GeoAmericas2020
4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

The importance of the technical specification when using geotextile tubes for mining applications

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ABSTRACT
Mining tailings disposal permanently brings about a contamination threat to groundwater of unprotected aquifers and surface water in dumping sites all over the world. The mining tailings burden and management problems are particularly important due to the high volume and complexity of material disposed. Developed in the early 60's, and first applied for mine tailings in early 2000's, the geotextile tube technology has been successfully used to contain and dewater hundreds of thousands of cubic meters of waste material every year around the world. Despite the simple concept of using filtration to separate the liquids from the solid part of a high moisture content material, the geotextile tube technology depends on several technical aspects to work properly and safely, such as, hydraulic and mechanical properties of the geotextile, filling ports, seaming and dewatering performance. Not to mention the operation of the system which is critical to achieve the expected results. In the last couple years, the state of Minas Gerais, Brazil has been struggling with major environmental disasters, caused by the collapse of two tailing dams. First failure happened in 2015 and the second event in 2019. Both catastrophic events resulted in flooding, deaths and material losses. Either in 2015 or 2019, as part of the remediation plan, several geotextile tube units were used to clean up the waterways from contaminated sediments and tailings. This paper compares the different specifications used in both projects and also discusses the importance of the technical specification when designing geotextile tubes to contain and dewater mining tailings highlighting its best practices.

1. INTRODUCTION

The containment of mine tailings has been one of the greatest challenges of modern geotechnical. The volumes involved, the environmental constraints and the reduction of areas available have shown the necessity of developing alternative methodologies for the disposal of these materials, replacing the traditional model of dams.

In the dewatering method context, woven geotextiles permit a great variability of applications in the form of hydraulically filled tubes. This conception differs from other dewatering methods because the pulp material is surrounded and encapsulated by the filtration system. In some applications, the use of flocculating agents for improving or increasing the dewatering process of contaminated residues is required. In function of the specific nature and high-water content of fine tailings, the mechanisms of filtration of the geotextile tubes, therefore, demand special approaches in the laboratory and field.

The technology of geotextile tubes and bags have been used as a geocontainment system since the 60's for marine applications, however it started to be used a dewatering process for sludge and contaminated sediments in the 1995, when lime and aluminum sulfate wastes from the Eagle Lake and Culkin Water Districts, Vicksburg, Miss., disposal lagoons were placed in two geotextile bags and one tube (donated by TC Nicolon Corp.) and closely monitored for filtration and consolidation testing. Since then many studies are being done about geotextile tubes technology and its benefits for many kinds of waste dewatering all over the world (Castro 2005 e Martins 2006).

2. MINING TAILINGS

Tailings are materials that remain from the processing and concentration of ores in industrial facilities, whose granulometric characteristics depend on the type of raw ore to be extracted (iron, bauxite, gold, etc.) and on the industrial processing process, which may cover a wide range materials, from non-plastic sandy to very fine-grained soils. They can be active (contaminated) or inert (uncontaminated). The liquid fraction of the tailings, the mud, is nothing more than the water released by the pulp, constituting, in general, a mixture of solids and water with concentrations in the range of 30 to 50% by weight.

The tailings can be discarded from the processing plant in solid (paste or bulk) or liquid (pulp) form, most commonly used. The disposal of these materials can be done on the surface, in underground cavities or in underwater environments. The choice of a system for the disposal of tailings depends on the nature of the mining process, the geological and topographic conditions of the region, in addition to the mechanical properties of the materials and their contaminating power.

The constant rupture of the traditional containment systems for these materials has caused a considerable impact on the environment. For example: modification of the local relief, degradation and removal of topsoil layers, suppression and impairment of vegetation areas, silting of waters and springs, induction and acceleration of erosion processes. They also cause impacts of a social nature, such as risks associated with the degradation or impairment of areas destined for housing and buildings, reductions in the flow of water courses and impairment of the quality of water destined for public supply. Socioeconomic issues, including those associated with the loss of human life, become preponderant elements for the consideration of the safety of tailings containment structures (Martins 2006).

In this context, and in order to attend the new environmental legislation, studies on technological alternatives for tailings disposal has being carried, that provide more stable structures, rapid rehabilitation of the area, reduction of percolation rates, minimization of the polluting potential over time, use of water and less impact on the environment.

