

# Fluctuation Effect of Reservoir Water Level on the Seepage of Earth-Fill Dam

Runi Asmaranto, Dian Sisanggih, Ridho Nur Aziz Rastanto



**Abstract:** Lots of dam failures are the result of uncontrolled seepage. The collapse of the Situ Gintung Dam in Tangerang, Banten-Indonesia in 2009 due to heavy rains caused the dam structure to collapse. This is due to increased pore water pressure in the landfill. To anticipate collapse due to uncontrolled seepage, it is necessary to monitor it based on the behavior of changes in rainfall and reservoir water levels. Seepage within the dam body is often monitored using instrumentation tools such as standpipe piezometer (standpipe piezometer) or electric piezometer. But often the piezometer cannot work properly because it is clogged, so it cannot monitor the condition of the seepage. Other instrumentations such as V-Notch are also used to measure seepage discharge. This study aims to determine the behavior of changes in the reservoir water level caused by changes in rainfall and its effect on body seepage of the earth-fill Type dam. By knowing the phenomenon of the behavior of the relationship between reservoir water infiltration and rainfall, it will obtain information on rainfall that endangers the dam which will affect the downstream. In this study, a case study of the Selorejo Dam was taken which has a large enough reservoir capacity of about 31 million m<sup>3</sup> which is included in the Brantas River Basin. The results showed that 5 piezometers devices were damaged (SL 1, SL 2, SL 4, SL 6, and SL 7) where they could not read the phreatic water level properly, and 2 piezometers were less sensitive to reading fluctuations in reservoir water levels, namely SL 10 and SL 11 which showed R<sup>2</sup> values of 29.78% and 39.4%, respectively. While the maximum seepage discharge is recorded at 1474 liters/minute, this is still below the critical discharge of 1630 liters/minute allowed for this dam, but this needs to be a concern, especially the discharge from toe drain from the left side seepage and C-area which is the leakage from the left support pedestal also contributes a larger discharge than other observation points

**Keywords:** Ngancar Reservoir, Erosion and Sedimentation.

## I. INTRODUCTION

Accurate estimation of the seepage flow through an Earth-fill type dam is important towards the assessment of the safety of the dam. In general, deterministic approaches that consider the soil permeability as a constant for a specific soil

layer are employed to perform the seepage analysis [1] [2]. A lot of dam failures are the result of uncontrolled seepage. The occurrence of the Situ Gintung Dam break in Tangerang, Banten, Indonesia in 2009 due to heavy rains caused the dam structure to collapse. This is due to the increase of pore water pressure in the soil heap [3] Monitoring of pore water pressure in a dam can be used by a piezometer instrument that is mounted on an Earth-Fill type dam [4]. To anticipate collapse due to uncontrolled seepage, then it is necessary to monitor the condition of the piezometer instrument based on the behavior of changes in rainfall and reservoir water level. According to the ICOLD (International Commission on Large Dams), the majority of failed dams either did not have any monitoring system or had a system that was out of order [1] [4]. Thus the soil fill type dam must be monitored regularly and continuously related to hydraulic behavior such as seepage flow and pore water pressure. Seepage within the dam body is often monitored using instrumentation such as standpipe piezometer as well as vibrating wire piezometer. But often the piezometer cannot work properly because it is clogged, so that cannot monitor the condition of the seepage. Other instrumentations such as V-Notch are also used to measure seepage discharge. This study aims to determine the behavior of changes in reservoir water level caused by changes in rainfall and its effect on body seepage of the Fill Type dam, one of which is the Selorejo Dam, located in Malang Regency.

## II. LITERATURE REVIEW

Earth-Fill type dam is a dam made of soil or rock fill which is compacted using a vibrator roller or other compactor on each stretch of the dam body with a certain thickness. Earth-Fill type dams are divided into several types, as shown in Table 1. [6] [8] [10].

### 2.1. Dam Instrumentation

USBR (1987) in Design of Small Dams has explained that Installation of geotechnical instruments in the fill type dam depends on the properties of the soil/rock layer which are influenced by factor of the geological history of soil/rock layers, as well as the time and other loads that work. Design planning must be carried out appropriately, not too expensive, and not potentially causing failure because it can cause loss of material, time, and casualties. Geotechnical parameters that need to be monitored in a soil fill dam construction, both during construction and operation to determine the behavior of the dam, namely seepage, pore water pressure, deformation, seismicity, etc. which affects the safety of the dam and its complementary structures. The purpose of instruments installation on a dam is to monitor the behavior caused by the forces acting on the dam. The monitoring of these instruments is required during construction, initial filling, and during reservoir operation.

Manuscript received on February 06, 2021.

Revised Manuscript received on February 10, 2021.

Manuscript published on March 30, 2021.

