ponds.

Water management is potentially the single largest factor that miners and designers must contend with when constructing a TSF. Water is a necessary component in the process of extracting ore, but can be difficult and expensive to remove once it is mixed with solid tailings particles. As a result, the most common disposal of these water-containing tailings, called a slurry, is to simply discharge into an embanked TSF (Vick, 1990).

These structures, just like any other water-retaining dam, can breach, releasing contents downstream. Despite modern advancements in TSF design, there have been numerous dam failures resulting in tragic loss of life and ecological devastation. Most notably in the last decade, the Brumadinho and Mariana Dam disasters in Brazil killed 278 people in downstream communities when TSF dams failed in 2019 and 2015, respectively (Rotta et al., 2020).

Similarly, in 2014, the Mount Polley tailings spill in British Columbia was the second largest tailings spill on record and caused extensive damage to adjacent watershed ecosystems when the TSF embankment was breached (Byrne et al., 2018). While there were numerous unique and underlying factors present in each of these structural failures, a shared element in the devastation was the large-scale release of unstable liquefied tailings.

Environmental and stability concerns aside, slurry requires a much greater volume in a TSF

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than solid tailings alone (Saunier, 2018). TSF expansions are costly and often accomplished through vertical "lifts" of the embankments so as to not extend the footprint.

Better utilization of the existing TSF volume creates an economic advantage for mining operations. Various methods have been used to dewater tailings for both stabilization and to minimize the overall volume they occupy.

Moisture can be removed from the solids using an extensive filtration process prior to the tailings being placed in their final location. This technique, known as dry stacking, provides the most stable tailings product but requires an immense filtration facility and increased operating costs. Natural and polymer-based thickeners can be added to slurry tailings to stabilize its structure. However, this method does not provide a solution to the issue of volume.

Gravity-based dewatering using drainage geocomposites may be the most cost-effective solution for many mining operations. This process uses a geosynthetic product, known as a geocomposite, consisting of two layers of geotextile encapsulating a drainage media on the upslope side of a TSF embankment.

This method effectively relies on the natural settlement of solid particles within the slurry. Subsequent smaller particles work to build up a natural filter while the drainage component removes the liquid from the tailings. However, the physical and chemical nature of many TSFs can cause tremendous stress on traditional geocomposites. As TSFs grow larger in size, high compressive loads can cause compression of the drainage core and intrusion of the geotextile component. These phenomena, known as creep and intrusion, respectively, can cause large reductions in dewatering capability. Further, high concentrations of fines can lead to clogging of the geotextile filter. High acidity can further accelerate degradation of the drainage components.

Description of multilinear drainage geocomposites

The use of geomembranes in mining applications has been widely documented. However, geocomposite compatibility studies with mined material are scarce and very limited information is available. A study by Smith and

Figure 1

Draintube composition.

Zhao (2004) clearly shows that drainage geocomposites lead to improved service and cost reduction in heap leaching. Gulec et al. (2005) indicated there were no major changes in the hydraulic and mechanical properties of polypropylene geotextiles after immersion in acid mine drainage for 22 months.

The multilinear drainage geocomposite (MLDG) used in this study was developed by Afitex-Texel and is called Draintube. It is composed of (Fig. 1):

- A nonwoven polyester/polypropylene geotextile acting as a filter.
- A series of corrugated polypropylene tubes spaced at regular intervals (1 to 4 m width). These perforated tubes provide most of the drainage capability of the product.
- A nonwoven thick polyester/polypropylene geotextile acting as the drainage medium and as a cushion to protect the underlying geomembrane.

Filtration applications with mine residues may be among the most challenging filtration applications. First, the high seepage forces and suspended particles that must be filtered can lead to clogging. Second, leachate is typically a highly loaded solution and mineralization can lead to chemical clogging (Faure, 2004; Fourie et al., 2010; Legge et al., 2009), although it is likely that a clogging problem would also occur with mineral drainage systems (such as gravels, see Giroud, 1996). In order to check if MLDGs are able to fulfil the function of a drainage and dewatering layers, long-term hydraulic properties, soil retention and chemical resistance must be evaluated. The results of experimental studies aiming at checking theses points are presented in the following sections.

Behavior under high-compressive load

With an ore density between 1.5 and 1.8, the compressive load on the drainage layer can reach 2 MPa (Thiel and Smith, 2004; Castillo, 2005). For planar geocomposites involving a planar

Figure 2

Transmissivity under different loads up to 2 MPa and 100 h (i = hydraulic gradient) (after Saunier et al., 2010).

