Seepage Analysis Beneath Gravity Concrete Dam Using Flow Net Method and PLAXIS 2D

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Abstract: Dam is a hydraulic structure that built across a river that construct especially for water supply, flood control, energy production, irrigation, recreation, and other. Many problems can occur on the dam construction such as seepage problem, which is seepage need to be controlled in purpose to meet the community's requirement. In this study, the design and seepage analysis of the construction of a dam built on a river with spanning 400 meters which has a water height of up to 12 meters were carried out. The selection of the solution was obtained based on a numerical method using PLAXIS 2D and analytical analysis with the flow net method of seepage discharge Based on the analysis results, the best solution is obtained by making a dam design that suits the needs where the dam is made with a width of 20 m and a height of 20 m and with the addition of a cut-off structure at the foot of the dam on the left and right sides to a depth of 18 m so that the seepage discharge that occurs in less than 500 m^3/day which is meet the community's requirement. This result indicate that a cutoff wall beneath the dam can reduce and control the seepage on a hydraulic structure, but to design the dam with cutoff wall a couple of analysis need to do to predict the seepage which is with the analysis the seepage problem can be handled..

Keywords: Seegape analysis, Concrete gravity dam, Cut off wall.

1. INTRODUCTION

A dam is a hydraulic structure of fairly impervious material built across a river to create a reservoir on its upstream side for impounding water for various purposes [1]. Many problems come to the dams, sometimes the dams have fallen into disrepair and finally face serious safety problems [2]. Dam are mainly divided into two parts based on their structure types: concrete dams and embankment dams [1]. The embankment dam was built from compacted permeable material such as gravel, and coarse or loose sand when used in a dam can lead to heavy seepage, that why the main reason for failures dam at embankment dam is seepage damage to the dam body [3]. To fight this problem, using an impermeable wall is the most existing way to be a dam seepage-proof system such as using a cutoff wall and its anti-seepage effect and it proves this solution can affect the stability of the dam too [4].

Gravity dam was one of the types of concrete dam where the gravity concrete dams are the first barriers in the history of human lives that made generally with roughly triangular cross-section [5]. For a river that has 12 meters high of water and the soil is not strong enough, a gravity concrete dam was chosen in case was the common dam used for a high dam that play key roles in water resources management and of course still uses the cutoff wall to make sure the stability of the dam and meet the community's requirement [6].

The community's requirement such as water supply was affected by seepage, and one of the problems that come is the seepage problem, seepage problems represent a special weight in the concrete dam safety [7]. Seepage is uncontrolled, where the water movement from the upstream go to the downstream is unmeasurable and it makes the seepage causes water loss from the reservoir, as well as erosion and finally causes piping to occur [8], that's why seepage calculation is very important in the design of the dam which need to be paid more attention [9]. But, simulating the flow of water through soil with a numerical model can be very complex which Is a boundary condition often change with time and cannot always be defined [10] and to be honest it's difficult to be master but some numerical analysis software widely used for seepage analysis such as PLAXIS 2D. Flow net us a method that can be used to calculate the seepage flow through the soil which is flow net is a kind of graphic method with two-dimensional seepage analysis [9,11] was explore the effect of downstream filters and cutoff wall with different filters and cutoff parameters [7]. They do a study to investigate and fill gaps explored in earlier research by considering more configurations and sheet pile that affect the uplift pressure and exit gradient with SEEP/W. [1] do a

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analysis to the behavior and the safety of the dam against seepage and a slope stability on a embankment dam. And [12] examined the effect of the cutoff wall and the horizontal drain on the flow discharge under the embankment dams with SEEP/W

In this study has present significant to analyses the best design and seepage behavior through the soil beneath the concrete gravity dam that focus on the effect of the cutoff wall by using a couple of analysis methods such as analytical method and numerical method, especially in high water levels and soft soil. By providing the actual condition of the soil in the site such as coefficient permeability and the applicant the actual condition to calculate with some of the configuration of the dam

2. METHOD

2.1. Field Study

The study site is located in South Melbourne, Australia. This area was a river used for the community's daily activity. The river has a groundwater level of 12 meters from the datum and the spanning of the dam is 400 meters. For water construction, permeability was needed, and the permeability test showed that the coefficient permeability of soil was 0,6048 m^3/day.

