And., Intl.,J., Appl Sci., Eng., Tech, Vol 04, No 01, March 2024
e-ISSN: 2797-0442

Study Comparative Stability of Dam Body with Geomembrane Core Material using GeoStudio Application

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Abstract— The availability of embankment material and the quality of the material is one of the problems in planning a dam, especially impermeable material which must be watertight. With the GeoStudio application, the dam will be modeled to observe the stability of the dam, especially against landslides and seepage. Modeling I is modeled with core zone material using upstream borrow clay material and modeling II using downstream borrow clay material. Modeling III and IV used the same core material with the addition geomembrane material between the transition zone and the upstream filter. The geomembrane was added to observe and compare the effect of use on the stability. The weir body was analyzed under conditions when the weir body was completed, flood water level, normal water level, low water level and rapid drawndown water condition. Modeling III with upstream borrow clay material and geomembrane between the transition zone and upstream filter is the design with the best stability with the most critical avalanche safety factor of 2.459 downstream of the weir under flood water level conditions. The seepage discharge downstream of the weir is 0.0017 m^3/dt/m and the maximum seepage discharge is 0.0026 m^3/dt/m under flood water level conditions.

Keywords: Landslides, Seepage, and Geomembrane.

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1. Introduction

Lau Simeme Dam is planned with zonal urugan dam type. The dam is located in Biru-biru District, Deli Serdang Regency, North Sumatra with a planned storage capacity of 21.07 million m^3. Lau Simeme Dam will be utilized as a source of irrigation for agricultural land, raw water supply, and as flood control infrastructure in Medan City and Deli Serdang Regency. A zonal urugan type dam is a dam with a weir body embankment consisting of rocks with different grain size arrangements in each particular layer [1]. Almost all soil materials can be used as dam body materials, except for soils that contain organic substances or other soluble substances [2]. The embankment material used is generally obtained from around the dam through a process of excavation, transportation, stockpiling and compaction[1]. The planned dam body material must be economical but also safe against possible structural failures, especially the possibility of landslides and seepage [3]. Slope stability is one of the basic factors that needs to be considered as an indication or benchmark of the safety of land on which a civil building is located. The safety factor is defined as the ratio between the resisting force and the driving force [4]. Seepage is defined as the property of a porous material that allow the flow seepage of liquid in the form of water or soil to flow through the pores. Soil pores are interconnected with each other, so that water can flow from a high point of lower energy [5]. The core material for the weir body in the Lau Simeme Dam project is still being explored and tested. Based on existing data, there are two planned materials that have been tested in the laboratory, namely clay borrow material upstream of the dam and clay borrow material downstream of the dam. Studies to study the use of materials around the dam to be used as impermeable core materials need to be carried out to obtain a

Received: 29 October 2023, Revised: 11 May 2024, Accepted: 13 May 2024
https://doi.org/10.25077/aijaset.v4i1.105

weir body design with the best stability, especially against possible seepage and landslides that occur due to various loading conditions. Geomembrane is a thin layer made of thin polymer sheets, the polymer composition of geomembrane is relatively difficult to penetrate compared to geotextiles or soil, even compared to dam core materials in general [3]. Low-permeability materials are always required to reduce migration of water through a dam body [6]. At the point, geomembranes have been used as an alternative method to traditional materials in seepage control [7]. GeoStudio is a geotechnical software used to model slope stability, soil deformation, heat and mass transfer in soil or rock, etc. It can perform a geotechnical analysis more easily and quickly than using manual calculations. Limit equilibrium formulations based on the method of colums are also being applied increasingly to the stability analysis of structures such as tie-back walls, slopes reinforced with soil nails or geosynthetics, and even the sliding stability of structures subjected to high horizontal loading arising [8]. The use of geomembrane material combined with borrow area material needs to be studied as an alternative design and to determine the effect of using geomembrane material on the stability of the dam body, especially against seepage. Therefore, it is necessary to conduct a comparative study of the stability of the dam body with geomembrane core material using the GeoStudio application.