\* Correspondence Author

**R. Asmaranto**, Associate professor, Department of Water Resources Engineering, Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia. Email: [runi\\_asmaranto@ub.ac.id](mailto:runi_asmaranto@ub.ac.id)

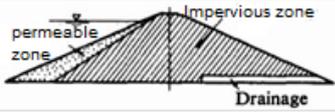
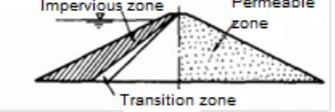
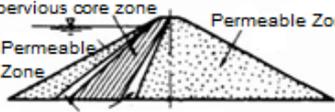
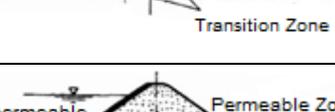
**D. Sisanggih**, Department of Water Resources Engineering, Faculty of Engineering, Universitas Brawijaya, Malang, Indonesia. Email: [singgi@ub.ac.id](mailto:singgi@ub.ac.id)

**R.N.A Rastanto**, Undergraduate Program on the Department of Water Resources, Faculty of Engineering, Universitas Brawijaya, Indonesia. Email: [ridhorastanto@gmail.com](mailto:ridhorastanto@gmail.com)

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

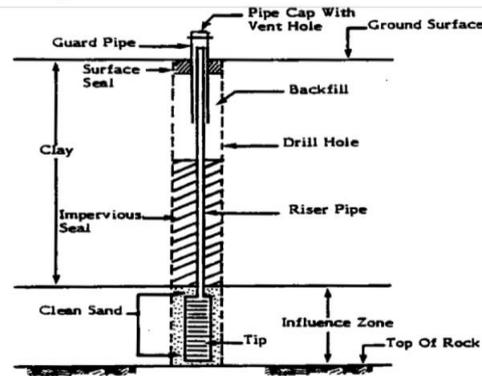
# Fluctuation Effect of Reservoir Water Level on the Seepage of Earth-Fill Dam

**Table 1 Earth-Fill Dam Types (USBR, 1987)**

Type	General Scheme	Information
Homogeneous Earth-Fill Dam		if 80% of all the materials forming the dam's body consist of materials with the same grade (grain size) and impervious.
Zonal Earth-Fill Dam	front core 	If the material that forms the body of the dam consists of material that permeable, but equipped with the impervious layer in the upstream.
	inclined core 	If the material that forms the body of the dam consists of material that permeable, equipped with an impervious core which the position is inclined to downstream.
	Vertical /central Core 	If the material that forms the body of the dam consists of material that permeable, equipped with an impervious core which the position is vertical.
Rock Fill Dam with Membrane/Facing		If the material for the body of the dam consists of water-permeable material, equipped with water-impermeable walls on the upstream, which are usually made of stainless steel sheets, reinforced concrete sheets, concrete asphalt, plastic sheets, etc.

## 2.2. Pore pressure instrument

Pore Pressure Measuring Instrument for stability checking and supervision of earthworks construction, data on changes in pore pressure at a certain place are needed before we can analyze the principles of effective pressure. The basic principle of the operation of the piezometer is that a porous element from the piezometer is inserted into the ground, so that groundwater can enter it and collected in the elemental unit. Measurement of water level or water pressure in piezometer tool can be used to calculate the amount of pore water pressure. Many pore pressure gauges have been developed over the past 4 decades. The piezometer tip is made in such a way, in order could measure the pore water pressure in partially or completely saturated soil layers, in soil compaction work, the plane where the soil meets the walls or pile foundations and in a structure that is subject to dynamic loads. Piezometer can also be used to measure the elevation of the phreatic water level that occurs inside the dam body.

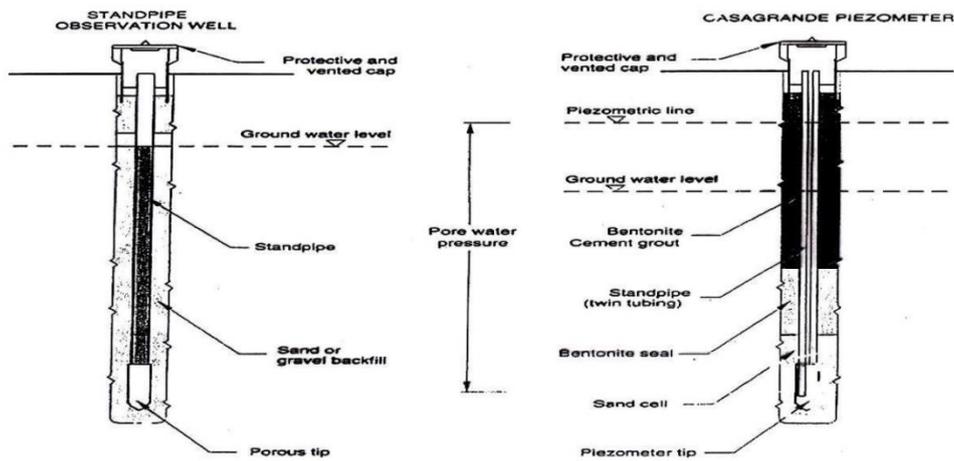


**Fig 1. Open System Piezometer**

Source: Instrumentation Module of Earth-Fill Type Dam of the Ministry of Public Work, 2017

Based on its working principle, there are 2 types of piezometers, namely open systems and closed systems. Types of measuring instruments for open system pore water pressure and groundwater, among others are standpipe piezometer which consists of 1) Porous-tube piezometer, namely the end of the pipe (piezometer tip) in the form of a pipe with porous holes/porous perforations) 2) Slotted pipe piezometer (the piezometer tip from the pipe that is sawed with a certain space) and observation pipe or well (observation well). While a closed system, among others are hydraulic twin-tube piezometer, pneumatic piezometer, and electric piezometer [7].





