Numerical Analysis of Seepage in the Bener Dam, Purworejo Regency, Central Java

Thuon Ranysakol[1] Wawan Budianta[1,*] I Gde Budi Indrawan[1]

[1] *Department of Geological Engineering, Universitas Gadjah Mada; Jl. Grafika Bulaksumur No.2, Kampus UGM, Yogyakarta, Indonesia*
[*]*Corresponding author. Email: wbudianta@ugm.mail.ac.id*

ABSTRACT
The earth-fill and rock-fill dam are designed to be used for long-term storage, hydropower, flood control structure. The dam is set to design against failure due to various causes that can result in releasing the water catastrophically to the downstream area as a flood hazard. The consequences of the dam's failure can damage the downstream area infrastructure, properties, and loss of life. One of the main reasons causing the sliding or failure of the body dam is the seepage. The most critical issue induced by seepage is piping, which is internal erosion due to water movement inside the dam's body, which leads to dam structure failure. In terms of piping, dissolution, erosion, and uplift pressure prevention, the design of the dam must impose limitations on the allowable quantity of seepage. The seepage monitoring and control is a significant factor to guarantee that the dam does not collapse. The objective of this study is to analyse the seepage rate which is running through the dam body of rock-fill dam that can affect the stability of the dam. The seepage analysis in this research is applied on the Bener dam, which is the rock-fill dam with the good quality andesitic breccia rock and fair quality andesitic breccia rock used as the shell and core. The research is conducted by computing the Phase2 software. The numerical analysis by Finite Element Method (FEM) is applied in the analysis with the shear strength reduction approach. In this analysis, two different cases of operation, steady-state seepage, and rapid drawdown, are considered. The rapid drawdown is divided into two stages which are the 10 days with a total head of 80 m, and 15 days with the total head of 50 m. As a result, the total seepage through the dam body is 0.00014 m^3/s for the steady-state seepage condition. Whilst the rapid drawdown condition after 10 days, 15 days have the total seepage through the dam body 0.00009 m^3/s, 0.000007 m^3/s, respectively. The strength reduction factor (SRF) for each stage is 3.11, 3.13, and 3.12, respectively. The results from this analysis method indicate that the seepage rate through the dam body is acceptable and will not affect the stability of the dam in both the steady-state seepage and rapid drawdown conditions.

Keywords: *Seepage, Numerical Analysis, Embankment dam, Steady state, Rapid Drawdown.*

1. INTRODUCTION

Embankment dams are the earthen structures that can be formed as earth-fill or rock-fill dams built for multipurpose objectives such as the flood control and water stoppage barrier for agriculture and production the energy [1]. The Bener dam, which will span the flood area of three districts downstream, is slated to be one of Indonesia's largest rock-fill dams. The inundation reservoir is situated on the grounds of three distinct villages, administratively. There are Burat Village, Bener, Gadingrejo Kepil, Wonosobo district, Kemiri Village, Gebang District Purworejo Regency, and Limbangan Village, Guntur. The embankment of main dam body has to be stable against any failure factors. One of the most critical issues in the embankment dams design and construction is the seepage [2].

Around 38% of the causes of embankment dam failure from previous events happened due to seepage [3]. The seepage can flow through the dam body and the dam foundation which have poor permeable material. The most difficult issue created by seepage is piping, which is inside damage effect of water movement inside the dam's body, which leads to dam structure failure [4]. The effects of the failure of the dam will cause the massive destruction, disaster, and loss of human life [3]. Seepage has to be properly controlled in terms of piping, dissolution, erosion, and uplift pressure prevention.

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Satisfactory performance in designing embankment dam have to consider mainly on seepage rate to ensure that dam will not fail or collapse.

This paper presents the study of seepage analysis of the rock fill dam with the numerical analysis by using the computational software. The study is set to estimate how much seepage flow can pass through an embankment or the base of an embankment dam. Moreover, the stability of dam while the seepage flow through the dam body will be also presented in different water level conditions. The Bener dam is chosen to be studied in this analysis.

2. METHODOLOGY

2.1. Research Location

The Bener Dam, which is the research area of this study, is located on the Bogowonto river in Guntur Village, Bener District, Regency of Purworejo, Central Java Province. The dam is situated in the coordinate area (UTM) X = 391256-391782 E and Y = 9160215-9160419 S. For more details, the location can be seen on the project location map in the **Error! Reference source not found.**.

