# The Influence of Water Balance for Slope Stability on the High Mine Waste Dump

*by* Supandi -

# The Influence of Water Balance for Slope Stability on High Mine Waste Dump

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**Abstract:** One of the vital parts of mining activity is optimizing the mine waste dump. This means that capacity needs to be conserved by the various aspects of the feasibility study. Hydrogeology is one of the main aspects of mine waste stability that needs to be controlled to ensure slope stability. Therefore, this research aims to determine the influence of water balance toward mine waste dump stability, especially for inclined basement. The analysis was carried out by distributing the constituent material grain size, permeability value mapping, determining the water balance behavior between recharge and discharge, and water behavior inside mine waste dump material. Also, fragmentation analysis was carried out to determine the layer porosity value, while the permeability test was used to examine the rainfall infiltration rate. It is important to decide on the equilibrium water flow between the recharge and discharge rates to ensure no water accumulates to mine waste dump. The groundwater behavior is examined by Rockscience software: Slide 6.0. The fragmentation analysis results showed that the top layer of the waste is composed of sand-boulder-sized material with porosity towards the contact zone and a little clay. Hydraulic conductivity material values range from 6 x $10^{-6}$ m/s and 3 x $10^{-2}$ m/s at the top and bottom layers of the mine waste dump. Rainfall and seepage are interrelated because a rise follows an increase in rainfall in seepage debit. Furthermore, rainfall tends to infiltrate into the mine waste dump material and retained at the contact zone. The large permeability difference between the in-situ material and the layer slope is approximately 14°, therefore, the water tends to flow following the contact zone and forms a seepage. The potential for water retention in the mine waste dump material is very small. Therefore, the pore pressure can be minimized, and stability of the mine waste dump slope maintained.

**Keywords:** Water control, seepage, hydraulic conductivity, coarse, disposal, optimization.

## 1. Introduction

Open-pit mining is defined as a surface drilling procedure that involves the extraction of minerals or ore deposits discovered relatively close to the surface of the earth, therefore the safety of the work area is paramount [1]. The operation's progression involves the optimization of its spatial proximity to maximize productivity and cost-efficiency [2, 3]. A specific requirement in this circumstance is the need to optimize the disposal of tailings embankment. This research is carried out in one of the coal mines located at Asam-asam area, South Kalimantan. The company desires to optimally backfill the mine with waste dump at the low-wall part of the pit to gain accessibility and ensure the embankment's safety. This research is aimed to determine the influence of water balance on the stability of mine waste dump, particularly an inclined basement.

Maintaining slope stability is one of the main aspects of determining the optimization of embankments [4]. It regulates and ensures that effective mining practices are carried out [5]. Slope stability on the low wall part is controlled by material properties and geometry of the bedding separated by layering or bedding contact between both materials [6] and the interaction of the water body in the embankment [7]. In addition, certain conditions need to be controlled to ensure the water does not affect slope stability [4]. Therefore, there is a need to establish regulations on water balance to prohibit the gradual development of pore pressure in the embankment, thereby maintaining the slope's stability. This research is carried out to discover the importance of water balance on the embankment's hydrogeological condition.

Data acquisitions are carried out on the field to realize its actual condition. Electrical resistivity tomography is used to aid the interpretation of the embankment's layer because it determines the distribution of the materials [8]. Fragmentation measurements are carried out on the surface to acquire the grain-size distribution using photographic and image analysis techniques and a scaling object [9]. Hydrologic conditions, such as seepage, are directly measured in the proximity of the test site to acquire the volume of discharge in the area. The already measured rainfall intensity of the area is utilized in analyzing the water balance [10].

Rockscience slide 6.0 is slope stability software with a two-dimensional transient finite element for the analysis of groundwater capabilities [11]. Furthermore, it is considered to be reliable [12]. The two-dimensional section is provided using ERT interpretations [13]. The rainfall intensity is represented as the infiltration in the embankment. The hydrogeological condition's dynamics were analyzed using the software [4], which focused on the flow vectors, pore pressure, and discharge of water from the embankment [14]. Rainfall flows as surface runoff and enters the mine waste dump material (see Fig.1). The direction of groundwater flow to the contact zone, which is the original rock layer, appears seepage [15].

Furthermore, the contact zone needs to be kept highly porous to maintain stability. Porosity is due to increased pore pressure, and this causes the zone to become a weak field. It is important to identify the characteristics of rocks as well as their geological conditions because it is the basis for mine waste management [16]. Subsequently, geological block models are also used to determine geomechanical and geochemical conditions, including the fragmentation of mine waste dump. These outcomes are used to control risks during operation, particularly in the management of Acid Mine Drainage (AMD) [17]. A mine closure plan needs to be optimized based on operating procedures. The formation of seepage based on geochemical conditions is essential for controlling the development of Acid Mine Drainage [18]. Waste rock pile modeling was carried out based on groundwater behavior. The distribution of water content is in accordance with the heterogeneity of the material [19]. All stages involved in mine water management is important from the operational to the completion of construction [20]. This study was carried out at one of the mining sites in the Kintap area, Tanah Laut, South Kalimantan, as shown in Fig.2.

