MODELING OF WATER SEEPAGE AT SINDANG HEULA DAM

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ABSTRACT

A embankment dam is a dam built by stockpiling materials such as stones, gravel, sand, and soil on a certain composition with the function of carrying or lifting the water surface contained in the reservoir [1]. One of the structural safety of a embankment dam is against water seepage. Water seepage that occurs on the slope body during flooding can affect the decrease in slope stability, where the seepage will cause piping symptoms [2]. This study aims to determine the seepage discharge value that occurs in the dam body. The object of this study was Sindang Heula embankment dam in Banten Province. The method used is to conduct an analysis using GeoStudio software with the SEEP/W feature for seepage discharge. Simulation run in two scenarios as steady state condition and transient. Both scenario also run at least on three reservoir water level conditions. They are water level during flood, normal water level and half of full water level. Steady state condition gave seepage flux about 3.773×10^{-6} m^3/sec/m^2 as maximum value. In another hand, 30 days transient simulation gave maximum value about 8.7188×10^{-4} m^3/sec/m^2 and it occurred in small reference time after initial run. This study infomed that SEEP/W has capability to simulate water flux through porous media of embankment dam.

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1. INTRODUCTION

As an agrarian country, Indonesia must have sufficient water resources so that it can be developed and used for cultivation and others. One of the uses of water resources is the construction of dams.

One of the dams in Indonesia is the Sindang Heula dam which is located in the channel of the Cibanten River on the border of Sindang Heula Village, Pabuaran District and Sayar Village, Taktakan District, Serang Regency, Banten. The Sindang Heula Dam is a type of rock dam with an upright core with a total capacity of 9.26 million m3 with a main dam height of 110.163 m and a length of 191.58 m. The benefit of the Sindang Heula Dam is the provision of raw water in the Serang City and Serang Regency areas.

Structural safety in dams must be designed and constructed in accordance with the development of science and technology, safe against structural failure, safe against hydraulic failure, and safe against seepage failure [3]. One of the safety of structures in dams is against water seepage. Water seepage that occurs on the slope body during flooding can affect the decrease in slope stability, where the seepage will cause piping symptoms (the process of engulfing fine soil particles that cause water flow in the slope body). If you experience piping symptoms in the dam, it can interfere with the stability of shear force, stability of rolling force, and soil bearing capacity which can result in avalanches on the slope. [4]

Therefore, this study aims to determine the value of seepage discharge that occurs in the dam body. The value was taken based on the results of material testing on the dam body with the help of Geostudio software analysis.

2. METHODS

The method used is to conduct dam analysis using GeoStudio software with the SEEP/W feature on seepage discharge.

2.1 Seepage

Groundwater flow is one of complex problem in water resources management and infrastructure. The problem is not merely about groundwater resources, but also its mechanisms in porous media, especially in water infrastructure. Groundwater mechanism primarily is driven by its static pressure along the system. Its mechanism can be translated as mathematical model. Numerical methods mostly is applied for solve the model. Many groundwater mechanisms such as seawater intrusion, exploration, seepage and so on were simulated numerically. Seepage as one of groundwater mechanism is driven by mathematical model.

Seepage is reservoir water that finds its way through porous material or a crack both in the body and the foundation, because basically the water stored in a reservoir will tend to find an exit (flow) to the downstream part. Every dam must experience seepage from its reservoir, but the magnitude of the seepage effect on the dam depends on the material of the dam body. Excessive seepage can affect the safety of the dam [5].

Analyzing the seepage capacity in the dam body was carried out using the manual formula and the Geo-Studio SEEP/W program. The governing differential equation for flow through an elemental volume in two-dimensions as described in the SEEP/W documentation is [6]:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) = \frac{\partial \theta}{\partial t} \tag{1}$$

where and are the hydraulic conductivity k_x k_y in the x- and y-directions, respectively, h is the total head, θ is the volumetric water content, and t is time.

For the one-dimensional consolidation discussion here, we will deal only with the flow in the vertical direction (y). The flow equation then becomes:

$$\frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) = \frac{\partial \theta}{\partial t} \tag{2}$$

In a consolidation analysis, equations are generally solved using pore-water pressure instead of total head. The relationship between total head (h) and pore-water pressure (u) is:

$$h = \frac{u}{\gamma_w} + y \qquad (3)$$

where is the elevation and is the unit y γw weight of water. Substituting for h in Equation 2 then gives:

$$\frac{\partial}{\partial y} + \left(\frac{k_y \partial u}{\gamma_w \partial y} + k_y \frac{\partial y}{\partial y}\right) = \frac{\partial \theta}{\partial t} \qquad (4)$$

The elevation is a constant and, therefore, the derivative of y with respect to y is unity. Then:

$$\frac{\partial}{\partial y} + \left(\frac{k_y \partial u}{\gamma_w \partial y} + k_y\right) = \frac{\partial \theta}{\partial t} \qquad (5)$$

$$\frac{\partial}{\partial y} + \left(k_y \left(\frac{1}{\gamma_w} \frac{\partial u}{\partial y} + 1\right)\right) = \frac{\partial \theta}{\partial t} \qquad (6)$$

The safety of seepage at dams follows the Grouting Guidelines for Dams of the Ministry of Public Works and Natural Resources which refers to the limits applicable in Japan (Japanese Institute of Irrigation and Drainage 1988) the value of the permissible seepage rate at the dam is as much as the total seepage from the reservoir that passes through the foundation and the dam body must not be more than 1% of the average river discharge that enters the reservoir [5]. When seepage flows from a finer granular layer to a coarser layer, it is possible for finer grains to escape through the coarser material.

2.2 Geostudio App

GeoStudio is a modeling software for geospatial engineers and geological scientists. The ability to accurately analyze and integrate specialized and applied tools in the fields of geophysical engineering and earth sciences has made this software a good tool among experts in this field [7]. Geostudio is integrated so that it is possible to use the results of one product into another. It is unique and powerful features greatly expand the types of problems that can be analyzed and provide the flexibility to acquire modules as needed for different projects [8].

2. 3 Data Analysis Methods

The data analysis method is used to help the modeling process that will be carried out, it can start from the study of literature, then the modeling process from the geostudio application. After entering all the fluid variables and soil variables. So, the application executes the seepage.

3. RESULTS AND DISCUSSION

3.1 Model Schematics

The Sindang Heula Dam is located on the Cibanten River, precisely in Sindangheula Village, Pabuaran District, Serang Regency, Banten Province. The Sindang Heula Dam after being designed by Geostudio has the following design:

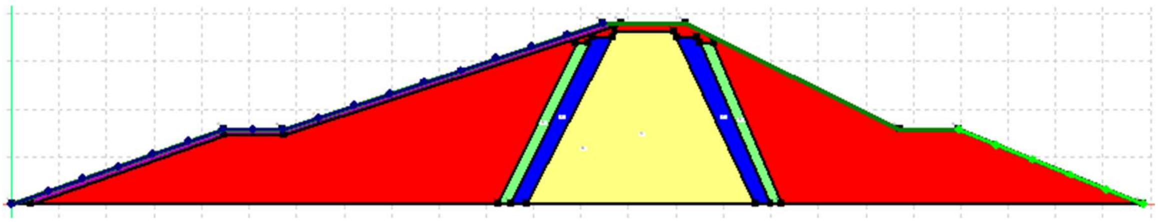

Figure 1. Sindang Heula Dam

3.2 Steady Simulation Results

The results of flood water level seepage, normal water level, half-filled water level and empty water level through the Geostudio application can be seen as blow:

3.2.1 Flood Water Level

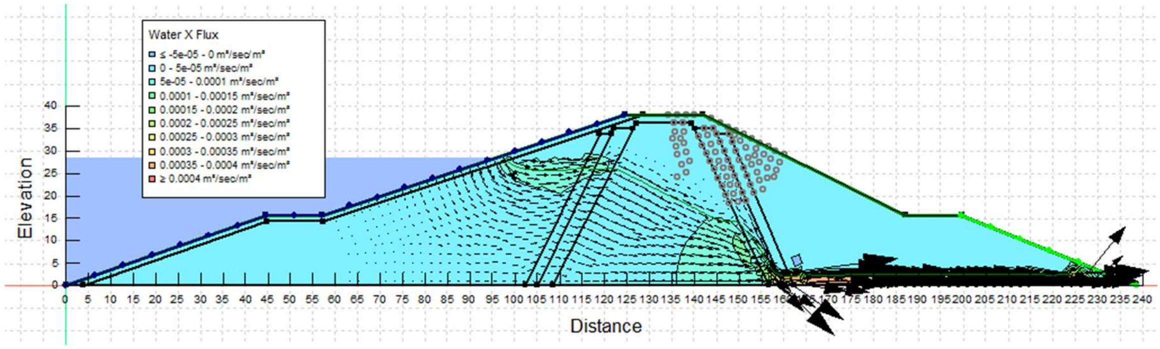

Figure 2. Water Seepage When Water Level Floods

From the analysis that has been carried out, the water flux value for each unit length (q) is 3.773×10^{-6} $m^3/sec/m^2$. Water seepage at the flood water level per unit length is $1.504\times\times10^{-7}$ $m^3/sec/m^2$.

3.2.2 Normal Water Level

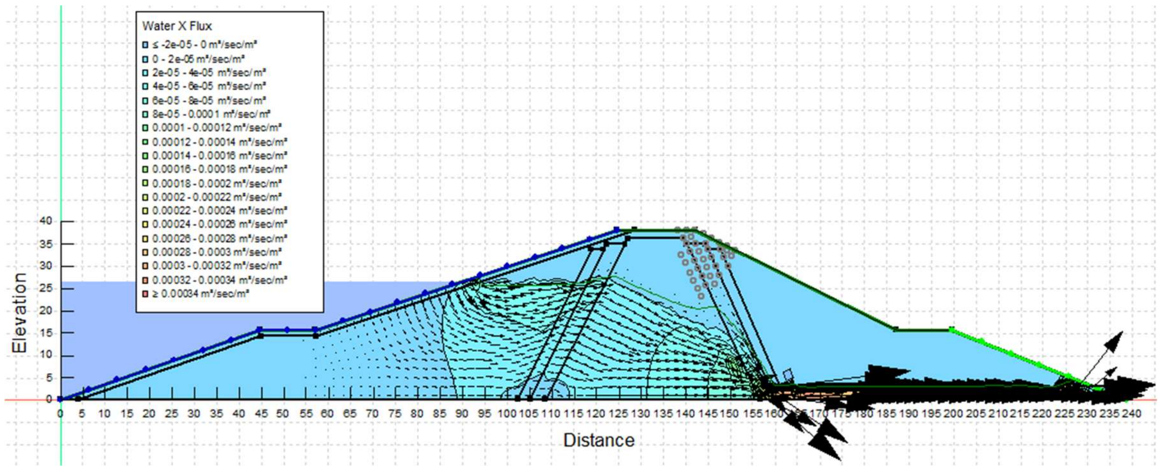

Figure 3. Water Seepage When the Water Level Is Normal

From the analysis that has been carried out, the water flux value for each unit length (q) is 2.867×10^{-6} $m^3/sec/m^2$. Water seepage at normal water level per unit length is $1.431\times\times10^{-7}$ $m^3/sec/m^2$.