Because the community's requirement was 500 m^3/day, a dam must be built to advice the requirement. The dam that was chosen is a concrete gravity dam, it was chosen based on quality and sustainability. The concrete dam will be stronger than an earth dam and the concrete dam cannot pass by water flows and it makes the water just flow to under the dam different with an earth dam, the water can flow through the dam and of course, the concrete dam took more effectivity than an earth dam in this case because the focus was to make the seepage can meet the community's requirement and not pass over it.

First, we know that water can't flow through impermeable material such as concrete, so the question is how the best design for the concrete dam can make the seepage meet the community's requirements. Some configuration is needed to see the best way that can be used. Many things can be done but, in this case, the solution that was used was to append a cutoff wall to the dam. A cutoff wall is a concrete wall that is built beneath the dam to reduce the water flow through it.

The primary focus of this field study was to explore the best cutoff wall that can be used to meet the community's requirement by analyzing the seepage with some of the methods that can provide the result. By employing the actual soil parameters such as the coefficient of the soil the study provides a true reflection of the actual condition at the study site.

2.2. Flow Net Analysis

Flow net was one of the analysis methods that can be used for seepage analysis. When the water level difference between the upstream and downstream of the reservoir remains constant, the seepage is stable so the total head and velocity are only functions of location it's according to Darcy's law and Laplace equation that the water flow of two-dimensional seepage analysis through homogeneous and isotropic aquifer is obtained [9].

The flow net was a combination of a number of flow lines (N_f) and equipotential lines (N_d), where a flow line is a line that connects from upstream to downstream in permeable soil. An equipotential line is a line that crosses along the potential head to all points that equal [13].

A flow net method to calculate the seepage behavior needs to be done with trial and error way, where the design needs to follow some rules like:

1. The equipotential lines can't cut the flow lines
2. The flow net design based on the number of flow channel
3. The equipotential lines can't intersect each other
4. The combination of flow lines and equipotential lines must form a rectangular shape

Darcy's law can be used to calculate the seepage [3], where is:

$$Q = k\ i\ A$$

Q represents the volume of water (m^3/day), k represents the coefficient permeability, i represents the gradient of hydraulic and A represents the area of the section. But the flow net is divided by the N_f and N_d so that the seepage flow can be reached with the formula:

$$q = \frac{N_f}{N_d}\ k\ h\ L$$

In case the dam was spanning along the river, the seepage must be calculated with the real spanning of the section and it is represented by L

2.3. Numerical PLAXIS 2D Analysis

One of the most existing approaches methods used in geotechnical analysis is a numerical method and computer simulations. Numerical approaches such as the finite element method (FEM) that has good efficiency in soil analysis. Considering the behavior of the soil as elastic-linear plastics and the validity of the Mohr-Coulomb failure criterion.

In this case, a numerical method that was used was a PLAXIS 2D. PLAXIS 2D is a two-dimensional analysis software that can be used for stability analysis, deformation, subsidence, compaction, settlement, and leakage in the field of geotechnics. So PLAXIS 2D has been used to evaluate the characteristics of the dam and analysis to investigate the amount of permeability due to the field condition of the dam [14].

The PLAXIS 2D analysis due to the seepage behavior of the dam using a linear plastic and input the coefficient permeability of soil with the focus of calculations to know the value of the seepage flow under the dam.

3. RESULTS

3.1. Seepage Analysis Under Gravity Dams with Flow Net

For the first configuration, the dam was designed with a height of 20 meters, a width of 20 meters, and a depth of 3 meters, the spanning of the dam is 400 meters across the river and the groundwater level is 12 meters.

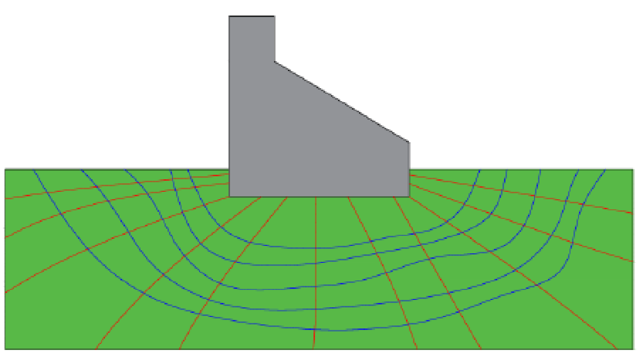

Figure 1a: Desain of the dam for the first configuration.