2. Method

Analysis was carried out on 4 modeling designs, namely modeling I: weir body with core clay borrow material upstream dam area, modeling II: weir body with core clay borrow material downstream dam area, modeling III: weir body with core clay borrow material upstream area with geomembrane layer between filter and transition upstream dam, modeling IV: weir body with core clay borrow material downstream area with geomembrane layer between filter and transition upstream dam. The design of the weir body is modeled using a computer program, GeoStudio 2022.1 version 11.4.2.250 for efficiency and effectiveness. The model of the weir body is drawn by inputting based on the coordinate points of the cross section of the weir body. Technical data of weir body collected from related parties and direct observation The materials data are processed as input materials in the program. Analysis of embankment landslide using Slope/w with mohr coulumb collapse method. Seepage analysis using seep/w program.

3. Result and Discussion

3.1 Boundary Conditions

In planning a dam, the least favorable loading combination is used by estimating the factors that affect the stability of the dam in terms of dimensions, direction and other characteristics. The factor of safety of the body of an earthfill dam is generally planned with a value of 1.2 or more. Table 1 shows the planned boundary conditions on the weir body.

Table 1. Boundary Condition

Condition	Original Elevation (m)		Input Elevation (m)	
	Base	Top	Base	Top
On completion of construction	202.542	253.5	0	50.958
Flood Water Level (FWL) Elv. +251.780	202.542	251.78	0	49.238
Normal Water Level (NWL) Elv. +246.800	202.542	246.8	0	44.258
Low Water Level (LWL) Elv. +224.200	202.542	224.2	0	21.658
Rapid Drawndown Normal Water Level – Low Water Level	224.2	246.8	0	22.6

3.2 Material Models and Running Analysis Result

Modeling I uses a weir body design with clay borrow core material in the upstream area of the dam. The modeling design is shown in Figure 1, material descriptions are shown in the Table 2, and the analysis result shown in Figure 2,3,4,5,6, and 7.

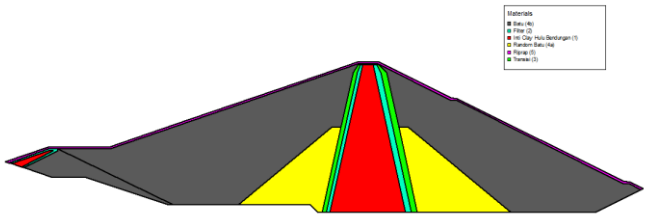


Figure 1. Design Modeling I

Table 2. Material Description Modeling I

Dam Embankment Material Detail			
Color Code	Type of embankment	Code	Material Source
	Core (1)	Clay	Borrow Area Upstream
	Filter (2)	Sand	Bingai River Sediment
	Transisi (3)	TP+TB+BX	Quarry Mardinding
	Random Rocks (4a)	TB+BX	Dam Excavation
	Rocks (4b)	DR	
	Riprap (5)	DR	Quary Mardinding