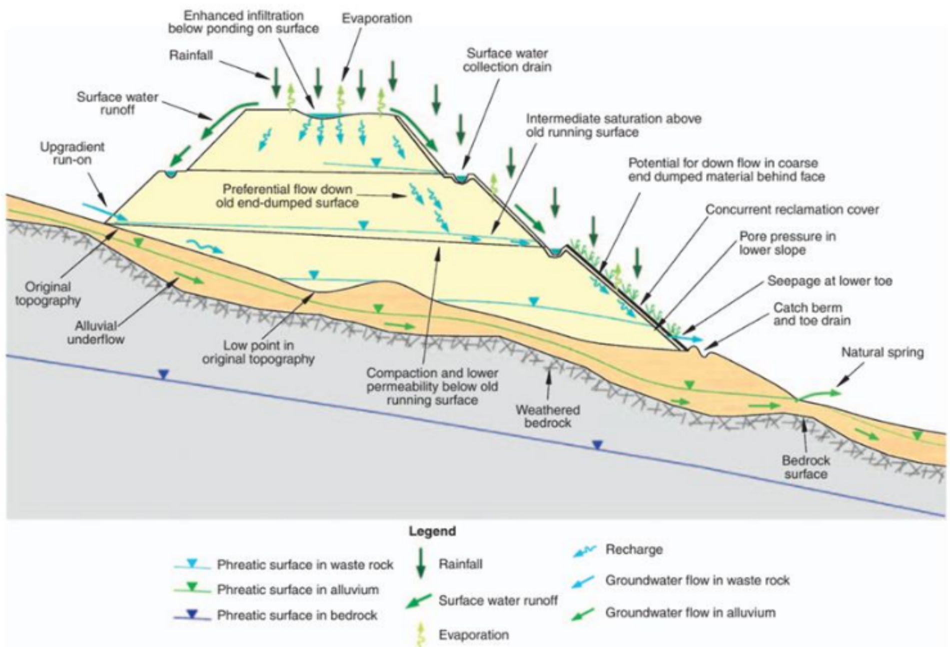


**Figure 6.1:** Conceptual hydrogeological model of a mine waste dump or stockpile

**Figure 1.** Conceptual hydrogeology model on mine waste dump of stockpile [15].

**Figure 2.** The research area in the Kintap area, Tanah Laut, South Kalimantan.

## 2. Material and Method

Data analysis was carried out by mapping the grain size distribution on the surface slope, discharge area, and the slope's top. Fragmentation was carried out using a split engineering program with output in the form of grain size distribution. The analysis and evaluation of permeability were carried out at 20 locations within the study area using ASTM D6539-13. Furthermore, the daily amount of rainfall was measured at rainfall stations. The amount of discharge is directly measured on the field to obtain the actual debit value, and the time is also recorded to validate the rainfall data. Mapping of the discharge point is also carried out to determine the correlation of groundwater balance in the mine waste dump. The geohydrological evaluation was carried out using a finite element method to obtain groundwater distribution patterns and movements. The results from the analysis show that the values of flow velocity are compared based on field measurements. Consequently, groundwater volumetric analysis was obtained at each location in the study area. Rockscience software is used to calculate the results from the analysis.

## 3. Research Result

The analysis is carried out based on certain parameters (Table 1), a transient groundwater finite element method, and a two-dimensional section of the embankment (Fig. 3). The distributions of the materials are shown in Fig. 3.

**Table 1.** Criteria of Analysis

| Criteria | Variable | | | |
|---|---|---|---|---|
| Surface Vertical Infiltration | 0.25; m/day | 0.5 m/day | 1 m/day | 2 m/day |
| Stages | Stage 1 | Stage 2 | Stage 3 | Stage 4 |
| | 3 hours | 6 hours | 12 Hours | 24 hours |
| Initial Stage | No water flow | | | |

**Table 2.** Layers Material on Mine Waste Dump

| Layers | Material | Hydraulic Conductivity |
|---|---|---|
| Upper Embankment Layer | Sand - gravel, with less clay | $6 \times 10^{-6}$ m/s |
| Lower Embankment Layer | Boulder with high porosity | $3 \times 10^{-2}$ m/s |
| Base (In situ) material | clay stone | Assumed Impermeable |

The variations in infiltration show the differences in rainfall intensity, which is used to determine its significance on hydrogeological conditions. The stages define the conditions per hour. It shows the duration of rainfall before it infiltrated the embankment. Vertical infiltration (rainfall) is the only source of water defined in the analysis. Therefore, in the initial stage, there is no flow of water.

The hydrological parameters reported in this study are flow vector, discharge, pore pressure, and seepage. Changes in any of these parameters aided in the identification of the hydrogeological condition in each stage.

