COMMON PRACTICE IN DEWATERING AND INNOVATIONS IN TALINGS DAMS USING PROPERLY DESIGNED GEOSYNTHETIC TUBES

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ABSTRACT

Geotextiles have been integral to tailings dam management for several decades, demonstrating their efficiency and resource optimization capabilities. They offer significant advantages in separation, reinforcement, drainage, and sealing, making them a reliable solution for reducing costs and enhancing the environmental performance of tailings management. This paper introduces innovative concepts for constructing tailings dam embankments using geotextile dewatering tubes and examines the corresponding stability considerations. Originally developed for dewatering sewage and sediments, geotextile tubes, when combined with carefully selected flocculation aids, can dewater and safely store a wide range of sludges, thereby reducing the required storage volumes.

1. INTRODUCTION

The mining industry plays a vital role in global economic development, producing essential raw materials. However, this process generates significant amounts of tailings, the residual materials left after the extraction of valuable minerals. According to the International Council on Mining and Metals, the mining industry produces approximately 5 to 7 billion tons of tailings annually worldwide. Proper management and storage of these tailings are crucial due to the potential for toxic contamination and the need for long-term storage solutions [1].

With approximately 3,500 active tailings dams registered worldwide [2], the rate of tailings dam failures is significantly higher than that of water supply dams (World Mine Tailings Failures, 2020). These failures can cause substantial damage and the environmental cost of releasing toxic mine tailings is often irreparable. Effective management and innovative solutions are essential to mitigate these risks and protect the environment and communities.

Despite advancements in geotechnical engineering, the construction of tailings dams still predominantly relies on conventional methods. While these traditional practices are well-established, they often present significant logistical and economic challenges. Sourcing suitable material in proximity to mining sites can be difficult and costly. Additionally, the construction process requires substantial labor for compaction and maintenance, which can further inflate costs. Given these challenges, there is a pressing need to explore more efficient and cost-effective alternatives.

One promising alternative is the use of geosynthetic dewatering tubes. Originally developed for dewatering sewage and sediments, these tubes can effectively dewater and consolidate various sludges, thereby reducing storage volumes and enhancing the structural stability of tailings dams. By decreasing reliance on conventional materials and labor-intensive methods, geosynthetic dewatering tubes offer a faster, more sustainable, and economically viable solution for tailings dam construction.

In addressing these challenges, the structural stability of tailings dams is paramount. Over time, geosynthetics have proven effective in reinforcing and separating functions for capping tailings ponds and strengthening dam walls made from low-shear strength materials. Their versatility in separating, filtering, draining, reinforcing, protecting, and sealing tailings dams makes them an essential component of modern tailings management.

This paper explores the application of geosynthetic tubes in tailings dam construction, focusing on their ability to dewater and consolidate tailings, thereby increasing the storage capacity of tailings ponds. Additionally, these tubes facilitate the reuse of water, which is increasingly important in water-scarce regions. This study introduces the principles of dewatering processes, dimensioning for dewatering purposes, and methodologies for incorporating geosynthetic dewatering tubes into tailings dam construction, providing a comprehensive overview of their potential benefits.

2. GEOSYNTHETIC DEWATERING TUBES

Geosynthetic dewatering tubes were originally developed for the purpose of sewage and sediments dewatering. In combination with carefully selected flocculation aids almost every type of sludge can be dewatered, stored safely which reduces the required storage volumes. The tubes are manufactured from special filter fabrics. Single units of this fabric are sewn together and this way large tubes can be assembled. Dewatering tubes with volumes ranging from 15 m³ up to more than 1650 m³ have been assembled and used beneficially in recent projects. This dewatering methodology extends the range of different dewatering possibilities. The dried solid content is enhanced and an increase in the overall safety factor can be achieved.

Detailed principles of dewatering using geosynthetic tubes are discussed by van Keßel [3], while Wilke & Breytenbach [4] provide a case study on a large-scale dewatering project. The ability to stack geosynthetic tubes vertically to increase storage capacity (see Figure 1) has led to their innovative application in the construction of tailings dam embankments.