3.2.3 Half-Filled Water Level

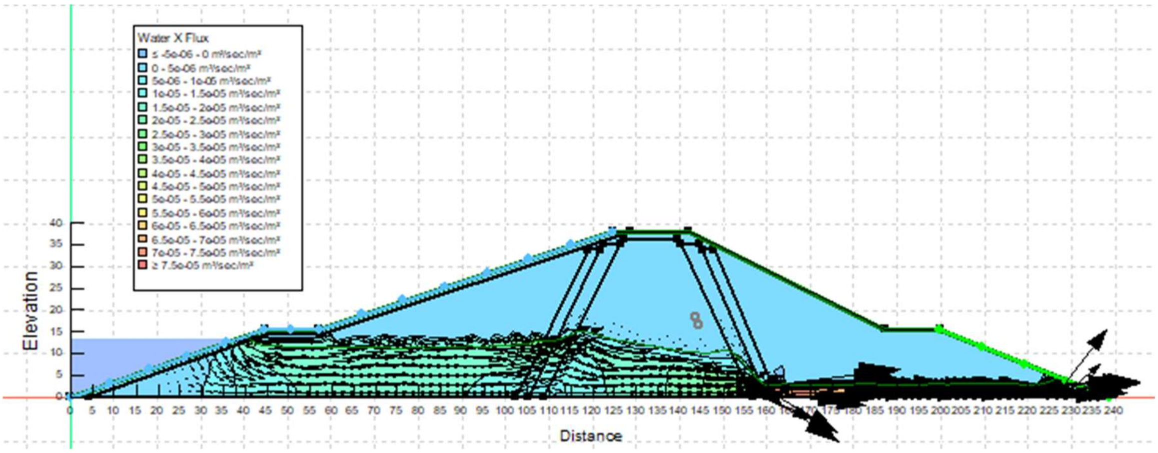

Figure 4. Water seepage when the water level is half filled

From the analysis that has been carried out, the water flux value for each unit length (q) is 6.518×10^{-7} $m^3/sec/m^2$. Water seepage at the half-filled water level per unit length of 4.560×10^{-8} $m^3/sec/m^2$.

3.2.4 Empty Water Level

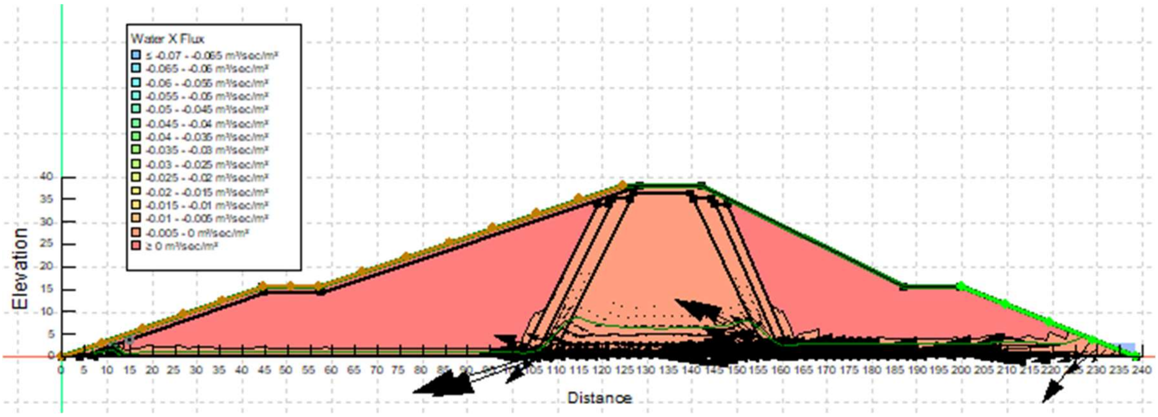

Figure 5. Water seepage when the water level is empty

From the analysis that has been carried out, the water flux value for each unit length (q) is -3.154×10^{-7} $m^3/sec/m^2$. Water seepage at the empty water level per unit length is -1.156×10^{-15} $m^3/sec/m^2$. Because the direction of water seepage at the empty water level is opposite to the Cartesian coordinate line, the result of the seepage is negative.

The recapitulation of water seepage results in steady state conditions can be seen below:

Table 1 Recapitulation of water seepage results under steady state conditions

	Q x flux ($m^3/sec/m^2$)
flood water level	3.37725×10^{-06}
normal water level	2.86716×10^{-06}
half-filled water level	6.51757×10^{-07}
empty water level	-3.15373×10^{-07}

3.3 Transient Simulation Results

The results of the transient simulation (fluid variable changes with time) can be seen below:

3.3.1 Flood Water Level

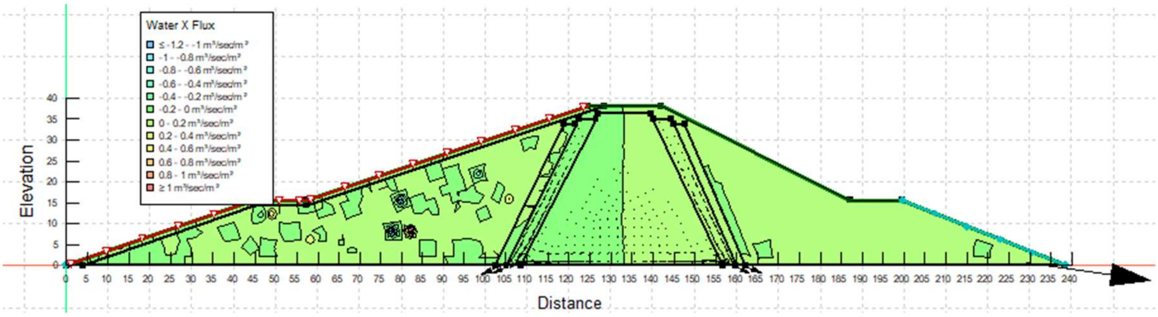

Figure 6. Transient Condition Water Seepage at Flood Water Level in 4.3 Days

Therefore, the maximum flow velocity value of the x direction (Water Flux X) is 1.1477 $m^3/sec/m^2$ and the minimum Water X Flux is -1.0465 $m^3/sec/m^2$. The water flux value for each unit length (q) is 9.6223×10^{-3} $m^3/sec/m^2$. The water seepage at the flood water level per unit length is $3{,}068\times10^{-13}$ $m^3/sec/m^2$.

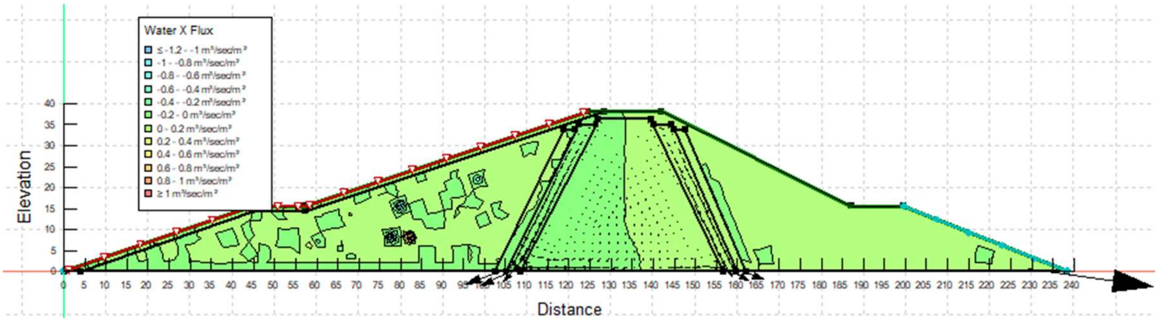

Figure 7. Water Seepage in Transient Conditions at Flood Water Level in 30 Days

Therefore, the maximum flow velocity value of the X direction (Water Flux X) is 1.1517 $m^3/sec/m^2$ and the minimum Water X Flux is -1.0481 $m^3/sec/m^2$. The water flux value for each unit length (q) is 9.6561×10^{-3} $m^3/sec/m^2$. Water seepage at the flood water level per unit length is 1.694×10^{-13} $m^3/sec/m^2$.

