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Seepage Analysis on Dam Design Alternatives Using GeoStudio Software (Case Study of Way Sekampung Dam)

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ABSTRACT

The Way Sekampung Dam Project in Pringsewu Regency, Lampung Province is the location of this research. This dam uses an embankment-type dam, whose heap consists of several material zones that make up the body of the dam. With the availability of material from dam heaps in the field and the discourse of design modifications, it is necessary to carry out a large analysis of the seepage discharge against alternative dam designs.

Large analysis of this seepage discharge using Geostudio 2012 software used the SEEP/W method of steady-state. Modeling used the input properties of each material that had been tested in the laboratory. The figure of the amount of seepage discharge (Q) was obtained from the phreatic line in the analysis.

The output resulting from this analysis was the magnitude of the seepage discharge (Q) in the design dam body, alternative 1 (one) 0.0000001409 m³ / second and alternative 2 (two) 0.00000194 m³ / second which could be concluded that the seepage discharge that occurred in the dam body still met the conditions set.

***Keywords*: Seepage, Dam Design, Geostudio.**

INTRODUCTION

Seepage is one of the problems that occurs in the body of the dam. The flow of seepage that occurs in the body of the dam can cause the exposure of fine grains of the material that makes up the dam. If the process of transporting the fine meterial takes place continuously, it will cause erosion of the dam foundation (piping & boiling).

In its construction, the requirements to meet the safety of a dam are by fulfilling the safety factor of the dam stability, foundation, and the quality of the dam management material. One of them is the magnitude of the seepage flow. In the discussion in this study, the limitation of the problem is only to determine the amount of seepage discharge (Q) when the water level condition is normal (Elv. 124.00 m).

In analyzing the magnitude of the seepage discharge in alternative dam designs, the 2012 series of Geostudio software was used, namely the steady-state with the SEEP / W method as a tool to calculate seepage on the dam body by inputting the properties of each zoning material that has been tested in the laboratory to determine the physical and mechanical properties of the soil, especially the hydraulic conductivity value water content and permeability of the material.

LITERATURE AND THEORETICAL REVIEW

According to Government Regulation Number 37 Article 1 of 2010 concerning Dams, that dam is a building in the form of a landfill, stone, concrete, and or masonry built in addition to holding and collecting water, it can also be built to hold and hold mining waste (tailings), or collect mud so that a reservoir is formed. A dam or reservoir is an artificial container formed as a result of the construction of a dam.

Seepage on the dam and foundation is an important factor in the stability of the dam. Seepage is a flow that continuously flows from upstream to downstream. This water flow is a flow from reservoir water through permeable materials, both through the body of the dam and the foundation.

Seepage on the urugan dam is an unavoidable occurrence. However, excessive seepage has the potential to harm the dam. Excessive seepage can result in reed erosion which is getting more developed and wider which is then followed by an avalanche or collapse of the bed. Seepage pathways can occur due to cracks due to settlement, shrinkage cracks in heaps made of high plasticity clay material and the presence of weak material in the tumbunan or foundation. Completion of seepage analysis of steady seepage and laminer flow conditions can be solved based on the Laplace and Darcy equations. Several ways have been developed to solve such equations for various cases of seepage summarized such as Figure 1.

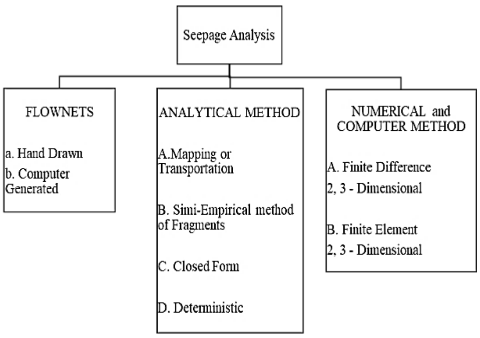


Figure 1. Various Methods of Seepage Analysis (Seepage) (Source: KEMENPU, 2017)

Computer models are used to solve Laplace equations for complex flows. The two main methods of the numerical model are the fine difference and finite element method. Both can be used to solve the problem of 2-D and 3-D seepage.

- ***Soil behavior models***

There are four different material models to choose from when using SEEP/W. give me the material models used in SEEP/W:

1. None (used to remove part of the model in the analysis)
2. Saturated / Unsaturated Model
   a. Hydraulic conductivity function, ratio and direction
   b. Water content function
   c. Air conductivity function (only if AIR/W is added)
3. The model is only saturated
   a. Hydraulic saturated conductivity (Ksat), ratio and direction
   b. Saturated water content
   c. Coefficient of compressibility of volume (Mv)
   d. Air conductivity is set to zero (only if AIR/W is added)
4. Interface model
   a. Normal conductivity and hydraulic tangent
   b. Air conductivity (only if AIR/W is added)

Groundwater storage – water content function

In saturated soils, all cavities are filled with water and the volumetric moisture content of the soil is equal to the porosity of the soil according to the:

$$\Theta w = nS \quad (1)$$

Where:

Θw = *the volumetric water content,*

n = *the porosity of the soil,*

S = degree of saturation (in saturated soils equal to 1.0 or 100%).

Porosity, n, corresponds to the ratio of cavities, e, by:

$$e = n/(1-n) = wGs/S \quad (2)$$

Where:

w = *the gravimetric water content,*

Gs = *the particle specific gravity.*

Storage function types and estimation methods

To estimate a data point function using a predictive/estimating method based on item size, the function is based on a sample set of functions built into software and a closed-form equation based on curve match parameters (Figure 2).

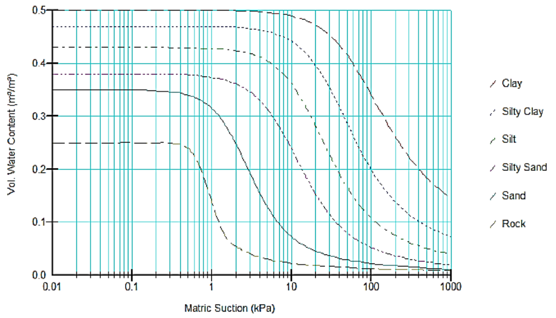


Figure 2. Sample functions in Geostudio (Source: SEEP/W user's manual Geostudio)

Hydraulic conductivity

The ability of the soil to transport or drain water in saturated and unsaturated conditions is reflected by the function of hydraulic conductivity. In saturated soils, all pore spaces between solid particles are filled with water. Once the air inlet value is exceeded, the air enters the largest pores and the air-filled pores become non-conductive channels flowing and increase the tortuosity of the flow path as shown schematically in Figure 3.

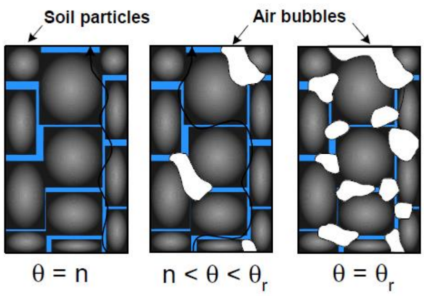


Figure 3. Availability of water-filled flow paths from saturation to residue (Source: SEEP/W user's manual Geostudio)

As a result, the ability of the soil to transport water (hydraulic conductivity) decreases. As the pore water pressure becomes more and more negative, the more pores are filled with air and the hydraulic conductivity decreases even more. Given this description, it is clear that the ability of water to flow through a soil profile depends on how much water is in the soil, which is represented by the volumetric moisture content function.

Conductivity function estimation methods

Method of *Fredlund et al, 1994*

This method consists in the development of an unsaturated hydraulic conductivity function by integrating the volumetric moisture content function curve. The equation used in this method is.

$$k_w = k_s \frac{\sum_{i=j}^{N} \frac{\Theta(e^y) - \Theta(\Psi)}{e^{y_i}} \Theta'(e^{y_i})}{\sum_{i=1}^{N} \frac{\Theta(e^y) - \Theta_s}{e^{y_i}} \Theta'(e^{y_i})}$$

Where:

kw = conductivity calculated for a certain moisture content or negative pore water pressure (m/s),

ks = measured saturated conductivity (m/s),

Θs = saturated volumetric water content,

e = real number (2.71828),

y = integration dummy variable representing the logarithm of negative pore water pressure,

i = interval between ranges j to N,

j = the smallest negative pore water pressure described by the final function,

N = maximum negative pore water pressure described by the final function,

Ψ = suction corresponding to the j-th interval,

Θ' = the first derivative of the equation...

$$\Theta = C(\Psi) \frac{\Theta_s}{\left\{ \ln\left[e + \left(\frac{\Psi}{a} \right)^n \right] \right\}^m} \quad (3)$$

a = approximately the value of soil air inlet,

n = parameters that control the slope at the turning point in the volumetric moisture content function,

m = parameters related to residual moisture

content,

C(Ψ) = correction functions defined as;

$$C(\Psi) = 1 - \frac{\ln\left(1 + \frac{\Psi}{C_r}\right)}{\ln\left(1 + \frac{1,000,000}{C_r}\right)} \quad (4)$$

Cr = constants associated with matric suction corresponding to residual water content.

A typical value is about 1500 kPa. The value of 1, 000, 000 in the above equation corresponds to a matric suction (in kPa) where there is no moisture left in the soil in the liquid or steam phase.

Method of Van Genuchten, 1980

Van Genuchten (1980) proposed the following closed-form equation to describe the hydraulic conductivity of soils as a matric suction function:

$$k_w = k_s \frac{\left[1 - \left(a\Psi^{(n-1)}\right)\left(1 + \left(a\Psi^{n}\right)^{-m}\right)\right]^2}{\left(\left(1 + a\Psi\right)^{n}\right)^{\frac{m}{2}}} \quad (5)$$

Where:

k_s = saturated hydraulic conductivity,
a,n,m = curve mounting parameters,
n = 1/(1-*m*),
ψ = required suction range.

- **Boundary Conditions**

In SEEP/W the main unknown variable or field variable is the total hydraulic head, which consists of the head pressure and elevation which are the components of gravity. In the form of the equation the head total is defined as:

$$H = u/\gamma w + y \quad (6)$$

H = Total head (meters or ft),

u = pore water pressure (kPa or psf),

γw = units of water weight (kN/m3 or pcf),

y = Elevation (meters or ft)

u/γw is the pressure head – represented in units of length.

Figure 4. indicates the total contour of the head (equipotential line) in the core. From here the amount of seepage through the core can be calculated.

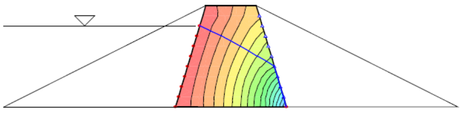


Figure 4. Equipotential lines in the dam core (Source: SEEP/W user's manual Geostudio)

METHODOLOGY

The following is the flow chart in writing this Final Project can be seen in Figure 5.

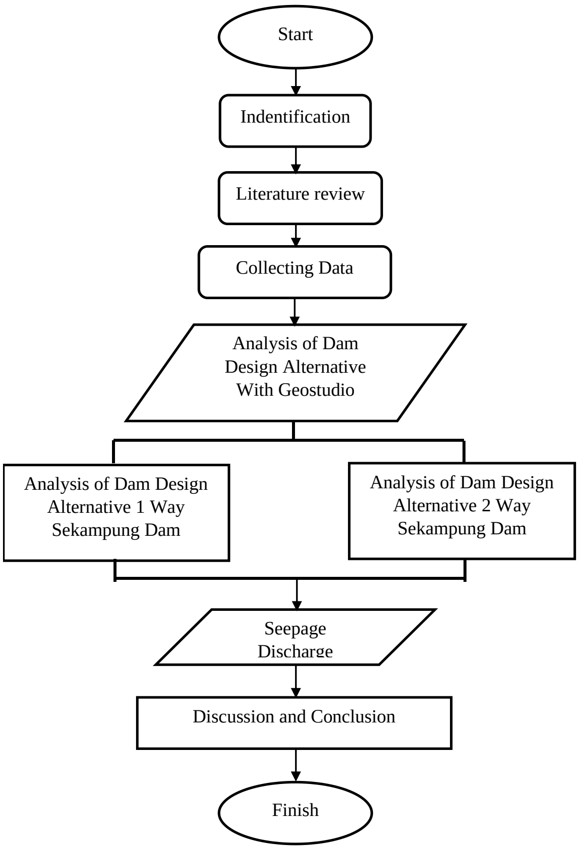


Figure 5. Seepage Discharge Calculation Flow Chart

- **Data Collection**

The data used in this study are secondary data. The data includes:

1. Study Area Description

The location of the Way Sekampung Dam project is in Pekon Bumi Ratu, Pagelaran District on the right of the river and

Banjarejo Village, Banyumas District on the left of the river, Pringsewu Regency, Lampung Province which is located at coordinates 104° 48' – 105° 08' East Longitude and 5° 12' – 5° 33' South Latitude (Figure 6)

Regional boundaries in the Way Sekampung Dam Project :

a. North : Central Lampung Regency

b. East : Pesawaran Regency

c. South : Pesawaran Regency

d. West : Tanggamus Regency

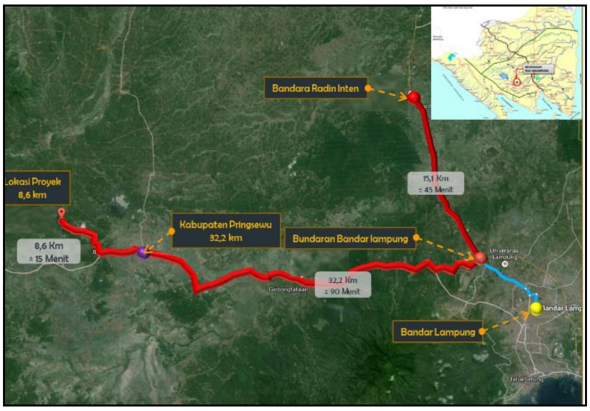


Figure 6. Research Location (Source: BBWS Mesuji – Sekampung, 2019)

2. Topographic data of the cross section of the Way Sekampung Alternative 1 and Alternative 2 Dams (Figure 1.7 and Figure 1.8).

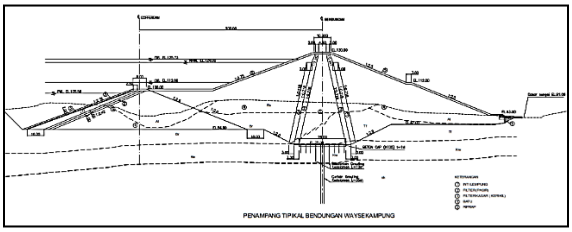


Figure 7. Alternative Design 1 Way Sekampung Dam

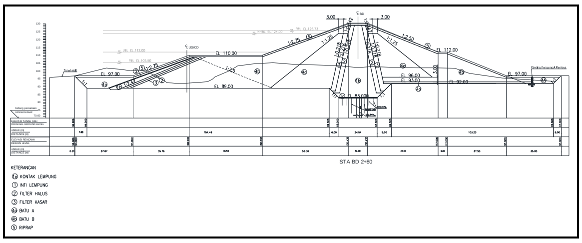


Figure 8. Alternative Design 2 Way Sekampung Dam

3. Properties index and soil parameters

The index of properties and soil parameters used in this final project can be seen in Table 1, Table 2, Table 3, Table 4 and Table 5 below:

Table 1 Core Material Technical Data (Source: BBWS Mesuji – Sekampung, 2019)

Data Teknis (Material Inti)				
Void ratio [e=G.ϒw/ϒd)-1]	e	=	1.073.378	
Porosity [n=e/1+e]	n	=	0.517695	
Specific Gravity	Gs	=	2.599.432	
Dry Density	γd	=	1.260.703	(gr/cm³)
Wet Density	γwet	=	1.686.865	(gr/cm³)
Koeff Permeability Inti	k	=	2.94E-07	(cm/dtk)

Table 2. Alternative Heap Material Parameters 1 (Source: BBWS Mesuji – Sekampung, 2019)

No	Material	Kepadatan			Kuat geser		Permeabilitas
		γsat	γwet	γdry			(K)
		(kN/m3)			C (kPa)	Ø (°)	(m/hari)
1	**ZONA 1** - Inti Lempung	17,40	16,50	12,40			2,54E-04
2	**ZONA 2** - Filter			17,10		33,40	1,89E+00
	ZONA 3 - Transisi						2,76E+01
3	**ZONA 4** - Random	19,10	18,20	14,90			1,45E+00
4	**Rip-Rap**			18,60		41,00	Lulus Air
5	**Pondasi Sekis**			17,10	16,30	30,00	4,32E-02

Table 3. Alternative Stockpile Material Parameters 2 (Source: BBWS Mesuji – Sekampung, 2019)

No	Material	Kepadatan			Kuat geser		Permeabilitas
		γsat	γwet	γdry			(K)
		(kN/m3)			C (kPa)	Ø (°)	(m/hari)
1	**ZONA 1** - Inti Lempung	14,00	13,28	9,92			2,94E-03
	U-U				14,906	15,41	
	C-U (Total)				25,105	16,48	
	C-U (Efektif)				22,124	19,52	
2	**ZONA 2** - Filter halus	11,52	11,28	10,88		32,12	1,24E+00
3	**ZONA 3** - Transisi	14,56	12,76	12,96		33,00	1,12E+01
4	**ZONA 4.1** - Batu 4a	18,48	18,40	18,24		36,15	5,99E+00
5	**ZONA 4.2** - Batu 4b	17,52	17,44	12,28		42,64	1,44E+02
6	**Rip-Rap**	18,88	18,08	17,60		39,00	Lulus Air
7	**Pondasi Sekis**	19,52	19,04	18,24	13,34	30,00	4,32E-02

Table 4. Volume of Water Content Material Alternate Stockpile 1 (Source: BBWS Mesuji – Sekampung, 2019)

No	Material	Sample Material	Vol. Water Content (m³/m³)
1	ZONA 1 - Inti Lempung	Clay	0,4
2	ZONA 2 - Filter	Sand	0,01
3	ZONA 3 - Transisi	Gravel	0,001
4	ZONA 4 - Random	Gravel	0,0001
5	Rip-Rap	Gravel	1,00E-10
6	Pondasi Sekis	-	0,5

Table 5. Volume of Water Content Material Alternate Stockpiles 2 (Source: BBWS Mesuji – Sekampung, 2019)

No	Material	Sample Material	Vol. Water Content (m³/m³)
1	ZONA 1 - Inti Lempung	Clay	0,4
2	ZONA 2 - Filter	Sand	0,01
3	ZONA 3 - Transisi	Gravel	0,001
4	ZONA 4.1 - Batu 4a	Gravel	0,0001
5	ZONA 4.2 - Batu 4b	Gravel	0,00001
6	Rip-Rap	Gravel	1,00E-10
7	Pondasi Sekis	-	0,5

- **Data Processing**

There are several stages of data processing that need to be done to analyze seepage using Geostudio software. The following are the stages of data processing in Geostudio software:

1. Inputting Material Parameters

To obtain the amount of seepage discharge (Q) in the alternative dam model to be analyzed in the Geostudio program, namely by adding a Hydraulic Conductivity Function to each zoning material.

By using Steady-State analysis which means that there is saturated/unsaturated material during the simulation. In this case, the Volume Water Content function is not required because no transient analysis is performed which means there is no change in storage within the domain. However, to use the internal estimation algorithm of the Hydraulic Conductivity Function (Hydrualic Conductivity Function), a Volume Water Content Function is required. The following are the stages of the Hydraulic Conductivity Function.

- In the KeyIn Materials menu to obtain the Hydraulic Conductivity Function, the Volume Water Content Function needs to be entered first. The volume of water content of alternatives 1 (one) and alternatives 2 (two) can be seen in Tables 4 and 5. Then select Estimate on the Vol. Water Content Function menu, select Estimation Method using Sample Function, enter the value of Water Content Volume and Sample Material according to the data used (Figure 9)

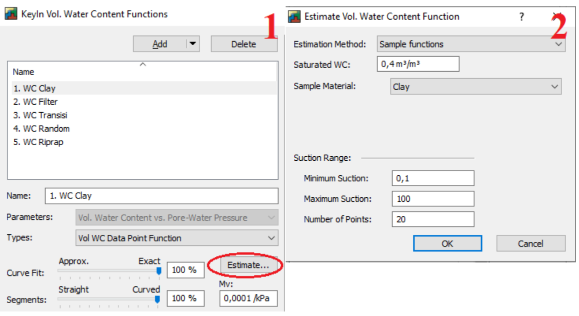


Figure 9. input Vol. Water Content using material samples in the estim menu vol. water content function

- After entering the estimated value of Vol. Water Content Function, then back on the KeyIn Material menu, select Hydrualic Conductivity Function then select Estimate, select Estimation Method and Vol. Water Content Fn according to the material that has been set in the previous stage (Figure 10).

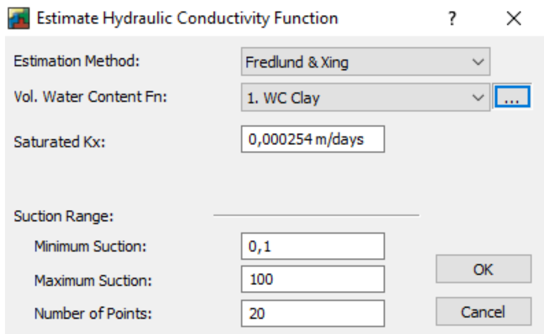
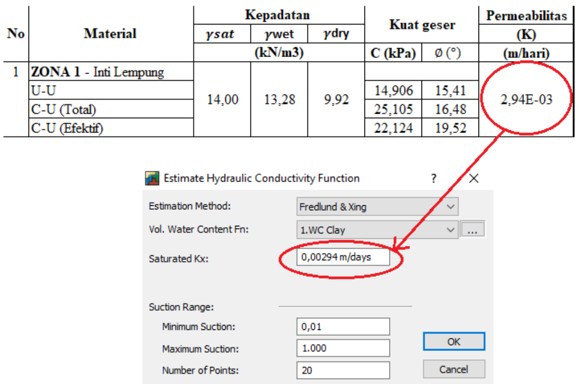


Figure 10. Estimation method selection and Vol.Water Content Fn on The Estimate Hydraulic Conductivity Function

- The Saturated Kx values in the Estimate Hydraulic Conductivity Function are input from the k values of the Permeability of each material zone from Table 2 and Table 3 (Figure 11).



No	Material	Kepadatan γsat	γwet	γdry	Kuat geser C (kPa)	ø (°)	Permeabilitas (K) (m/hari)
		(kN/m3)					
1	ZONA 1 - Inti Lempung						
	U-U	14,00	13,28	9,92	14,906	15,41	2,94E-03
	C-U (Total)				25,105	16,48	
	C-U (Efektif)				22,124	19,52	

Figure 11. Inputting the value of k in the Estimation Hydraulic Conductivity Function

The output of this Hydraulic Conductivity Function will show the Phreatic Surface (groundwater level) on the dam body, pore-water pressure contour (see Figure 12) and total head contour (see Figure 13) after model simulation.

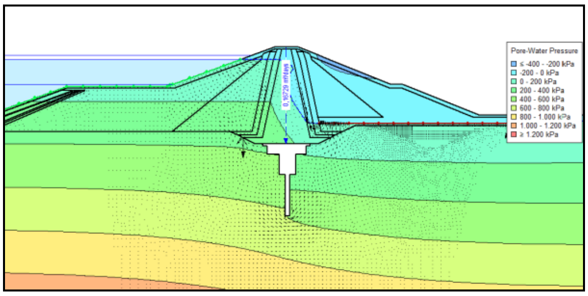


Figure 12. Pore-Water Pressure contours

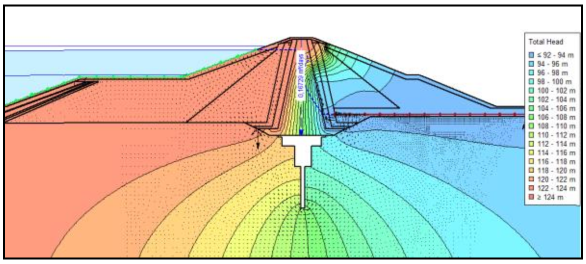


Figure 13. Contour Total Head

Description:

 = Phreatic Surface Line (Groundwater Level)

2. Determination of Boundary Conditions

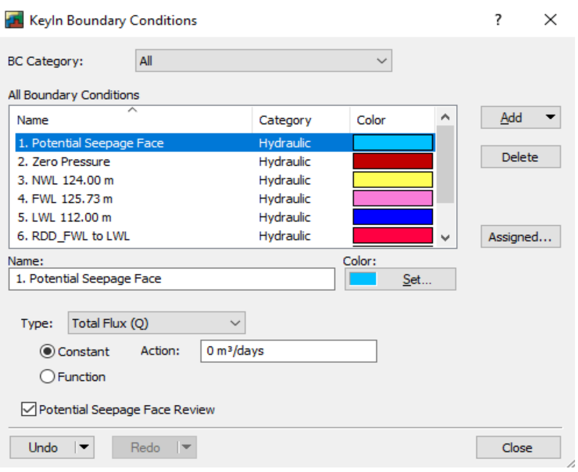


Figure 14. KeyIn Boundary Conditions

Added KeyIn Boundary Conditions (Figure 14) to the alternative model of the dam. These KeyIn Boundary Conditions work for:

• Determining the water level of the reservoir to be analyzed,

• Potential Seepage area to determine how much Q (discharge) seepage is produced on the body of the dam under review, the magnitude of the seepage discharge on the area under review can be seen by activating the Flux Section,

• Zero Pressure area to determine the flow direction/Flow Path on alternative models.

After the Boundary Conditions in the points above are created, then determine the Boundary area by assigning it to the model using the Draw Boundary menu (see Figure 15)

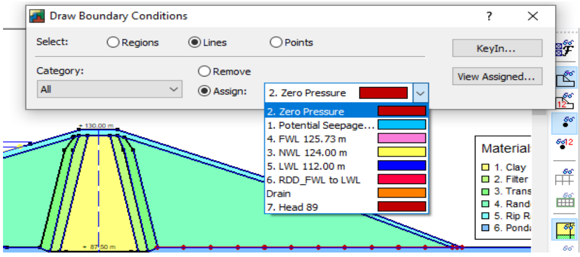


Figure 15. Draw Boundary on alternative models

After the KeyIn Boundary Conditions are determined, the model is ready to start the simulation (running) by selecting the start button in the Solve Manager window.

The output of the KeyIn Boundary Conditions will be visible in the model after simulation, the height of the reservoir water level (Figure 16), Potential Seepage (Figure 17), and Zero Pressure (Figure 18).

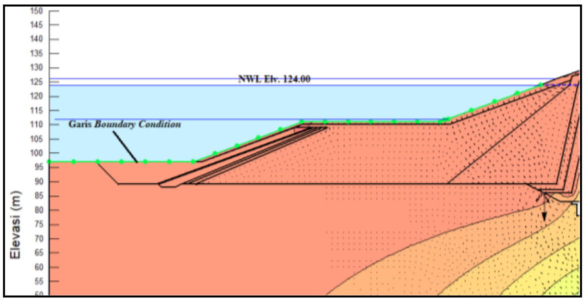


Figure 16. The height of the water level of the reservoir at an elevation of 124.00

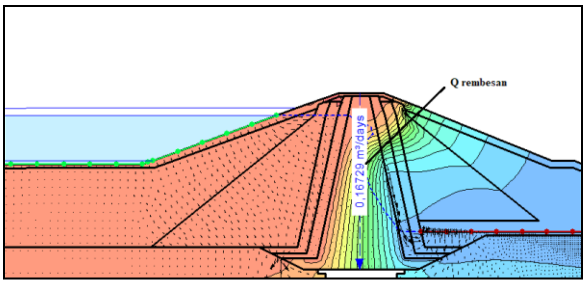


Figure 17. Potential Seepage is indicated by the Flux Section line

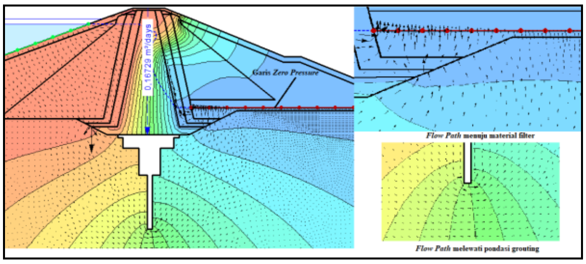


Figure 18. Zero Pressure and flow direction (Flow Path)

RESULT AND DISCUSSION

Alternative 1

The results of the seepage analysis (Seep/W) using Geostudio software in an alternative design of 1 (one) dam under normal water level conditions show that the amount of seepage discharge (Q) at the dam axle location is 0.012177 m^3/day. (Figure 19)

Alternative 2

Results of running seepage analysis (Seep/W) using Geostudio software on alternative design of 2 (two) dams under normal water level conditions shows that the amount of seepage discharge (Q) at the dam axle location is 0.167290 m^3 / day. (Figure 20)

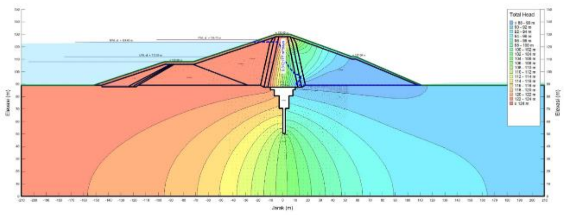


Figure 19. Alternative running results 1

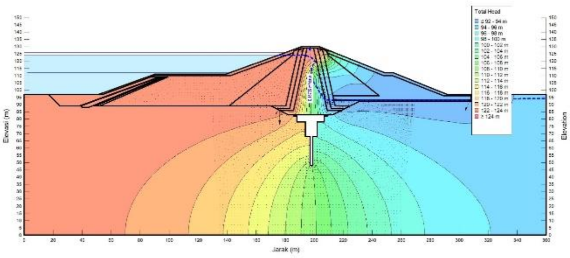


Figure 20. Alternative running results 2

From the results of the seepage capacity analysis using the SEEP / W program in the Geostudio software, the seepage capacity for each alternative dam design on the axle of the dam, is as follows :

- Alternative Q 1: 0.0090664 m^3/day = 1.05E-07 m^3/s
- Alternative Q2: 0.167290 m^3/day = 1.94E-06 m^3/s

Referring to the restrictions applicable in Japan (Japanese Institute of Irrigation and Drainage), the magnitude of the leakage rate passing through the foundation and body of the dam should not exceed 1% of the average river discharge entering the reservoir (Department of Public Works, Grouting Guidelines for Dams, 2005: 21).

It is known that the average river Q on the Way Sekampung River (Technical Data of BBWS Mesuji-Sekampung, 2019) is 33.25 m^3/s.

From the excerpt (Department of Public Works, Grouting Guidelines for Dams, 2005: 21) and the average river Q on the Way Sekampung River (BBWS Mesuji-Sekampung Technical Data, 2019), it was obtained 1 % of the average Q of the river = 0.3325 m^3/s.

Then Q Alternative 1 and Q Alternative 2:

Q Alternative 1:

0.000000105 m^3/s < 0.3325 m^3/s (OK)

Q Alternative 2:

0.00000194 m^3/sec < 0.3325 m^3/s (OK)

CONCLUSION AND SUGGESTION

Conclusion

From the results of the previous discussion in Chapter IV, it can be concluded that the seepage capacity that occurs in the foundation and body of alternative dams 1 (Q = 0.000000105 m^3 /s) and Alternative 2 (Q = 0.00000194 m^3 / second) still meets the conditions set.

Suggestion

From the analysis carried out, it is still necessary to evaluate the analysis. So as to get the results of a representative analysis of the actual field conditions.

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Conflict of Interest: None

Source of Funding: None

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