Evaluation Of Seepage Discharge On Jatibarang Dam Based On Instrumentation Data Monitoring

Siswanto, Suprapto

More than 90% of dams in Indonesia are fill type dams (rocks and soil). Rockfill dam has better stability than the homogeneous soil dam. So that it is possible to be made leaner in volume. The disadvantage of rockfill dam lies in the core zone which functions as an *impermeable zone*. Fill type dam failures are usually caused by: *seepage*, *piping, overtopping, hidraulic failure* and *structural failure*. At the fill type dam seepage occupy the first ranks towards the risk of failure. Dam failure is statistically potentially large happened in the first 5 years since i*mpounding*. Geotechnical design and engineering is a major challenge due to the many influential factors. Rock fill dam with zonal core is a combination of various material properties. Geometry and drainage design will affect the seepage and *phreatic line* properties that occur. So it is not easy to make an analysis of seepage with these limitations. Based on the evaluation of the instrument since the impounding period of May 2014 to November 2018, data was obtained that seepage discharge was 648,864 liters/day. The discharge is still below the maximum allowable limit. So it can be assumed that the body of the Jatibarang dam is safe towards seepage that occurs.

Keywords: Seepage, Instruments, Piezometer, V-Notch, Rockfill Dam

1. INTRODUCTION

The needs of raw water are increasing along with the growth of civilization and increasing population. Water resources management must also be seen as something that *integrated, comprehensive and interdependency.* So that the natural resource management must be conceptually and intact [1]. Until nowadays it has been built as many as 213 dams spread throughout Indonesia and many more new dams will be built. This is conducted in an effort to minimize the problem deviation (*too little, too much & too dirty*) of surface water [2]. The acceleration of water resources infrastructure development, through the Ministry of Public Works and Public Housing, has planned the construction of new dams as many as 65 large dams between 2014 - 2019. But in general in terms of age, dams in Indonesia are already over 50 years old [3]. Large dams in Indonesia included in the high risk category which can be a source of disaster. Disaster management must be applied in an integrated manner both pre and post-disaster. Knowing the risks early is one of the important disaster mitigation actions to be carried out [4]. Dam problems caused by seepage occupy the first rank in the assessment of these risk categories [5]. If there is a failure of the dam, then the disaster caused is a flood on a broad scale that will have an impact on infrastructure losses, loss of life and also the environment [6]. There are six main factors causing the failure of the rockfill dam namely: runoff, seepage, pipeline leakage, upstream fill damage, slope stability and other causes (earthquake, liquefaction, sabotage, etc.). Dam failure due to seepage has a risk frequency of 25% compared to the consequences of five other factors. Whereas when viewed from the age of the dam after flooding/ i*mpounding* between 0-100 years, the percentage of failure occurs at the age of 0-5 years dam by 50%. Special for failures caused by seepage during the 0-5 year period also have a risk of 50% [7]. Therefore it is important to carry out periodic and intense monitoring and evaluation of dam safety, especially for young dams [8].

- *Siswanto, Civil Department of Diponegoro University, Indonesia.*
- *Suprapto, Indonesian Committee on Large Dams, Indonesia.*

2. DATA AND METHODS

The condition of foundation and geology of the dam base are substantial to the seepage and stability of the dam. Jatibarang is in the active fault of Semarang. The stratigraphy composition of the Jatibarang dam based on a lithostratigraphic sequence from old to young namely resin tuffan sandstone unit, resin breccia unit and alluvial deposit unit. The geological structures that develop in the form of faults and fractures among others the Sekaran vertical fault and Gribiksari horizontal fault. From the results of the analysis it was found that the type of fault in the form of left vertical fault and right horizontal fault [9]. Based on the geological data led the jatibarang dam prone to seepage with (lugeon value > 5) and foundation engineering is necessary even though the stability of the foundation is quite good [10]. Seepage on homogeneous soil fill type dam are influenced by the material permeability coefficient (k), upstream/downstream slope (i) and *total head (h)* [11]. Building a dam in a fault area can increase the risk of seepage even though its stability is considered sufficient. But efforts of the foundation improvement with the application of cutoff wall show better results in seepage handling compared to upstream blanket and curtain grouting [11] [12]. Uncontrolled seepage and phreatic lines have a major effect on slope stability of the dam body especially when rapid draw down [13].

Jatibarang Dam is the central core rockfill type dam (**Error! Reference source not found.**). The dam which has a height of 77 m with a length of 200 m has a capacity of 20,4 million m^3. The dam construction began on October 15th, 2009 and was completed on May 5th, 2014 while at the same time the impounding phase began. The operational certification of this dam obtained on May 11th 2015[14]. The main uses of this dam is as flood control (230 m^3/sec) and also the raw water supply of the Semarang City Local Water Company amounting to 1.050 liters/sec with the development of 1.000 liters/second.

