E3S Web of Conferences **569**, 19003 (2024) https://doi.org/10.1051/e3sconf/202456919003
GeoAmericas 2024

Numerical modeling for mining dam cover infiltration design with geosynthetics: A trade off study

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Abstract. In the mining dam closure project, depending on the classification of the tailings, cover systems are used to reduce precipitation infiltration over time, avoiding future environmental impacts associated with metal leaching. Furthermore, reduced infiltration promotes reservoir drainage and therefore improved geotechnical stability. The covering system can be built from different materials, natural or synthetic, or even using waste itself. The main objective of this study is to present the results as a trade-off study of a one-dimensional modeling performed considering 3 configurations of geosynthetic covers, using the SOFTWARE SEEP/W emphasizing the importance and impact of the presence of geosynthetics. Since numerical models constitute an essential tool in the development of engineering projects, computational numerical modeling was carried out using Brazilian climatic parameters from the National Institute of Meteorology in conventional and automatic stations, and historical geotechnical parameters for a structure located in the state of Minas Gerais. Gerais (Brazil). For the comparison of the cover configurations, the thickness and type of the geosynthetic were varied. The results emphasize the importance of studying numerical modeling in the pre-closure design phase, to define a viable, economical and sustainable coverage, and contribute to the use of geosynthetics in this type of application.

1 Introduction

The mining tailings consisting of sulfide minerals, in the presence of water and oxygen, contribute to the generation of acid drainage and leaching of metals though the time. The process to prevent possible environmental contamination and provide improvements in the geotechnical stabilization of the dam is the implementation of coverage of the tailings/residues with layers of different kind of soils, granular material or geosynthetics.

Cover systems are typically deployed during the operation and decommissioning phase of mining dams in order to reduce the transport of contaminants by reducing the rates of water infiltration into the reservoir. Thus, this de-straining was analysed using one-dimensional (1D) infiltration models from Geostudio's SEEP/W software that calculates the percolation

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of water (inside the reservoir), through saturated and unsaturated media, considering the interaction between the climatic conditions of the region and the geotechnical and hydraulic properties of the roofing materials (Prinz et al. 2022)

Geosynthetics are materials composed of natural or synthetic polymers used in works that require a high level of durability, such as the implementation of roofs in the decommissioning process of mining dams. In this context, the use of geosynthetics plays an important role in the coverage because it contributes to the process of reducing the infiltration of water inside the tailing's reservoir in the long term. Thus, for the modeling, the following geosynthetics were considered: non-woven geotextile, geomembrane, geosynthetic clay liner, and a woven geotextile. The non-woven geotextile has the purpose of barring the initial water, separating the filtered waste from the geomembrane layer. The geomembrane is one of the types of geosynthetics widely used in the mining area and consists of continuous and flexible blankets composed of one or more synthetic materials, with low permeability functioning as a flow barrier. The geosynthetic clay liner acts as a flow barrier due to its low permeability and is used for base waterproofing and coverage of landfills and industrial waste, protection of groundwater on highways, airports and railways, dams and dikes, drainage channels, rainwater containment basins, reservoirs and artificial lakes.

The woven geotextile consists of a high tensile modulus woven geotextile with a multi-layered construction of woven fibers of various dimensions specifically positioned relative to adjoining fibers to create three times the water flow and an increase in AOS sieve size.

In view of the above, the main objective of this study is to present the results as a trade-off of a one-dimensional (1D) modeling performed considering 3 configurations of geosynthetic roofs, using the SEEP/W software (developed by Geo-Slope International Ltd) emphasizing the importance and impact of the presence of geosynthetics for a tailings dam located in the state of Minas Gerais, Brazil.

The results presented are preliminary and may not represent a real field condition due to numerical modeling being a staging/model of reality. In addition, there is no knowledge of the geotechnical properties/parameters of the materials that will be used in the future in the decommissioning process of the dam. With this, some parameters were estimated and may present changes in the future. In addition, future studies are recommended to evaluate which cover layers would be most suitable for improving the efficiency of the final cover.

2 Methodology

Based on climatic and geotechnical parameters, composite numerical modeling was performed using the SEEP/W software.