3.3.2 Normal Water Level

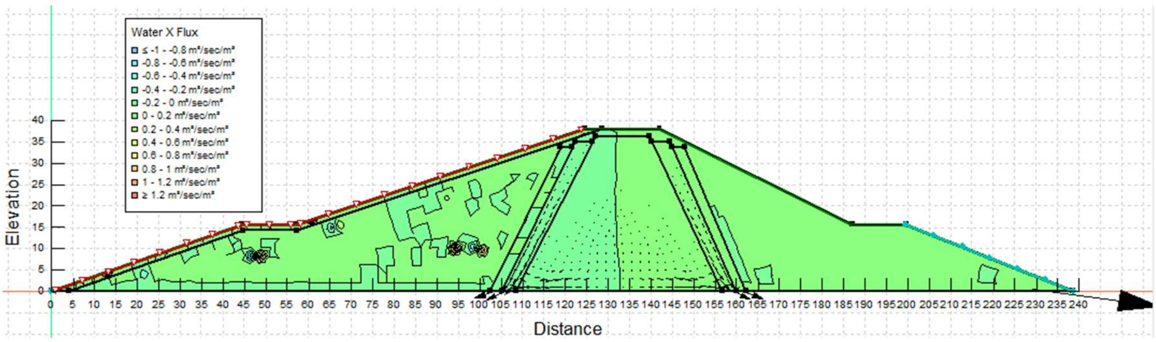

Figure 8. Water Seepage Transient Conditions at Normal Water Level in 1.4 Days

Therefore, the maximum flow velocity value of the x direction (Water Flux X) is 1.4775 m^3/sec/m^2 and the minimum Water X Flux is -1.1602 m^3/sec/m^2. The water flux value for each unit length (q) is 1.2388×10^{-2} m^3/sec/m^2. Water seepage at normal water level per unit length of -1.004×10^{-14} m^3/sec/m^2.

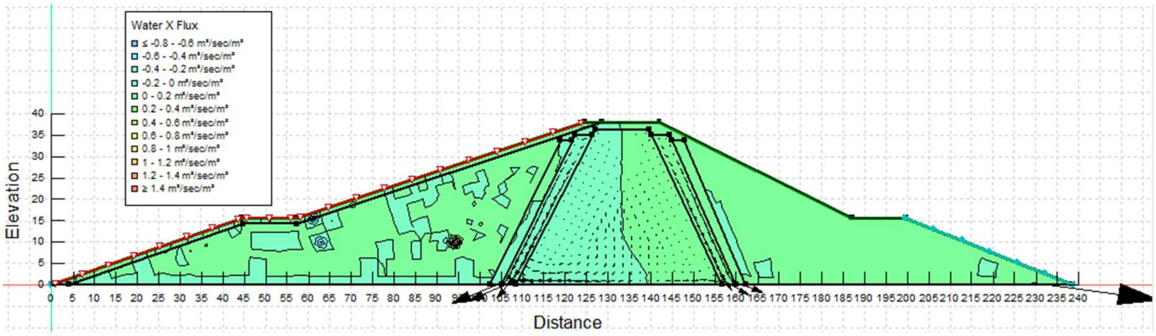

Figure 9. Water Seepage in Transient Conditions at Normal Water Level in 30 Days

Therefore, the maximum x-directional flow velocity value (Water Flux X) is 0.74167 m^3/sec/m^2 and the minimum Water X Flux is -1.0506 m^3/sec/m^2. The water flux value for each unit length (q) is 6.2183×10^{-3} m^3/sec/m^2. Water seepage at normal water level per unit length is -6.809×10^{-15} m^3/sec/m^2.