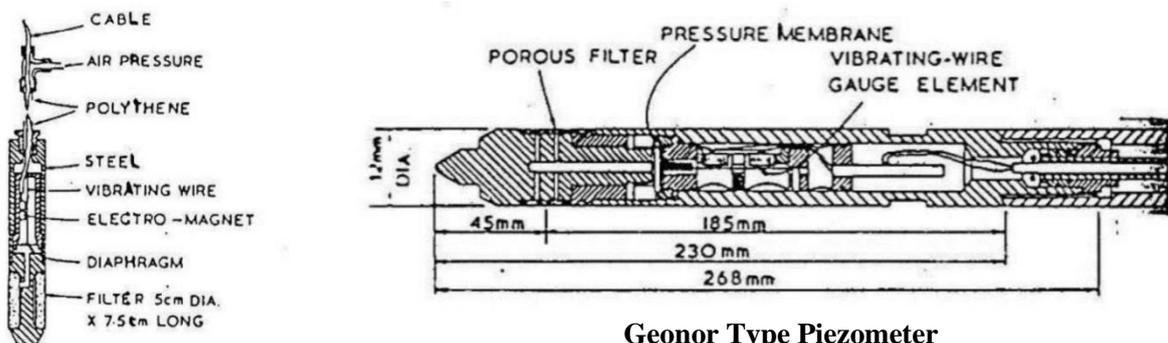
**Fig 2. Principle Difference between Stand Pipe Piezometer and Observation Well**

Source: Module Instrumentation of Earth-Fill Type Dam of the Ministry of Public Works, 2017

**2.3. Vibrating Wire Piezometer**

This type uses the principle of vibrating wire, the same as in load measurement. The pore water pressure that enters through the filter is responded to by the diaphragm that presses the vibrating wire, where the changing frequency is recorded on the reading device, so that changes in pore water

pressure can be known. To avoid damaging the electrical system against the danger of lightning, it is recommended that the cables are wrapped tightly and thickly and then buried into the ground. Installation of the anti-lightning system should be carried out by a competent expert.

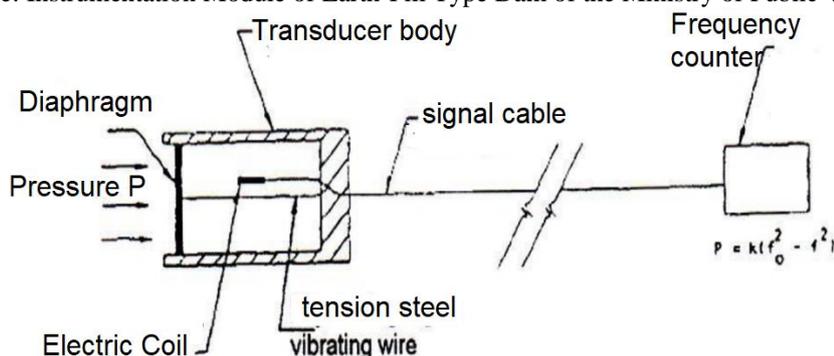


**Geonor Type Piezometer**

**BRS (Penman, 1960)**

**Fig 3. Geonor and BRS type piezometers**

Source: Instrumentation Module of Earth-Fill Type Dam of the Ministry of Public Works, 2017



**Fig 4. Working Principle of Vibrating Wire Piezometer**

Source: Instrumentation Module of Earth-Fill Type Dam of the Ministry of Public Works, 2017

**2.4. Seepage Measurement Instrumentation**

Seepage gauge at Earth-Fill type dams is used to measure the amount of seepage that through, around and under the dam. Monitoring of seepage that arising in downstream is required to assess the behavior of the dam at the time of the first filling of the reservoir. An early indication of potential problems is often expressed with changes in the rate of seepage observed.

In addition, monitoring the concentration of solids level in seepage water can also provide important information.

# Fluctuation Effect of Reservoir Water Level on the Seepage of Earth-Fill Dam

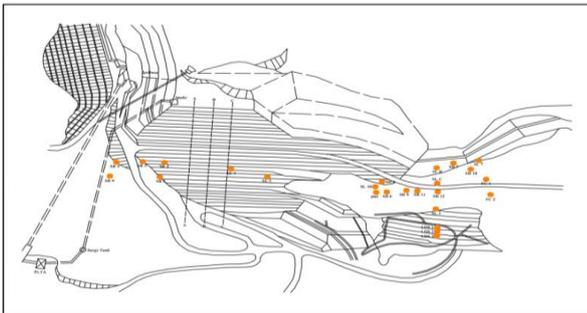
The observations of the seepage rate can be correlated with measurement of piezometric pressure, used to check the effectiveness of drainage channel, suction wells, and wall-barriers. Seepage measurements usually performed during the service life of the dam to monitor the long-term performance. Suction wells, outlet drainage (outlet), channel, and ditches are usually used to measure in places that experience seepage.