Figure 1 Complete dewatering field showing with fifth tube layer, Wilke & Breytenbach (2015)

2.1 Dewatering Process

The dewatering process in geosynthetic tubes employs typical filtration mechanisms, notably gravimetric cake filtration, supplemented by crossflow filtration due to the tube's geometric shape. This design enables the geosynthetic tube to function as a permeable barrier, allowing water to drain through the fabric while reducing the volume of sludge. Solid particles are retained inside the tube, and as the dewatering progresses, the concentration of solids in the remaining material increases. Over time, a natural filter cake forms on the fabric's inner surface after the initial startup phase.

Dewatering occurs in cycles, consisting of successive phases of filling and draining. The process begins with static drainage as soon as filling is initiated. As shown in Figure 2, the filling volume is limited by the maximum containment capacity of the geotextile tubes, which is determined by the tensile strength of the tube and its seams. Once the maximum design height is reached, filling is halted to achieve the desired level of dewatering. After the material has been adequately dewatered and consolidated, refilling can resume. Following these cycles of filling and refilling, the tubes take on an elliptical shape.

This process allows for efficient dewatering, reducing storage volume requirements and enhancing the stability of the stored material. The repeated cycles of filling and dewatering ensure that the tubes can accommodate varying volumes of sludge while maintaining structural integrity and facilitating effective solid-liquid separation.

2.2 Dewatering tube dimensioning

The dimensioning of geosynthetic dewatering tubes is guided by two main design considerations: tensile strength and filter properties required for containing the tailings.

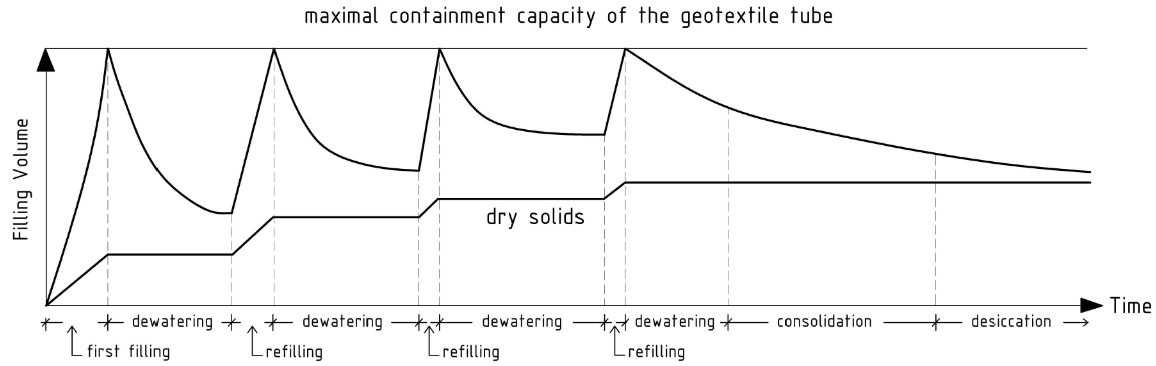

Figure 2 Schematic diagram of the dewatering sequence with geotextile tubes [3]

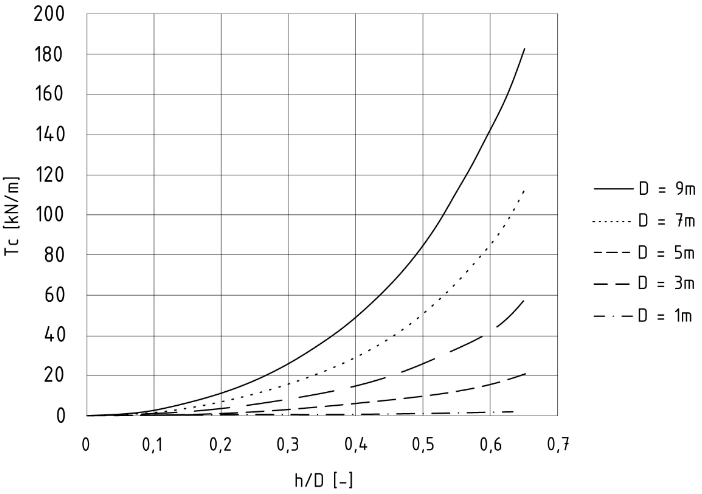

Figure 3 Tensile strength as a function on filling ratio [5]