3. GEOTEXTILE TUBES FOR MINING APPLICATIONS

3.1 Introduction

Dewatering is a stage by which the tailings must be submitted due to the large volume presented or the difficulty of safe transportation.

Currently the disposal of tailings in ponds is the technique commonly used, however this presents a series of difficulties, such as: they are built in large areas; involve high costs in its construction; failures in the bottom liner of the lagoon, which can lead to contamination of the soil and groundwater; and the fact, that these lagoons are associated with a containment dam, therefore, subject to rupture by accumulation of waste and consequent increase in tensions. The rainy season aggravates the delay in separating the liquid part from the solid, bringing the risk of overflowing.

The dewatering technique by geotextile tubes allows to reduce the moisture content of these materials and contain contaminants that may be present, showing, in some cases, a better performance in comparison to conventional techniques and can also be used as a resource to optimize the dewatering process already employed for this purpose.

3.2 *Pioneer Applications*

The pioneering application of geotextile tubes in mining date from 2004, in the Chalkidiki peninsula, Greece, Maden Lakkos and Mavres Petres mines, and in the titanium dioxide processing plant at a mining company in Baltimore, USA.

In the Greek mines, the initial waste disposal system used two ponds: one filled while the other drained the material until it could be excavated and transported to the drying area. The expansion of the mine led to an increase in production and the existing lagoons became insufficient, being necessary to use a method of disposal of fine tailings that needed a shorter time than that of traditional processes, having been adopted the dewatering method with the aid of geotextiles, for better meeting the needs of the project (Newman et al. 2004).

In the Baltimore mine, the mining company's titanium dioxide processing plant had problems with the tailings disposal, since the ponds used for this purpose were depleted. For the company to guarantee the continuity of its operation, all the waste would have to be removed and disposed of in another area. In 2004, this removal was avoided by using geotextile tubes 142 meters long and 18.3 meters in circumference. The tubes were stacked in seven layers to maximize the containment capacity of the area ("Miratech - Ten Cate Nicolon. "Geotube® - Dewatering Technology", versão 5.2. Seção: Aplicações – Mining & Mineral Processing, 2005").

3.3 *Highlights Observed for the Application of Geotextile Tubes in Mining*

During many years of observation regarding the studies and the implementation of geotextile tubes for mining tailing dewatering, it is clear that the technique must be applied considering the specific characteristics of each mining company, such as physical and chemical properties of the tailings, volumes of production, areas available for disposal, etc. In addition to this, the technique has been shown to be of great importance in the environmental recovery of the areas affected by the last rupture events that occurred.

Nevertheless, we bring in this paper the importance of the importance of the technical specification so that the technique may be applied successfully. Like all geotechnical structure, or tailing disposal process, the implementation of geotextile tubes also requires a good design, which considers the correct assumptions and specialized team throughout the operational period with the appropriate safety processes.

4. TECHNICAL SPECIFICATION

4.1 *Mechanical Properties*

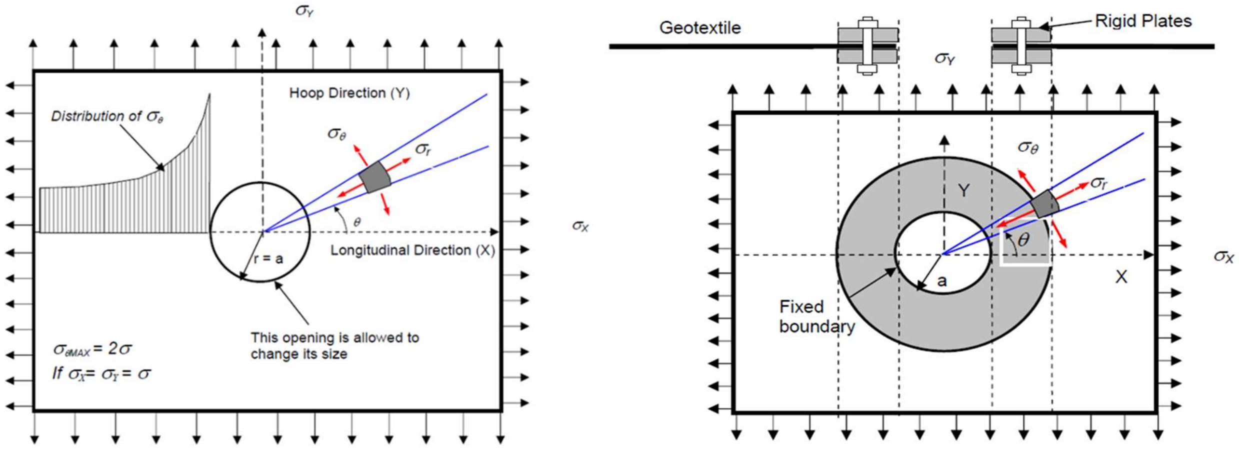
The geotextile tube is submitted to high pressures during the multiple pumping cycles of the dredged material, which is one of the most critical moments for the entire process especially for the geotextile. It's very important to use a high tenacity, low creep and low elongation geotextile to endure all the phases of the process: installation, multiple pumping and dewatering cycles, consolidation and stacking when necessary. It's worth noting that in all those phases the geotextile tubes, most of the time, will be exposed to sunlight, consequently subject to UV degradation. It is crucial that the geotextile has UV protection additives in its composition.