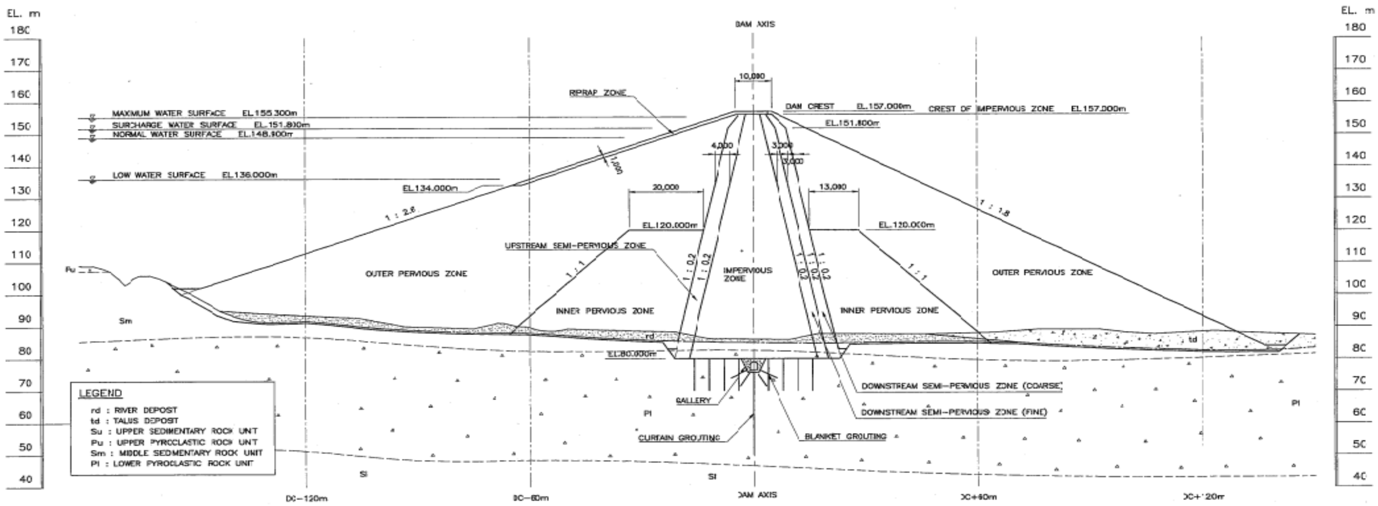

Fig. 1 Typical Section of Jatibarang Dam

The analysis used in this study is the evaluation of the results of instruments reading which installed on dams for a certain period with a maximum safety number set according to technical or design requirements. So that not conducted re-modeling with various boundary conditions scenarios.

2.1 Seepage

When the dam operates, seepage can occur inside the dam's body. There are at least two dangers, namely seepage and also the decreasing stability of the dam body. Dam stability decreases due to increasing pore water pressure inside the dam's body, so that shear strength (cohesion and shear angle) between soil particles increases so that the stability decreases [15]. Therefore, besides choosing the right material, the geometry design and drainage selection also affect the safety of the dam towards the danger of seepage. Basic calculation as seepage analysis lies in the impermeable zone. Seepage analysis is done by drawing the seepage line (phreatic line), which can be seen in **Fig.2**.

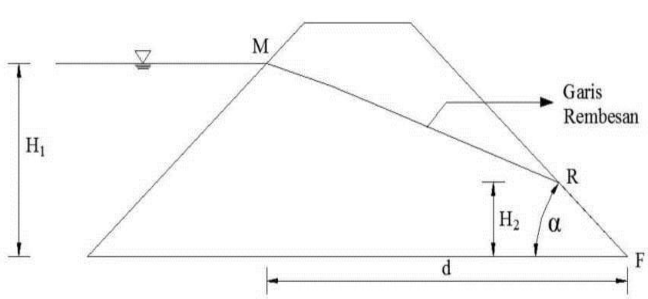

Fig.2 Seepage line [16]

The seepage line is determined by the pore water pressure that occurs in the body of the dam. This pore water pressure can be monitored at any time using the piezometer instrument. According to[17], seepage in the dam needs to be controlled to prevent piping (pipe formation in the body of the dam due to loss of embankment material). One of the seepage controls is by analyzing seepage discharge. The basic concept in calculating the discharge in water flow in saturated soil layers is using Darcy's Law shown in Equation **Error! Reference source not found.**.

$$q = k.i.A \quad (1)$$

where:
q = Seepage discharge (m /second)
k = Permeability coefficient (m/second)
i = Hydraulic gradient
A = Soil sectional area that is passed by water (m)

In the downstream of the dam body, there is an area that is an exit seepage. At this point the hydraulic gradient can also be called exit gradient. If the exit gradient value is too large, it can potentially cause piping. Gradient where this conditions occur is called *critical gradient* (i_{cr}), So that, the value of i_e must be less than the value of i_{cr}[18]. The danger of piping lies in the core base and slope base of the downstream of dam fill. But each dam has different properties and material properties so modeling is needed to ensure it [19]. Along with the needs of calculations that are increasingly complex and require high accuracy, there are many software available to help numerically modeling either 2 or 3 dimensions. In general, the basic method used is Finite Element Method.