The necessary tensile strength is calculated using linear membrane theory and depends on factors such as the tube's circumference, maximum filling height, and maximum pumping pressure, as outlined by Leshchinsky et al. (1995). In practical applications, software tools such as GeoCoPS or SOFTWIN are used to determine the fabric's required tensile strength. These tools can also apply specific reduction factors for geosynthetic products to account for potential strength loss due to creep (RF_{CR}), installation damage (RF_{ID}), weathering (RF_{W}) and chemical and biological effects (RF_{CH}), as detailed in ISO TR 20432:2007.

It's important to note that the required tensile strength increases exponentially with the filling height, as illustrated in Figure 3. The vertical axis of Figure 3 shows the required tensile strength τ_c while the horizontal axis represents the filling ratio (h / D) where h is the actual filling height and D is the tube diameter. Therefore, optimizing the storage capacity relative to tensile strength is crucial as the filling height increases.

Traditional design criteria are not directly applicable for filtration; thus, the filter behavior is based on empirical trials and experience. This involves assessing the relationships between the type of sludge, geotextile, and flocculent used. Wilke & Hangen (2011) provide a comprehensive overview [5], referencing Giroud (2005), Cantré (2008), Liao & Bathia (2008), and Adylik (2006). Additionally, Satyamurthy & Bhatia [6] discuss the significant role of flocculation and its impact on dewatering efficiency.

This approach ensures that the geosynthetic tubes are designed to meet the specific requirements of each tailings application, maximizing safety and efficiency while minimizing environmental impact.

3. CONSTRUCTION OF TAILINGS DAMS

3.1 Common Practice

Tailings dams are crucial for securely storing mining by-products, and their construction methods depend on the ore and tailings characteristics. The most common methods—upstream, downstream, and centerline—each have unique advantages and challenges. The choice of method is influenced by site conditions, risk assessment, project economics, available construction materials, discharge requirements, rainfall intensity, seismic resistance, raising rates, and relative costs (US Environmental Protection Agency, 1994).

A tailings facility typically begins with a starter dam, built before tailings deposition. This dam may include drainage and sealing elements, similar to a water storage dam. As it fills, the dam height is progressively increased using tailings or imported fill. However, using tailings can be limited due to their poor mechanical and hydraulic properties. For more detailed information on the options for constructing and raising tailings dams, refer to ICOLD Bulletin No. 194 (2023).

3.2 Construction Methodologies using Geosynthetic Tubes

The construction of downstream tailings dam embankments using geotextile dewatering tubes involves several key practical considerations (see Figure 4):

3.2.1 Embankment Footprint (dewatering area)

Traditionally, geotextile dewatering tubes are placed on a prepared surface capable of supporting the loads expected from the filled tubes. This area must facilitate the drainage of filtrate escaping the tubes and be resistant to erosion. The dewatering footprint should be graded to slope perpendicular to the longitudinal axis of the tubes at a gradient of $\leq 0.1\%$, and along the longitudinal axis at $\leq 1.0\%$.

3.2.2 Filling of Geotextile Dewatering Tubes

Tailings are discharged into the dewatering tubes on the prepared area using a manifold system. The flow is directed in a controlled manner to each tube through the use of valves and tube inlets. This controlled filling process allows for precise management of the dewatering operation, ensuring that each tube is filled to the desired capacity and that the overall stability of the embankment is maintained.

3.2.3 Staged filling of Dewatering Tubes

To achieve the staged raising of tailings dam embankments, enabling the containment of tailings in the basin, dewatering tubes must be placed and filled in a manner that mimics conventional downstream construction methodologies. When constructing the starter wall with dewatering tubes, they are placed longitudinally along the dam embankment. This placement facilitates the rapid installation of subsequent geomembrane barrier and protection layers. As additional raises of the tailings dam become necessary, upstream dewatering tubes should be installed in the same orientation.