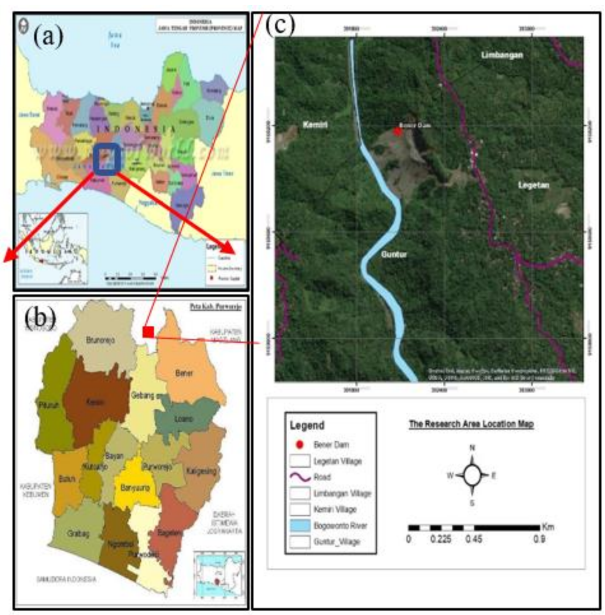

Figure 1 (a) Map of Indonesia showing the location of purworejo regency, (b) Purworejo regency map showing the Bener District, (c) The Location of Bener Dam, Purworejo Regency, Central Java Province (Source: https://www.google.com/maps).

2.2. Research Methodology

2.2.1 Geological Condition

The regional rock units of the research area consist of Alluvium Unit (Qa), the Sentolo Formation Unit (Tmps), and the Kebobutak Formation (Tmok) based on the regional geological map of Yogyakarta [5] as shown in Figure 2. The Kebobutak formation is set to be the dominated formation in this area [5]. This formation unit consists of andesite, tuff, tuff lapilli, agglomerates, and inserts of andesite lava. [4].

Based on [6], the surface rock types investigation in the area of dam are the andesitic breccia and polimik breccia. Andesite breccia is a volcanic rock, and its composition ranges from hypersthene andesite to hornblende-augite andesite and trachyandesite. According to the study of [7], the andesitic breccia is the dominant rock type in this research location. This research was conducted by doing 105 stations of field investigation, mainly the outcrop surrounding the Bener dam area for both upstream, downstream and around the dam facilities area. In addition, surface sample of rock was collected from 35 stations [8]. The result of this research shows that the research area was the andesitic breccia rock type. The research area contains the normal fault along the left bank at the upstream of the dam and two fault lines at the downstream location.

According to [5] the Regional Geological Map of Yogyakarta, Jawa with 1:100.000 scale there is a column stratigraphy indication in the region of our study area which is showed that the regional stratigraphy consists Alluvium, Volcanic Breccia (Qb), Sentolo Formation (Tmps), Jonggrangan Formation (Tmj), Kebobutak Formation (Tmok) and Nanggulan Formation (Teon) in that order from the top. The regional column stratigraphy is described in the Figure 2.

Based on the report of [9], the subsurface sampling was collected from 15 boreholes by conducting SPT test from BBWS (Balai Besar Wilayah Sungai Serayu Opak) [9] indicates that the subsurface and surface rock are also dominated by andesitic breccia rock type. Then the andesitic breccia rock type is perfectly used as the rockfill material for the embankment of dam construction. The influenced parameters to be used in the modelling and analysis of the seepage are the geometry of the slope (the height and slope inclination), the material properties (cohesion, angle of friction, unit weight, and rock quality parameters) in the research area.

Moreover, the engineering geological aspects such as geomorphology (geological surface conditions), lithology (soil and rock), geological structures (rock layer discontinuities, faults, joints), hydrogeological are needed to study geological parameters in the research location [10]. According to [11], the geometry of main dam body has a height of 156 m with a crest of 13.40 m width. The downstream slope inclination is 1:1.4 while the upstream slope inclination is 1:1.5 as shown in the Error! Reference source not found. [11].