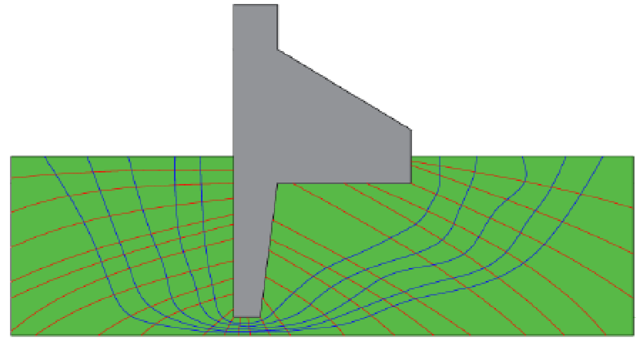

Figure 1b: Desain of the dam for the second configuration.

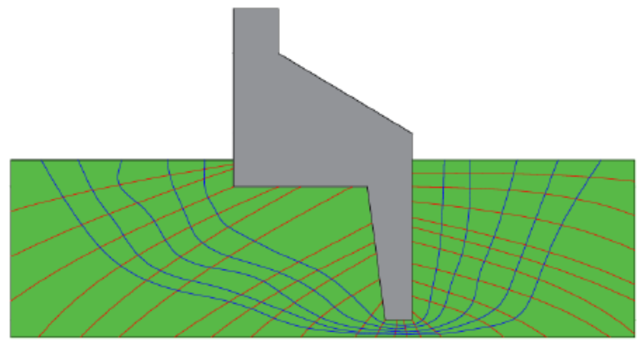

Figure 1c: Desain of the dam for the third configuration.

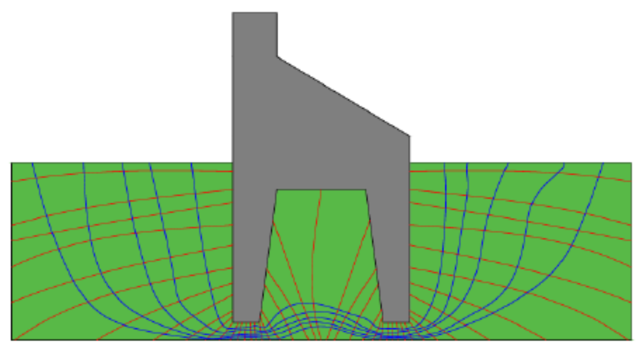

Figure 1d: Desain of the dam for the fourth configuration.

Figure **1** presents the configuration design of the concrete gravity dam and the design for seepage analyses using a flow net. The observations revealed the design with different cutoff walls where is the cutoff wall affects the number of the equipotential lines, the analyses done with the same number of flow lines which is 6 and the number of the equipotential lines for each configuration is 6, 26, 26 and 48. Using the equation for seepage analyses got that the seepage flow result for each configuration is 1451,52 m^3/day, 669,93 m^3/day, 669,93 m^3/day, and 362,88 m^3/day. The fourth configuration can meet the community's requirement.

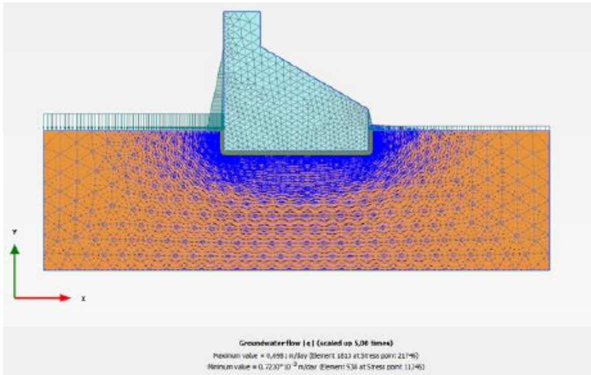

Figure 2a: Desain of the dam for the first configuration.