For optimal load distribution across the base of the tailings dam footprint, dewatering tubes that do not form part of the starter walls can be positioned perpendicular to the embankment direction. This configuration enhances embankment stability and ensures uniform load distribution, reducing the risk of structural failures.

3.3 Failure Mechanisms and Safety Considerations

Due to the pollution and contamination associated with tailings, failures of tailings dams can lead to severe environmental damage and even loss of life. Ensuring the long-term functionality and safety of tailings facilities is therefore the highest priority in tailings dam design. As highlighted in ICOLD Bulletin 194, comprehensive theoretical and experimental investigations into new design concepts, construction methods, and materials are recommended. This section presents initial safety observations.

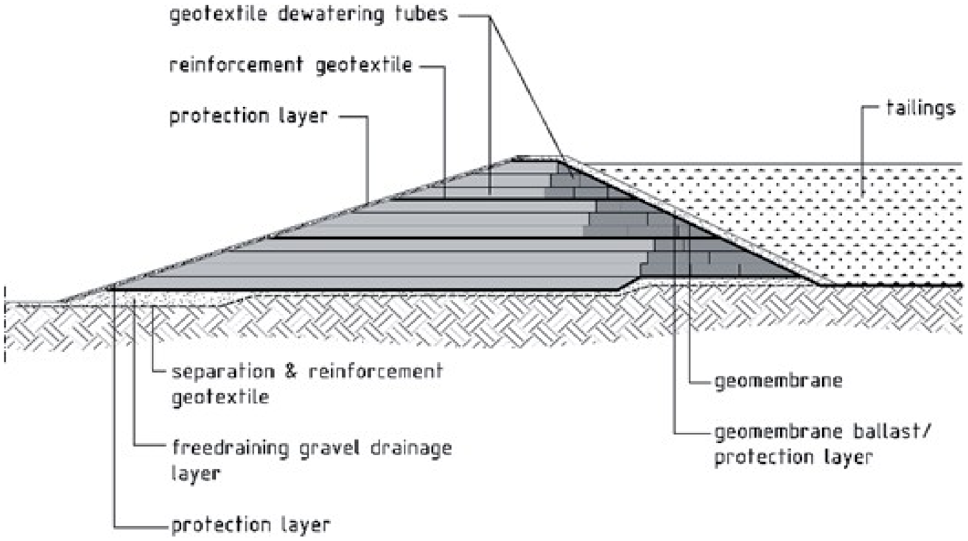

Figure 4 Construction Concept: Dewatering tube tailings dams

Understanding all potential failure mechanisms is essential for safety considerations. The innovative construction methodology described above must meet all safety provisions required for conventionally designed and constructed tailings dams. According to the US Environmental Protection Agency (1994), these provisions include guarding against slope failure due to rotational sliding, foundation failure, overtopping, erosion, piping, and other forms of overtopping.

In the equilibrium assessment, the dewatering tubes should be considered as individual elements. A guideline developed in [7] for structures built with single geotextile-encapsulated sand elements, such as bags, mattresses, tubes, or containers, outlines all potential failure mechanisms for these systems. The dimensioning of the dewatering tube in terms of the required tensile strength in the textile and the loss of material is covered in Section 2.2. Therefore, equilibrium analysis should regard the tube as a discrete element. Stability analysis of groups of elements should be based on field tests or laboratory tests to build on initial stacking experience (see Figure 1) and understand the interaction behavior of individual tailings tubes.