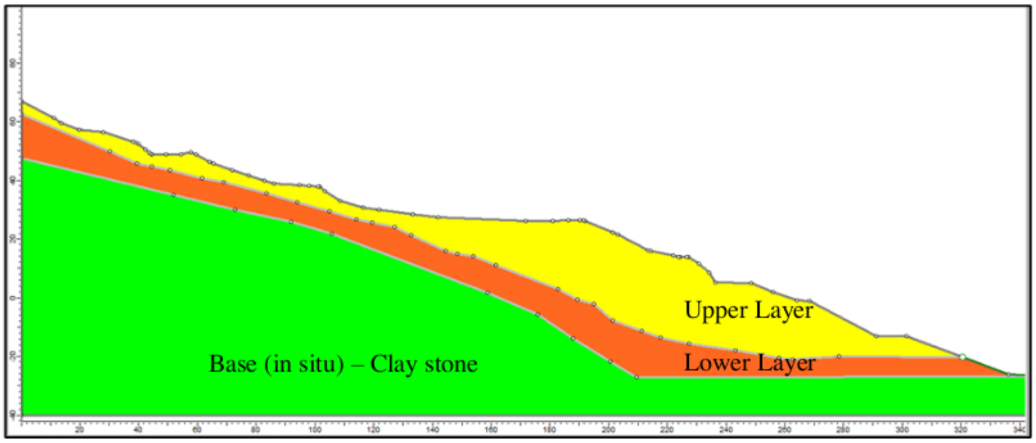


**Figure 3.** Illustration of the two-dimensional models of analysis.

### *3.1 Evaluation Rainfall*

The daily amount of rainfall was measured at rainfall stations. This study was carried out during the rainy season in order to determine the behavior of both surface and subsurface water. The measurement results show that the average rainfall intensity is 4 mm/hour, and its peak is 26 mm/hour, which was detected once during the research. The measurement of seepage was carried out at 35 slope locations, as shown in Fig. 4. Therefore, whenever it rains and at every 1-hour interval, it runs out of water or becomes stable at a certain discharge. Seepage debit was discovered to be stable after 12 hours of rainfall. According to the results from this measurement, the average seepage is 200 ml/hour.

The measurement from the rainfall intensity and seepage is shown in Fig. 5. In addition, the seepage debit increases 6 hours after heavy rainfall. This shows that there is a correlation between rainfall intensity and seepage debit, which is important for slope stability. This implies that no water is retained in the mine waste dump material. However, when there is excess water in the material, it increases pore pressure, which shows that the water in the embankment is completely drained. Supposing the groundwater in the mass of pile is properly drained, it is, therefore, necessary to verify the grain size distribution of the material. Analysis of the grain size distribution is carried out using digital methods such as split engineering software. The samplings of locations are carried out at a minimum of 3 points, where each point is approximately 5 x 3 square meters. According to the processed data, the grain distribution ranges from sand to boulder (2-1000 mm), as shown in Fig. 6. The average value of D60 is approximately 100 mm therefore, the material is highly porous.