2.2 Seepage Safety

In planning modeling it is necessary to evaluate the safety of the dam with various boundary conditions, namely *end of construction, steady* and *transient analysis.* Seepage security can be evaluated by several methods and is considered safe if :

1. Comparing *exit gradients* to *critical gradients* where $i_e < i_{cr}$.
2. Seepage Index or Q Index where QI<1 [20]
3. Seepage discharge.

Seepage evaluation in this study only uses instrument data that already installed. Then the third security analysis is carried out, namely seepage discharge analysis based on seepage monitoring (V-Notch) instruments. In the certification of dam safety design in Indonesia, the reference is that seepage is considered safe if it is less than 1% average annual runoff and less than 0.05% of gross storage capacity [13]. According to [16] allowed seepage discharge no more than 2-5% of the average discharge that enter the reservoir. While the allowable seepage discharge according to [21] is as follows **Error! Reference source not found.**:

Table 1 *Criteria for seepage in the body of the dam (Look, 2007)*

Dam height (m)	Seepage: Litres/day/meter, (Litres/minute/meter)	
	O.K	Not O.K
< 5	<25 (0.02)	>50 (0.03)
5 - 10	<50 (0.03)	>100 (0.07)
10 - 20	<100 (0.07)	>200 (0.14)
20 - 40	<200 (0.14)	>400 (0.28)
> 40	<400 (0.28)	>800 (0.56)

2.3 Instrument Data

Instrument data is recorded since the instrument was installed. In general, recording is carried out with high frequency at the beginning (construction and initial impounding) and periodically along with dam operations. This study analyzes instrument data from impounding of May 2014 to November 2018. There are thirteen (13) instruments installed in the Jatibarang Dam as presented in

Table2. Placement of instruments is carried out according to design requirements. But due to the crucial location of the central zone rockfill dam is located in the core zone so that the main instruments are more focused on this location.

Table2 Type and number of instruments

No.	Instrument type	STA	Total
1.	Electrical Piezometer	100, 145, 190	24
2.	Pneumatic Piezometer	145	8
3.	Pressure Cells	145	3
4.	Seepage Water Pressure Observation Head	66, 91, 113, 154, 182 204, 231	7
5.	Fondation Deformation Meter	145	1
6.	Electrical Tri-Axial Joint Meter	153, 162	2
7.	Magnetic Extensometer	145	1
8.	Inclinometer	145	1
9.	Strong Motion Accelerograph	143	2
10.	Surface Movement Marker	100, 145, 190	21
11.	Standpipe Piezometer in Bore Hole	Abutment& Downstream	7
12.	Terminal Boxes	108, 149, 186	3
13.	Seepage Measuring Facilities	150	2
14.	Digital Readout Unit		1

Evaluation of seepage discharge is done by measuring seepage that occurs in Seepage Monitoring (SM) instruments or commonly called V-Notch. There are 2 instruments installed, namely SM1 and SM2. V-Notch calculation is done in two ways, manual and automatic. This method is conducted as a calibration and validation. Along with this measurement, measurements of the reservoir water level/Tinggi Muka Air (TMA) were also carried out. The results of measurement and processing of the data are as follows:

a. Water Pressure on Seepage Observation (SO)

The core zone is an area that is prone to changes in pressure and shear that may occur. So that almost all instruments are placed in this zone. Water pressure has a different value - according to its elevation and location. In order to be analyzed thoroughly then (SO) is placed in series on the same STA from upstream to downstream with various elevation combinations. Theoretically, the higher the water level, the higher/deeper the elevation, then water pressure will also be higher, and will decrease to near the exit point. Pressure data is measured (***Fig.3***) along with discharge data (**Fig. 5**) that comes out in each of seepage observation. This data can later be analyzed by comparing the pressure and the results of seepage discharge that occurs.