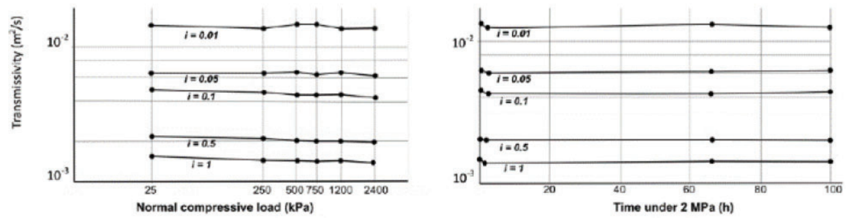


Figure 3

Cross section of an experimental leaching cell. Over 90 days, acid leachate percolates through the ore, then the MLDG.

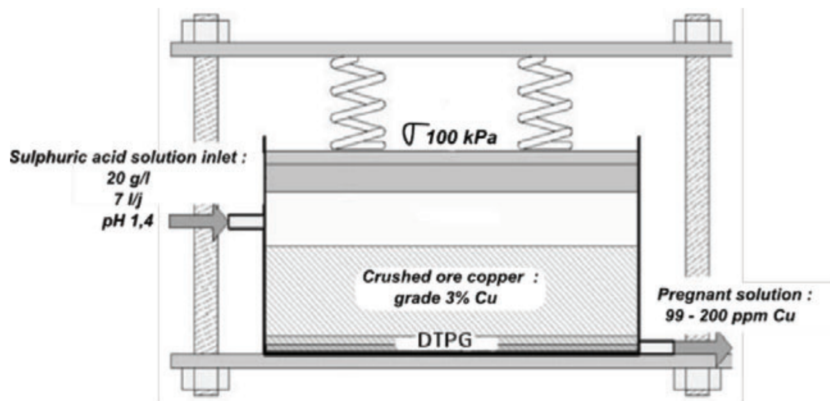
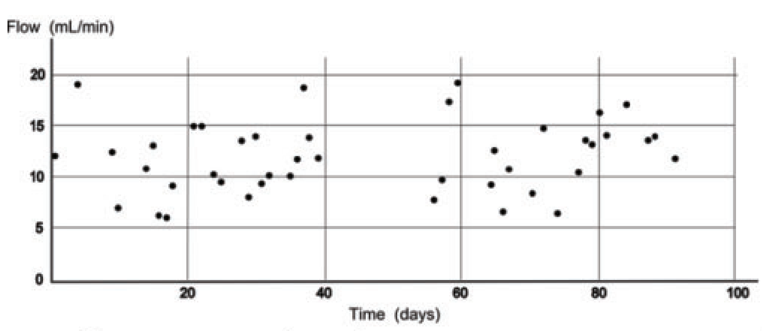


Figure 4

Typical flow rate under a hydraulic head of 5 mm.



drainage core (such as biplanar or triplanar geonet), it has been shown by several authors that the hydraulic properties of these geosynthetics are adversely affected by such high-compression stresses. However, Saunier et al. (2010) have shown that the particular structure of Draintube MLDG is favorable to the development of an arching effect around the pipe. Consequently, the transmissivity is not affected by the compression stress nor by time, as no creep can develop in the pipe. Their results are reported in Fig. 2.

Behavior in an acid leaching environment

Long-term flow tests were conducted to observe the performance of Draintube MLDG when subjected to acid circulation at a concentration representative of those used in the mining industry for three months. The MLDG was installed in the bottom of cells measuring 100 mm × 200 mm (4 in. × 8 in.), and then covered with 1 kg (2.2 lb) of crushed copper ore with an average grade of 3 percent Cu. A nominal stress of 100 kPa was applied to the system for the duration of the test (Fig. 3).

An average daily flow of 15 L/h/m² of the 20 g/L sulfuric acid solution with a pH of 1.4 was recirculated over 90 days through each cell.

From Fig. 4, it is possible to observe that the flow rate remained relatively constant over time, which suggests that no clogging occurred and that the MLDG maintained functionality over the duration of the test.

Visual inspection carried out at the end of the tests found that the perforated pipes of the Draintube MLDG were completely free of particles (Fig. 5). Permittivity tests conducted on the upper geotextile filter (in contact with the ore) found a decrease in permeability in the range of 10 percent, confirming the visual observation of a geotextile appeared almost "clean" on its inner side, compared to the outside.

Based on these observations, it was concluded that circulation of sulfuric acid through the ore/geocomposite system is not likely to create any clogging problem on the surface, or in the drainage media. The particular MLDG tested consisted of a 25-mm diameter perforated pipe and a geotextile with a 120-µm filtration opening size. Although the experiment was conducted under a normal load of 100 kPa, the lack of sensitivity of the product to compression loads up to 2,400 kPa suggests that these observations are likely to be applicable to the high normal loads typically found in heap leach pads.