4.1.1 Tensile Strength

Tensile strength is an essential property for the geosynthetic that fabricates the geotextile tubes. It is important to highlight that this property refers to the wide width tensile strength in both directions, cross machine direction (CMD) and machine direction (MD) (ASTM D4595), factory seam strength (ASTM D4884) and filling ports (ASTM D6241 – modified).

4.1.2 Fill Ports

Yuan et al 2008 discuss the stress concentration around geotextile tube filling port and compares the stresses in flexible (or deformable) ports and in rigid ports. Field observations indicate that a geotextile ring around the geotextile tube port is subjected to higher stress than the area farther away from the port as evidenced by severe tensioning and sometimes rupture around the port. According to Yuan et al 2008, for the deformable geotextile tube port, the tensile stress in the circumferential direction at r = a increases to 2 times the uniform stress applied to the longitudinal and hoop direction of a geotextile tube. In the other hand, for the rigid geotextile tube port, the tensile stress in the circumferential direction around the port is less than the uniform stress applied to the longitudinal and hoop direction of a geotextile tube. Figure 1 shows stress distribution around a flexible and rigid fill port according to Yuan et al 2008 and their numerical analyses.



(a) Flexible fill port (b) Rigid fill port

Figure 1: Stress distribution around flexible (a) and rigid (b) fill ports.

4.1.3 Factor of Safety

The Factor of Safety in the circumferential direction represents the ultimate machine direction tensile strength of the geotextile divided by the stress exerted in the circumferential against the machine direction of the geotextile at a given fill height with a given relative density of fill material. The Factor of Safety in the axial direction represents the ultimate seam strength of the cross-machine direction divided by the stress exerted in the axial direction against the cross-machine direction seam strength at a given fill height with a given relative density of fill material.

Regarding the Factor of Safety of the fill port, Yuan et al 2008 addresses that the tensile stress in the circumferential direction around the rigid port (at r = a) is reduced to 67% of the applied uniform tensile stress. This is compared with σ_θ increased to 200% (i.e., stress concentration factor = 2) of the applied uniform tensile stress for a deformable port. It's important to highlight though, that the stress on the geotextile reaches only the maximum during the filling operation. As soon as the filling stops, the stress rapidly decreases and is not a constant load.

Based on field experiences and research reported by TenCate Geosynthetics, that created the dewatering function for geotextile tubes in 1992 in conjunction with the US Army Corp Of Engineers (USACOE), it's recommended a minimum of FS equal to 3. The original, TenCate and USACOE, Factor of Safety was 5.0 against tensile failure. Since that time, more than 200 million cubic meters have been contained and dewatered in high performing woven geotextiles units on more than 2,000 projects. Working with experienced dewatering contractors, it was developed installation and filling techniques to ensure that projects are completed in a safe working environment.

4.1.4 Volumetric Capacity

Volumetric capacity of a geotextile tube stands for the volume of dewatered material per linear meter. With that being said, the higher the volumetric capacity, the higher cost effective the system will get. Many are the aspects that may influence the volumetric capacity and that is what is going to be discussed in this topic.

Immediately related to the dimensions (circumference and length) of the geotextile tube, the volumetric capacity also depends on the geotextile mechanical properties, such as, tensile strength, seam strength and elongation. In order to resist the high pressures during the multiple cycles of pumping/dewatering, the geotextile must be woven into a stable network such that the yarns retain their relative position, avoiding the loss of solid particles and clogging. It is recommended that the geosynthetic and seaming be tested for unloading and reloading cycles (ASTM D4595 – modified) in order to obtain the best product specification.