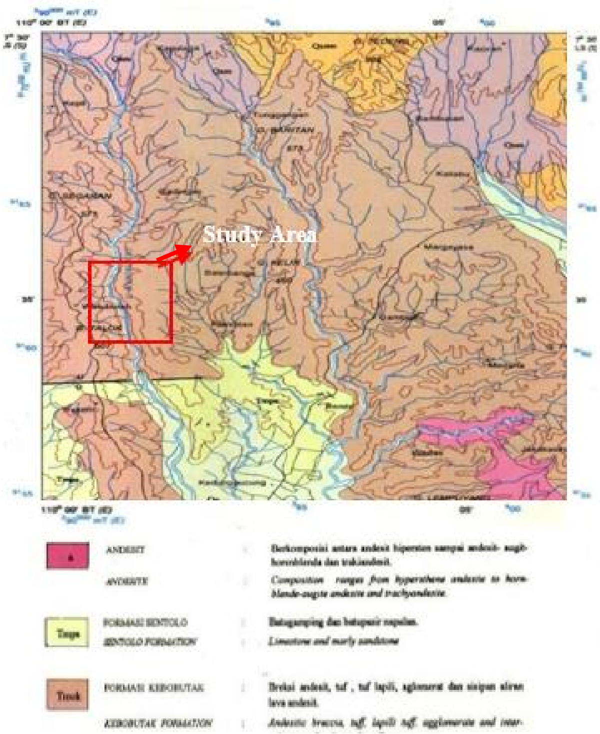

Figure 2 Regional Geological map of the Yogyakarta, Jawa by [5].

Table 1 The Bener dam body material detailed, after [11].

Zone	Classification
1	Rock Foundation from quarry or excavation results. Andesite and/or volcanic breccia, moderately weathered to fresh rock.
2	Concrete Membrane, water proof material
3	Fine filter, manufactured and processed from slightly weathered rock and fresh basalt.
4	Random material, produced and processed from moderately weathered materials.
5	Rockfill transition zone, processed from slightly weathered material to fresh andesite rock.
6	Rockfill from quarry or excavation. Andesite rock, or slightly weathered until fresh rock.

The Bener dam is the zoned rock fill type of dam which is divided into 6 functions of the body such as rockfill, rockfill site, filter transition, impervious layer, membrane concrete, and riprap with the foundation rock below. The zoned classification of the dam is described in the Table 1 above.

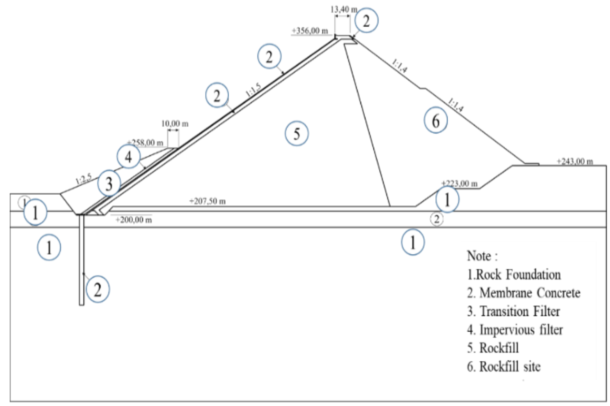

Figure 3. The geometry of Bener dam and the functional zone by [11].

2.2.2 *Seepage in Embankment Dams*

An average compaction with impermeable core widths of 15 % to 20 % of the water head can roll the rockfill dam, which is usually performed if the filter layers are not involved [12]. For this reason, appropriate filters are placed to control the seepage water. The earth-fill dam and rockfill dam may consist of the membrane of metal, concrete, asphalt, or earth-fill as water barriers.

In many cases, the permeability of the rockfill outnumbers that of the relatively impervious core by orders of magnitude. For the sake of drawing a flow net, the presence of rockfill zones can be ignored in such circumstances. Based on [13], The total head loss from upstream to downstream of the dam is determined by using the equation 1 below.

$$Q = k\Delta h \frac{N_f}{N_d}, \quad (1)$$

$per\ unit\ width$ Where: Nf is the number of flow lines. Nd is the number of equipotential lines. Δh is the total head difference k is the permeability coefficient Q Total seepage per unit length. The value such as 1.6 x 10^{-4} m^3 /s/m or 2 % of annual river income suppose acceptable [14].