Filtration compatibility with tailings and gradient ratio

Tailings stored as a slurry in a TSF creates a challenge for geotextile filtration. High concentrations of fines separated from the soil can create a cake on the surface of the geotextile, reducing its permeability, thus endangering the efficiency of the system and the stability of the geotechnical structure.

To evaluate the filtration behavior of the geotextile filter in the MLDG, a modified gradient ratio test was developed to model the existing mechanisms of the slurry as it is deposited on the geotextile filter. The following hypotheses were considered to develop the experiment:

- First, the slurry reaches the geotextile with a solid/water ratio of 72 percent water/28 percent solid.
- In the early stage of the slurry/geotextile interaction, the water head will be similar to the height of the slurry, and the system will settle.
- Eventually, more material will reach the deposit and will increase the water head, and eventually hydraulic gradient prevailing in the vicinity of the interface.

Considering these hypotheses, a strategy was developed using a testing apparatus conforming to ASTM D5101, modified to model the scenario described above. A slurry was prepared to the prescribed solid/water ratio using a tailing with particle size distribution shown in Fig. 6a.

To initiate the test, this slurry was deposited in a liquid form (Fig. 6b) on the surface of the geotextile filter and selected for its filtration opening size less than 70 µm (per CGSB 148.1 n°10). This led to a total head of about 300 mm above the geotextile.

A valve located downstream of the geotextile was opened to initiate the test. The downstream section of the test cell was connected to a container with a free surface and at a height of 150 mm above the geotextile. Thus, the initial conditions were a water (slurry) head of approximately 300 mm upstream from the geotextile and 150 mm downstream. A "slurry head" of 150 mm was then applied on the geotextile filter, creating a flow through the geotextile while also allowing the slurry to settle.

The flow rate was measured along with the hydraulic head monitored under the geotextile at distances of 25 and 75 mm above the slurry. The combination of decreasing head pressure and sedimentation of the tailings was maintained until the upstream and downstream head equalized at 150 mm. In the process, the soil/geotextile interface developed a structure similar to what would likely be formed in the field.

After equalization, the upper portion of the test cell was closed and the standard gradient ratio test was initiated using the standard apparatus (Fig. 7), which applied a hydraulic gradient of 1.0. During the test, the same hydraulic head was monitored under the geotextile at distances of 25 and 75 mm and above the soil/slurry. The flow rate continued to be measured as well.

As there is no precise limit to differentiate a "soil" from a "slurry" during the deposition phase, it was not possible to determine a flow rate through the porous media. Therefore, to calculate a permeability of a soil, geotextile or slurry, it was decided that a "permittivity" of the entire system would be calculated by dividing the flow rate by the total water head. This value was considered to be a sufficient indicator to observe a trend (that is, an increase or reduction of permeability over time). It is also a practical way to normalize the flow rate to the water head and to analyze the geotextile interface behavior during the slurry deposition stage of the test.

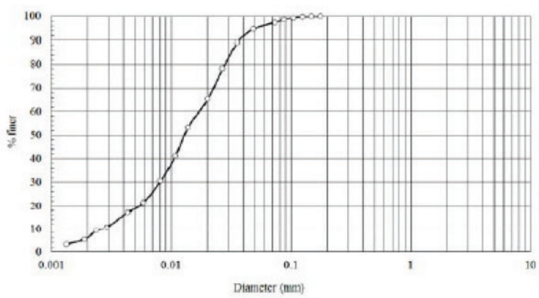
Results and observations are presented in Figs. 8 to 11. The

Figure 5

External and internal views of the MLDG after three months of percolation of sulfuric acid.

Figure 6a+b

Gradation of the tailing.



(a) Gradation

Figure 7

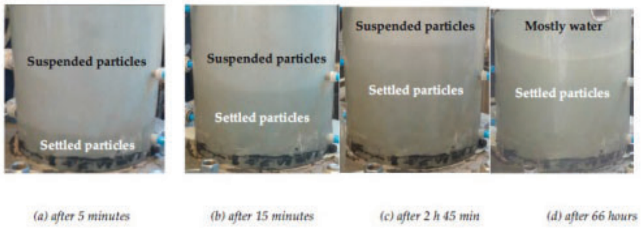
Setup of the filtration test (Gradient Ratio, ASTM D5101).

following observations were made:

- The permittivity of the system, calculated by dividing the flow rate per unit area at a given time by the total hydraulic head, first decreased to reflect the accumulation of soil particles at the surface of the geotextile (Figs. 8 and 9). It eventually stabilized and remained constant until the end of the first part of the test (sedimentation). After the complete settlement/deposition of the soil particles, the second phase of the test was initiated with the constant head test. The permittivity remained at the same level as measured before. It was therefore concluded that the permittivity of the system remained stable over time and that no clogging mechanism developed as the water flowed through the system. In order to estimate the permeability of the tailing/geotextile system, the permittivity was multiplied by the height of soil after deposition (measured from the outside of the cell, as shown in Fig. 8d). A value of 6×10^{-5} cm/s was determined, which was similar to the tailing permeability documented by the owner. With a consistent permeability of the system similar to that of the native material, the system was considered to be stable.
- Gradient ratio values of approximately 3 were observed and remained stable throughout the duration of the test (Fig. 10). Although 3 is at the upper limit of what is generally considered acceptable, it must be analyzed considering two factors: (1) First, the soil was not compacted, but installed in a slurry form. Consequently, the arrangement of sedimented particles is likely to be more compact in the vicinity of the filter, where the water has the greatest potential for being drained, and to generate a soil-like structure rather than sludge. (2) Second, it does not evolve over time, indicating that the permeability of the tailing/geotextile interface does not decrease more rapidly than the permeability of the tailing, measured at a distance from the interface. It is concluded from the gradient ratio test that the geotextile filter is not blocked/clogged because the gradient ratio values remained stable through the duration of the test.
- The analysis of the evolution of the water heads (Fig. 11) shows that more than half of the head loss occurs between the top of the soil and the piezometer located at a distance of 76 mm from the geotextile: that is, on the very top of the sedimented slurry. This observation can be explained by the sedimentation process, which favors segregation of the particles with the coarser particles settling first. As a result, the gradation of the soil progresses, with a decreasing concentration of coarser particles, as the distance to the geotextile increases. This mechanism favors creation of a very fine-grain layer on the top of the soil surface, which exhibits a lower permeability, thus a higher head loss on the upper layer, as observed in Fig. 8.

Figure 8

Settlement of the slurry during the first stage of the test.



Conclusion

The results of the gradient ratio test indicate that the geotextile filter was not blocked or clogged and the gradient ratio values remained stable throughout the duration of the test.

It was observed that the permittivity of the system was stable over time, indicating that no clogging mechanism developed as the water flowed through the system. Additionally, the permeability of the geotextile/tailing system was similar to that of the native material and no decrease of permeability was observed, suggesting that the system was stable.

Overall, it can be concluded that the tested geotextile, with a FOS of 70 µm (maximum average value as measured per CGSB 148.1 n°10) offers a good filtration performance of the tailing with the given particle size distribution, prepared as a 28 percent solid/72 percent water slurry during both sedimentation and filtration under a hydraulic gradient of 1.0.

These filtering characteristics, combined with long-term performance under high normal loads (demonstrated by Saunier et al.), suggests that Draintube MLDGs can be considered a practical solution for applications involving harsh chemical conditions and fine-grained materials. ■

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Figure 9

Permittivity versus time.

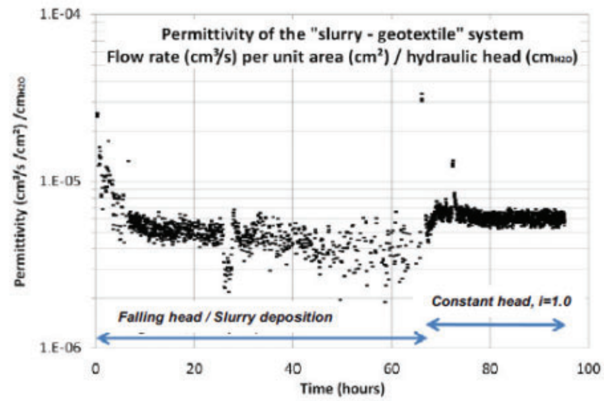

Figure 10

Gradient ratio versus time.

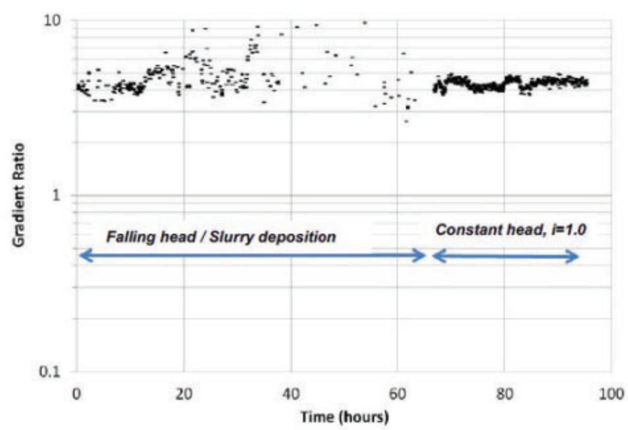

Figure 11

Water head versus time.