Analysis Seepage Under Pandanduri Dam Body Based on the Electrical Resistivity Tomography (ERT) Survey and the SEEP/W Program

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Abstract. The utilization of water resources for various necessities keeps increasing from year to year, as the impact of the growth of population and the development of the activity. Dams have great benefits and keep great potential danger and risk of physical damage and failure function. This study aims to determine the water discharge that seeps through the body of the dam and the foundation of the Pandanduri Dam. The Electrical Resistivity Tomography (ERT) method uses multiple electrodes to measure resistivity value and pattern distribution on the subsurface material. The finite element method uses SEEP /W software. Seepage analysis was carried out on steady flow (steady seepage) at a reservoir water level of 276.78 m. This research shows that Pandanduri Dam has multiple zones on the dam body with a score of low resistivity of 5 Ω–25 Ω and is identified as a dangerous seepage dam. The analysis results are the seepage discharge below the body dam, calculated with a SEEP/W of 1.204 l/sec, and seepage on the dam must be more minor from a provision of 1% of the annual inflow (3.19 m^3/s), so the seepage discharge maximum allowable is 31.9 l/sec. The full seepage discharge measured in the v notch is 0,88 l/sec. The seepage on the dam is more minor than the permissible seepage discharge, so the seepage discharge through the dam body is safe for the dam.

Keywords: Electrical Resistivity Tomography (ERT) · Pandanduri Dam · seepage discharge · SEEP/W Program

1 Introduction

Pandanduri Dam is a Zonal embankment Dam with an upright core in the main dam body and the cofferdam body [1]. Pandanduri Dam is located in Suwangi Village, Sakra District, East Lombok Regency, and can be used for irrigation water supply. It has a total area of 5,168 ha, of which 2,511 ha are in the Pandanduri area and 2,657 ha in the Suwangi area [1]. There is seepage at the Pandanduri Dam in the tunnel section and saddle dams 2 and 3b, the condition of the leaking water is clear/clear and does not carry sand or other material, so research on the potential for seepage needs to be carried out to explain the possibility that the aquifer at the Pandanduri Dam affects tunnel leakage and seepage under the saddle dam [1].

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The groundwater basin in the research area is located in the Mataram – Selong CAT [2]. Based on Toto Ridwan and Purwanto Sudadi (2000) Hydrogeological Map of Lombok Island and West Sumbawa Island, around the northern part of Pandanduri Dam, there is a moderately productive local aquifer, and the southern part is a productive aquifer [3].

The rock units found on the island of Lombok consist of volcanic, sedimentary, and intrusion rocks whose ages range from Tertiary to Quaternary. Meanwhile, the dam area's rock units and surroundings are groups of Lombok Volcanic rocks whose ages range from the Late Pliocene to the Early Pleistocene and unconformably overlap the underlying formations. This Lombok Volcanic rock group consists of the Kalipalung Formation (TQb), inter-fingering deposited, and the same age as the Kalibabak Formation (TQp). Then the upper part is the Lekopiko Formation (Qvl) which is covered with Alluvium (Qa) [4].

2 Methodology

The measurement of the resistivity value in this study was carried out for ten passes at 6 locations of the Pandanduri Dam. These measurements were carried out using the geoelectric-resistivity dipole-dipole configuration method. The track length is about 120 m to 240 m, using the Resistivity meter MAE X612EM. This instrumentation makes it possible to visualize a pseudo-section preview derived from all data that has just been recorded in the field using a dipole-dipole configuration [5].

Based on the differences in their characteristics, scientists can distinguish the types of rock layers that make up the earth. Information on rock layers below the surface is widely used in various scientific fields such as disaster, geotechnical, and hydrology [6].

Dam seepage analysis was carried out using the finite element method using the SEEP/W software program. Seepage analysis was carried out under steady seepage conditions at normal reservoir water level (NWL). The amount of seepage that occurs (v notch) should be smaller than the amount of seepage calculated [7] (Fig. 1).

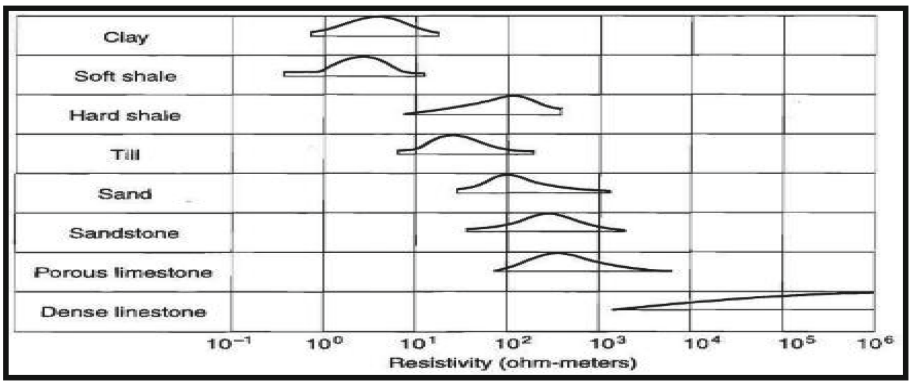

Fig. 1. Resistivity values of several rock types assuming the rock conditions are saturated with water. (Todd & Mays, 2005) [8].

3 Results and Discussion

3.1 Geoelectric Interpretation

The measurement of resistivity values was carried out in 10 passes at 6 locations of the Pandanduri Dam (Fig. 2). The measurements were carried out using the 2D Geoelectric Resistivity method with a dipole-dipole configuration. The results of 2D measurements in the form of cross-sectional resistivity values were analyzed based on their resistivity values to delineate the various rock layers found at the research site (Table 1).

Location 1 is 80 m long on the left hillside of the tunnel; Location 2 is on tracks 2, 3, 4 and 5, 160 m to 240 m long at the top of the dam; location 3 is on track 6, 200 m long on the tunnel path from downstream of the rip-rap dam to the outlet, location 4 on track 7 length 240 m at the downstream location of the dam to the right above the drainage channel, location 5 on track 8 length 240 m around OW-10 downstream of saddle dam 2, and location 6 on track 9 and 10 measurements 240 m at the location under the saddle dam 3b near a residential area there is a dug well that overflows.

Location 1 Track 1 is 80 m long on a small hill to the left of the tunnel. Measurements in this area are possible because of the possibility of seepage through the small hill to the left of the tunnel from the inundation direction into the tunnel channel (Fig. 3). The groundwater can be found in the depth range of 1 m to 12 m below the ground surface. The 2D cross-section stretches in an East-West direction. The resistivity range value at location 1 is 5–750 Ω with an error rate of 3.9%.

The first layer, with rock resistivity values between 5–75 Ω with the dominant color light blue - dark blue, is a layer of wet sandy breccia rock with a thickness of up to 16 m (between elevations 286–280 m). This layer is thought to have aquifer potential with shallow depth, so it can be said to be a type of unconfined aquifer layer. The second layer, with rock resistivity values between 75–250 Ω with light green-yellow-orange colors, is an andesite breccia layer with a thickness of 8 m (between elevations of 282–274 m). This layer

Table 1. Geoelectric Measurement Location

No	Location	Line	Easting	Northing
1	The hill on the left side of the tunnel	Line 1	116.43732167E	8.68418167S
2	Left As Dam	Line 2	116.43694833E	8.68447167S
	Center left As Dam	Line 3	116.43481167E	8.68482833S
	Center right As Dam	Line 4	116.43265000E	8.68515167S
	Right As Dam	Line 5	116.43046000E	8.68548167S
3	Above the tunnel lane	Line 6	116.43673833E	8.68541667S
4	Dam downstream drainage	Line 7	116.43132833E	8.68579333S
5	Downstream saddle dam 2	Line 8	116.43980667E	8.68186833S
6	Downstream saddle dam 3b	Line 9	116.43994833E	8.67734667S
	Downstream saddle dam 3b	Line 10	116.44044167E	8.67746333S

Fig. 2. Geoelectric Measurement 2D. Source: Google Earth Pro, Pandanduri Dam, Lombok Island

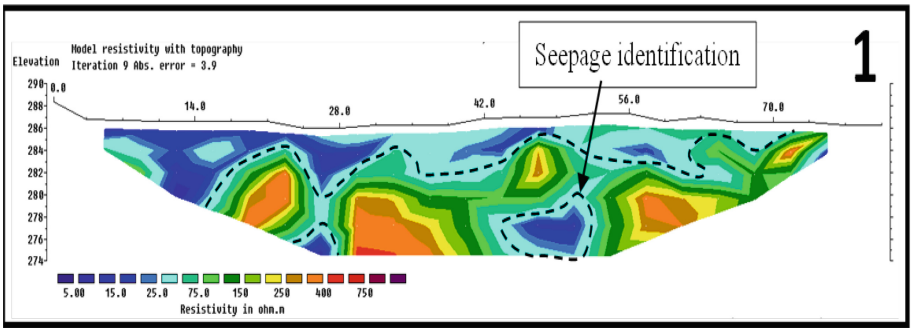

Fig. 3. Location Measurement 1 Track 1

is a type of aquitard/aquiclude due to the rock's impermeable nature. The third layer, with rock resistivity values between 5–25 Ω with a dominant dark blue color, is a type of sandy breccia with medium grain size with a thickness of 4 m (between 278–274 m elevation). This layer is thought to have the potential for aquifers to cause seepage in the dam tunnel.

Location 2 Tracks 2, 3, 4 and 5 lengths 160 m to 240 m at the top of the dam. Measurements of this area indicate the potential for seepage from under the dam into the tunnel channel (Fig. 4). The groundwater can be found at 35 m below the ground surface.

The 2D cross-section stretches in an East-West direction. The resistivity range value at location 2 is 5–750 Ω with an error rate of 1.3%–9.6%. The first layer with rock resistivity values between 5–15 Ω with the dominant color light blue - dark blue, which

is the top layer of the dam with a thickness of up to 20 m (between elevation 290–270 m). The second layer, with rock resistivity values between 75–750 Ω and light green – dark red color, is a layer of dam embankment with a thickness of 40 m (between elevation 280–240 m). It is an impermeable layer. The third layer on the leftmost path, with rock resistivity values between 50–150 Ω with light green - dark green colors, is a type of layer that can drain water with a thickness of 20 m (between 260–240 m elevation). This layer is thought to have aquifer potential, which can cause seepage in the dam tunnel.

Location 3 Track 6 is 200 m long at the location of the tunnel path from downstream of the dam rip-rap to the tunnel outlet. Measurements in this area show the potential for groundwater above the tunnel channel, which can be allowed to enter the tunnel channel (Fig. 5). The groundwater depth can be found between 1 m to 25 m below the ground surface. The 2D cross-section stretches in a North-South direction. The resistivity range value at location 3 is 5–750 Ω with an error rate of 2.7%.

The first layer with rock resistivity values between 5–75 Ω with the dominant color light blue - dark blue, a layer of wet sandy breccia rock with a thickness of up to 30 m (between elevations 285–255 m). This layer is thought to have aquifer potential with varying depths, so it can be said to be a type of unconfined aquifer layer.

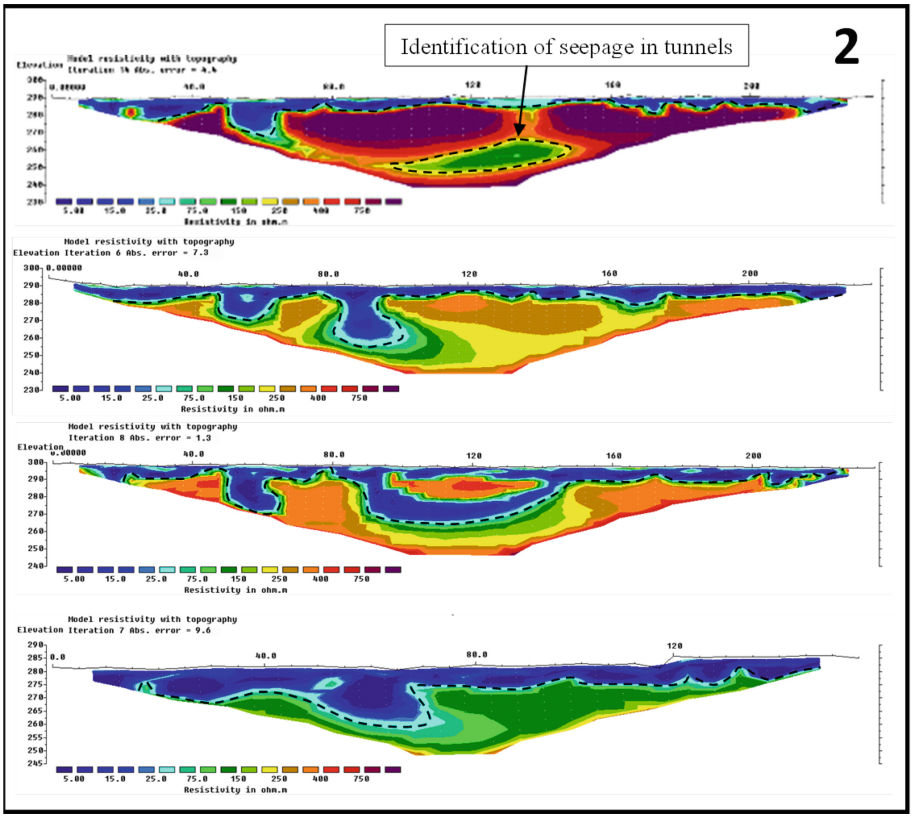

Fig. 4. Location Measurement 2 Tracks 2, 3, 4 and 5

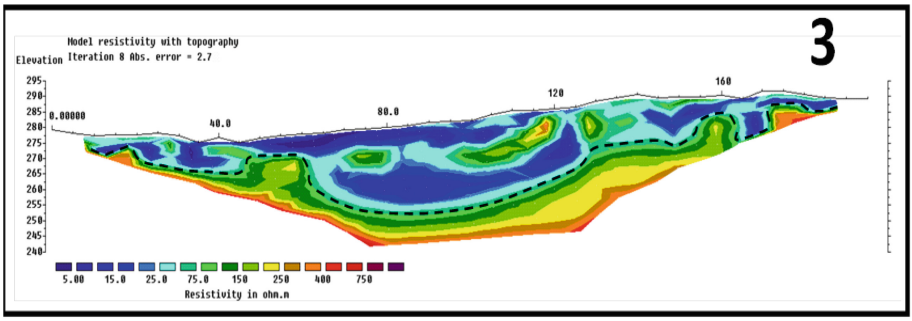

Fig. 5. Location Measurement 3 Tracks 6

The second layer with rock resistivity values between 100–400 Ω with a light green-yellow-orange color is an andesite breccia layer with a thickness of 15 m (between elevations of 255–240 m). This layer is a type of aquitard/aquiclude due to the rock's impermeable. This layer is bedrock with a dam tunnel at the bottom.

Location 4 Track 7 is 240 m long at the downstream location of the dam on the right above the drainage channel. Measurements in this area show the potential for groundwater under the drainage canal to seep into the drainage channel above it (Fig. 6). The depth of groundwater can be found in the depth range of 30 m to below 60 m below the ground surface. The 2D cross-section stretches in an East-West direction. The resistivity range value at location 4 is 5–750 Ω with an error rate of 3.9%.

The first layer, with rock resistivity values between 5–25 Ω with the dominant color dark blue, is a layer of wet sandy breccia rock with a thickness of up to 10 m (between elevations 290–280 m). This layer is thought to have aquifer potential with shallow depth, so it can be said to be a type of unconfined aquifer layer. The second layer, with rock resistivity values between 75–150 Ω with light green–yellow–orange colors, is a compact sandy breccia layer with a thickness of 50 m (between 280–230 m elevation). This layer is a type of aquitard/aquiclude due to the nature of the rock that can pass a limited amount of water. The third layer, with rock resistivity values between 5–25 Ω

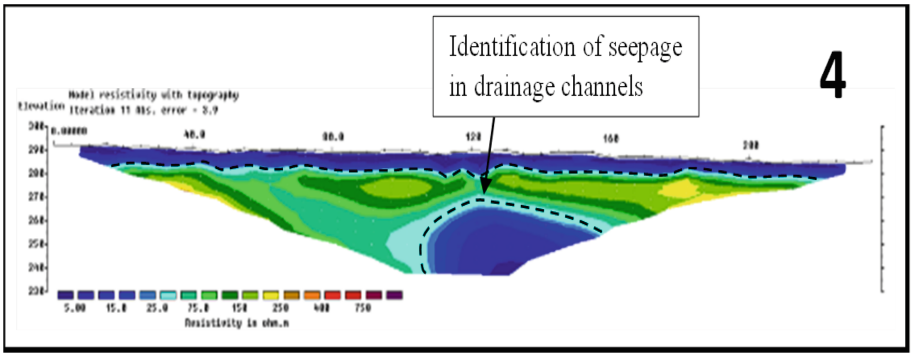

Fig. 6. Location Measurement 4 Tracks 7

with a dominant dark blue color, is a type of sandy breccia with medium grain size with a thickness of 30 m (between 260–230 m elevation). This layer is thought to have the potential for aquifers to cause seepage in the downstream drainage channel of the dam, which is a leaky aquifer layer.

Location 5 Track 8 120 m long at a location around OW-10, under saddle dam 2. Measurements in this area show the potential for groundwater under the OW-10 well that can seep into the OW-10 well so that the OW-10 well drains water to the surface with a discharge of 0.06 l/sec (Fig. 7). Groundwater depth can be found in the range of 15 m to 30 m below the ground surface. The 2D cross-section stretches in a North-South direction. The resistivity range value at location 5 is 5–750 Ω with an error rate of 6.2%.

The first layer, with rock resistivity values between 5–25 Ω with the dominant color dark blue, is a layer of wet sandy breccia rock with a thickness of up to 15 m (between elevations of 270–255 m). This layer is thought to have aquifer potential with shallow depth, so it can be said to be a type of unconfined aquifer layer. The second layer, with rock resistivity values between 75–150 Ω with light green–yellow colors, is a compact sandy breccia layer with a thickness of 50 m (between 265–245 m elevation). This layer is a type of aquitard/aquiclude due to the nature of the rock that can pass a limited amount of water. The third layer on the left side of the track, with rock resistivity values between 5–25 Ω with a dominant light blue color, is a type of sandy breccia with medium grain size with a thickness of 10 m (between 260–250 m elevation). This layer is thought to have aquifer potential that can cause seepage in well OW-10 downstream of saddle dam 2, a leaky aquifer layer.

Location 6 Tracks 9 and 10 are 240 m long at the location below the saddle dam 3b. Measurements in this area show the potential for groundwater under the resident's well so that it can seep in, causing the resident's well to run off water to the surface with a discharge of 0.05 l/sec. The depth of groundwater can be found in the range of 20 m below the ground surface. The 2D cross-section stretches in a North-South direction (Fig. 8). The resistivity range value at location 6 is 5–750 Ω with an error rate of 8.5% and 9.8%.

The first layer, with rock resistivity values between 5–25 Ω with the dominant color dark blue, is a layer of wet sandy breccia rock with a thickness of up to 20 m (between 280–260 m elevation). This layer is thought to have aquifer potential with shallow depth,

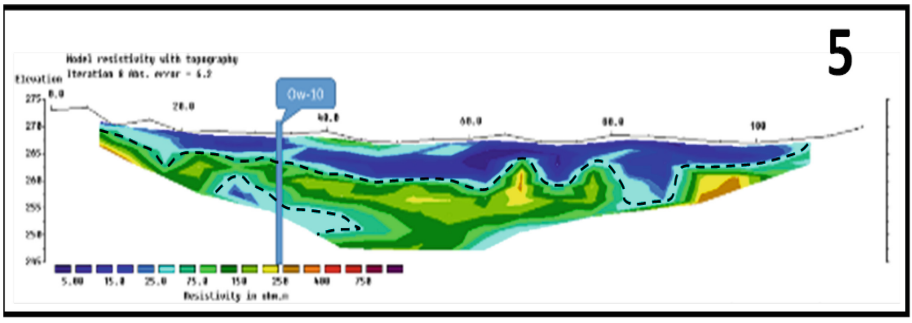

Fig. 7. Location Measurement 5 Tracks 8

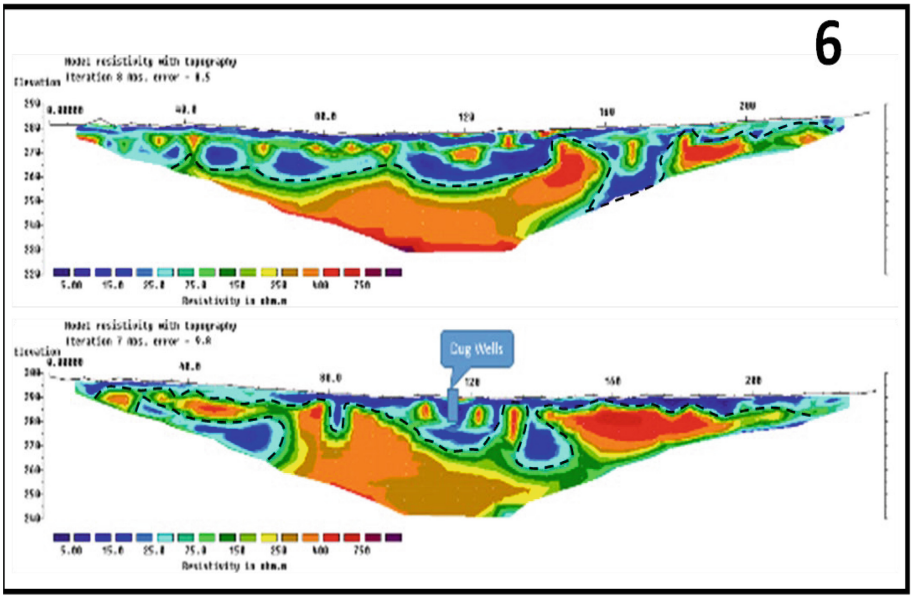

Fig. 8. Location Measurement 6 Tracks 9 and 10

so it can be said to be a type of unconfined aquifer layer. The second layer, with rock resistivity values between 250–750 Ω with yellow-red colors, is an andesite breccia layer with a thickness of 50 m (between elevations 290–240 m). This layer is a type of aquitard/aquiclude due to the impermeable of the rock. The third layer on the left side of the track, with rock resistivity values between 5–25 Ω with a dominant color of light blue – dark blue is a type of sandy breccia with medium grain size which has a thickness of 15 m (between elevation 280–265 m). This layer is thought to have aquifer potential that can cause residents' wells to run off water to the surface. The bottom influences this; an impermeable layer makes groundwater pressured out through residents' wells.

3.2 Seepage Analysis in Dam Body with SEEP/W Software

Dam seepage analysis was carried out using the finite element method using the SEEP/W software program. Seepage analysis was carried out under steady seepage conditions. The material parameters (Table 2) are based on the heap Resume Data from the field test results.

Pandanduri Dam is a zonal type with an impermeable core in the middle, with a height of 42.00 m to the foundation excavation. The upstream slope is 1:2.50, and the downstream slope is 1:2.30. Based on piezometer readings (Fig. 9) dated August 29, 2022.

From the results of the seepage analysis obtained at NWL 276.78 (Fig. 10), the amount of seepage per meter width (water flux) that passes through the center of the dam (STA 0 + 650) is:

$qf = 7.02 \times 10^{-6}$ m^3/sec/ meters wide
MAW Elevation = EL. 276.78 m

Table 2. Pandanduri Dam Material Design Parameters

No	Material	γ dry	γ wet	γ sat	ϕ'	c	K
		(KN/m^3)	(KN/m^3)	(KN/m^3)	o	(Kpa)	(m/dt)
1	Core	12.753	16.785	17.511	16.029	25.000	6.60E−08
2	Fine filter	15.147	17.658	18.796	35.000	0.000	1.34E−03
3	Random	15.676	16.922	17.462	30.940	13.500	2.30E−05
4	Rip-rap	15.696	18.639	19.620	37.000	0.000	4.00E−03
5	Foundation	0.000	27.936	28.127	39.000	0.000	1.00E−04

Source: BWS Nusa Tenggara 1 in the report on Permohonan Sertifikasi Pengisisan Awal Waduk Pandanduri year 2014

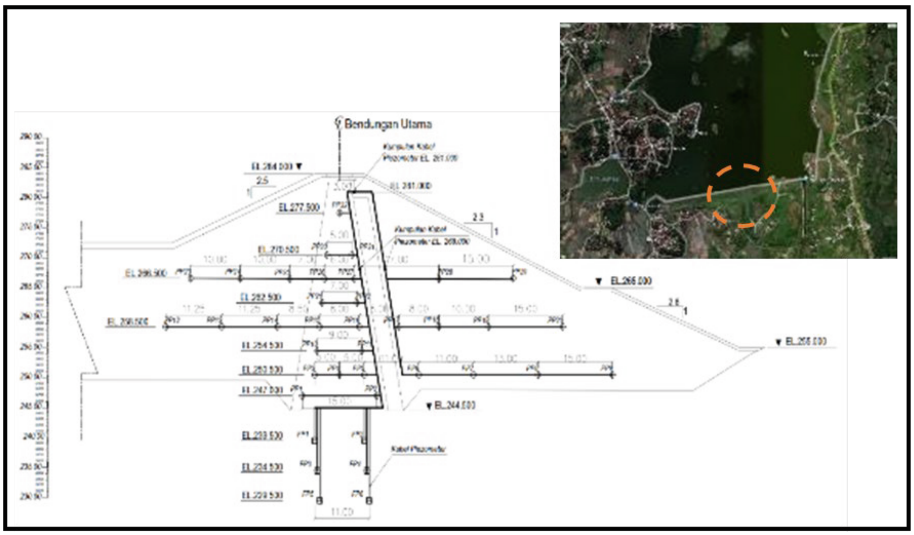

Fig. 9. Pandanduri Dam Piezometer Position STA 0 + 650. *Source: BWS Nusa Tenggara 1 in the report on Permohonan Sertifikasi Pengisisan Awal Waduk Pandanduri year 2014 and* Google Earth Pro

Dam base elevation = EL. 238.145 m
Dam height (H) = EL. 276.78 m – EL. 238.145 m = 38.635 m

Cross-sectional area

lengthening the dam (A) = 6,626.45 m^2 (be measured)

Equivalent width along the dam

(Bek) = A/H
= 6,626.45/38.635

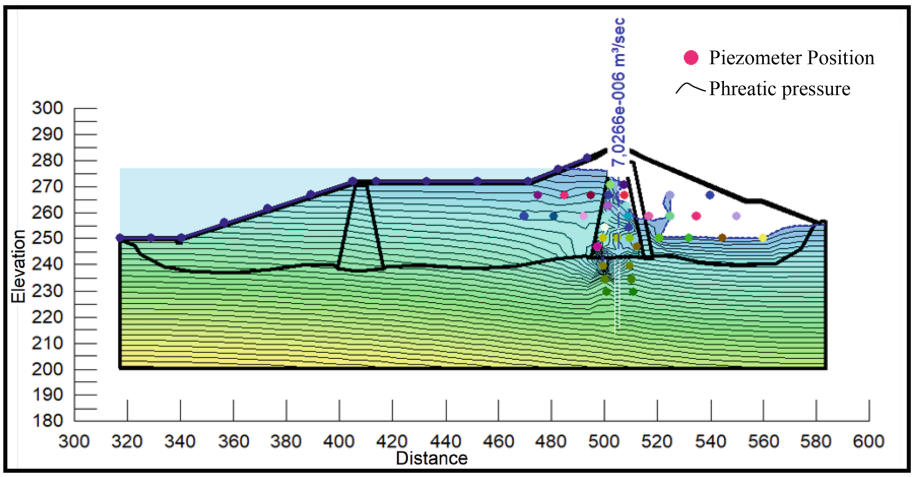

Fig. 10. Seepage Analysis of Pandanduri Dam Body

= 171.5141 m

Amount of seepage through the dam (Qmeasured)

= qf × B ek
= 7.022 × 10–6 m^3/sec/m × 171.5141 m
= 0.001204 m^3/sec
= 1.204 l/sec

From the measurements with a measuring cup on August 29, 2022, the v-notch discharge is 0.88 lt/sec (Qr) at the water level of the El. + 276.78 m

Qr < Qmeasured (ideally)
0.88 < 1.204

Maximum seepage discharge at v-notch before reservoir filling is 0.370 l/sec

Qr < Qmeasured (ideally)
0.370 < 1.204

After filling and operating the reservoir, the maximum amount of seepage discharge measured in the v-notch is 1,253 l/sec

Qr < Qmeasured (ideally)
1.253 > 1.204 (still in range)

Based on the analysis, the amount of seepage through the dam has a conditional value (Qr < Qcount) [8], so seepage through the Pandanduri Dam is eligible. Seepage that occurs in the dam must be more minor than the required provisions, which is 1% of the average annual inflow that enters the reservoir [8], where the yearly average inflow at the Pandanduri Dam is 3.19 m^3/sec, the maximum seepage discharge permitted is 0.0319 m^3/sec or 31.9 l/sec.

4 Conclusions

1. Based on the results of data processing, Electrical Resistivity Tomography (ERT) 2-D Pandanduri Dam has a low resistivity value (<50 Ω) with a sandy breccia lithology, an intermediate resistivity value (50–250 Ω) with a compact sandy breccia lithology, a high resistivity value (250–500 Ω) with andesite breccia lithology, and very high resistivity values (>500 Ω) with compact bolder andesite lithology.
2. Based on the correlation of 2-D Electrical Resistivity Tomography (ERT) data, Pandanduri Dam has two potential aquifers: unconfined and leaky aquifers. Unconfined aquifers are found at shallow depths (about 20 m from the surface) with rock lithology in the form of sandy breccia rocks. The leaky aquifer is considered compact sandy breccia or andesite breccia with an average thickness of about 20 m.
3. Seepage discharge on the body of the dam with the water level elevation of El. + 276.78 m calculated with a SEEP/W of 1,204 l/sec. On 29 August 2022, the v-notch discharge was 0.88 lt/sec. Based on the analysis of the amount of seepage through the dam is below the required value (Qr < Qcount) 0.88 lt/sec < 1,204 lt/sec, seepage through the Pandanduri Dam is eligible.
4. Seepage in the dam must be smaller than the required provisions, namely 1% of the average annual inflow that enters the reservoir where the average annual inflow at the Pandanduri Dam is 3.19 m3/sec, the maximum allowable seepage discharge is 0.0319 m3/sec or 31.9 l/sec. Seepage discharge on the body of the dam with the water level elevation condition of El. + 276.78 m calculated by SEEP/W of 1,204 l/sec, so Qr = 1,204 l/sec < 31.9 l/sec

References

1. Karya, I.: Laporan Akhir Pekerjaan Proses Sertifikasi OP Bendungan Pandanduri, Nusa Tenggara Barat, BWS Nusa Tenggara 1 (not published), p. 266 (2015).
2. Pamsimas: Peta Cekungan Air Tanah Nusa Tenggara Barat https://geochemsurvey.com/download-peta-cat-cekungan-air-tanah-indonesia, p. 1 (2020) (Last accessed June 2022).
3. Toto, R., Purwanto, S.: Peta Hidrogeologi Pulau Lombok dan Pulau Sumbawa Bagian Barat: Departemen Energi dan Sumberdaya Mineral, sekala 1:250.000, 1 lembar, (2000).
4. Andi, M.S., Atmawinata, S., Hermanto, B., Setyogroho, B., Amin T.C.: Peta Geologi Lem-bar Lombok, Nusa Tenggara Barat: Pusat Penelitian dan Pengembangan Geologi, skala 1:250.000, 1 lembar (1994).
5. Hamzah, A.: Modul Geolistrik, Fakultas Teknik Sipil Perencanaan dan Kebumian: Institut Teknologi Sepuluh Nopember, p. 8, (2020).
6. Rusli, M.: Investigasi Potensi Agregat Geoteknik Dengan Metode Geolistrik, Jurnal Promine, 3(1), pp. 36 – 44 (2015).
7. Astuti, Y., Masrevaniah, A., Marsudi, S.: Analisa Rembesan Bendungan Bajulmati terhadap Bahaya Piping untuk Perencanaan Perbaikan Pondasi. Jurnal Teknik Pengairan, 3(1), pp. 51 – 60 (2012).
8. Todd, D.K., Mays, L.M.: Groundwater Hydrology, John Wiley and Sons Inc: New Jersey, p. 652 (2005).