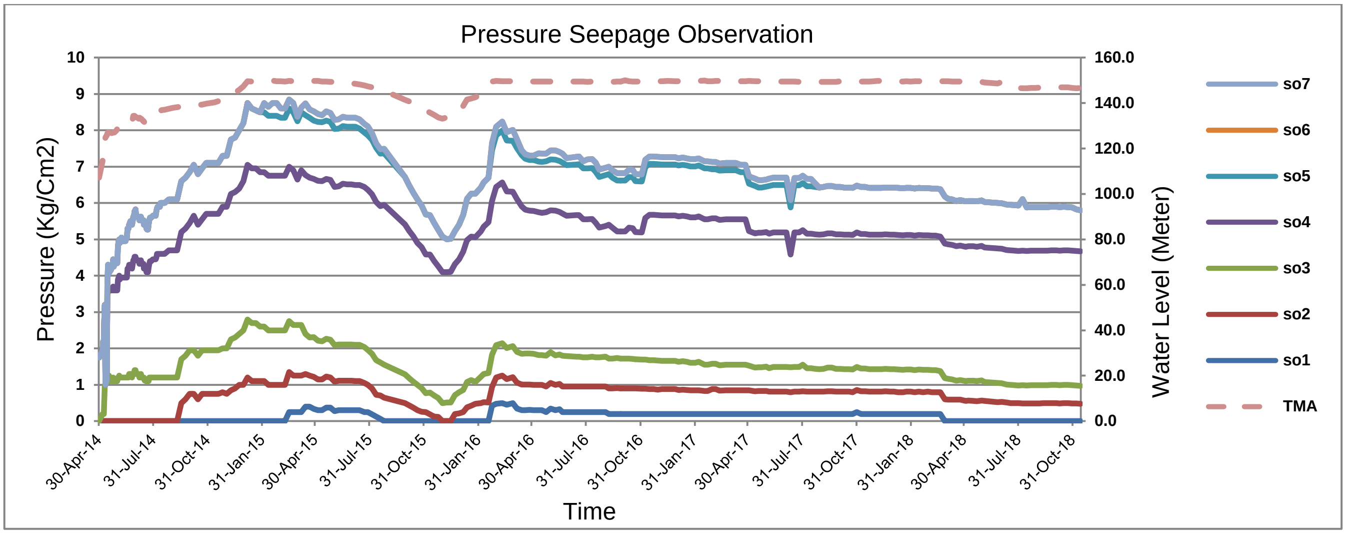

Fig.3 *Graph of Water Pressure on Seepage Observation*

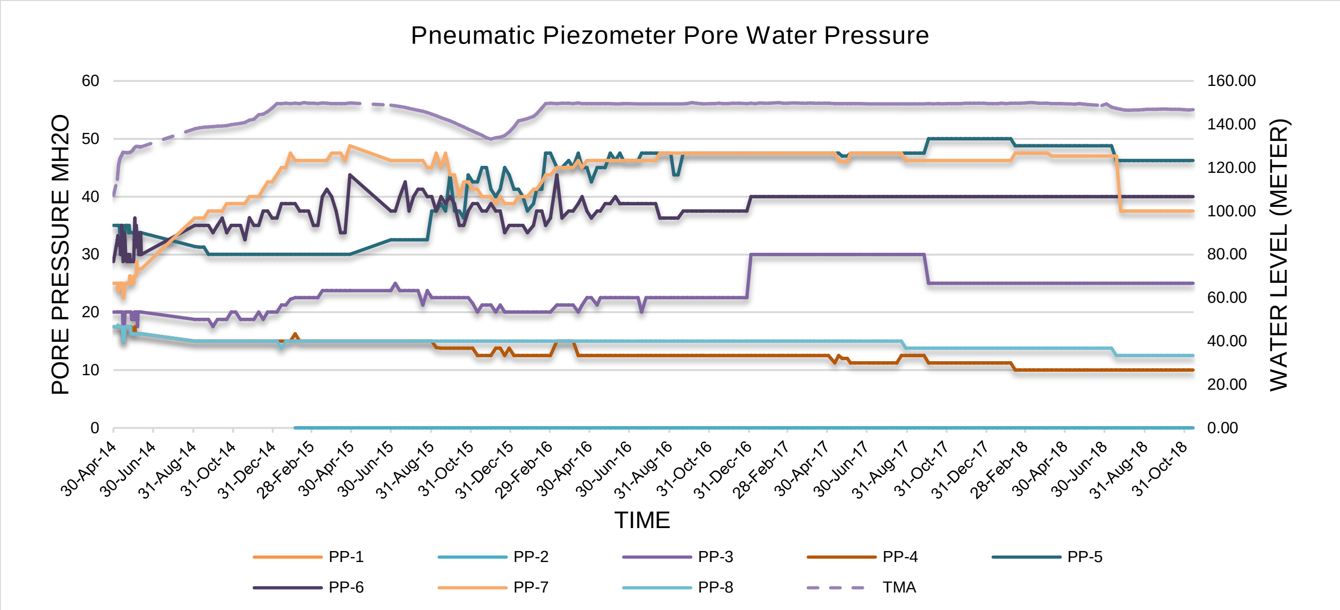

Fig. 4 *Graph of pore water pressure on the measured pneumatic piezometers*

b. Pore Water Pressure On Piezometer

The piezometer on the Jatibarang dam consists of 3 types, namely: *Electric Piezometer* (P = 24 pieces), *Pneumatic Piezometer* (PP: 8 pieces) and *Stand Pipe Piezometer* (SP: 7 pieces). Electrical piezometers spread in the body of the dam. While the pneumatic piezometer is only at STA 145 where there are many instruments that record information on seepage and body movement of the dam in the core zone. Stand Pipe piezometer is placed on the right and left abutments of the dam body as well as water level control. The presence of various types of piezometers at the core location besides functioning as a control and confirmation, it is also used as a substitute if there is a broken piezometer. The electrical piezometer has a higher damage potential compared to the pneumatic piezometer. With the distribution and type of piezometer installed, the main piezometer used for dam body evaluation is the type of electric and pneumatic. After operational dam there are electrical piezometer damage as many as 7 units (P7, P8, P9, P10, P16, P22, P23) so that not produce data. The main cross section can be represented by retrieving Pneumatic Piezometer data installed on STA 145. Pore pressure based on the instrument data processing can be seen in the graph (Fig. ***4***) .