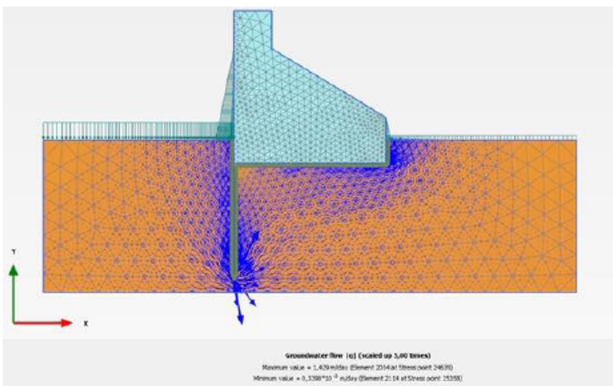

Figure 2b: Desain of the dam for the second configuration.

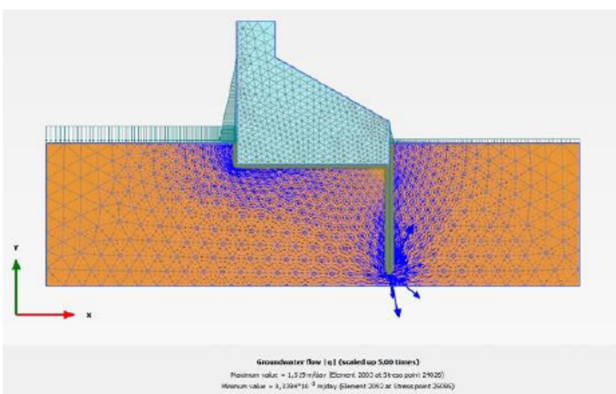

Figure 2c: Desain of the dam for the third configuration.

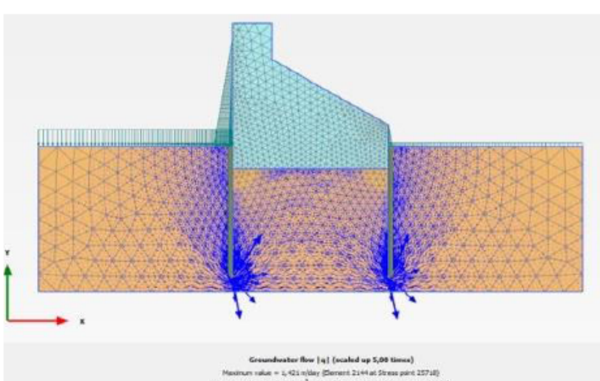

Figure 2d: Desain of the dam for the fourth configuration.

Figure **2** presents the configuration design of the concrete gravity dam and seepage analyses using the numerical method with PLAXIS 2D, where is the seepage flow value for each configuration is 1446 m^3/day, 678,6 m^3/day, 679,6 m^3/day, and 483,6 m^3/day.

4. DISCUSSION

4.1. Seepage Analysis using Flow Net Method

The flow net method is used to study seepage under a theoretical case of a concrete dam like a gravity dam. The study analyzed seepage behavior in a trial-error way: tri-al-errors must follow some rules. Based on the flow net method the groundwater flow is constructed with a flow line and equipotential line.

The flow net is used for some configurations, and we see that the ratio between the flow line and the equipotential line is crucial. If the ratio between the flow line and the equipotential line increases, the seepage flow under the dam increases, too.

Because of that, the flow net's construction belongs to how we design it. As we know, in actual conditions, the groundwater can flow through the void of soil, and it can be everywhere. One of the approach methods we used is flow net, to compare some configura-tions to get a close result, some assumptions must be used. For this analysis, the flow line for all configurations are same, so that the transformation of the dam shape and dimen-sion just will affect the equipotential line.

We know that the seepage flow requirement for the community is just 500 m3/day which means the dam has to overcome the requirement, then we give four configurations to see what the best design can be used. At first configuration, we made it just simply as a gravity concrete dam, and the result of the seepage flow is still higher than the community's requirement.