3.3.3 Half-filled Water Level

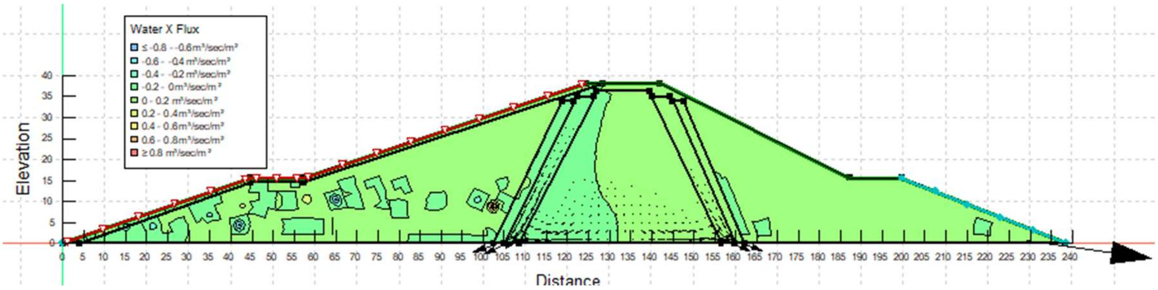

Figure 10. Transient Water Seepage at Half-Filled Water Level in 1.1 Days

Therefore, the maximum flow velocity value of the x direction (Water Flux X) is 0.95242 m^3/sec/m^2 and the minimum Water X Flux is -0.66259 m^3/sec/m^2. The water flux value for each unit length (q) is 7.9853×10^{-3} m^3/sec/m^2. Water seepage at the half-filled water level per unit length is 1.314×10^{-9} m^3/sec/m^2.

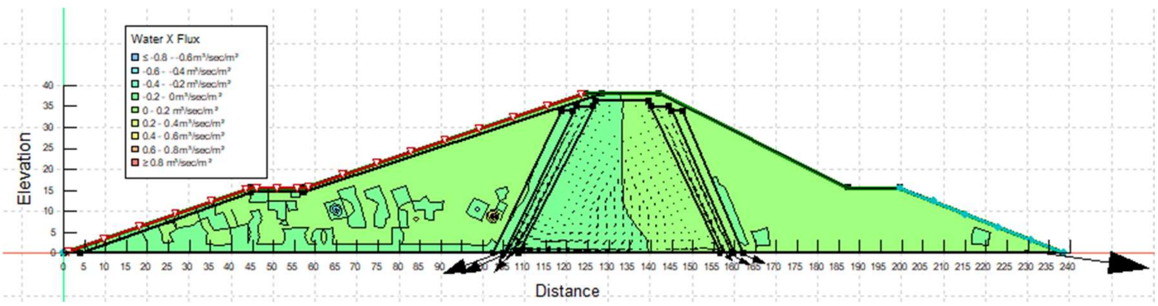

Figure 11. Transient Water Seepage at Half-Filled Water Level 30 Days

Therefore, the maximum flow velocity value of the direction x (Water Flux X) is 0.96237 m^3/sec/m^2 and the minimum Water X Flux is -0.68492 m^3/sec/m^2. The water flux value for each unit length (q) is 8.0687×10^{-2} m^3/sec/m^2. Water seepage at the half-filled water level per unit length is 3.244×10^{-13} m^3/sec/m^2.

3.3.4 Empty Water Level

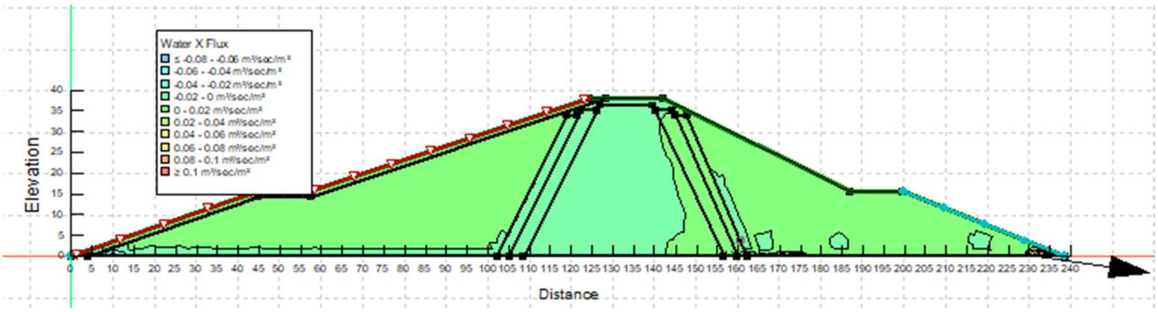

Figure 12. Transient Water Seepage on Empty Water Level in 2.4 Hours

Thus, the maximum flow velocity value of the direction x (Water Flux X) is 0.10399 m^3/sec/m^2 and the minimum Water X Flux is -0.067012 m^3/sec/m^2. The water flux value for each unit length (q) is 8.7188×10^{-4} m^3/sec/m^2. The seepage of water at the empty water level per unit length is -2.046×10^{-13} m^3/sec/m^2.