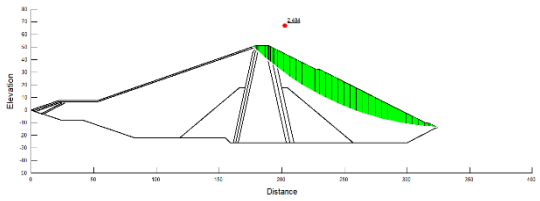


Figure 2. Downstream landslide profile

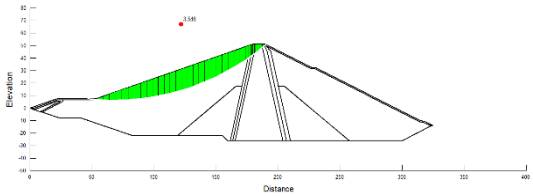


Figure 3. Upstream landslide profile

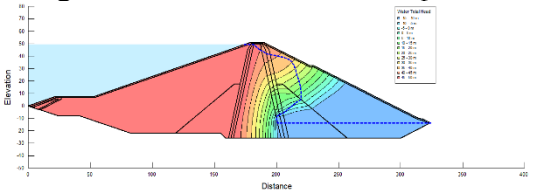


Figure 4. FWL Seepage Profile

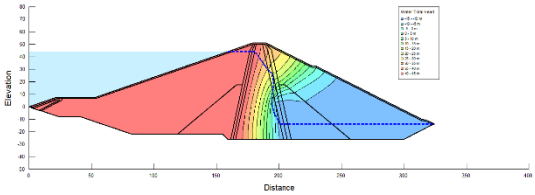


Figure 5. NWL Seepage Profile

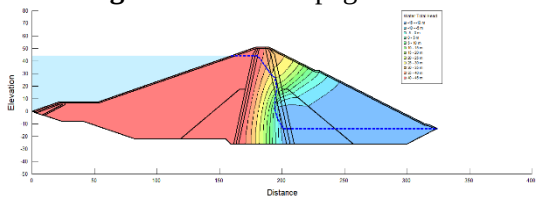


Figure 6. LWL Seepage Profile

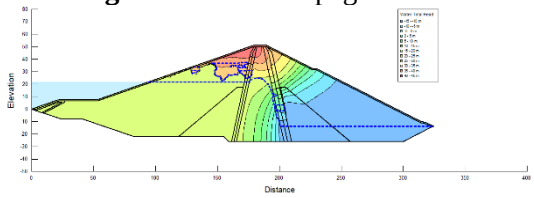


Figure 7. Rapid DrawnDown Seepage Profile

In modeling II, the design of the weir body with clay core material borrows the downstream area of the dam. The modeling design is shown in Figure 8, material descriptions are shown in the Table 3, and the analysis result shown in Figure 9,10,11,12,13, and 14.

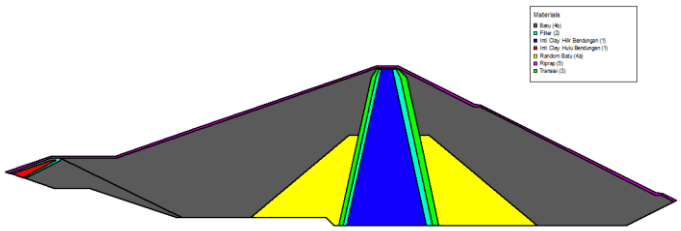


Figure 8. Design Modeling II

Table 3. Material Description Modeling II

Dam Embankment Material Detail			
Color Code	Type of embankment	Code	Material Source
	Core (1)	Clay	Borrow Area Downstream
	Filter (2)	Sand	Bingai River Sediment
	Transisi (3)	TP+TB+BX	Quarry Mardinding
	Random Rocks (4a)	TB+BX	Dam Excavation
	Rocks (4b)	DR	Quary Mardinding
	Riprap (5)	DR	