One solution that can be used is to add a concrete wall called a cutoff wall. As we know water flow can flow through impermeable material such as concrete so if there is a cutoff wall beneath the dam it decreases the seepage flow. However, we must design a cutoff wall that can be used for the requirement. Because we preserve the number of the flow line, the cutoff wall will be affected to the number of equipotential lines which is the cutoff wall will increase the number of equipotential lines make the ratio between the flow line and equipotential lines smaller, and make the value of seepage flow decrease as well.

Four configurations were used and analyzed with the flow net method to know the values of seepage flow under the dam summarized in Table **1**

Table 1: Seepage Flow Under the Dam with Flow Net Method

Configuration	Seepage Flow
Configuration 1	1451,52 m^2/day
Configuration 2	669,93 m^2/day
Configuration 3	669,93 m^2/day
Configuration 4	363,88 m^2/day

That result proved that adding a cutoff wall would decrease the seepage flow, but adding a cutoff wall on one side of the dam still did not meet the community's requirement, when the cutoff wall was added to both sides (upstream and downstream) the seepage flow can reach the community's requirement.

4.2. Seepage Analysis using PLAXIS 2D

PLAXIS 2D is one of the software that can be used to calculate the seepage flow under the dam. In PLAXIS 2D we create modeling of the dam and calculate the water flow and the output of the analysis will be a value of the seepage flow.

The study analyzed seepage behavior through four dam configurations with different shapes (cutoff wall) to recommend the most appropriate configuration based on seepage behavior.

Table 2: Seepage Flow Under the Dam with PLAXIS 2D

Configuration	Seepage Flow
Configuration 1	1446 m^2/day
Configuration 2	678,8 m^2/day
Configuration 3	678,8 m^2/day
Configuration 4	362,6 m^2/day

Table **2** shows the summary of the results from the four configurations and it proves that with the numerical method, the result of the seepage flow would decrease with cutoff addition beneath the dam.

4.3. Comparison of Result From Flow Net and PLAXIS 2D Method

The seepage flow under the dam using the flow net method and PLAXIS 2D is pre-sented in Table **3**. The results revealed both the flow net method and the PLAXIS 2D model.

Table 3: Seepage Flow Under the Dam with PLAXIS 2D

Configuration	Flow Net	PLAXIS 2D
Configuration 1	1451,52 m^2/day	1446 m^2/day
Configuration 2	669,93 m^2/day	678,8 m^2/day
Configuration 3	669,93 m^2/day	678,8 m^2/day
Configuration 4	362,6 m^2/day	362,6 m^2/day

The result shows that the values between the flow net and PLAXIS 2D are not too different whereas the first configuration with a simple gravity concrete dam can't meet the community's requirement even with flow net or PLAXIS 2D. The second and third configurations show that a cutoff wall on one of the sides of the dam, cannot meet the community's requirement because the seepage flow is still higher. But when the cutoff wall was added on both sides, the value of seepage flow was reduced until meet the community's requirement.

5. CONCLUSIONS

Based on the seepage theory, this paper's analysis of seepage under the gravity concrete dam uses a flow net method and a numerical method using PLAXIS 2D. In this case study, the dam needs to meet the community's requirements, and some configurations are analyzed to know how the best solution and design can be used. The final result shows that the gravity concrete dam with 20 meters of height and 20 meters of breadth, spanning 400 meters needs adding cutoff at both sides of the dam (upstream and downstream) until 18 meters of depth to meet the community's requirement which is the fourth configuration. Seepage flow analyses show that the value with the flow net method is 363,88 m^3/day and with PLAXIS 2D is 362,6 m^3/day which means the seepage flow value is below 500 m^3/day so the community's re-quirements are met, so it is best to design configuration in this case.

AUTHOR CONTRIBUTIONS

Conceptualization, M.H.A.P. and V.A.; methodology, M.H.A.P.; software, M.H.A.P.; validation, M.H.A.P., V.A. and N.N.; formal analysis, M.H.A.P.; investigation, V.A.; resources, V.A.; data curation, M.H.A.P.; writing—original draft preparation, M.H.A.P.; writing—review and editing, V.A.; visualization, M.H.A.P.; supervision, N.N., R.N; project administration, V.A.; funding acquisition, V.A. All

authors have read and agreed to the published version of the manuscript.

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Not applicable.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

Data are contained within the article.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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