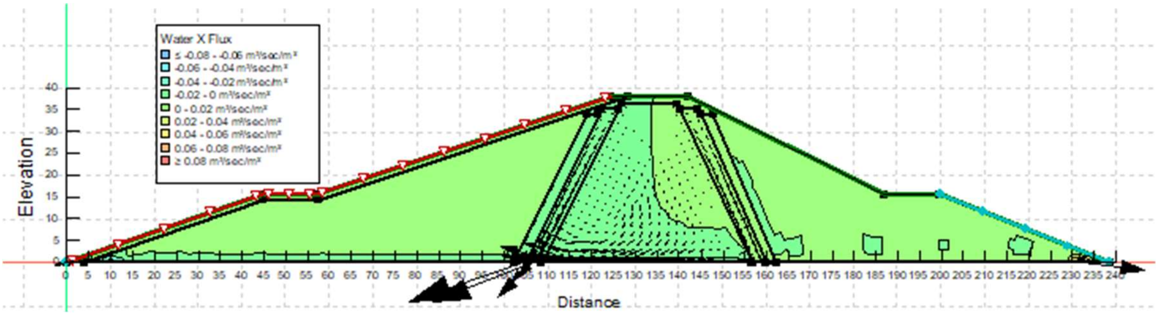

Figure 13. Transient Water Seepage on Empty Water Level in 30 Days

Therefore, the maximum flow velocity value of the direction x (Water Flux X) is 0.089728 m^3/sec/m^2 and the minimum Water X Flux is -0.66089 m^3/sec/m^2. The water flux value for each unit length (q) is 7.523×10^{-4} m^3/sec/m^2. Water seepage at the empty water level per unit length is -4.091×10^{-13} m^3/sec/m^2.

Based on the condition of the water level, it can be seen according to the table below:

Table 2 Recapitulation of Transient Simulation Results

Water Level	Water Flux X Beginning (m^3/sec/m^2)	Water Flux X end (m^3/sec/m^2)
flood water level	9.6223×10^{-3}	9.6561×10^{-3}
normal water level	1,2388×10^{-2}	6,2183×10^{-3}
half-filled water level	7.9853×10^{-3}	8.0687×10^{-2}
empty water level	- 8.7188×10^{-4}	- 7.523×10^{-4}

4. CONCLUSION

The results of the analysis that have been carried out are obtained from the value of water seepage in the steady condition of flood water level of 3.773×10^{-6} m^3/sec/m^2, water seepage at the normal water level of 2.867×10^{-6} m^3/sec/m^2, water seepage at the half-filled water level of 6.518×10^{-7} m^3/sec/m^2, water seepage at the empty water level of 3.154×10^{-7} $m^3/sec/m^2$. The value in the transient simulation on the flood water level on day 4.3 was 9.6223×10^{-3} $m^3/sec/m^2$, on day 30 was 6×10^{-3} $m^3/sec/m^2$. In the transient simulation on the normal water level on day 1.4, a seepage value of 1.388×10^{-2} $m^3/sec/m^2$ was obtained, on the 30th day a seepage value of 3.3137×10^{-2} $m^3/sec/m^2$ was obtained. In the transient simulation on the half-filled water level on the 1.1st day, a seepage value of 7.9853×10^{-2} $m^3/sec/m^2$ was obtained, on the 30th day a seepage value of 8.0688×10^{-2} $m^3/sec/m^2$ was obtained. In the transient simulation on the empty water level at 2.4 o'clock, a seepage value of 8.7188×10^{-4} $m^3/sec/m^2$ was obtained, on the 30th day a seepage value of 7.523×10^{-4} $m^3/sec/m^2$ was obtained.

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