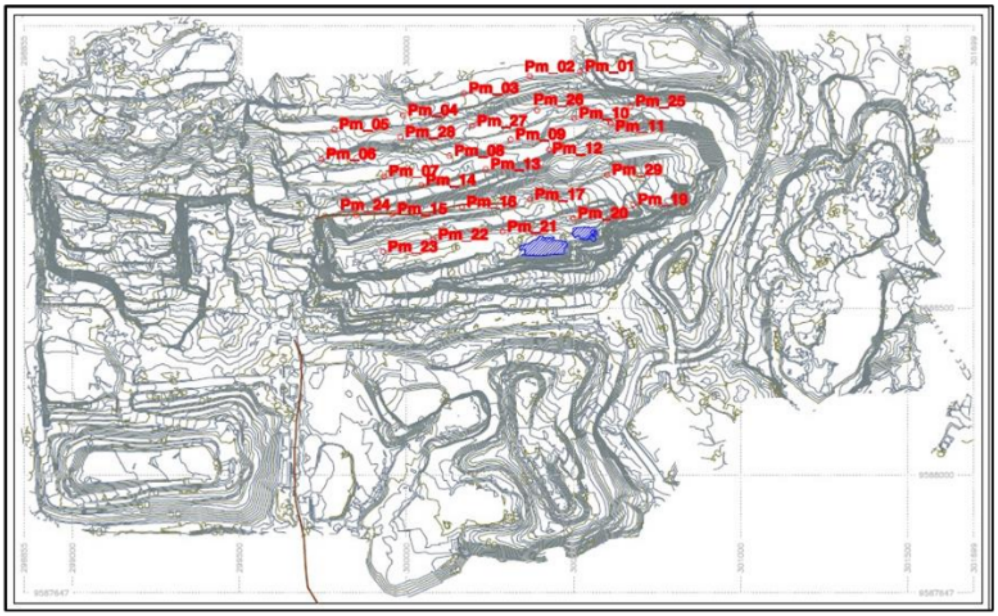


**Figure 4.** Actual rainfall intensity and seepage measurement data.

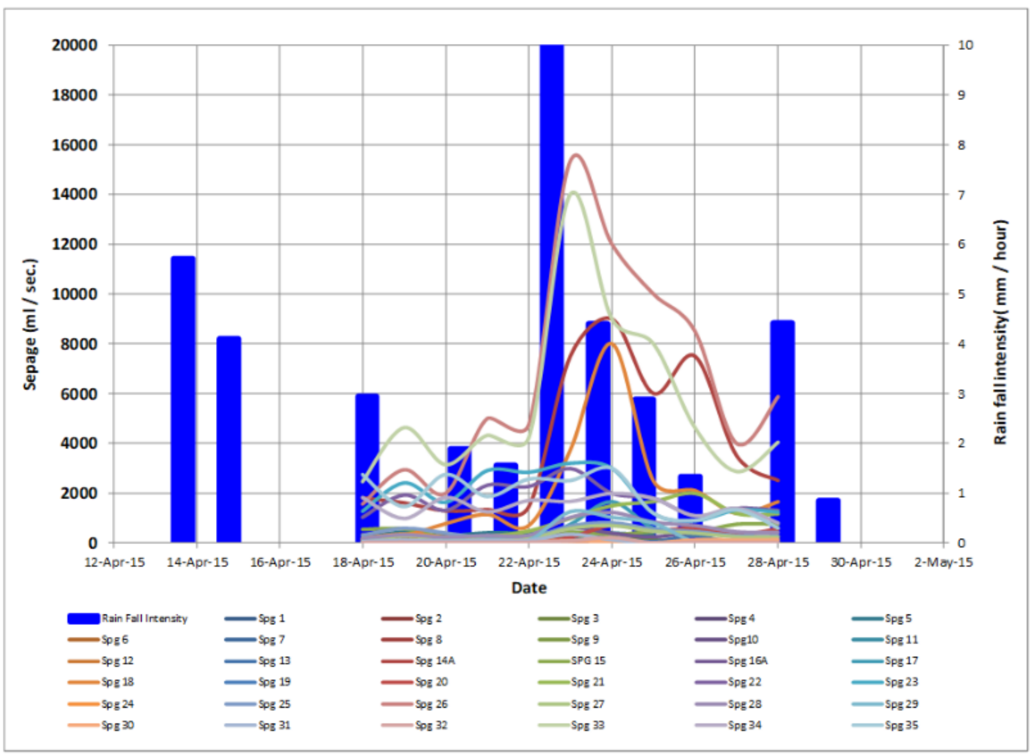


**Figure 5.** Correlation between rainfall intensity and seepage debit at the mine waste dump.

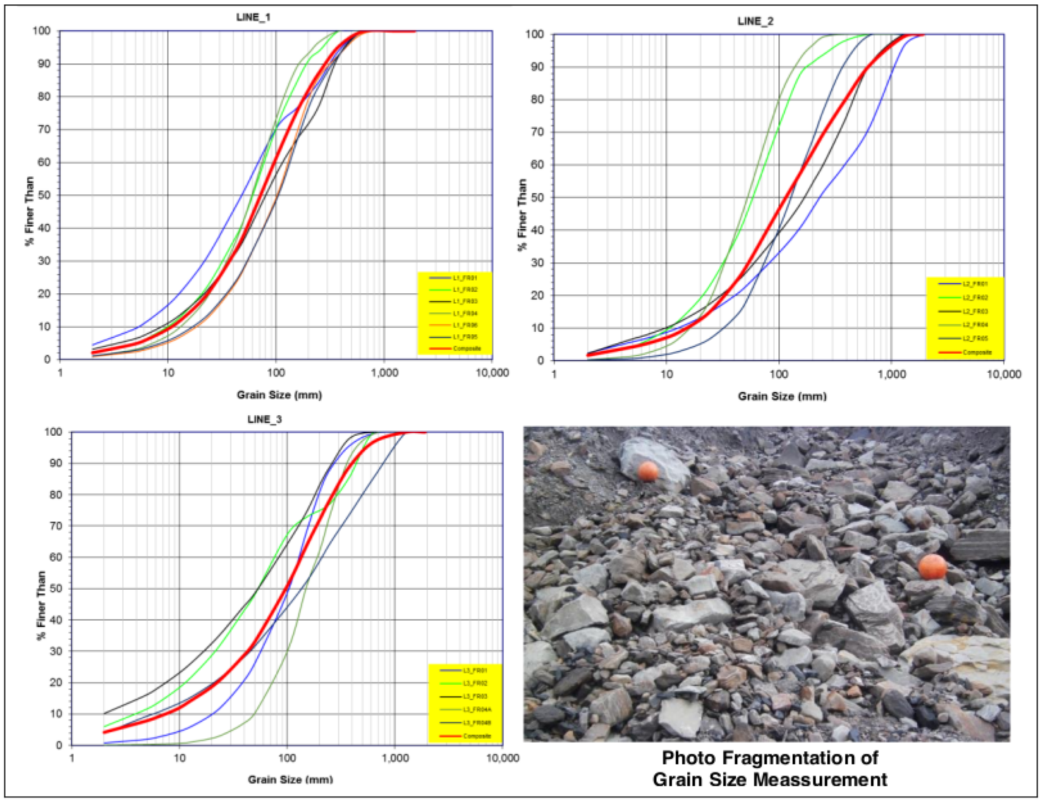


**Figure 6.** The results from the fragmentation analysis of mine waste dump material, particularly on the top side.

*3.2 Flow Vectors in The Embankment and Significance of Rainfall Intensity*

According to figure 7, the vertical surface infiltration in the embankment is the intensity of the rainfall. Some of the water infiltrate and percolate into the lower layer of the embankment, which functions as a drainage system. The total discharge velocity and the flow vectors in the body of embankment are also shown in fig.7. The right bottom part of the figure shows the discharges through the embankment.

The vectors in the upper part of the embankment are restricted. This condition's occurrence is due to the low hydraulic conductivity in the upper layer of the embankment. Therefore, this limits the percolation of water from the surface to the lower parts of the embankment. However, most of the water flowing through the surface is referred to as runoff water.