The type of fill port, flexible or rigid, plays a huge role in the entire process in terms of safety as well as allows the tube to be pumped to higher heights, allowing more material to be contained within a single dewatering unit.

4.1.5 Stacking

Multiple layers of Geotube® units have been successfully stacked in several projects around the world since late 90's, such as the Badger US Army Ammunition Plant project (first stacking project for dewatering application), Canal do Fundão project, in Rio de Janeiro, Brazil (Stephens et al 2011), Embraport project, in Sao Paulo, Brazil (Stephens and Melo 2013), Base Naval, in Rio de Janeiro, Brazil (Melo and Stephens 2015), Ashtabula River remediation project Ohio, USA (Cretens 2009) and Fox river cleanup project. The Ashtabula River remediation project stacked 11 layers of woven geotextile tubes filled with contained and dewatered dredged material.

The stacking design should verify the geotechnical conditions of the dewatered material, foundation and structural stability of the stacked layers.

4.2 *Hydraulic Properties*

Geotextile tubes are fabricated to dewater high moisture content material, which is the filtration of the solids and the separation of the liquids that pass through the pores of the geosynthetic. With that being said, the hydraulic properties of the geotextile play a huge role in the dewatering process, considering that the geotextile must be retain the solid particles and release the liquids without clogging. This successful combination results in a larger volume and a better quality of the water in terms of suspended solids in a shorter period of time. Consequently, the solid mass within the geotextile tube consolidates faster increasing the percent of solids targeted.

A faster consolidation and dewatering process permit the project to quickly move on to the next phase, which is the final destination of the dewatered solids, such as, bury the entire dewatering cell, cut the tubes open and transport the solids to the final destination or simply leave the tubes where they are with no cover. In this case it is expected that the geotextile used to fabricate the tubes is UV resistant for at least 8 years, based on actual project experience, and that its structure does not permit the rain drops to infiltrate and rehydrate the solids within. The consolidation time of a slurry also depends on its physical and chemical characterization, besides the utilized chemical conditioning, such as polymers, flocculants, and coagulants.

The main hydraulic properties for this application are Apparent Opening Size (AOS) (ASTM D4751), Water Flow Rate (ASTM D4491), and Pore Size Distribution, for instance O_{50} and O_{95} (ASTM D6767).

4.3 *Testing*

4.3.1 Cone Test

The Cone Test is a fast and easy test to determine how well a sludge sample dewaters in the geotextile. The test is designed to evaluate the efficiency of the candidate polymers and to help predict the percent moisture remaining in the sludge after dewatering in cone. The user will measure the time it takes for free water to be released from the sludge, how well the dewatered sludge releases from the geotextile, the volume of effluent released from the sludge, and the quality of the effluent.

4.3.2 Small-Scale Bag Test

This test method is used to determine the flow rate of water and suspended solids through a geosynthetic permeable closed bag used to contain high water content slurry such as dredged material (ASTM D7880/D7880M – 13). The Small-Scale Bag Test, or Pillow Test, is a demonstration of sludge dewatering using a geotextile tube. The purpose of the test is to visualize the dewatering process, evaluate the efficiency of the selected polymer, analyze the clarity of the effluent and predict achievable percent solids.

Many projects around the world, including Brazil, have demonstrated the importance of this particular test. For instance, the project in Rio de Janeiro, where a large amount of contaminated sediments was dredged from the Canal do Fundao. The design was based in several cone tests to select the right polymer, dosage and charge of the flocculant and also small-scale bags testing to determine the operation of the system based on how the dewatering was going to perform. (Castro et al 2009, Stephens et al 2011).

5. RECENT BRAZILIAN EXPERIENCES

5.1 *Fundao Dam Disaster*

5.1.1 Background

The Fundao Dam disaster occurred on November the 5th of 2015, when an iron ore tailings dam in Mariana, Minas Gerais, Brazil, suffered a catastrophic failure, resulting in flooding that destroyed the village of Bento Rodrigues. The tragedy left hundreds of families displaced and killed 19 people. The failure of the dam, owned by the Brazilian mining company Samarco, caused the discharge of around 60 million cubic meters of iron waste that flowed into the Doce River, causing toxic brown mudflows to pollute the river and beaches near the mouth when they reached the Atlantic Ocean 17 days later. The disaster created a humanitarian crisis as cities along the Doce River suffered water shortages.