2.2.3 *Finite Element Method*

The most extensively used approach is the Finite Element Method (FEM) which the entire domain is split into different or elements that are connected by nodes. At these nodal sites, forces and stresses are estimated using a material constitutive model. The combination of all the elements is known as a "mesh" or a "grid" [1]. Moreover, the types and size of elements play a critical part for analyzing to get acceptable outcomes. In case the mesh is too big or too coarse mesh, the results may not be accurate as fine mesh or small mesh. In Finite Element Analysis (FEA), Strength Reduction Method (SRF) is mainly used to obtain the factor of safety (FS) of slope stability problems in terms of using cohesion and the friction angle parameters reduced. These parameters are continuously reduced (by the same number) in small increments until failure occurs.

$$SRF = FS = \frac{c}{c_{reduced}} = \frac{\tan \emptyset}{\tan \emptyset_{reduced}} \quad (2)$$

Table 2 The input parameters of composed materials of the dam for modelling, after [7], [9]

Input Material	Unit weight (kN/m^3)	Young Modulus (MPa)	UCS (MPa)	GSI	Poisson Ratio	Cohesion (kPa)	Friction Angle (°)
Good Andesitic Breccia (Rockfill)	23.978	5458	31.05	72	0.35	-	-
Fair Andesitic Breccia (Rockfill site)	20.601	5458	31.05	51	0.35	-	-
Filter Transition	18.73	50000	-	-	0.4	15840	35.82
Impervious Layer	11.125	50000	-	-	0.4	30.519	15.67
Membrane Concrete	23	50000	-	-	0.4	10000	40
Foundation Rock	23.29	11030	26.121	70	0.35	-	-

2.2.4 *Software Phase2*

Rocscience analyzes the slope stability by using Finite Element Analysis with the software of Rocscience, Inc Phase2 [15]. Phase2 is a two-dimensional plastic finite element program that is used to find stresses and displacements of slope excavation or underground construction and any type of geotechnical engineering project. This software utilizes the SSR approach (Shear Strength Reduction) [16]

The material properties of each dam function are studied by [9]. The results indicate that there are two types of andesitic breccia rock which are the good quality andesitic breccia rock with 72 of GSI value, and the fair quality andesitic breccia rock with 51 of GSI value as shown in **Error! Reference source not found.**. According to [5], the andesitic breccia samples were taken to do a compression point load index (PLI) test which is an index used to know the value of uniaxial compressive strength (UCS) in a rock indirectly in the laboratory which gives the results of rock strength and stiffness parameters of rockfill site in this project as shown in the **Error! Reference source not found.**.

Table 3 The traffic loading values for stability analysis by Indonesian GeoGuides, after [17].

Road Class	Traffic Loading (kPa)
I	15
II	12
III	12

Moreover, the traffic distributed loads of the dam crest have to be considered in the analysis since it will be an external loading effect. Based on [17], the road is designated as road type 1 with 15 kPa. The safety factor of the slope stability analysis must be greater than 1.5, as required in [18], as shown in the Table 3. Three different operational scenarios are addressed in this study: steady-state seepage, rapid drawdown after 10 days, rapid drawdown after 15 days.

3. RESULTS AND DISCUSSION

After gathering the information and the input parameter, we can find the parameters such as shear strength parameter, GSI, Stiffness parameters, and dam geometry. So, we can compute the software Phase2 8.0 for Finite Element Method to get the seepage flow rate through the dam body within 3 different stages which are the steady state seepage, the drawdown after 10 days and 15 days. In addition, we also get to know the stability of embankment slopes by SRF (Strength Reduction Factors). The seepage discharge analysis for the steady-state seepage condition showed the seepage discharge leaked from the upstream to downstream through foundation was 1.4×10^{-4} m^3 /s. Whilst, the seepage discharge analysis for the rapid draw down condition in 10 days and 15 days showed the seepage discharge leaked from the upstream to downstream through foundation was 0.85×10^{-4} m^3 /s, and 0.07×10^{-4} m^3 /s. Table 4 shows the result of seepage quantity in each reservoir condition. The seepage flow rate of all steady-state seepage and rapid drawdown stages are greater than 1.6×10^{-4} m^3 /s of the allowable value of seepage discharge.

The variation of the seepage flow rate comparing to the duration of drawdown of reservoir water is presented in the Figure 4. The result of seepage quantity is acceptable due to the seepage in the dam is in the allowable range. Whilst, the safety factor of embankment slope result is larger than minimum value. These indicated that the probability of safety had exceeded the recommended limit. Thus, the embankment dam was stable during the water drawdown rapidly.

Table 4 Result of seepage and strength reduction factor in different condition of reservoir water.