Seepage monitoring devices can be divided into two, namely:

1. Flow/discharge rate monitor, this is conducted by installing a "weir" or "flume" which is placed in a certain location to measure the leakage discharge. An abnormal increase in leakage discharge can cause dam safety problems.
2. Water quality monitor, this is done by comparing the quality of water in the reservoir and the quality of water leaking in downstream of the dam. Water sampling must be carried out periodically. To this water samples conducted the test of chemical elements and their sediment levels. The results of monitoring include the following:

- Symptoms of dissolution in rock foundations which can result in shear strength decrease and increase in foundation permeability.
- Symptoms of *piping* on the body or dam foundation.

The seepage measuring device is usually placed in the deepest valley in the downstream of the dam foot. This study observed the behavior of phreatic flow in the body of the Selorejo dam, and measured the seepage discharge that came out of the downstream. the goal is to determine the safety level of the dam against seepage views. Piezometer instrumentation attached as shown in Figure 5 below.



**Fig 5. Layout of the Ground Water Level (GWL) Instrumentation at the Selorejo Dam**



**Fig 6. Location of study**

Source: Operation and Maintenance Manual of Selorejo Dam, 2019

## III. RESULT AND DISCUSSION

### 3.1. Result of seepage analysis

Selorejo dam is located in Jawa Timur Province, including the Brantas River area, as shown in Figures 6 and 7. Figure 8 shows the cross section of the Selorejo dam. This dam was built in the period 1963 - 1970, is a Zonal Earth-Fill type dam from the soil, tuff, sand and sand & gravel with a length of 450 m and a height of 49 m with an Effective storage volume: 54.600.000 m<sup>3</sup> (1970) 30.677.000 m<sup>3</sup> (2016). Type of the dam is a homogeneous Earth-Filling. (Public Work research and development center, 1995). The dam was completed in 1970. The dam is equipped with seepage control instruments in the form of a piezometer and a V-Noch threshold. Until now, 12 of the VWP (vibrating wire piezometer) type piezometers have been installed, totaling 12 of them, but 5 are damaged/not functioning. Meanwhile, 1 piece of V-notch seepage gauge is in good condition. In addition, 25 units of groundwater level (observation well) instrumentation and 21 settlement control units are also provided.