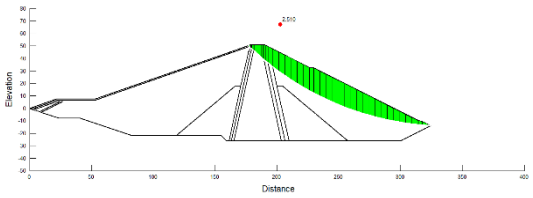


Figure 9. Downstream landslide profile

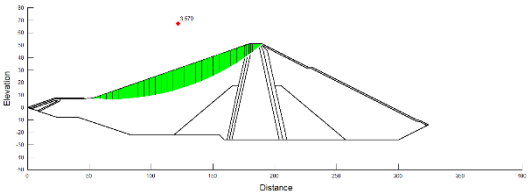


Figure 10. Upstream landslide profile

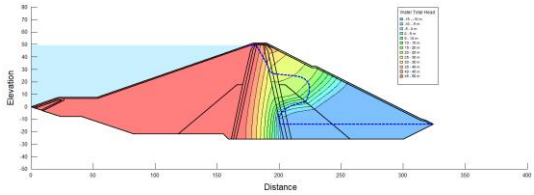


Figure 11. FWL Seepage Profile

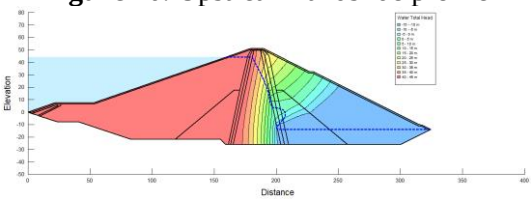


Figure 12. NWL Seepage Profile

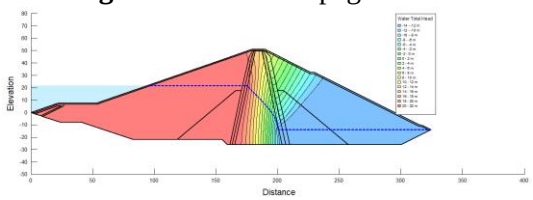


Figure 13. LWL Seepage Profile

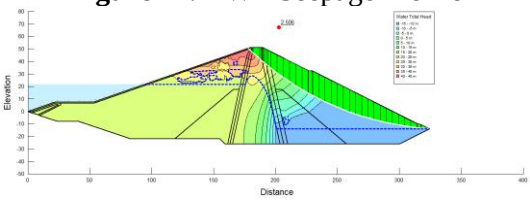


Figure 14. Rapid DrawnDown Seepage Profile

In modeling III, the core material (zone I) uses clay borrow material upstream of the dam with a geomembrane layer between the transition zone and the filter upstream of the dam. The modeling design is shown in Figure 15, material descriptions are shown in the Table 4, and the analysis result shown in Figure 16,17,18,19,20, and 21.

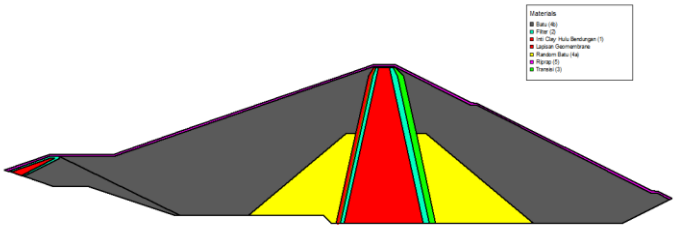


Figure 15. Design Modeling III

Table 4. Material Description Modeling III

Dam Embankment Material Detail			
Color Code	Type of embankment	Code	Material Source
	Core (1)	Clay	Borrow Area Upstream
	Filter (2)	Sand	Bingai River Sediment
	Geomembrane	Geomembrane	
	Transisi (3)	TP+TB+BX	Quarry Mardinding
	Random Rocks (4a)	TB+BX	Dam Excavation
	Rocks (4b)	DR	Quary Mardinding
	Riprap (5)	DR	