There is an insignificant change in discharge due to the increase in rainfall intensity, as shown in Fig. 8. The upper layer's hydraulic conduct limits the flow of water in the lower part of the embankment. This is confirmed by the value of discharge velocity on the upper layer of the embankment shown in Figure 7.

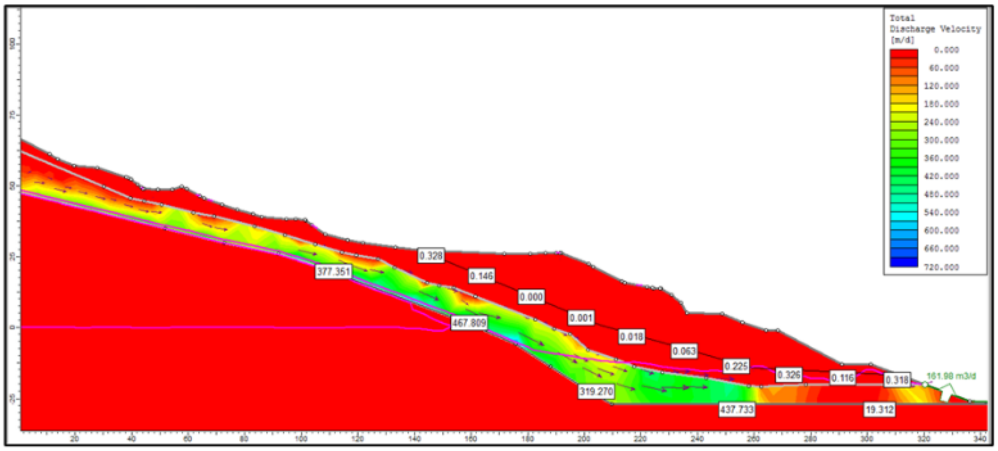


**Figure 7.** Distribution of total discharge velocity in the embankment (showing the vertical surface infiltration).

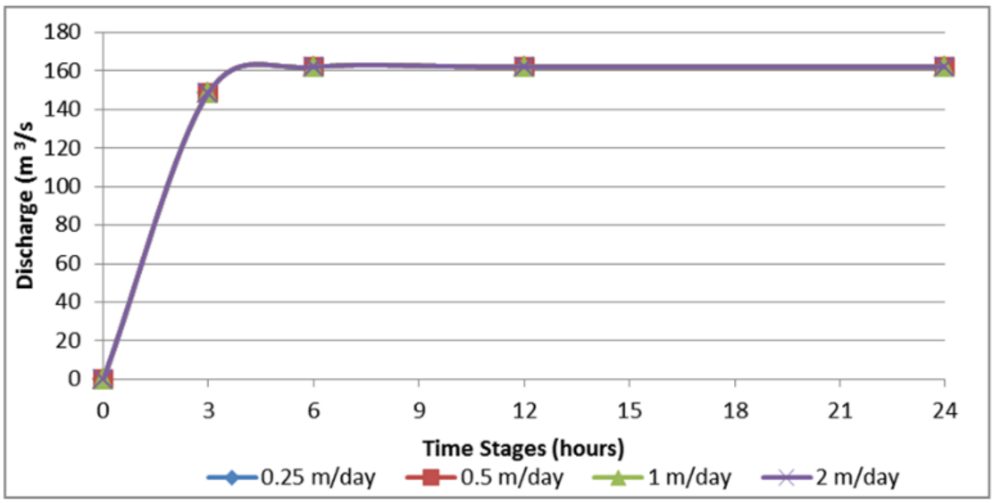


**Figure 8.** Correlation of time stages and water discharges for various vertical infiltration.

The total discharge velocity in the lower layer is significantly higher than the upper layer. The lower layer serves as a drainage system in the embankment. Meanwhile, the upper layer has an extremely low total discharge velocity and hydraulic conductivity. Percolation occurred gradually in the upper layer until it reached the lower layer. However, a significant increase was detected where the conductivity is higher. The following figures show the vertical and horizontal discharges of the embankment section, as shown in Figures 9 and 10.