Fig. 7. Citra image of selorejo reservoir

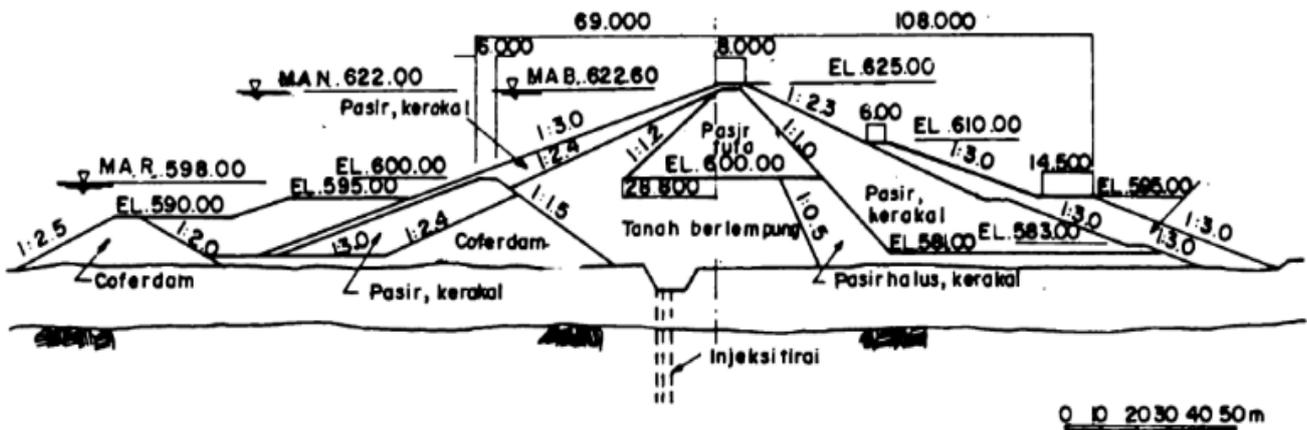


Fig 8. Cross Section of the Selorejo Dam

As it is known that the Selorejo Dam is planned based on the flood discharge with a 1.000 year return period. The results of the flood routing obtained that: 1) Based on the design flood hydrograph  $Q_{1000}$  with a flood peak of  $920 \text{ m}^3/\text{sec}$  (inflow), obtained the maximum reservoir water level (FWL) elevation as high as  $+623,14 \text{ m}$  with a maximum outflow of  $360 \text{ m}^3/\text{sec}$ . 2). While the results of the analysis based on the design flood hydrograph  $Q_{200}$  with a flood peak of  $60 \text{ m}^3/\text{second}$  (inflow), obtained the reservoir water level (FWL) elevation as high as  $+622,60 \text{ m}$  with a maximum outflow of  $260 \text{ m}^3/\text{second}$ . Design Flood from the flood routing results obtained that : 1) Based on the design flood hydrograph  $Q_{1000}$  with a flood peak of  $476,70 \text{ m}^3/\text{sec}$  (inflow), obtained the maximum reservoir water level (FWL) elevation as high as  $+622,90 \text{ m}$  with a maximum outflow of  $320,70 \text{ m}^3/\text{sec}$ . 2) While the results of the analysis based on the design flood hydrograph  $Q_{200}$  with a flood peak of  $267,40 \text{ m}^3/\text{sec}$  (inflow) obtained a maximum reservoir water level (FWL) elevation as high as  $+622,07 \text{ m}$  with a maximum outflow of  $167,20 \text{ m}^3/\text{sec}$ . Echo sounding measurements of Selorejo Reservoir carried out by Perum Jasa Tirta I, namely in 2015, 2016, 2017, 2018 and 2019. As for the comparison graph of volume calculation results based on the results of echo sounding measurements in 2019 is as follows.

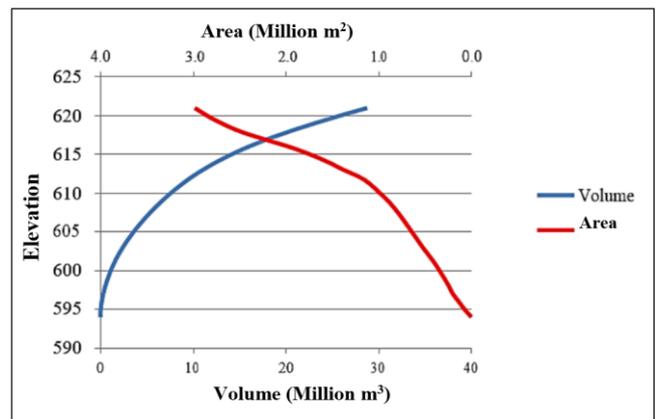


Fig 9. Relation of Water Level Height - Volume - Elevation in Selorejo Reservoir  
(Source: Perum Jasa Tirta, 2019)

Based on the measurement results, it is found that the elevation and volume are as follows :



## Fluctuation Effect of Reservoir Water Level on the Seepage of Earth-Fill Dam

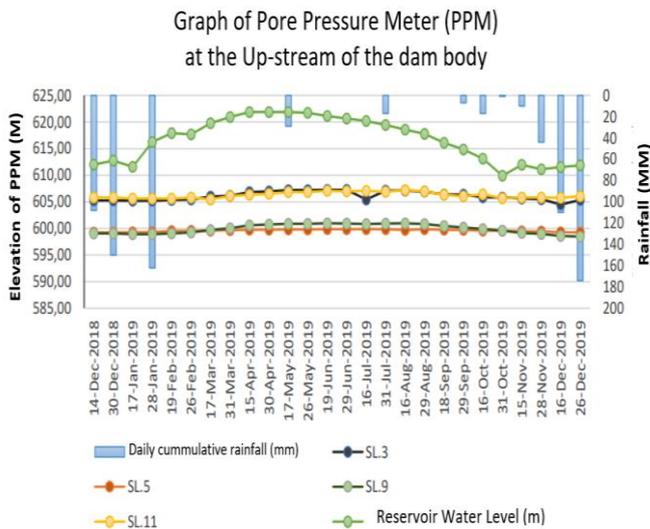
**Table 2. Relation of elevation and reservoir volume**

Elevation	Volume (million m <sup>3</sup> )
LWL +598,00	0,53
HWL+622,00	31,81
FWL +623,14	35,32
Effective Volume	31,27

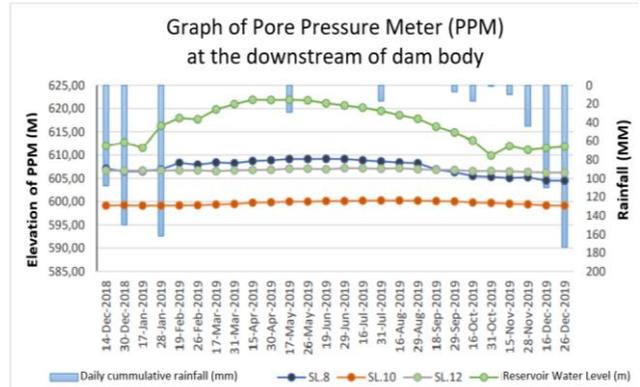
Based on the results of this echo sounding, it can be seen that the storage volume has decreased by 23,33 million m<sup>3</sup> over the life of the dam 50 years, or decreased by 42,73%. This reduction is due to the large rate of erosion and sedimentation in the Konto watershed, which is the upstream of the Selorejo reservoir.