Reservoir Condition	SRF	Result Seepage Quantity (m^3/s)	Allowable Seepage Quantity (m^3/s)	Status
Steady-State Seepage	3.11	0.00014		
Rapid Drawdown (10 days)	3.13	0.00009	<1.6×10^{-4}	Acceptable
Rapid Drawdown (15 days)	3.12	0.000007		

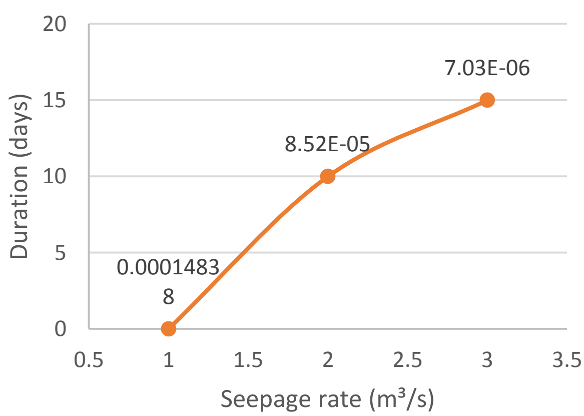

Figure 4. The chart of Total discharge within the duration of drawdown.

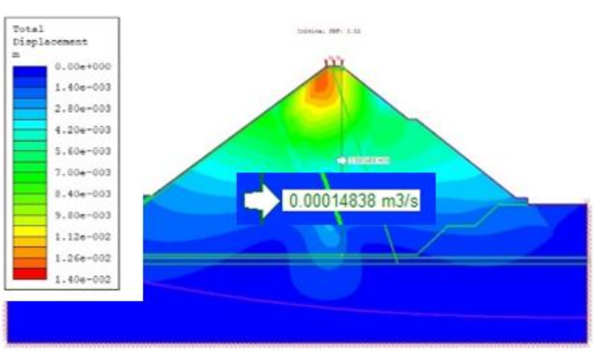

Figure 5. The seepage quantity and displacement at the steady-state seepage condition.

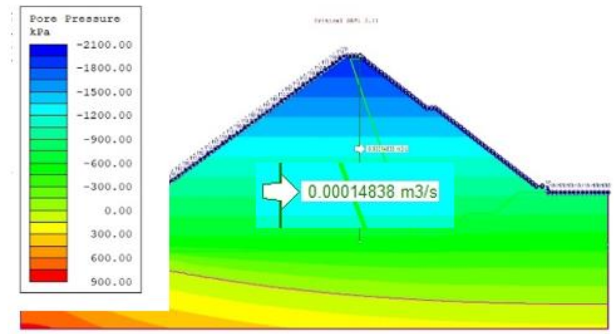

Figure 6. The pore pressure rate and the seepage quantity at the steady-state condition.

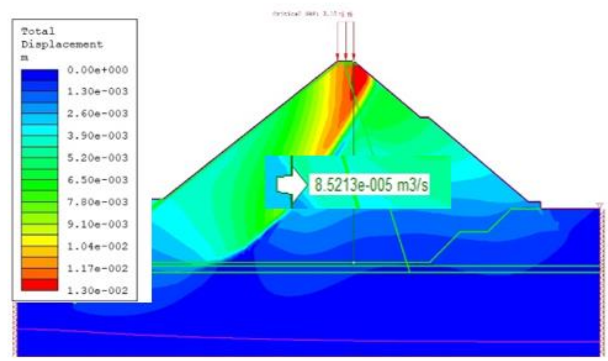

Figure 7. The seepage quantity and displacement at the rapid drawdown after 10days condition.

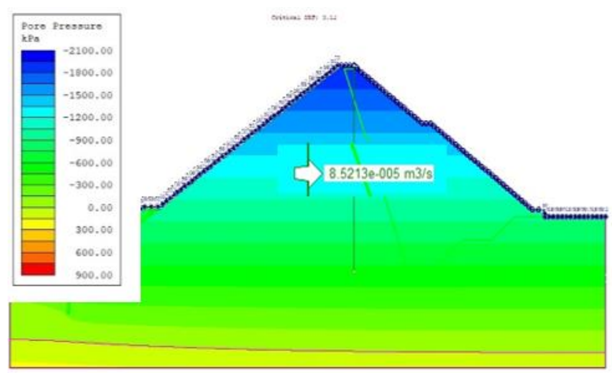

Figure 8. The pore pressure rate and the seepage quantity at the rapid drawdown after 10days condition.