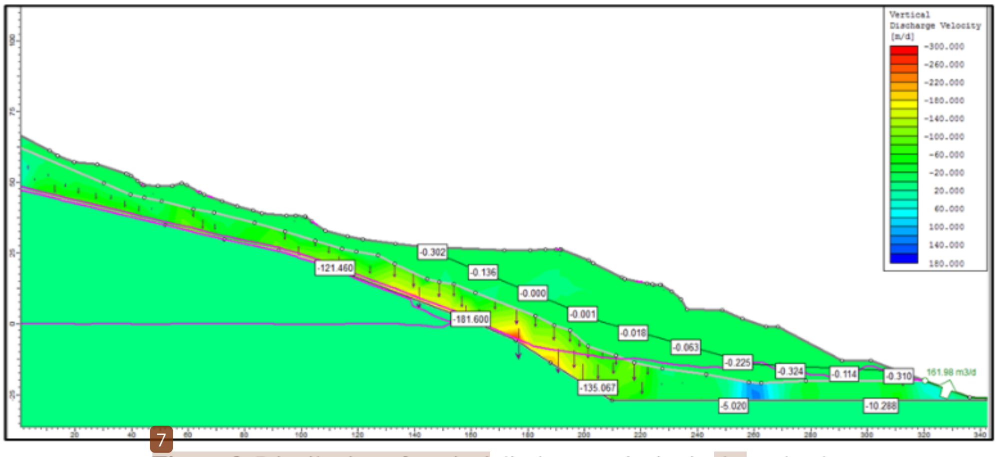


**Figure 9.** Distribution of vertical discharge velocity in the embankment.

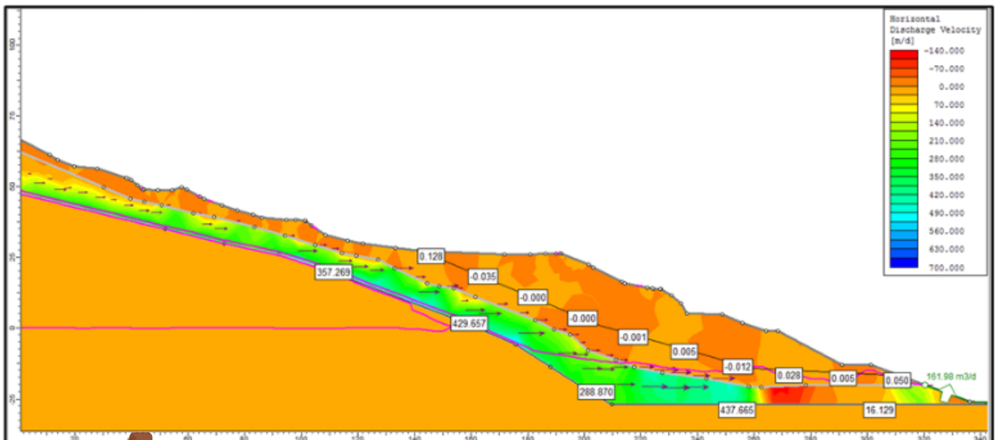


**Figure 10.** Distribution of horizontal discharge velocity in the embankment.

Vertical discharge has a more significant effect than horizontal discharge during the percolation process in the upper layer of the embankment. Meanwhile, discharge in the lower layer tends to be horizontal due to restricted infiltration towards the base. This correlates to the hydraulic gradient of the embankment, as shown in Fig. 11, where the upper layer has a significant high hydraulic gradient, which is used to predict the discharge velocity in the embankment.

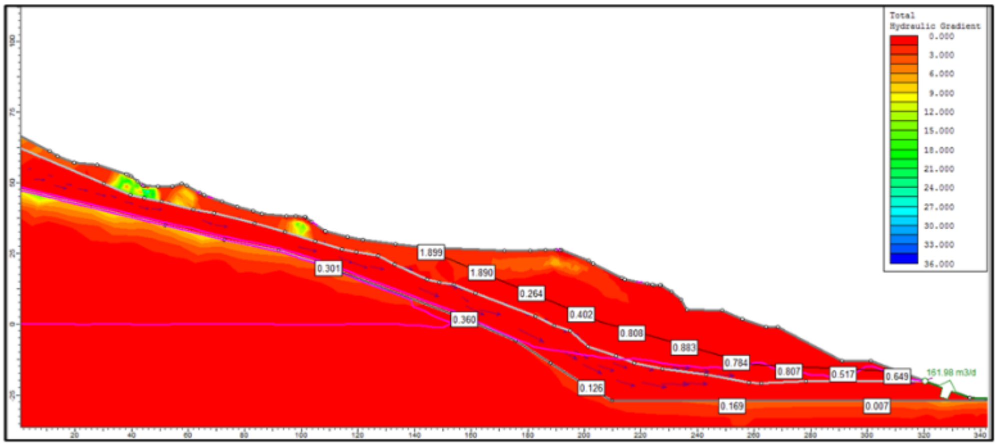


**Figure 11.** Distribution of hydraulic gradient in the embankment.

*3.3 Initial Pore Pressure Build Up and Drainage Characteristics of Lower Layer Embankment*

The section's pore pressure is reviewed using the query point located on a certain part of the embankment. Figure 8 shows the pore pressure distribution of the embankment on the time stage, 6 hours after the initial rainfall. Query points are created on the contact zone between the embankment and in situ base materials.