The geotextile surrounding the tailings acts as a reinforcing element within the tailings dam embankment. Consequently, a tailings dam constructed with geosynthetic tubes can be classified as a geotechnical structure reinforced with geosynthetics. Many national guidelines for such structures exist worldwide. For instance, in Germany, the "Recommendations for Design and Analysis of Earth Structures using Geosynthetic Reinforcements" (EBGEO 2010) addresses various geotechnical applications, although it does not specifically mention regulations for structures built with tubes. However, the provisions for geosynthetic reinforcements can be applied to the described construction methodology. According to EBGEO (2010), geosynthetic reinforcements applied to a slope or embankment must be analyzed for the following failure mechanisms:

- Rupture of geotextiles reinforcement
- Pull out of geotextile reinforcement
- Slope Stability
- Sliding on the embankment base
- Sliding along reinforcement layers

- Bearing failure
- Squeezing out

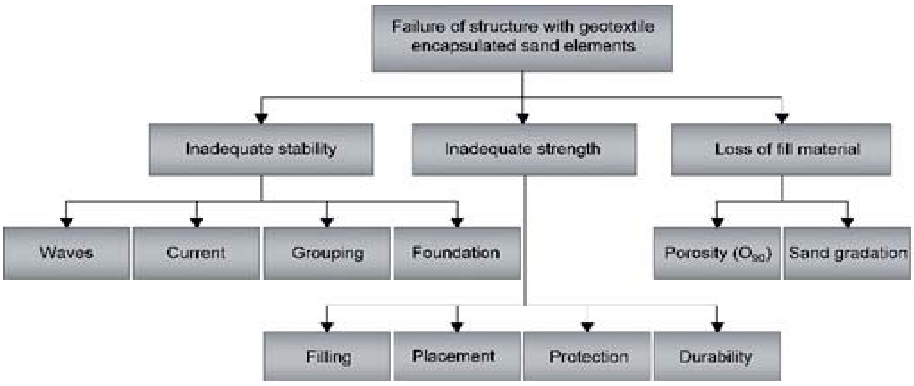

Figure 5 Fault Tree for a structure with geotextile-encapsulated sand elements [7]

Recommended design procedures are available in EBGEO (2010) and other guidelines addressing geosynthetic reinforcements.

3.3.1 Analytical Methods

The required geotechnical limit state analysis determining the safety against failure of the structure is already a settled science. This section explores various analytical approaches for evaluating tailings dams constructed with geosynthetic dewatering tubes and identifies uncertainties that require further research.
In conventional slope stability analysis software, the inclusion of geosynthetic tubes is currently limited. One way to account for the beneficial effects of these tubes is by increasing the shear strength parameters, or by considering the tensile design strength of the fabric.
Xu & Sun [8] introduced an apparent cohesion arising from small geosynthetic bags using Equation 1. This formula was developed and numerically proven for bags measuring several decimeters.

$$c = \frac{T}{\sqrt{K_p}} \cdot \left(\frac{K_p}{H} - \frac{1}{B}\right)$$

With	c	Apparent cohesion	[kN/m²]
	T	Tensile design strength of soil bags	[kN/m]
	K_p	Passive earth pressure coefficient, $K_p = (1+\sin\varphi)/(1-\sin\varphi)$	[-]
	H	Height of single geotextile bag	[m]
	B	Width of single geotextile bag	[m]

The application of this approach for large dewatering tubes has not been proven yet. As can be seen in Figure 6 the back calculated “apparent” cohesion for three different tensile strengths was estimated considering a friction angle φ = 20°, a height of 2.0 m and a width range from B = 1.0 to B = 15.0 m. This calculation shows that the apparent cohesion does not increase significantly for widths of greater than about 6 m.
This approach was compared to a slope stability analysis performed using GGU-Stability software. An example embankment with H = 10 m, a slope of 1:2, with a crest width L_w = 5.0 m. The tailings had a friction angle φ' = 20°. The tensile strength of the dewatering tubes (H = 2.0 m, B = 10.0 m) was assumed to be T = 40 kN/m in both machine and cross-machine directions. This converts, according to Equation 1 and Figure 6, to an equivalent of c = 26 kN/m². The stability analysis was based on a global safety factor, without considering partial safety factors. The computed factors of safety for the two methods are shown in Table 1. The results

show that the apparent cohesion approach yields a higher safety factor than the tensile design strength approach.