5.1.2 Remediation

Years before the disaster, nonwoven geotextile tubes were tested to dewater the mine tailings with poor results in terms of dewatering performance, low volumetric capacity and unstable stacking layers. After the Fundao Dam failure, many areas were affected including the Candonga Dam, which had its level critically increased due the mudflow. In a pilot scale and in order to remediate the problem, woven geotextile tubes were used to dewater the part of the tailings. It was performed laboratory tests and the small-scale test to design the pilot project. The material reached great results in terms of dewatering performance, increasing its percent of solids from 53% to 80% in 21 days. Due the low elongation of the GT500 woven geotextile and its dewatering properties, the stacking process had no issues whatsoever and the pilot project was a success (Freitas Silva 2017).

5.2 *Brumadinho Dam Disaster*

5.2.1 Background

The Brumadinho dam disaster occurred on 25 January 2019 when Dam I suffered a catastrophic failure. Dam I was a tailings dam at the Córrego do Feijão iron ore mine, which is located over 9 km east of Brumadinho, Minas Gerais, Brazil. The rupture released a 20 m high tidal wave of mine tailings, which means approximately 12 million m3 of mine tailings, causing the death of more than 300 people downstream.

The cleanup project specified the use of woven geotextile tubes to remediate the contaminated areas. The remediation plan consisted in treating the water of two rivers, Ferro Carvao and Paraopeba, which were contaminated with up to 15 m of sediments and dredging more than 2 million m3 of tailings into hundreds of woven geotextile containers. The cleanup project divided the job in two phases. Phase 1, to build a Wastewater Treatment Plant to treat the water from Ferro Carvao river and dewater the sludge using geotextile tubes. Phase 2, to dredge the sediments from Paraopeba river and dewater it in geotextile tubes in a separate area, since this is where most of the tailings are deposited.

5.2.2 Project Design

The sediments were collected and tested to determine the chemical conditioning process through Cone Tests and also its behavior under dewatering conditions performing the small-scale test. The findings were processed using two software tools: the Geotube® Estimator and the Geotube® Simulator. The first one, Geotube® Estimator, provided the quantity of tubes in linear meters that was necessary to contain and dewater the 2 million cubic meters of tailings. The quantity of geotextile tubes depends on the physicochemical characteristics of the tailings, in situ and targeted, and the operation system. The second one, Geotube® Simulator provided the geometry of each unit at a given time, efforts exerted on the fabric (Machine Direction and Cross Machine Direction), on the seaming and on the fill port, and respective Factors of Safety for a given geotextile. For this project, it was used the TenCate GT500.

Figure 2: Woven Geotextile Tubes in operation during Phase 2 in Brumadinho, Brazil.

The software tools provided all three Factors of Safety greater or equal than 3, volumetric capacity of 32.46 cubic meters per linear meter for a 36.5 m circumference tube, pumped up to 2 m with a material with 2.4 g/cm^3 of density. Figure 2 shows the woven geotextile tubes being operated during Phase 2.

6. COMPARING SPECIFICATIONS

6.1 Introduction

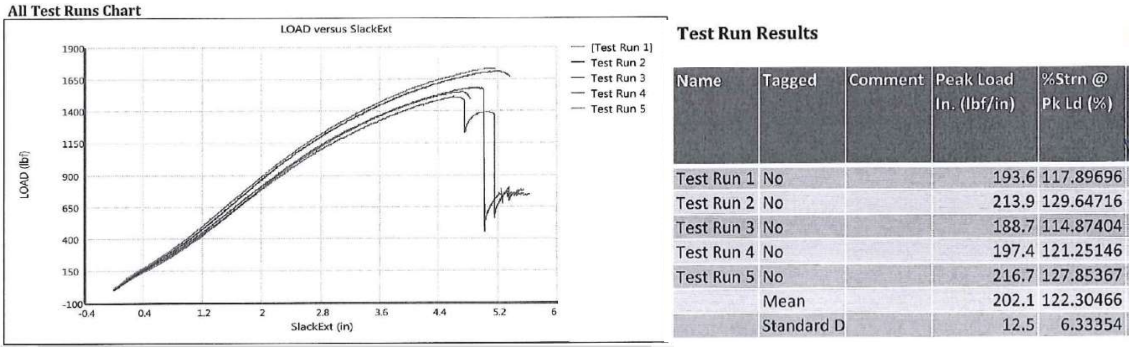
To compare geotextile tube specifications, it is paramount to make sure it is being compared apples to apples. The material to be dewatered needs to be characterized to make sure its density and specific gravity are determined; these parameters play a key role in determining the stresses exerted on the used geosynthetic. Whatever is the calculation method chosen to determine the geometry of the tube and the stresses (circumferential, axial and fill port), it's very important to compare the maximum pumping height, the circumference of the tube and consequently the volumetric capacity of each unit when designing the geotextile tubes.