Figure 12 shows the correlation of distance among query points (a) between time stages on the horizontal axis (b) against pore pressure in the vertical axis. The value of pore pressure on each of the query points is shown by each vertex of the correlation chart (a), while the values for the different stages appeared as a single curve because they are relatively equivalent. Consequently, each query point's pore pressure needs to be compared with the different time stages to understand the dynamics of the hydrogeological condition (b).

There is an insignificant increase or change in the pore pressure due to the infiltration of water after the initial saturation. The only noticeable increase in pore pressure occurred in the initial stage because the saturation process was void. The other stages showed a decrease in pore pressure due to elongated infiltration. This occurred when the water input and output is equivalent. Water balance is reached after the initial stage of 0.125 day (3 Hours) due to drainage caused by the porous and conductive lower layer.

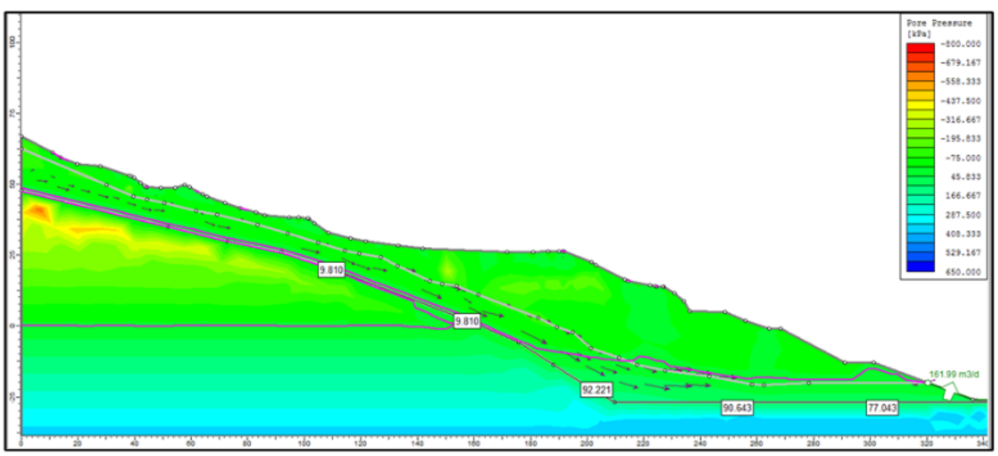

**Figure 12.** Query points on the contact zone between embankment material and in situ based on a cross-sectional pore pressure distribution.

In addition, an increase in time, causes an increase in the amount of infiltrated water, thereby causing a rise in its level in the embankment. The saturation and drainage process in each of the stages is illustrated on the two-dimensional distribution of the embankment's volumetric water content, as shown in Fig. 13.

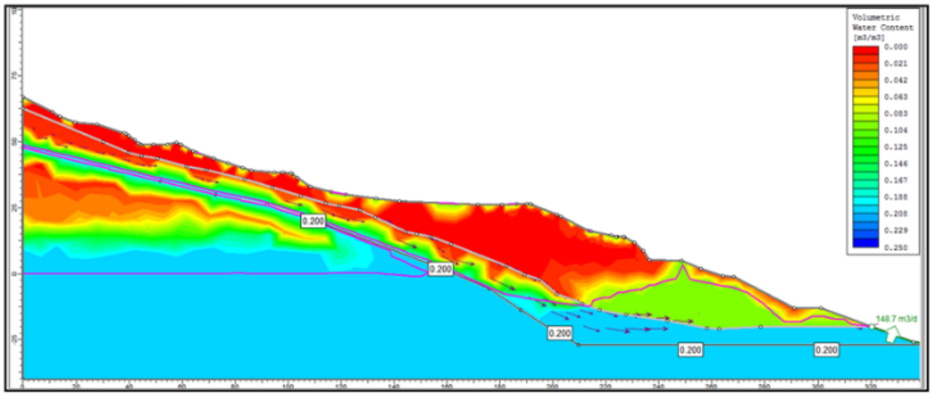


**Figure 13.** Models of volumetric water content in each of the 3-hour stages.

Figure 14 shows a 3-hour stage condition, there was a significant increase in the saturation process of the material in the initial stage, as well as a large increase in water content, particularly in the lower layer of the pile top. Water balance starts at this stage.