Another crucial aspect of equilibrium is the degree of pore pressure dissipation and stability during tube filling. Test results indicating the development of undrained vane shear strength are presented in Wilke et al. (2016b). The importance of pore pressure dissipation and its impact on local stability require further analysis, which is beyond the scope of this paper. This analysis will depend on various factors, including the filling and construction schedule and the rate of rise of the facility. For low rates of rise, undrained conditions may exist only in the upper dewatering tubes and can thus be neglected.

Table 1 Results of comparison between different approaches

Approach	Angle of friction φ	Cohesion c	Design Strength (single layer) T	Design strength (double layer) T	Factor of Safety
	[°]	[kN/m²]	[kN/m]	[kN/m]	[-]
Apparent cohesion	20.0	26.0	-	-	2.38
Tensile design strength	20.0	0.0	40	80	1.49

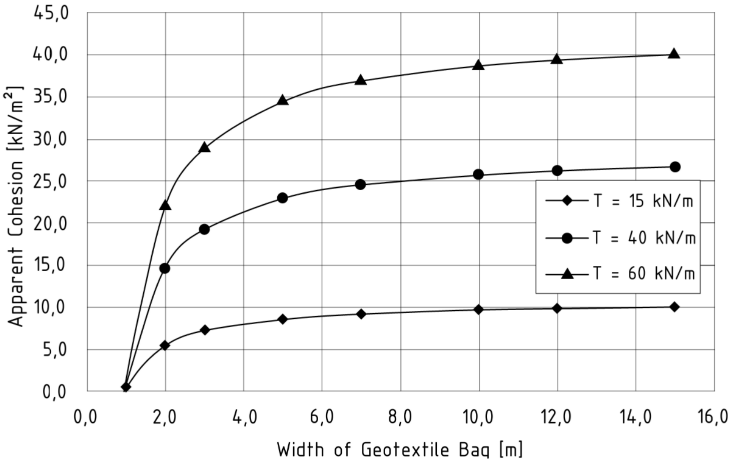

Figure 6 Apparent cohesion calculated using Eq. 1 depending on width of geotextile bags, H = 2,0 m. φ' = 20°

In addition to in-slope stability, potential failure due to sliding at the dam base and along inter-tube surfaces must be considered. Possible slip surfaces include those between the tube fabric and tailings or between two dewatering tubes, i.e., fabric on fabric. Therefore, it is crucial to establish the interface frictional behavior through shear box tests to accurately assess these potential failure mechanisms.

4. OUTLOOK AND CONCLUSION

This paper has presented early concepts regarding the use of geosynthetic dewatering tubes in the construction of tailings dams. This innovative methodology enhances the storage capacity of tailings ponds by utilizing tailings as embankment fill material. By employing this approach, the need for transporting and installing imported granular fill materials is significantly reduced, thereby lowering overall costs.

By integrating dewatering tubes into the construction of tailings dams, mines can significantly reduce liquid waste volume, minimize the environmental footprint, and conserve water resources. This approach enhances the stability and safety of tailings dams while aligning with global efforts to promote water conservation and sustainable mining practices. Consequently, adopting dewatering technology represents a strategic innovation, mitigating water scarcity risks and promoting more sustainable and responsible mining operations.

The principles of the dewatering process, along with the dimensioning of dewatering tubes in terms of the required tensile strength and filtration properties, have been demonstrated. Recent dewatering projects have successfully implemented the stacking of tubes [4]. Practical experiences related to the construction of tailings dam components using geosynthetic dewatering tubes, with a particular focus on the downstream raising method, have been introduced in this paper.

To mitigate the possibility of failure, it is essential to consider the primary failure modes in the design. The lack of specific design guidelines for dewatering tubes can be addressed by integrating existing guidelines for tailings dam design, encapsulated sand containers [7] and geosynthetics in retaining structures or slopes (EBGEO 2010 or other national guidelines).

Future research should focus on using stability analysis (both analytical and numerical), field trials, and laboratory tests to study the behavior of stacked dewatering tubes. Verification of analytical models is crucial to enhance the reliability of stability analyses for tailings dams constructed with dewatering tubes.

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