The modeling was performed considering a time of 1825 days (5 years) to analyze the efficiency of the coverage and the following coverage configurations (from ci-ma down) were considered, namely:

- Case 1: configuration with 0.40 m of topsoil, 0.60 m of clay and 2.5 m of filtered tailings.
- Case 2: configuration with 0.40 m of topsoil, 2 mm of geomembrane and 2.5 m of fil-auger tailings.
- Case 3: configuration with 0.40 m of topsoil, 2.5 m of filtered tailings, 1 mm of non-woven geotextile, 1 mm of geomembrane, 5 mm of bentonite geocomposite, 1 mm of woven geotextile of the RS580i type.

From these configurations, it is possible to analyze the comparison of Case 1 considering the use of the geomembrane with Case 2 that does not have a geomembrane and with this a layer of clay was included and concluding with Case 3 with the insertion of three more geosynthetics without the insertion of clay.

2.1 Geotechnical Parameters

The geotechnical parameters admitted for the preliminarily determined materials were established from laboratory and field geotechnical tests on the structure in question and other parameters were estimated based on professional technical experience. Table 1 presents the summary of the cases analyzed with their respective geo-technical parameters and thicknesses.

Table 1. Summary of the cases analyzed with the geotechnical parameters used in the modeling.

		Unit	**Case 1**	**Case 2**	**Case 3**
Thickness	Topsoil	m	0,40	0,40	0,40
	Non-woven geotextile	mm	-	-	1.00
	Geomembrane	mm	-	2	1.00
	Geosynthetic Clay Liner	mm	-	-	5.00
	Woven Geotextile	mm	-	-	1.00
	Clay	m	0,60	-	-
	Filtered tailings	m	2,5	2,5	2,5
Permeability	Topsoil	m/s	1.85E-05	1.85E-05	1.85E-05
	Non-woven geotextile	m/s	-	-	3.7E-03
	Geomembrane	m/s	-	1.00E-12	1.00E-12
	Geosynthetic Clay Liner	m/s	-	-	1.00E-11
	Woven Geotextile	m/s	-	-	6.11E-02
	Clay	m/s	1.00E-08	-	-
	Filtered tailings	m/s	1.00E-04	1.00E-04	1.00E-04

2.2 Climate Parameters

The performance of the roof is evaluated based on the climatic data considered for the given region of the dam. The water available for infiltration to occur usually comes from precipitation and with this, it is essential to have knowledge of the basic characteristics of rainfall in addition to being quantified for different intensities, duration and frequency according to the region. (Mendes, 2019)

With this, a compilation and analysis of the daily climatic data was carried out considering the annual data, of the symbolic years of the driest, average and rainy year, recorded in an INMET station located close to the site, having the record of the historical series of the period from 1940 to 2001. From the analysis of the precipitation record, the hydrological year 1970–1971 was selected as the dry year, 1969–1970 as the average year, and 1982–1983 as the wet year.

The climatic parameters used as input data in the software were: precipitation, relative humidity, average wind speed, maximum and minimum temperature, in addition to the values of solar radiation that were estimated from the latitude of the dam area. These conditions were applied (on the surface of the top layer of the covers) as a boundary condition in each corresponding year.

The daily precipitation data of the selected years (dry, medium and wet) recorded in the period of October and September (hydrological year) were considered in the execution of the modeling. For the driest year, a total rainfall of 998.2 mm was recorded, for the average year 1486.6 mm and for the wet year 2078.9 mm. To insert these data in the modeling, the following sequence was adopted: 1st and 2nd year - medium, 3rd year - wet, 4th year - medium and 5th year dry. It is noteworthy that the 1st year was disregarded to stabilize the initial condition of the coverage materials assumed in the modeling.

Due to the absence of data in some years analyzed, we adopted the subsequent year representative of each analysis (example: it was considered the second driest year because the first year did not have wind speed data). From the definition of these years, the other climatic data (relative humidity, maximum and minimum temperature and velocity of the ven-to) were considered according to the driest, average and wettest years.