It is also recommended that a series of testing is performed (See item 4.3) with the geosynthetic in action, which means to dewater the flocculated or not sludge or tailings. This is going to reveal how the proposed geotextile is performing in terms of retained material volume, percent of solids dewatered material and turbidity of the filtrate. The data will be crucial to design the entire system.

6.2 Nonwoven versus Woven Geotextile

Considering the Brumadinho project, this item compares the machine direction stress vs. strain curves of a typical nonwoven geotextile with 900 g/m2 of weigh (Figure 3) and the GT500 woven geotextile (Figure 4), taking into consideration that the Circumferential Tensile Force is 24.52 kN/m (140 lb/in) from the software Simulator.

This Circumferential Force is exerted on the Machine Direction and the Axial Force is exerted on the Cross-Machine Direction of the used geosynthetic for the Brumadinho project. The tubes are fabricated connecting panels through circumferential seams.



Name	Tagged	Comment	Peak Load In. (lbf/in)	%Strn @ Pk Ld (%)
Test Run 1	No		193.6	117.89696
Test Run 2	No		213.9	129.64716
Test Run 3	No		188.7	114.87404
Test Run 4	No		197.4	121.25146
Test Run 5	No		216.7	127.85367
	Mean		202.1	122.30466
	Standard D		12.5	6.33354

Figure 3: Typical nonwoven geotextile stress vs strain curve – machine direction (900 g/m2 of weight)

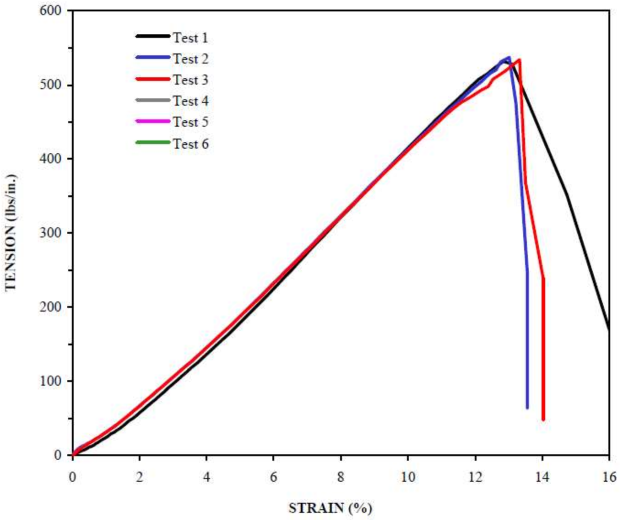


Figure 4: GT500 woven geotextile stress vs strain curve – machine direction (Brumadinho project)

7. CONCLUSION

It is important to always keep in mind that designing geotextile tubes requires a strong and low deformation geotextile to resist the high pressures and possibly stacking procedures, especially for mine tailings containment and dewatering applications, which involves high volumes of heavy material.

Over the years, researches, testing and experience have taught the market that nonwoven geotextiles are not the proper material to be used for dewatering tubes because of its high elongation and poor dewatering. These characteristics alone may cause failures and consequently severe environmental impact. Nonwoven geotextile tubes are not cost-effective, because of its low productivity and low volumetric capacity. Its high elongation also makes stacking even more challenging and dangerous process.

Last but not least, when designing geotextile tubes for mine tailings containment and dewatering, it is key to evaluate not only the fabrication geosynthetic, but the performance of the tube in terms of dewatering, filtrate quality, maximum pumping height, volumetric capacity and Factors of Safety, for instance, for Circumferential Forces, for Axial Forces and Filling Ports.

ACKNOWLEDGEMENTS

The authors thank TenCate Geosynthetics for the information provided.

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