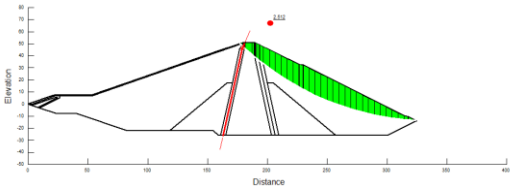


Figure 16. Downstream landslide profile

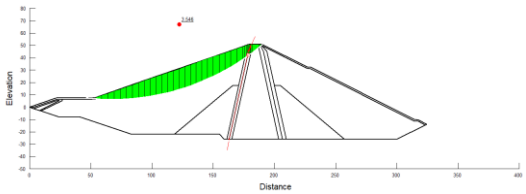


Figure 17. Upstream landslide profile

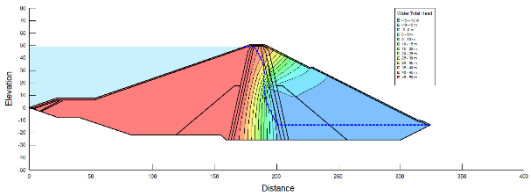


Figure 18. FWL Seepage Profile

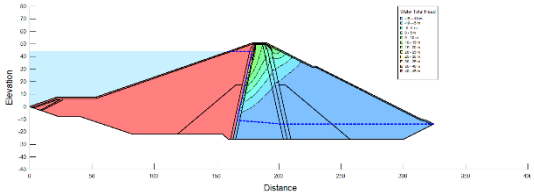


Figure 19. NWL Seepage Profile

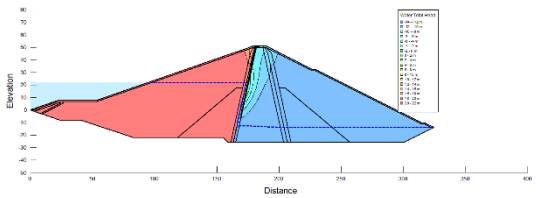


Figure 20. LWL Seepage Profile

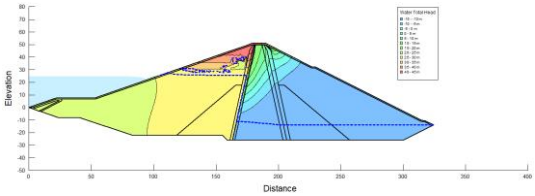


Figure 21. Rapid DrawnDown Seepage Profile

In modeling IV, the core material (zone I) uses clay borrow material downstream of the dam with a geomembrane layer between the transition zone and the filter upstream of the dam. The modeling design is shown in figure 22, material descriptions are shown in the Table 5, and the analysis result shown in figure 23,24,25,26,27, and 28.

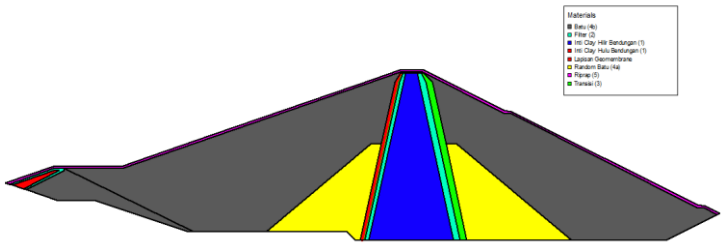


Figure 22. Design Modeling IV

Table 5. Material Description Modeling IV

Dam Embankment Material Detail			
Color Code	Type of embankment	Code	Material Source
	Core (1)	Clay	Borrow Area Upstream
	Filter (2)	Sand	Bingai River Sediment
	Geomembrane	Geomembrane	
	Transisi (3)	TP+TB+BX	Quarry Mardinding
	Random Rocks (4a)	TB+BX	Dam Excavation
	Rocks (4b)	DR	Quary Mardinding
	Riprap (5)	DR	