c. Seepage Discharge

The main design of the seepage discharge monitoring system is only based on two instruments of Seepage Measurement (SM*)*. The location of this instrument in the gallery at STA +150 with elevation is at +76,5 below the core zone in the downstream of the filter. SM 1 measures seepage on the left side of the gallery while SM2 measures seepage on the right side of the gallery. The results of the calculation will be a combination of SM1 and SM2 (Fig.6).

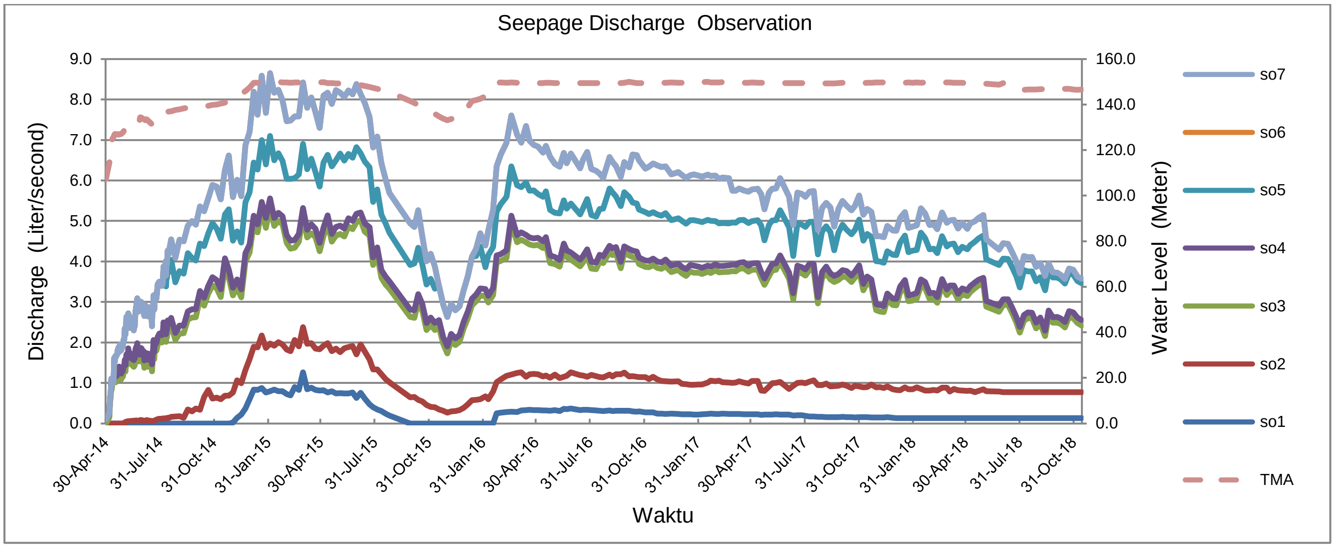

Fig. 5 Seepage graph on Seepage Observation

Reservoir water level has a large influence on seepage discharge that occurs. There is an anomaly in filling the initial reservoir, so that the data cannot be used as an operational reference. Based on empirical data from several reservoirs in Indonesia, seepage discharge rates have a fairly consistent pattern after 2 seasons where runoff occurs at least 2x periods. In addition, if the rainfall is high enough the dam can be tested by raising the water level on the high water level and then lowering it to a low water level. This repeated loading will stabilize the pressure reading on the piezometer so that the pattern can be analyzed.