### 3.2. Relationship of Reservoir Water Level Fluctuation with Piezometer

To determine the behavior of changes in rainfall with seepage of the dam body that is monitored on a piezometer, then a graph of the relationship between the two variables is made. The results of data from visual observations for 1 year from December 2018 to November 2019 can be compared with where it can be seen whether in one year there is an anomaly in the piezometer elevation. The piezometer elevation value in December can be analyzed by knowing the data record for one year, meaning that if the data in December still follows the trend line in one year, then it can be concluded that the Pore Pressure Meter is still in a normal/safe condition.. In addition, based on graphic information, it can be seen that changes in rainfall around the reservoir are sufficient to cause changes in piezometric elevation. This means that the piezometer can read changes in reservoir water level fluctuations due to changes in rainfall. However, the response to the increase in rainfall does not directly increase the elevation of the piezometer water level, it takes about 1 month to be read on the piezometer, this is because the travel of depressed / phreatic water in the body of the dam is very slow because it has to pass through the soil media that permeable and the impermeable zone.

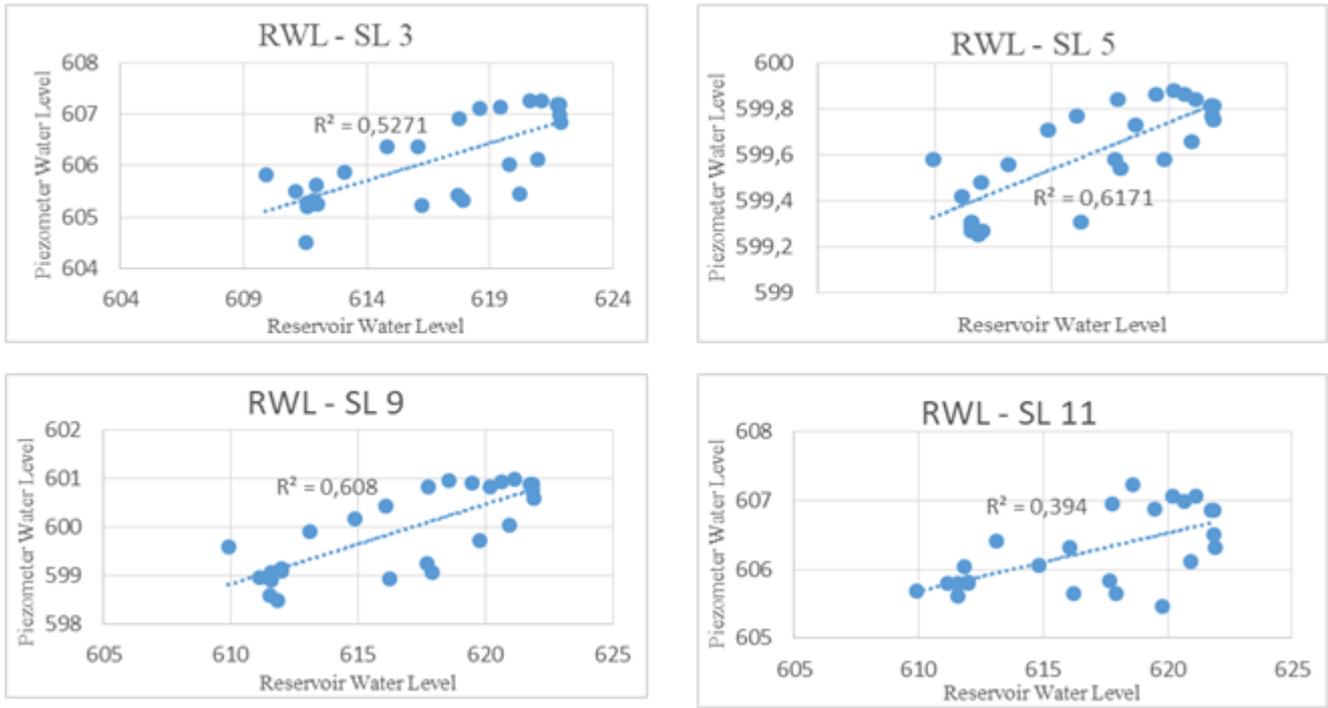


**Fig10. Graph of Pore Pressure Meter (PPM) Measurement Results in the Upstream of the Selorejo Dam Body**



**Fig 11. Graph of Pore Pressure Meter Measurement Results in the Downstream of the Selorejo Dam Body**

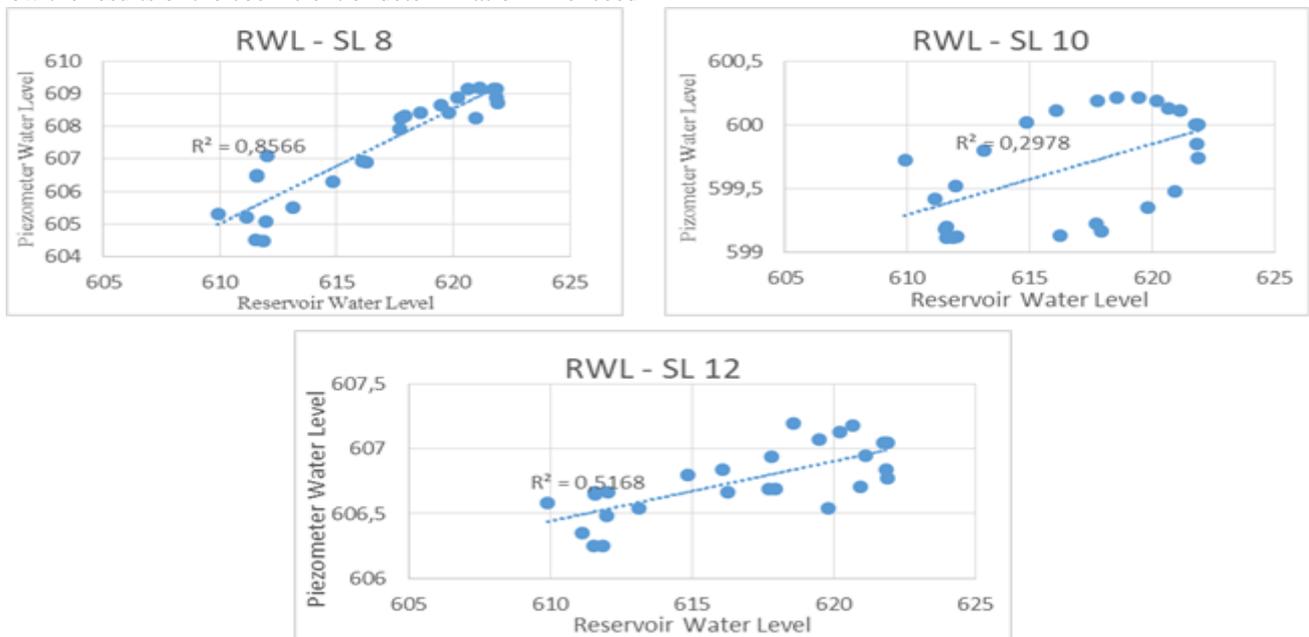
In the upstream and downstream data presented in the graph, it can be seen that the data in December 2019 still followed the existing trend line and was still in safe condition. The highest Pore Pressure Meter (PPM) data for upstream occurred on the measurement on July 16, 2019 with an elevation of +620,20 m also still following the existing trend line so that it was still observed normally. For downstream, the highest measurement occurred on 19 June 2019 with an elevation of +621.13 m also still following the existing trend line so that it was still observed normally. In one year of the measurement of the Pore Pressure Meter, the data monitored was still in normal condition and there were no anomalies. This shows that the phreatic level elevation in the core of the dam is still stable. It can be concluded that the rock composition at the core of the Selorejo Dam is still stable and the seepage at the core of the Selorejo Dam is also in normal conditions.



**Fig 12. The coefficient of determination between the upstream piezometric water level change and the reservoir water level**

The figure 12 above shows the relationship between the reservoir water level which is affected by the rainfall recorded at the pielschal of the dam to the piezometer water level installed on the upstream slope of the dam. Piezometers with numbers SL 3, SL 5, SL 9 and SL 11 show a different behavior where the three piezometers (SL 3, SL 5 and SL9) show the results of the coefficient of determination  $R^2$  exceed