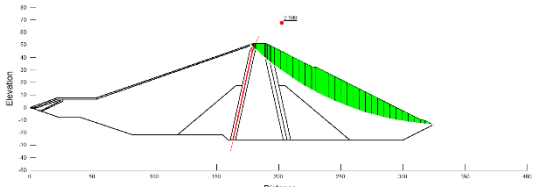


Figure 23. Downstream landslide profile

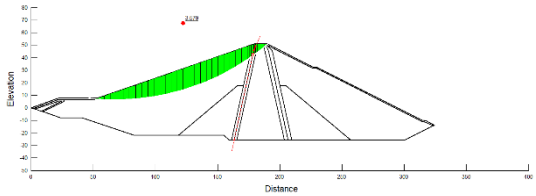


Figure 24. Upstream landslide profile

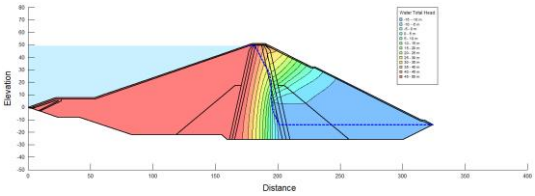


Figure 25. FWL Seepage Profile

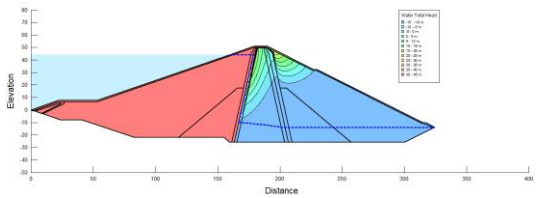


Figure 26. NWL Seepage Profile

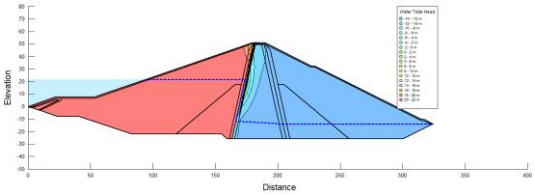


Figure 27. LWL Seepage Profile

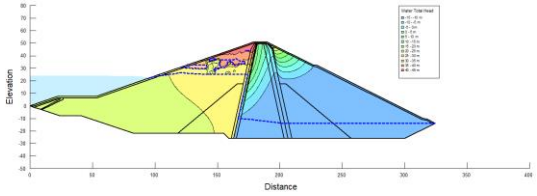


Figure 28. Rapid DrawnDown Seepage Profile

3.3 Slope And Seepage Results

Based on the results of running analysis, the safety numbers of landslides that occur upstream and downstream of the weir body under each loading condition are obtained. The maximum seepage discharge that occurs in the weir body and the discharge that occurs downstream of the weir is

obtained from the program in units of m³/det/m². The discharge obtained in the program is multiplied by the length of the weir body and then compared with the acceptable allowable discharge according to the requirements based on the Grouting Guidelines for Dams by the Departemen Pekerjaan Umum 2005, which is 1% of the average river discharge. The results of slope and seepage shown in Table 6.

Table 6. Weir body avalanche and seepage analysis results

Analysis	Condition	Upstream/ Downstream	Model			
			I	II	III	IV
Critical Avalanche Safety Factor	On completion of construction SF = 1.3	Downstream	3.546	3.579	3.546	3.579
		Desc	Safe	Safe	Safe	Safe
		Upstream	2.484	2.510	2.482	2.508
		Desc	Safe	Safe	Safe	Safe
	Flood Water Level +49.238 SF = 1.5	Hulu	3.715	3.775	3.717	3.775
		Desc	Safe	Safe	Safe	Safe
		Hilir	2.407	2.449	2.459	2.486
		Desc	Safe	Safe	Safe	Safe
	Normal Water Level +44.258 SF = 1.5	Hulu	3.521	3.541	3.527	3.586
		Desc	Safe	Safe	Safe	Safe
		Hilir	2.481	2.443	2.479	2.504
		Desc	Safe	Safe	Safe	Safe
	Low Water Level +21.658 SF = 1.5	Hulu	3.202	3.581	3.202	3.263
		Desc	Safe	Safe	Safe	Safe
		Hilir	2.481	2.506	2.479	2.504
		Desc	Safe	Safe	Safe	Safe
	Rapid Drawndown Normal Water Level – Low Water Level After 30 Days SF = 1.3	Hulu	3.158	3.239	3.124	3.239
		Desc	Safe	Safe	Safe	Safe
		Hilir	2.481	2.506	2.479	2.532
		Desc	Safe	Safe	Safe	Safe
Downstream Seepage Discharge (m³/s/m)	Flood Water Level +49.238 Q ijin = 0.0167	Desc	0.0017 Safe	0.00140 Safe	0.00267 Safe	0.0017 Safe
	Normal Water Level +44.258 Q ijin = 0.0167	Desc	0.0019 Safe	0.00137 Safe	0.00003 Safe	0.00003 Safe
	Low Water Level +21.658 Q ijin = 0.0167	Desc	0.0007 Safe	0.00052 Safe	0.00001 Safe	0.00001 Safe
Maximum Seepage Discharge (m³/s/m)	Flood Water Level +49.238 Q ijin = 0.0167	Desc	4.5413 Not Safe	6.4875 Not Safe	0.0026 Safe	0.0714 Not Safe
	Normal Water Level +44.258 Q ijin = 0.0167	Desc	0.1038 Not Safe	1.2975 Not Safe	0.00002 Safe	0.00002 Safe
	Low Water Level +21.658 Q ijin = 0.0167	Desc	0.0007 Safe	0.0005 Safe	0.00001 Safe	0.00001 Safe

Slope

From Table 6 , it is obtained that in modeling I the critical safety number occurs downstream of the weir with flood water level conditions, namely 2,407. In modeling II, the critical safety number occurs downstream of the weir with normal water level conditions, namely 2,443. In modeling III, the critical safety number occurs downstream of the weir with a flood water level condition of 2,459. In modeling IV, the critical safety number occurs downstream of the weir under flood water level conditions, namely 2,486. In each modeling, the critical safety number that occurs is still higher than the given acceptance criteria of 1.5 so that each modeling is safe against landslides.

Determining the point as the center of the circle and the radius of the circle produces a model of the sliding plane by measuring the distance between the crest of the slope and the toe of the slope. The circle should cut through the crest to the foot of the hill. Comparison of the sum of all forces acting as a driving force and resisting force on each piece results in the SF value. At the time of post-construction SF modeling I and III have the same value as well as modeling II and IV. This happens because the value of the height of the top of the slope to the foot of the slope is the same. The height of the top of the slope and the foot of the slope is the driving force while the unit weight, cohesion and angle of friction criteria of the material produce the resisting force value.

Seepage

In modeling I, the maximum seepage discharge that occurs downstream under normal water level conditions is 0.0019m^3/dt/m. In modeling II, the maximum seepage discharge that occurs downstream under flood water level conditions is 0.00140 m^3/dt/m. In modeling III, the maximum seepage discharge that occurs downstream at flood stage conditions is 0.00170 m^3/dt/m. In modeling IV the maximum seepage discharge that occurs downstream at flood stage conditions is 0.00170 m^3/dt/m. When viewed from the maximum seepage discharge that occurs in the weir body, modeling I, II and IV do not meet the allowable discharge requirements.

The seepage value is influenced by Hydraulic conductivity. Hydraulic conductivity is the ability of soil to pass water, either in saturated or partially saturated conditions. Hydraulic conductivity in partially saturated soil is significantly affected by changes in pore number and degree of saturation. The amount of hydraulic conductivity in partially saturated soil is not constant, it depends on the value of VWC, thus it can be said that the hydraulic conductivity of partially saturated soil depends on the value of soil suction [9]. Hydraulic conductivity in partially saturated soils can be determined by plotting the function of matric suction on the SWCC which is the relationship curve between the degree of saturation or volumetric water content and matric suction, using the permeability coefficient in saturated soils (ksat) [9]-[10].

The high moisture content of the materials that make up the dam body, especially in the impermeable, transition and filter zones, causes the permeability coefficient in saturated conditions to be higher, causing the seepage discharge that occurs to be higher. The direction of seepage is also influenced by the anisotrophy coefficient of each material that makes up the dam body. In the impermeable zone material, a high anisotrophy coefficient value causes the seepage direction on the y-axis to be faster than the seepage direction on the x-axis. The difference in anisotrophy of each material affects the direction and discharge that occurs in the weir body.

4. Conclusion

Modeling III with core material using clay borrow upstream area with a geomembrane layer between the filter and transition zones is the safest modeling. The most critical upstream avalanche safety factor is 3.717 and the most critical downstream safety factor is 2.459 occurring under flood water level conditions. These figures meet the minimum safety factor requirements according to SNI 8064: 2016 which is 1.5. The downstream seepage discharge that occurs is 0.00267 m^3/s/m lower than

the maximum allowable discharge of 0.0167 $m^3/s/m$. The maximum discharge that occurs in the weir body is 0.0026 $m^3/s/m$ under flood water level conditions, this figure meets the maximum allowable discharge requirements that occur, namely 0.0167 $m^3/s/$ m.

Acknowledgment

Thanks to the Civil Engineering Study Program for funding assistance for publication fees.

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