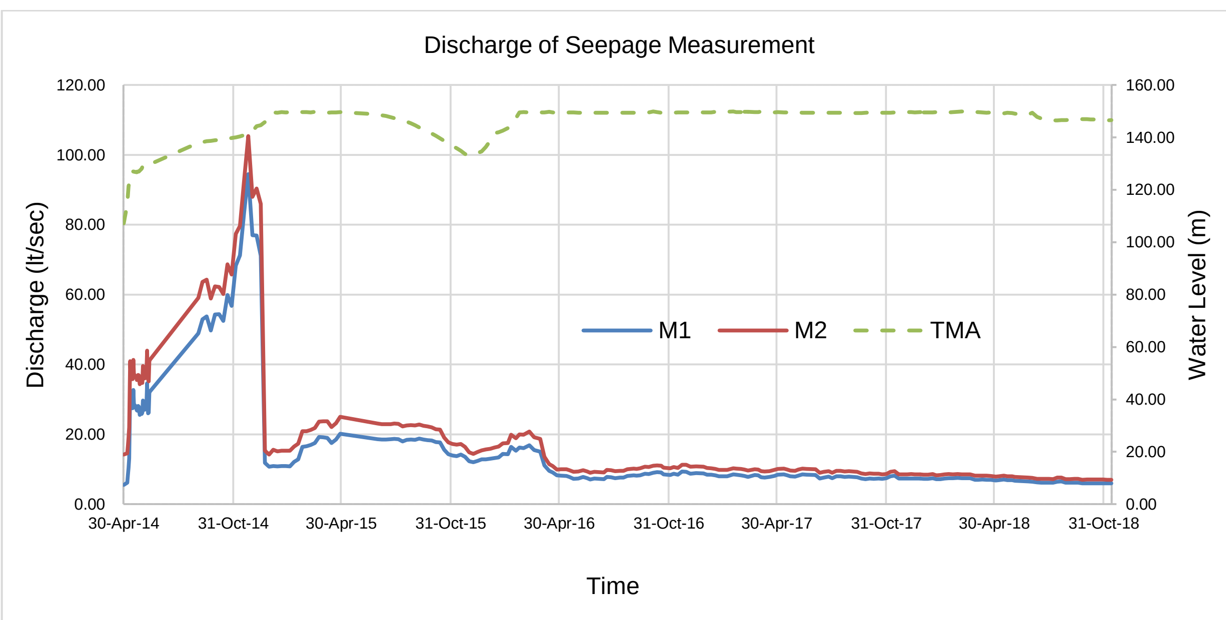

Fig.6 Graph of measured seepage on the dam's body

During impounding there were symptoms of seepage at the spillway contact and also in the divertion tunnel. Besides that the downstream slope of the dam (right and left) also has seepage. Considering the need for further analysis, this seepage discharge is also measured manually (**Fig.7**).

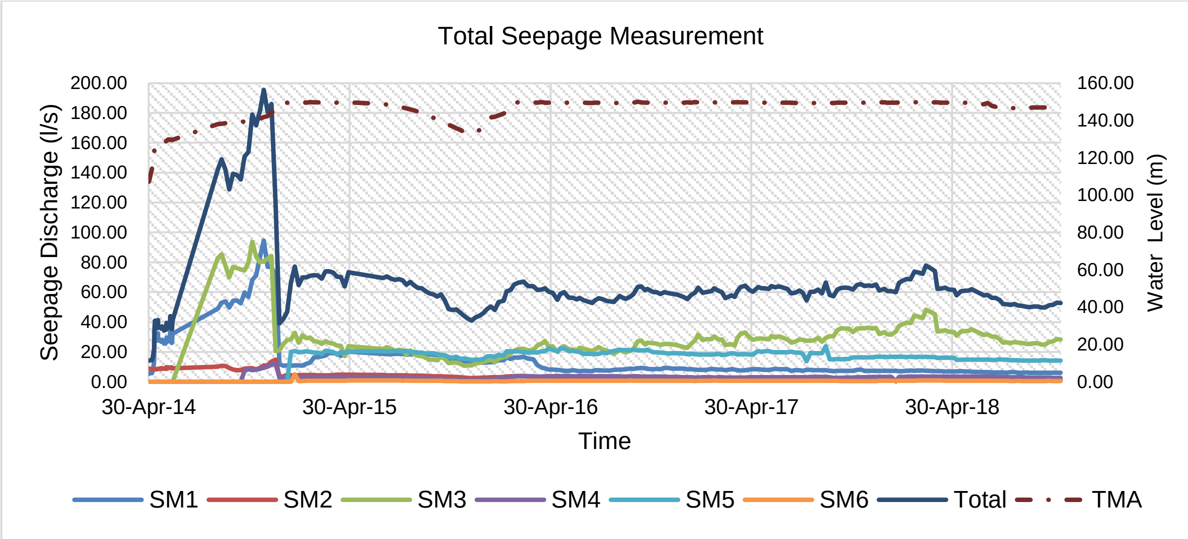

Fig.7 Total discharge measurement graph

3. RESULTS AND DISCUSSION

3.1 Seepage Observation (SO)

The Jatibarang Dam has been filled with reservoir water up to past through normal elevation (+149.3) the peak on January 17th, 2015 was recorded +149.91 m . After that conducted the operation test of the reservoir water level lowering to a low water level with the lowest point on December 1st, 2015 recorded equal to +133.15 m. From the initial operation of the reservoir, the SO instrument responded quite good (***Fig.3***&***Fig. 4*****Fig. 5**). After passing two time of the water pressure runoff and also the SO discharge showing a stable trend, it tends to decrease even with a high water level (steady state).

3.2 Pore Water Pressure

Data readings on the piezometer must be carried out continuously since the instrument is installed to see the characteristics of behavior changes in the body of the dam. Unusual changes do not mean a sign of danger, but must be evaluated first. There is a correlation between the response pattern and the correlation between instrument reading and reservoir water level [22]. Piezometer has responded and produced data since it was installed when construction (embankment) was carried out in accordance with the elevation and its position was conducted (this study was analyzed from the beginning of impounding). But the data produced still does not have a pattern and a good correlation between reservoir water level with the pore head. The pattern of the relatively consistent relationship between reservoir water level and the pore head readable in September 2014 (Figure 8).

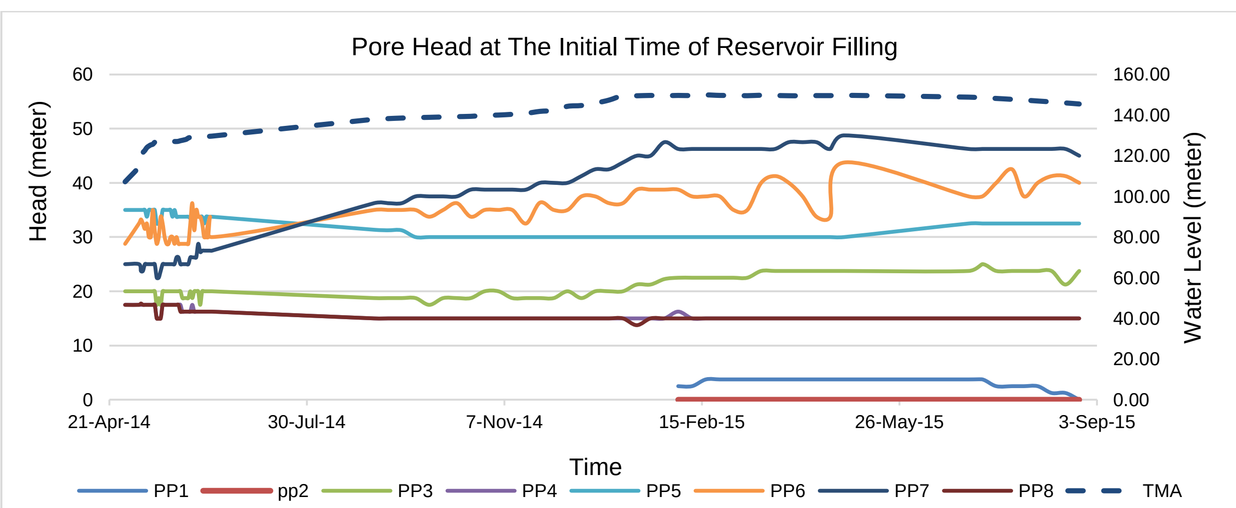

Fig.8 Correlation of pore water pressure with the reservoir water level

The most reactive piezometer is PP-7 which is located on the STA-145 upstream with + 85m elevation. Pore water pressure will affect the seepage discharge that occurs, so to see if seepage is still considered normal need to obtain seepage data from V-Notch. Based on relationship data that reads PP-7 and reservoir water level there is a lag time of 2-4 weeks. This means that when there is a maximum decrease in reservoir water level, it takes between 2-4 weeks to respond and read on the instrument. Along with the reservoir operation period, the lag time response of this instrument will decrease.