2.3 Desing Assumptions and Criteria

Some assumptions and design criteria were pointed out during the advancement of one-dimensional numerical modeling:

- No vegetation data were used.
- Four types of geosynthetics were considered: non-woven geotextile, geomembrane, geosynthetic clay liner, and a woven geotextile.
- The thickness and permeability of the filtered tailings were not altered in the 3 cases.
- From the location (latitude) of the region, solar radiation was estimated.
- A water level at the surface of the tailings in pulp (2.5 m) was estimated every year. - It was applied at the base of the geomentria, a boundary condition referring to a constant total water load (equal to the applied level – meters per water column) in order to simulate the infiltration after the implantation of the roof.

3 Results and Discussion

From the definition of the climatic and geotechnical parameters of the preliminarily available materials, the modeling was developed and the results are presented in Table 2.

Table 2. Results of the modeling of the tailings dam.

Case	**Findings**							
	Annual percolation at the base				**Annual infiltration rate**			
	(m^3/year)				**(%)**			
	Year 2 - medium	**Year 3 - wet**	**Year 4 - medium**	**Year 5 - dry**	**Year 2 - medium**	**Year 3 - wet**	**Year 4 - medium**	**Year 5 - dry**
Case 1	0.598	0.752	0.570	0.501	40.4	36.3	39.0	50.2
Case 2	0.040	0.053	0.040	0.012	2.7	2.5	2.8	1.2
Case 3	0.000	0.000	0.000	0.000	0.06	0.0	0.0	0.0

Based on the results presented, Case 1 presents a high annual infiltration rate compared to the other cases due to the absence of the application of geosynthetics. It should be noted that the use of a clay layer requires erosion control measures because it is likely to reduce its efficiency associated with the appearance of cracks in the long term.

Inserting a layer of 1 mm of geomembrane considering 10-12 m/s of permeability (Case 2), the infiltration rate decreased significantly compared to Case 1. Adding the geosynthetics in Case 3, the perception of the reduction of the annual infiltration rate compared to the other cases is notorious. Figures 1, 2 and 3 show the graphs of the relationship of precipitation versus percolation at the base over the 5 years.

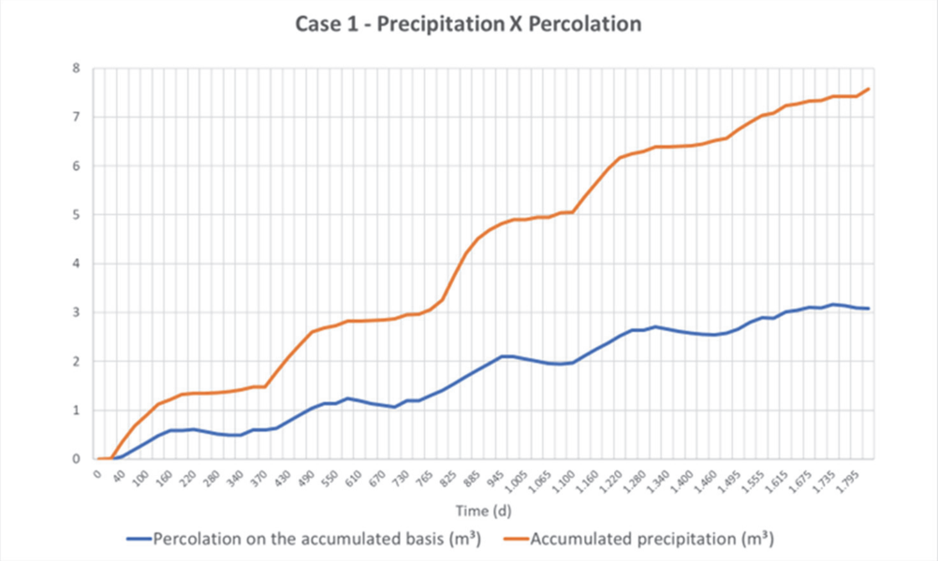

Fig. 1. Graph of precipitation x percolation in Case 1.