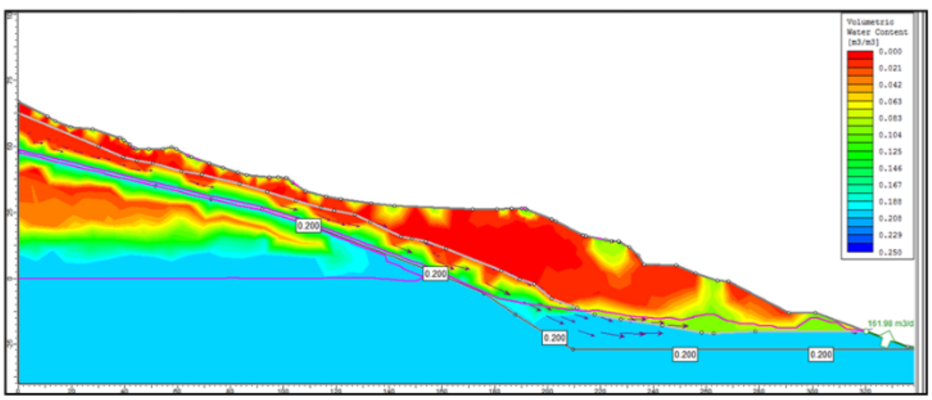


**Figure 14.** Models of volumetric water content on each of the stage 6-hour stage.

Subsequently, there is a decrease in the discharge at the bottom layer of the pile from 3-hour to 6-hour stages. The maximum discharge at the bottom layer was reached at this stage, thereby decreasing subsequent stages.

The maximum bottom discharge is achieved due to the continuation of rainfall, and desaturation kept occurring till the 12-hour stages. This was followed by a gradual increase in moisture content on the top layer of the pile to the 24-hour stage as shown in figures 15 and 16.

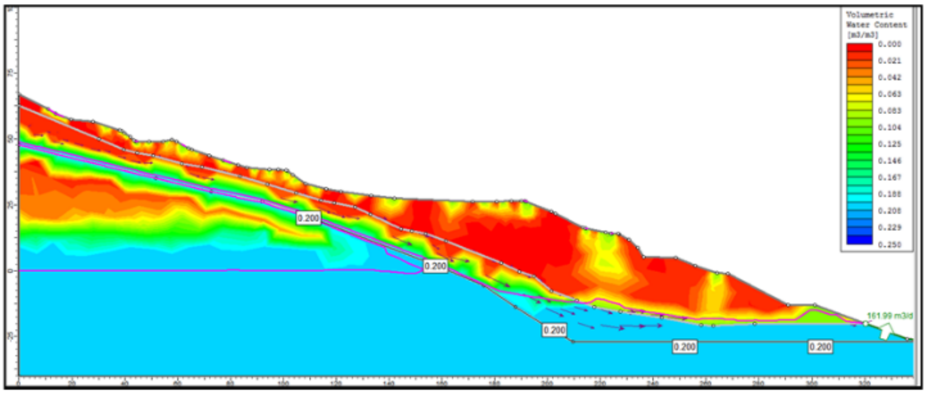

**Figure 15.** Models of volumetric water content on each of the 12-hour stages.

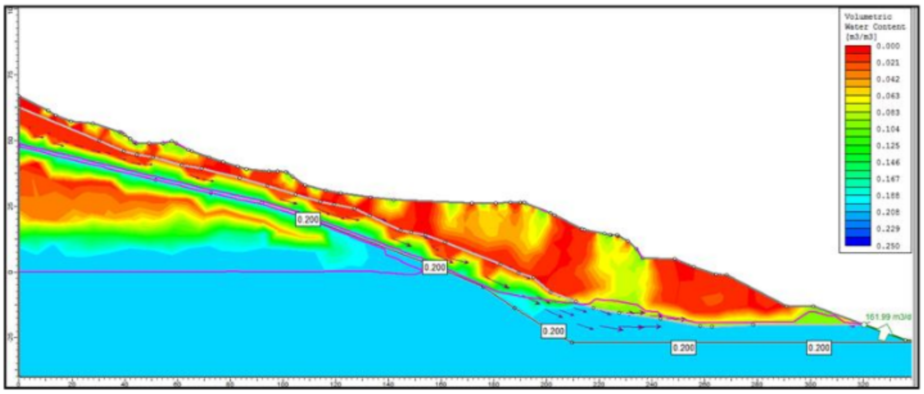

**Figure 16.** Models of volumetric water content on each of the 24-hour stages.

## 4. Conclusion

Groundwater is a major factor in determining the slope stability and safety of the embankment. Water balance in the embankment needs to be maintained to ensure that the hydrogeological condition is regulated. In this circumstance, the layering of the material is selectively carried out to ensure the effective performance of the drainage system in the embankment. This is illustrated in the analysis where the hydrogeological condition is controlled by the drainage system in the embankment body. The drainage system allows groundwater to flow through the base of the embankment, which consisted of coarse-grained materials while the finer and less conductive materials restrict water infiltration. Therefore, the source of water is limited, and the infiltrated water is easily extracted from the embankment. This study shows that the water balance is realized in 3-4 hours after the initial saturation of the embankment. Continuous rain, causes the drainage process to extract the excess water, thereby prohibiting further saturation on the embankment.

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