3.3 Seepage Discharge

Seepage discharge that coming out through V-Notch is clear and does not contain clay material or other suspicious material. So that it can be assumed not to carry the core material granules which can result in piping and inner landslides. Dams that have a high risk of pollution contamination can use multiple methods as an additional analysis, especially if downstream conditions are used as community wells [23]. In addition, the type resistivity geoelectric method can also be paired to predict the seepage distribution pattern and the depth of pollutants that occur [24] The quantity of seepage that passing through the dam's body determines the safety of the dam itself. Every dam height has a maximum amount of seepage that can be tolerated. The seepage total discharge that passing through the dam body is presented in Figure 9 below:

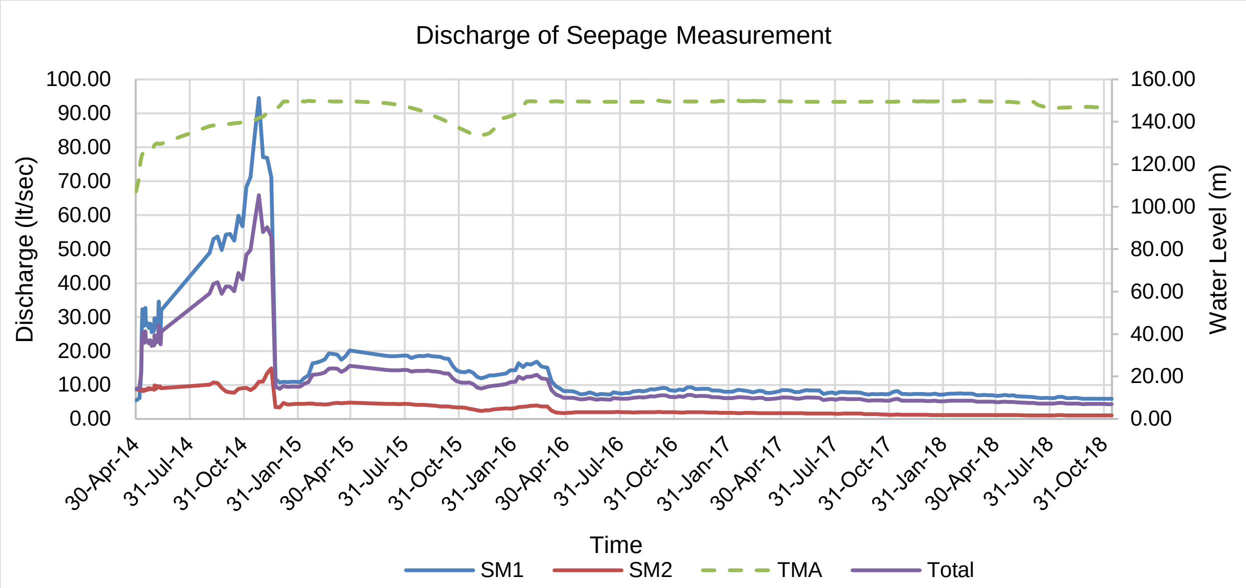

Fig.9 *Seepage graph (V-Notch) on the body of the Jatibarang dam*

To determine the safety of the dam towards the seepage discharge that occurs, the reservoir water level is taken in the last normal condition. Seepage discharge measured at normal elevation + 149.3 is as follows:

Date	: 3 Juli 2018
Water Level	: + 149.38
DischargeSM1+SM2	: 7.51 lt/sec = 648,86 m^3/day

The amount of filtration flow capacity (Qh) must meet Qh requirements <1% from average annual runoff and Qh < 0,05 % from Gross Storage Capacity.

a. Qh < 1% from average annual runoff
 = 1,13 m3/sec x 1%
 = 0,0113 m3/sec
 = 976,32 m3/day (OK)

b. Qh < 0,05% from Gross Storage Capacity
 = 20.150.000 x 0,05 %
 = 10.075 m3/day (OK)

In addition to calculating discharge, seepage water through v-notch is visually clear and does not carry material grains. Based on the evaluation above, the Jatibarang Dam is safe from the dangers of filtration (seepage).

4. CONCLUSION

Based on the analysis and evaluation of seepage instrument data on the Jatibarang dam period April 2014 - November 2018, it can be concluded as follows:

1. Seepage instruments have shown a fairly good response. Correlation & pattern of instruments with reservoir water level fluctuations began to form at the beginning of 2015 and showed a consistent pattern from mid-2017.
2. In general, pore water pressure and seepage that occur has an increasingly stable trend and tends to decrease.

Seepage that occurs is 648.864 liters/day where the discharge is smaller than the allowable maximum discharge. In addition, visually the seepage water is clear and does not carry material grains. So it can be assumed that the Jatibarang dam is safe from the danger of seepage. Dam safety evaluation is an evaluation of movement, displacement, seepage, hydroclimatology instruments and seismic instruments. Seepage evaluation alone is not enough to make a complete analysis. So that a comprehensive evaluation is needed to ensure the safety of the Jatibarang Dam.

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