50%, meaning that shows the reservoir water level fluctuation variable has a strong contribution to the piezometer water level variable. Meanwhile, SL 11 has a 39,4% relationship between the two variables, which indicates that the piezometer condition needs to be controlled further during the dam inspection.



**Fig 13. The coefficient of determination between the downstream piezometric water level change and the reservoir water level**

The figure13 shows the relationship between the reservoir water level which is affected by the rainfall recorded at the pielschal dam to the piezometer water level installed on the downstream slope of the dam. Piezometers with numbers SL 8, SL 10, and SL 12 show different behavior where the two piezometers (SL 8 and SL 12) show the results of the coefficient of determination  $R^2$  exceeding 50%, which means that the reservoir water level fluctuation variable has a fairly

strong contribution to the piezometer water level variable. Whereas SL 10 has a 29,78% relationship between the two variables, which shows that the piezometer that is installed also needs to be further controlled during the dam inspection.



# Fluctuation Effect of Reservoir Water Level on the Seepage of Earth-Fill Dam

Seeing some of the damage that exists in the seepage monitoring equipment, especially the filtration flow on the body of the dam, especially at the Selorejo Dam, has shown that several (5) damaged devices cannot read the flow in the dam body, then the dam inspection activities should pay attention to the reliability of the instrument whether it can still function properly.

### 3.3. Seepage Value Analysis of the Selorejo Dam

Based on field observations, there are 9 of catching points locations of seepage discharge that come out of the Selorejo Dam. Monitoring locations and measurement methods are as follows :

**Table. 3. The location for observing seepage and leaks at the Selorejo dam**

No	Name	Location	Category	Measuring instrument
1	Toe drain	Left Abutment	seepage	V-Notch
2	SP-4	Left Abutment	leakage	Container
3	SP-5	Left Abutment	leakage	Container
4	(LA)-1	Left Abutment	leakage	Container
5	(LA)-2	Left Abutment	leakage </td <td>Container</td>	Container
6	(LDS)	Left Abutment	leakage	V-Notch
7	WC-Area	Left Abutment	leakage	V-Notch
8	C-Area	Left Abutment	leakage	V-Notch
9	(RA)	Right Abutment	leakage	V-Notch

The total seepage discharge is the total discharge measured in instruments number 1 to 9 in the table above, where each discharge is measured at the same time in order to obtain the cumulative volume of the catchment per unit time. The results of calculations that show the correlation between the total measured discharge and the reservoir water level fluctuations are shown in the figure.