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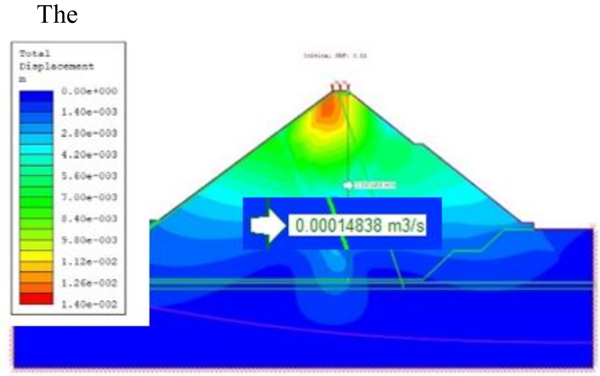

Figure **5** and

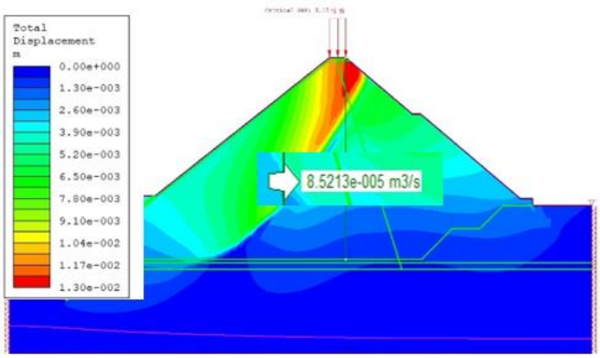

Figure **7** are the illustrations of total displacement of the dam body with the water filling reservoir of 110 m and 80 m in depth, respectively. For instance, the maximum seepage discharge of 110m total head is 0.00014 m³/s. The

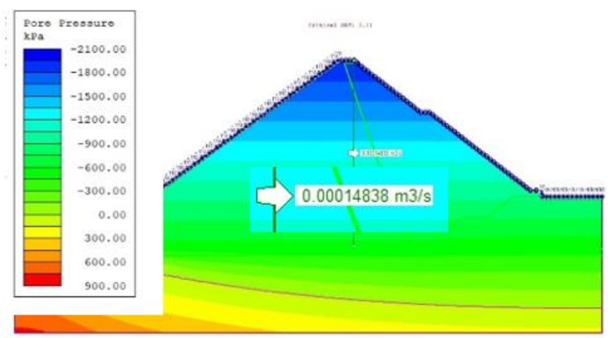

Figure **6** and

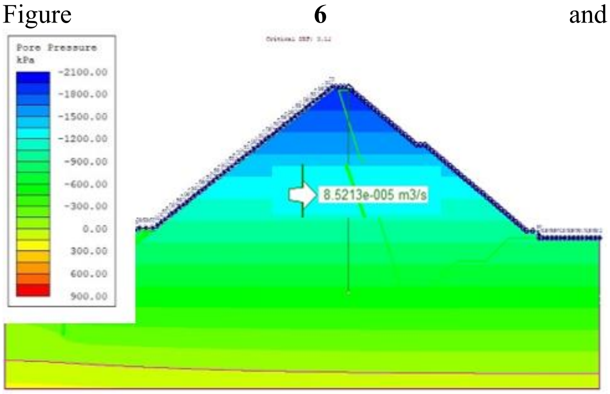

Figure **8** are the illustration of total discharge through the dam body and pore water pressure variation within its depth of the reservoir water level of 110 m and 80 m in depth. For instance, the discharge through the dam body is 0.00014 m³/s, and 0.0000852 m³/s of 110m total head, and 80m total head, respectively.

4. CONCLUSION

The seepage analysis of the Bener dam, a rockfill dam with high quality andesitic breccia rock as the shell and fair quality andesitic breccia rock as the core. The Phase2 software is used to carry out the analysis. With the shear strength reduction approach, the finite element method (FEM) is used in the study. The steady-state seepage of 110 m total head with ponded water load, and rapid drawdown are all evaluated in this research. The rapid drawdown is divided into two stages: 10 days with an 80-meter total head and 50-meter ponded water load, and 15 days with a 50-meter total head and ponded water load. As a result, the total seepage through the dam body is 0.00014 m³/s for the steady-state seepage condition. Whilst the rapid drawdown condition after 10 days, 15 days, the total seepage through the dam body is, 0.000085 m³/s, 0.000007 m³/s, respectively. The strength reduction factor (SRF) for each stage is 3.11, 3.13, and 3.12, respectively. In both steady-state seepage and fast drawdown scenarios, the results of this analysis approach show that the seepage rate through the dam body is acceptable and will not impact the dam's stability.

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