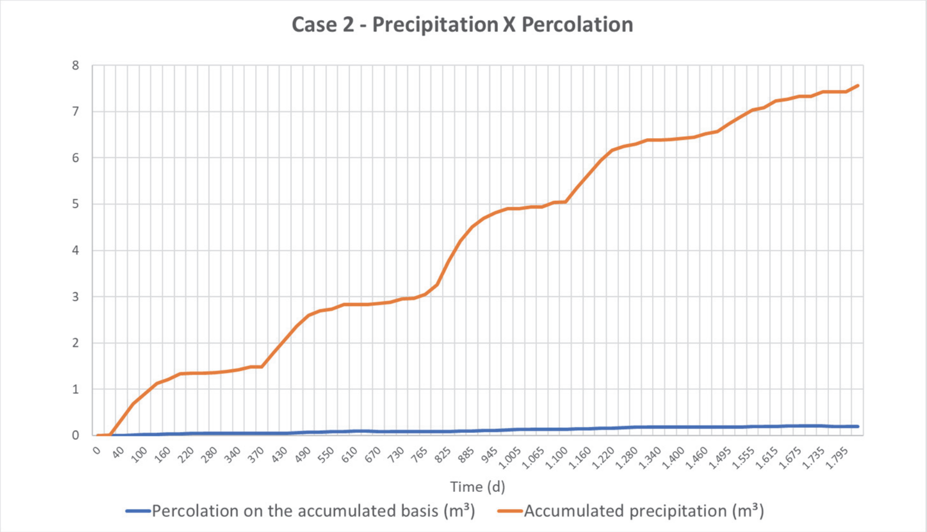

Fig. 2. Graph of precipitation x percolation in Case 2.

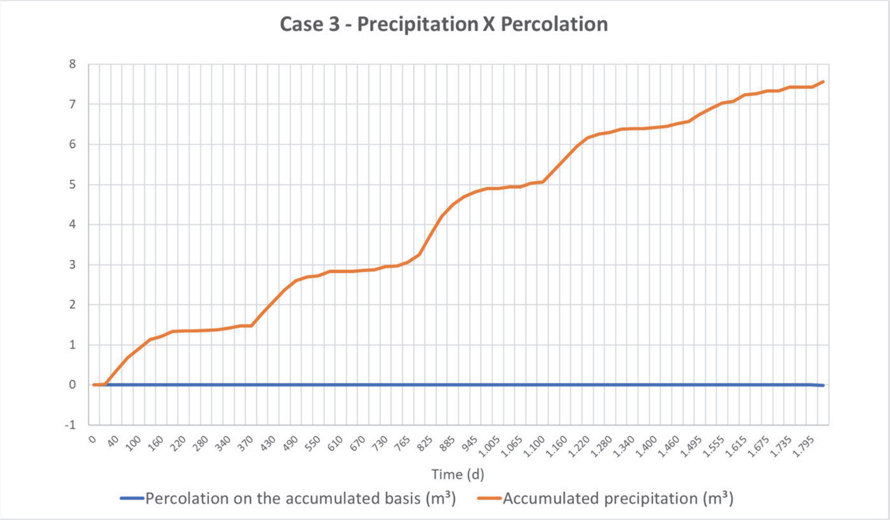

Fig. 3. Precipitation x percolation graph in Case 3.

The results show that the use of geosynthetics plays an important role in reducing infiltration in the coverage system. However, it is important to note that the use of geosynthetics is usually limited to the size of the area due to the high cost of application and the need for special care during installation. With this, it is important to select the materials of a reliable manufacturer that present a product with a good quality, integrity so that the results achieved in the long term are positive, with good durability.

4 Conclusion

The results highlight the importance of the study on numerical modeling in the pre-closing project phase to define a viable, economic and sustainable coverage, in addition to the contribution of geosynthetics in this type of application. Professional experience, both national and international, has contributed to emphasize that although each dam has its own specific coverage configuration, the determination of a standard methodology can contribute to the reduction of coverage failures over time. Thus, the costs for the treatment of eventual contamination through the transport of contaminants caused by failures in the roofs, tend to be higher compared to the cost of an implementation of a functional coverage system. The results indicated that the roofing system using geosynthetics (Case 3) non-woven geotextile, geomembrane, geosynthetic clay liner, and woven geotextile type is efficient and reduces the infiltration over the time.

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