**Figure 15. The Relation between of reservoir water level and total seepage discharge**

From the figure above, it can be seen that the largest seepage discharge occurred in May 2019 where it was recorded cumulatively at 1474 liters/minute where this discharge was

still below the allowable seepage discharge for the Selorejo dam of  $Q = 1630$  liters/minute. However, it becomes the concern that the contribution of discharge from the toe drain location comes from the seepage of the left abutment and the C-area (left abutment toehold) which is the leakage which contributes to a larger discharge than other observation points.

## IV. CONCLUSION

Based on the results of the above analysis, it can be concluded that several things related to the seepage behavior of the Selorejo dam are as follows:

1. Some piezometers are quite sensitive to describe the behavior of changes in the reservoir water level that affects the phreatic line in the dam body among others the SL 3, SL 5 and SL9 piezometers (attached to the upstream slope of the dam) and SL 8 and SL 12 piezometers (installed on the downstream slope of the dam) all have a value of determination coefficient  $R^2$  that exceeds 50%.
2. Piezometer SL 10 (downstream slope) and SL 11 (upstream slope) show symptoms of less sensitivity with  $R^2$  values of 0,2978 and 0,394 respectively, meaning that it shows a relationship of 29,78% and 39,4% or both of these piezometers are each is strongly influenced by other variables of 70,22% and 60,6%.
3. Based on the results of the evaluation of the condition of the tools in the field, it can be seen that from the 12 piezometer devices installed, only 7 piezometers can be read, the rest, namely SL 1, SL 2, SL 4, SL 6 and SL7 show equipment failure that cannot read properly since 2012 and 2016.

The maximum recorded seepage discharge is 1474 liters/minute, this is still below the critical discharge of 1630 liters/minute that allowed for this dam. However, this becomes a concern for dam managers to make efforts to control leakage that more widely.

## ACKNOWLEDGEMENT

The writer would like to express the deepest gratitude to the Institute for Research and Community Service, University of Brawijaya Malang, for the funding 2020 in conducting research and also thank profusely of Perum Jasa Tirta I Malang, as the manager of the dam for the opportunity to conduct this research.

## REFERENCES

1. Gui S, Zhang R, Turner JP, Xue X. Probabilistic slope stability analysis with stochastic soil hydraulic conductivity. *J Geotech Geoenviron Eng* 2000;126 (1):1–9.
2. Liu, Lei-Lei, et al. "Effects of spatial autocorrelation structure of permeability on seepage through an embankment on a soil foundation." *Computers and Geotechnics* 87 (2017): 62-75.
3. Asmaranto, r., Suryono, A., & Hidayat, M.2019. Inspections of Hydro-Geotechnical on Ngancar Dam. *Civil and Environmental Science Journal*, 2(2), pp.117-127. doi:https://doi.org/10.21776/ub.civense.2019.00202.5
4. Guo, X., et al. "An analytical model for the monitoring of pore water pressure inside embankment dams." *Engineering Structures* 160 (2018): 356-365.
5. Al Islami, Auliya Nusyura, et al. "Analisis Stabilitas Bendungan Selorejo Akibat Rapid Drawdown Berdasarkan Hasil Survey Electrical Resistivity Tomography (Ert)." *Jurnal Mahasiswa Jurusan Teknik Sipil Universitas Brawijaya*, vol. 1, no. 3, 2014.

6. USBR (1987) Design of Small Dams. A Water Resources Technical Publication. United States Department of The Interior, BUREAU OF RECLAMATION. Third Edition
7. Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2017). Modul Instrumentasi Bendungan Urugan Pelatihan Perencanaan Bendungan Tingkat Dasar. Bandung: Kementerian Pekerjaan Umum dan Perumahan Rakyat
8. Sosrodarsono, Suyono. (1989). Bendungan Type Urugan. Jakarta: PT Pradnya Paramita.
9. Perusahaan Umum Jasa Tirta I (2019). *Operation and Maintenance Manual for the Selorejo Dam. Malang: PJT I*
10. Duncan, W., et al. Design of small dams . A water resources technical publication. Final report. No. PB-95-176368/XAB. Bureau of Reclamation, Denver, CO (United States). Engineering and Research Center, 1987.

### AUTHORS PROFILE



**Runi Asmaranto** Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia. Member of Indonesian Association of Hydraulics Engineers (HATHI) and the website of National Committee on Large Dams (INACOLD) (Email: [runi\\_asmaranto@ub.ac.id](mailto:runi_asmaranto@ub.ac.id))



**Dian Sisingih** Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia. Member of Indonesian Association of Hydraulics Engineers (HATHI) (Email: [singih@ub.ac.id](mailto:singih@ub.ac.id))



**Ridho Nur Aziz Rastanto** Undergraduate Program on the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia.