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Dam Body Safety Evaluation Pre and Post Impounding Use Instrumentation Data on Raknamo Dam in East Nusa Tenggara Province

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Abstract— *A complete water governance system is already a very vital need for the community. Therefore, the availability of methods in water management is one of the main factors to increase the development and growth of a water management network system. This study aimed to find out the pattern of pore water pressure, settlement, and seepage on the body of the Raknamo dam after construction. In addition, the purpose of this study is to find out the dam is safe or not limited to seepage, settlement, and slope stability. Based* on the results of numeric analysis (SEEP / W) on the body of the *dam is* 0.00176^{m3}*/s < 0.014 m3/s, then the barrier is still safe against maximum discharge seepage. While based on the actual reading results in the field (Instrument V-Notch) is 0.00427 m3/s < 0.014 m3/s*, the dam is still safe against maximum seepage dischar*ge. Based on the results of numerical analysis (SIGMA / W) at the core of the dam is 0.00334 < 0.02, the barrier is still safe because the settlement does not exceed the allowable limit. Based on the results of numerical analysis (SLOPE / W) for the stability of the slopes of the Raknamo dam, with conditions without earthquakes, with static earthquakes 100 years, and with dynamic earthquakes OBE and MDE.*

Keywords— *Security Evaluation; Impounding; The body of the dam; Numerical Analysis; Raknamo Dam.*

I. INTRODUCTION

A complete water governance system is already a very vital need for the community. Therefore, the availability of methods in water management is one of the main factors to increase the development and growth of a water management network system. A dam is a construction built to hold the rate of water into a reservoir or lake. Often dams are also used to drain water to a hydroelectric power plant (PLTA). Urugan dams are the most complex civil buildings that are very dangerous when they fail or collapse. The collapse of a dam will cause a major disaster for the downstream area in property and fatalities. Dam safety plays a critical role. Therefore the security of this type of dam needs to be checked, checked, and recorded continuously about the performance and behavior of the dam and its complementary buildings or particular other objects by direct measurement, observation, and reading, using equipment or instruments. Field instrumentation is essential in geotechnical engineering techniques for the design and construction of dams. Instrumentation is the basis of dam evaluation and provides evaluation data in the monitoring and monitoring program and inspection of dam safety for future purposes. According to Sari et al. (2017)[1], The higher the reservoir water level, the greater the pore water pressure that will occur and will also impact increasing seepage discharge and affect the settlement of the dam body. Based on the results of reviews obtained from several journals, no one has discussed the pattern of reservoir operations more deeply. For that, the author will discuss the safety of the dam until the time the reservoir operating design was carried out using instrumentation data and analyzed using numerical models. This study aimed to find out the pattern of pore water pressure, *settlement*, and seepage on the body of the Raknamo dam after construction. In addition, the purpose of this study is to find out the dam is safe or not limited to seepage, *settlement*, and slope stability.

II. REVIEW OF LITERATURE

In designing dam instrumentation and evaluating the results of instrumentation observations, basic geotechnical knowledge is needed. Therefore, the key to successfully assessing the behavior of dams of the urugan type and levees lies in the foresight of experts in evaluating the results of instrument observations (Kep Men of Regional Infrastructure Settlements, 2004). Aspects that need to be known are mainly related to pore water pressure, seepage, soil tension, foundation deformation characteristics, and heap materials. In addition to a detailed explanation of the basics of geotechnical knowledge, it is also necessary to reference procedures or other engineering guidelines, reference books on geotechnical, and information on design considerations, and the construction of dams of the urugan type (Kep Men Settlement Of Regional Infrastructure, 2004). The primary purpose of instrumentation is to generate data that is useful in determining whether a dam or foundation can function according to predetermined safety aspects. Suppose the dam has a specific foundation condition or design form. In that case, the instrumentation will help to monitor whether the design concept during construction and operation has met the criteria or not. A complete monitoring program should be developed primarily for conditions and specialized forms in the field. If the foundation's situation or the shape of the dam design is not particular, the need for instrumentation will be reduced. The installation of dam instruments has significant meaning because it can be helpful to as:

1. Analytical estimate of dam safety.
2. Long-term behavioral forecasts.
3. Legal evaluation (legal aspect)
4. Development and verification for the design to come.

Based on some previous references to the safety of dams caused by pore water pressure, seepage, horizontal and

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vertical movement of the dam body, relaxation on the upstream slopes, and the effect of earthquakes on dam safety include Xiaoping Chen, Jingwu Huang (2011)[3] with the results of the study m to a reduction of strength used in numerical analysis effectively in reducing progressive failure caused by fluctuations in reservoir water level. The advanced failure of the slope can be illustrated as follows: (i) decreased resistance at the foot of the slope; (ii) grinding at the foot of the slope; (iii) decrease in the strength of the soil near the gerusan area; (iv) changes in slopes; and (v) further decrease in the carrying capacity of the land. Sanjay Nimbalkar, V.S. Ramakrishna Annapareddy, Anindya Pain, (2018)[4] with the study results that is the difference in the safety value factor of this method with that of the pseudo-static process to different kh values. The trend of the results of this study is very similar to that of pseudo-static methods. Variations in the safety factors of the study with a rigid and flexible foundation for different internal swipe angle values. Mohammad Rashidi, S. Mohsen Haeri (2017)[5] with the research results, i.e., the reduction of downstream random deposits obtained from instruments and numerical modeling in the two periods mentioned above. At the end of construction, these results are close to each other. This trend continues to be constant in the dam's foundation after the initial filling of the reservoir. Comparison of pore water pressure in the first layer obtained from instrumentation measurement and numerical modeling at the end of construction.

A. Earthquake Analysis

Earthquake load is the load or force of inertia that arises from earthquake shock at ground level. Maximum ground acceleration, ag is an earthquake acceleration obtained from earthquake risk analysis using an empirical formula from Fukushima-Tanaka. Still, it has not been corrected on the influence of local soil types. The earthquake load to design new dams or the safety evaluation of existing buildings is obtained from MDE, OBE, and sometimes RIE. Depending on the conditions, a barrier can be evaluated against one or more earthquake loads. The main requirement of earthquake-resistant dam design is to protect public safety, life, or property. Earthquake parameters can consist of one or more of the characteristics of shaking at ground levels, such as acceleration, speed or transfer, and the variety of speech or history of earthquake acceleration times that provide their characteristics for MDE, OBE, and RIE. The selection of parameters can be made deterministically or probabilistically earthquake disasters or a combination of both. For example, the acceleration relationship of an earthquake with the repeat period to determine the MDE and the OBE consists of a maximum earthquake acceleration (peak ground acceleration, PGA) and a specific form of earthquake welcome (spectrum). Earthquake parameters that reflect the magnitude of MDE, OBE, or RIE are often used as input data for numerical analysis of dams. The results of such numerical analysis are used to evaluate dam behavior and dam safety that produces the magnitude of the shaking.

To prevent unsanctioned due to decreased shear strength, due to increased pore pressure that can lead to liquefaction processes, excessive deformation, and high wave influence, it is necessary to note the following:

1. Compaction of urugan on the construction of urugan dam must be adequately done by the specified specifications.
2. The slope for the dam is 1:2.5 to 1:3 (vertical: horizontal). For rock-type dams with upright or sloping cores, the slope of the hill can be made steeper.
3. The slope stability analysis's static load safety factor for the critical avalanche field is 1.5 times greater than the minimum safety factor required for earthquake loading conditions.
4. The minimum guard height is adjusted to look at rsni T-01-2002.

If the condition cannot be met, a deformation analysis must be carried out using the Newmark or seed.

B. Minimum Safety Factor

The minimum safety factor value for each loading condition indicates the criteria in the slope stability analysis. The safety factor for slope stability analysis is defined as the total allowed ground shear resistance to ground shear voltage. Safety here is necessary to maintain balance along the field's surface that has the potential for landslides or slips. The minimum safety factor for slope stability design is determined primarily based on consideration of supervisory factors against pore water pressure and the strong assumption of material shear. Safety factor criteria are considered against the following:

1. Based on analysis from USBR using the way of the balance of limits.
2. If the analysis method is different, then the safety factors are other, even for the same dam with the same physical properties of the material and loading conditions.
3. For loading conditions after construction, excessive pore water pressure will increase within the watertight zone of the dam or foundation. This is because the soil cannot be fully consolidated during the construction period. Therefore, the use of effective shear vital parameters significantly affects safety *factors.*

III. Research Methodology

A. Research Location

Raknamo Dam is located in Raknamo Village Raknamo Village Amabi Oefeto District Kupang East Nusa Tenggara Province. Raknamo dam is part of the utilization of water resources to overcome water shortages both for raw water and irrigation water that people in Kupang Regency have experienced.

B. Construction Activity Information

PT carried out the construction of the Raknamo Dam. Waskita Karya (Persero) Tbk. on December 4, 2014, and can be completed on December 28, 2017, the dam began initial filling of the reservoir (impounding) on January 9, 2018.

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C. Supporting Data

In this study, supporting data is needed to perform the analysis process. The data required to complete the analysis on the study are as follows:

1. Instrument Reading Data
    a. Instrument Pisometerreading: The basic principle of the workings of a picometer is that an element that is porous from the picometer is inserted into the ground, so that groundwater can enter it and collect in the element unit. Measurements of the water surface or water pressure inside the pisometer can calculate the magnitude of the pore water pressure.
    b. Automatic Double Fluid Settlement Device (ADFSD): This system is planned to measure the settlement continuously with a tubing mounted around the geometry of the dam horizontally at a specific elevation (horizontal loop).
    c. Inclinometer readings: This inclinometer instrument is installed to observe or monitor a horizontal movement within a layer of soil or rock. Aluminum or plastic pipes with four grooves angled between 90° are installed in a borehole, or at the stage of ground hoarding, or on the walls of a structure. Large dams that use this instrument include the tarbela dam (Pakistan) and Wadaslintang (CentralJava).
    d. Reading of The Seepage Measuring Instrument: This instrument is installed to observe; (a) Symptoms of dissolution on rock foundations that may result in decreased shear strength and increased foundation permeability, (b) Symptoms of reed erosion (Piping) on the body or dam foundation.
2. Instrument Reading Data
    The data that will be used for the analysis process in this study are:
    a. Data Debit Inflow
    b. Data Debit Outflow
    c. Soil Mechanics Data (Heap and Foundation Materials)
    d. Dam Instrument Cross-section data and dam instrument plan

D. Data Analysis

The supporting data used will be analyzed, to analyze the data will be described as explained below.

1. Inflow and outflow discharge data and technical data on reservoir operations are obtained from existing data to analyze reservoir simulations. Based on the results of reservoir simulations, high water level values can be obtained according to reservoir operating patterns so that it can be continued with analysis using numerical models (Using Geostudio Application 2012).
2. Soil mechanics data (heap and foundation materials), namely dam security against seepage, settlement, slope stability, are analyzed using goestudio applications 2012 (SEEP/W, SIGMA/W, and SLOPE/W).

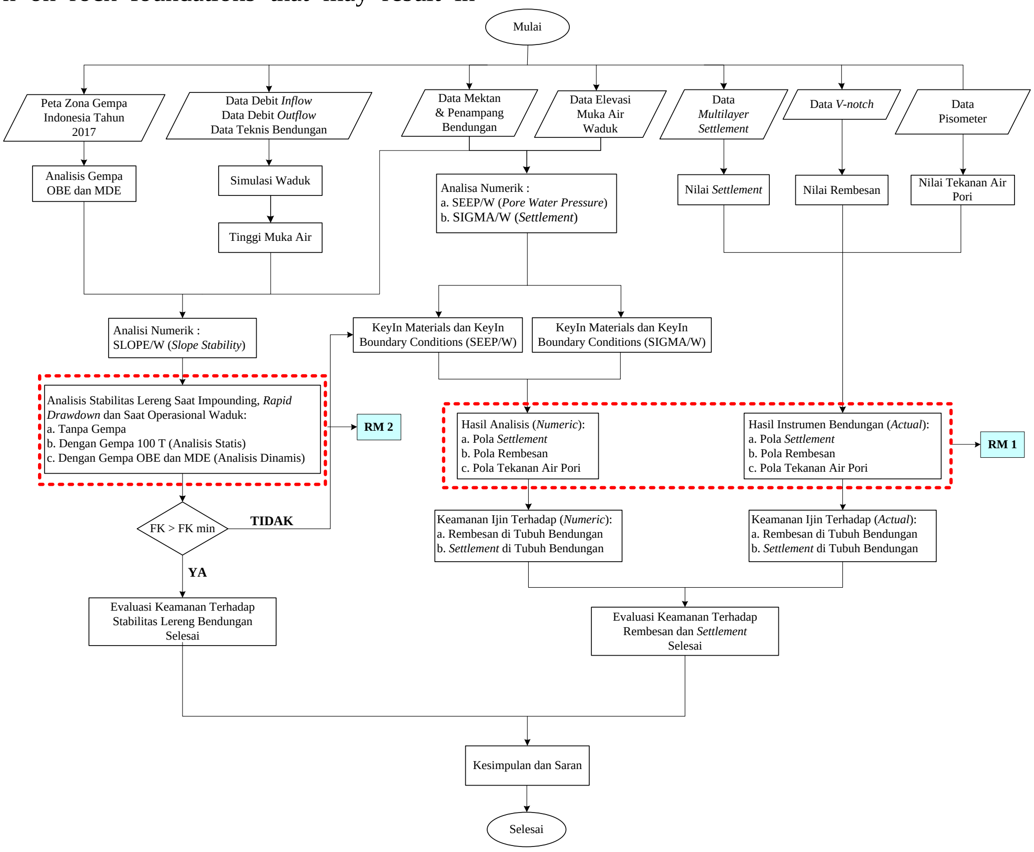

Fig. 1. Research Flow Chart.

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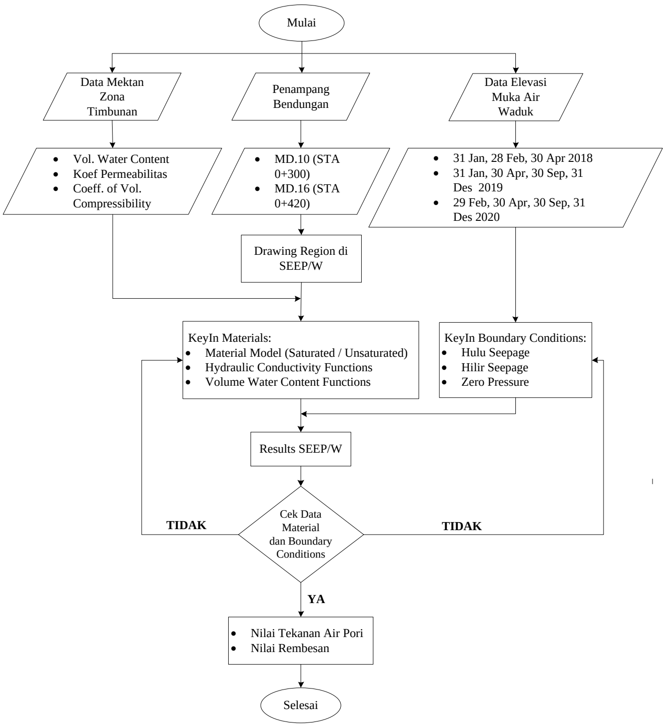

Fig. 2. Numerical Analysis Flow Chart.

3. Dam instrument cross-sectional data and dam instrument floor plans are used to describe the cross-section of the dam according to the current instrument installation position so that it can be analyzed with numerical models. At the same time, the dam instrument floor plan data is needed to know the part of the installation of instruments on the dam.
4. Pisometer data is used to compare the pore water pressure value at the beginning of impounding with instrument reading data until the end of 2020. Pisometer data is also used to draw water level elevation lines or phreatic lines that occur in the body of the dam, as well as further analysis of the pore water pressure that occurs in the body of the dam with numerical models.
5. Multilayer settlement data is used to compare the steep decline in the dam body at the beginning of construction until after impounding with instrument reading data until the end of 2020.
6. V-notch data is used to compare how much discharge seepage value occurs at the beginning of impounding with instrument reading data until the end of 2020.

E. Research Flow Chart

The process of collecting data arrives at the analysis of data so that several conclusions based on the results of this study can be seen in figure 1.
In figure 2 is a flow chart of numerical analysis.

IV. RESULT

Instrumentation data used as analysis is; Vibrating Weir Piezometer, Multilayer Settlement, and V-Notch. The position or installation plan for each instrument on the Raknamo Dam can be seen in Figure 3. The installation of tools at the core of the Raknamo Dam can be seen in Figure4.

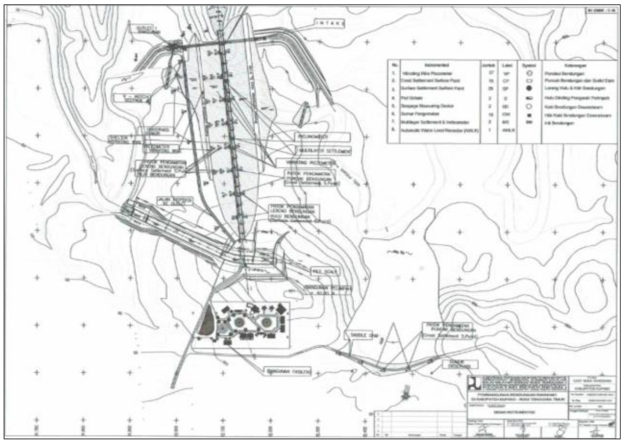

Fig. 3. Raknamo Dam Instrument PlacementPlan.

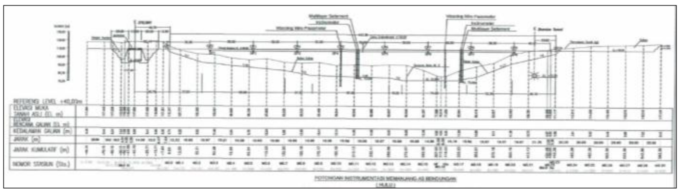

Fig. 4. Elongated Pieces of Instruments on the U.S. Raknamo Dam.

A. Hoard Material Data

The heaped material used in the Raknamo Dam consists of 5 heap zones, namely; zone 1 (core), zone 2 (smooth filter), zone 3 (rough filter), zone 4 (random), zone 5 (rip-rap),

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division of the heap zone MD-10, MD-11 and MD.16, MD-17 can be seen in Figure 5 and Figure 6 below. The heaped material for each of these heap zones was obtained from the results of testing in the laboratory by PT. Indra Karya. The parameters for each heap zone can be seen in Table I.

TABLE I. Parameters of Material Stacking Of RaknamoDam.

Hasil Pengujian Laboratorium	Satuan	Material Inti	Filter Halus	Filter Kasar	Material Random	Rip - rap
		Zona 1	Zona 2	Zona 3	Zona 4	Zona 5
Spesific Gravity (GS)	-	2.67	2.73	2.77	2.75	2.76
Berat Tanah Jenuh Air (γ_{sat})	t/m^3	1.85	1.95	1.90	2.15	1.95
Berat Tanah Basah (γ_{wet})	t/m^3	1.54	1.65	1.55	1.99	1.65
Berat Tanah Kering (γ_{dry})	t/m^3	1.36	1.54	1.42	1.81	1.25
Kohesi (c)	t/m^2	0.36	0.03	0.00	1.54	0.00
Sudut Geser (φ)	°	17.47	30.00	27.00	35.00	36.00
Modulus Young (E)	kPa	1,000	17,000	45,000	125,000	135,000
Poisson's Ratio (v)		0.25	0.32	0.30	0.27	0.25
Permeability (K)	m/dt	1.19.E-07	8.00.E-06	1.83.E-04	5.28.E-05	8.00.E-01
Volume Water Content (WC)		0.2688	0.3271	0.3654	0.4112	0.4763
Coffisiend of volume compressibility (mv)	cm^2/gr	2.27.E-05	2.04.E-04	1.84.E-04	1.25.E-04	1.25.E-04

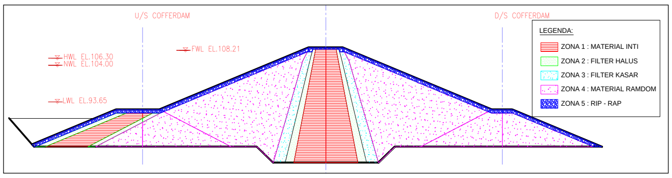

Fig. 5. Material Heap Zone On MD-10, MD-11.

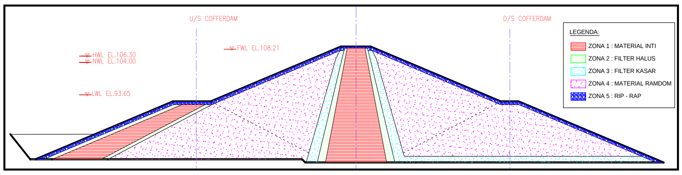

Fig. 6. Material Heap Zone on MD-16, MD-17.

B. *Numerical Analysis*

The numeric analysis conducted in this study uses the application "Geostudio 2012", where this application can help analyze pore water pressure and seepage that occurs using the "SEEP / W" tool. As for analyzing settlements that occur in the dam core pile can be used tools "SIGMA / W. To investigate the pore water pressure and seepage in the dam body, the process must first be inputted data. The analysis of numeric pore water pressure MD.10 (STA 0+300) is calculated based on changes in reservoir water level from 2018 to 2020 (can be seen in Table II). Changes in the water level of this reservoir significantly affect the value of pore water pressure that occurs in the dam. Based on the numerical analysis results done with the last 2-year period (2018-2020), the highest pore water pressure value for the MD.10 cross-section (STA 0+300) occurred on April 30, 2019, can be seen in figure 7.

Analysis of Numeric Pore Water Pressure MD.16 (STA 0+420) is calculated based on changes in reservoir water level that occurred from 2018 to 2020 (can be seen in Table III). Changes in the water level of this reservoir significantly affect the value of pore water pressure that occurs in the dam. Based on the numeric analysis results done with the last 2-year period (2018-2020), the value of pore water pressure that occurred in the MD.16 cross-section (STA 0 +420) occurred on April 30, 2019 can be seen in figure 8.

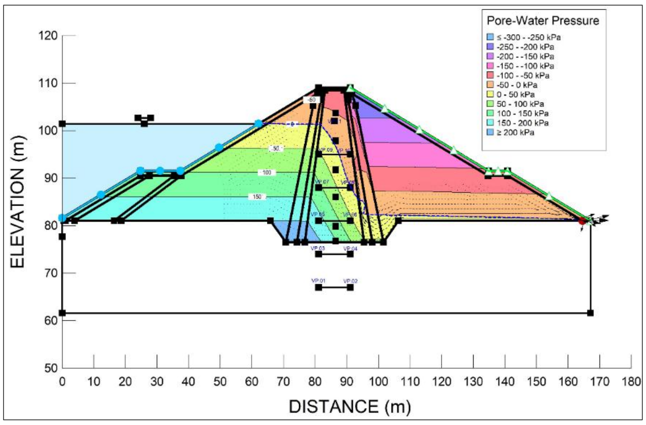

Fig. 7. Pore Water Pressure MD.10 (April 30, 2019).

TABLE II. Results of Pore Water Pressure Analysis At SEEP/W - MD.10 (STA 0+300).

Code	Elv. Muka Air (m)	Date (day)	Pore Water Pressure (PWP) - SEEP/W (kPa)						
			VP.05	VP.06	VP.07	VP.08	VP.09	VP.10	VP.11
A	87,500	31-Jan-18	43,43	16,88	-23,95	-44,12	-97,63	-106,01	-170,33
B	93,650	28-Feb-18	105,48	41,39	44,60	-1,91	-20,43	-49,73	-102,93
C	94,950	30-Apr-18	116,23	45,12	56,27	4,26	-5,12	-39,78	-75,22
D	96,400	31-Jan-19	128,14	49,08	69,18	9,68	9,74	-28,99	-75,22
E	101,400	30-Apr-19	166,83	60,62	109,95	3,03	55,91	-30,53	-33,63
F	99,200	30-Sep-19	150,98	55,43	94,26	21,28	36,99	-4,30	-44,75
G	98,500	31-Dec-19	145,94	55,86	88,49	23,42	30,29	-9,87	-52,38
H	100,119	29-Feb-20	159,43	61,84	102,62	30,25	45,54	-6,72	-37,62
I	99,735	30-Apr-20	156,15	58,59	99,79	30,58	42,41	3,37	-38,30
J	98,834	30-Sep-20	147,70	54,05	90,66	16,69	33,30	-9,29	-49,48
K	98,690	31-Dec-20	146,02	53,00	88,74	9,91	31,62	-14,29	-52,72

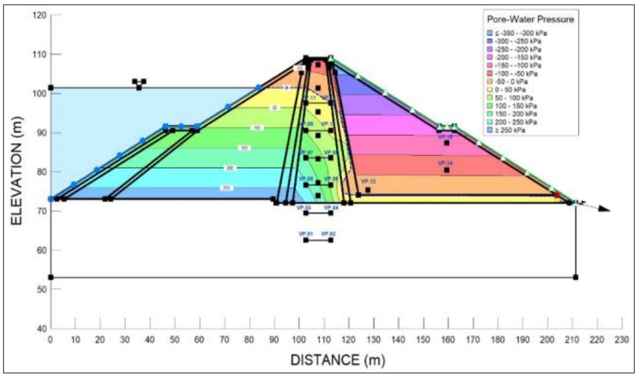

Fig. 8 Pore Water Pressure MD.16 (April 30, 2019).

TABLE III. Results of Pore Water Pressure Analysis At SEEP/W - MD.16 (STA 0+420).

Code	Elv. Muka Air (m)	Date (day)	Pore Water Pressure (PWP) - SEEP/W (kPa)										
			VP.05	VP.06	VP.07	VP.08	VP.09	VP.10	VP.11	VP.12	VP.13	VP.14	VP.15
A	87,500	31-Jan-18	78,43	28,80	15,77	-21,61	-53,44	-76,41	-128,86	-136,35	-14,68	-64,15	-132,79
B	93,650	28-Feb-18	135,24	47,53	77,08	-0,82	20,35	-33,17	-53,57	-78,29	-12,98	-63,12	-131,77
C	94,950	30-Apr-18	150,38	61,42	93,47	37,12	35,82	-1,13	-32,46	-52,59	-13,32	-63,33	-131,97
D	96,400	31-Jan-19	157,31	59,69	99,62	4,95	44,71	-29,46	-19,30	-61,29	-12,10	-62,58	-131,22
E	101,400	30-Apr-19	205,88	92,97	151,99	85,53	96,84	40,82	36,98	2,04	-12,20	-62,64	-131,28
F	99,200	30-Sep-19	177,90	55,85	124,42	16,64	73,06	15,18	15,14	-21,04	-11,68	-62,33	-130,97
G	98,500	31-Dec-19	172,74	54,68	118,83	17,62	66,67	11,10	8,20	-27,69	-11,88	-62,45	-131,09
H	100,119	29-Feb-20	194,92	87,20	140,30	76,17	84,62	29,54	24,42	-8,41	-12,41	-62,77	-131,41
I	99,735	30-Apr-20	180,98	55,69	127,45	8,04	77,04	10,98	20,27	-19,45	-11,32	-62,11	-130,75
J	98,834	30-Sep-20	182,93	76,14	128,63	62,95	73,29	35,06	11,98	-12,95	-12,74	-62,97	-131,62
K	98,690	31-Dec-20	175,28	68,03	117,91	11,65	64,15	-40,97	9,25	-53,36	-11,13	-61,99	-130,63

Subsequent Analysis of Numeric Discharge Seepage (Flux) MD.16 (STA 0+420). Pore water pressure that occurs in dams based on the results of numeric SEEP / W analysis that has been done with the last 2-year period (2018-2020), then from the effects of pore water pressure that occurs will also be known the value of seepage (flux) that happens at the location

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of MD.16 (STA 0 + 420) can be seen in figure 9.

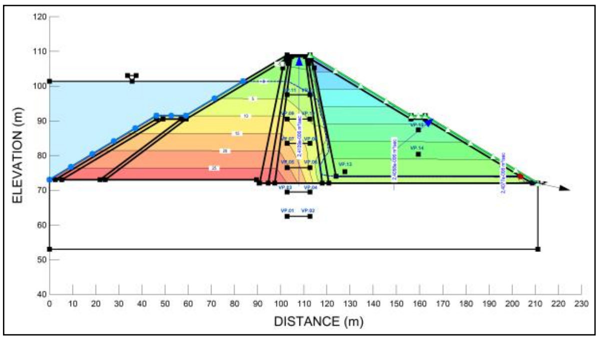

Fig. 9 Seepage (Flux) MD.16 (April 30, 2019).

In figure 9. The seepage value that occurs in the cross-section of MD.16 when the water level is at an elevation of 101.40 m, the value of seepage can be known from the results of flux analysis shown in figure 9. The seepage value in the cross-section uses the effects of analysis flux located at the downstream foot of the dam. The seepage value that occurs over two years can be seen in Table IV below.

TABLE IV. Seep/W Analysis Results at SEEP/W - MD.16 (STA 0+420).

Tanggal	*Code*	Tinggi Muka Air (m)	Debit *Numeric* (m^3/dtk/m)	Panjang Pondasi (m)	Debit *Numeric* (m^3/dtk)
(1)	(2)	(3)	(4)	(5)	(6)=(4)*(5)
31-Jan-18	A	87,500	7,3256,E-07	540	0,00040
28-Feb-18	B	93,650	1,8831,E-06	540	0,00102
30-Apr-18	C	94,950	1,6628,E-06	540	0,00090
31-Jan-19	D	96,400	2,4878,E-06	540	0,00134
30-Apr-19	E	101,400	2,4077,E-06	540	0,00130
30-Sep-19	F	99,200	2,7896,E-06	540	0,00151
31-Dec-19	G	98,500	2,0830,E-06	540	0,00112
29-Feb-20	H	100,119	3,2635,E-06	540	0,00176
30-Apr-20	I	99,735	2,9143,E-06	540	0,00157
30-Sep-20	J	98,834	2,0715,E-06	540	0,00112
31-Dec-20	K	98,690	3,1369,E-06	540	0,00169

The Analysis of Numeric Settlement MD.11 (STA 0+320) was conducted based on the dam body's pore water pressure during the last 2-year period (2018-2020). The settlement that occurs in the core pile of the dam's body is very dependent on the pore water pressure that occurs. Payments that appear at MD.11 (STA 0+320) can be seen in figure 10.

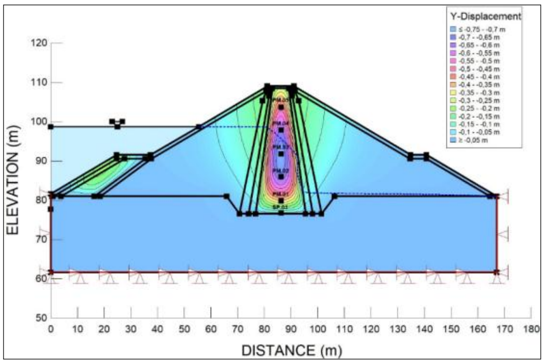

Fig. 10. Settlement MD.11 (December 31, 2020).

TABLE V. Seepage Analysis Results at SIGMA/W - MD.11 (STA 0+320).

Code	Elv. Muka Air (m)	Date (day)	*Settlement* - SIGMA/W (m) SP.01	PM.01	PM.02	PM.03	PM.04	PM.05
A	87,500	31-Jan-18	-0,0277	-0,2943	-0,5975	-0,6541	-0,5714	-0,4124
B	93,650	28-Feb-18	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
C	94,950	30-Apr-18	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
D	96,400	31-Jan-19	-0,0277	-0,2946	-0,5984	-0,6557	-0,5738	-0,4162
E	101,400	30-Apr-19	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
F	99,200	30-Sep-19	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
G	98,500	31-Dec-19	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
H	100,119	29-Feb-20	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
I	99,735	30-Apr-20	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
J	98,834	30-Sep-20	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165
K	98,690	31-Dec-20	-0,0280	-0,2949	-0,5987	-0,6560	-0,5742	-0,4165

C. *Validation of Raknamo Dam Instrument Data*

Existing weir piezometer, multilayer settlement, and V-Notch vibrating instrument data are validated or compared between instrument reading data in the field with numeric analysis results at POSITION MD.10 and MD.16 for piezometer instruments as well as MD.11 and MD.17 for multilayer settlement instruments. Data from instrument readings in the field (actual data) compared to the results of numeric analysis (SEEP / W). This validation is based on several dates in January 2018 - December 2020 to see more clearly how the results of seep / W analysis and actual piezometer data in the location of MD.16 (STA 0 +420) can be seen more clearly be seen in Table VI.

TABLE VI. Seep/W Analysis Results and Actual Piezometer Data - MD.16 (STA 0+420).

		Code	A	B	C	D	E	F	G	H	I	J	K
		TMA (m)	87.500	93.650	94.950	96.400	101.400	99.200	98.500	100.119	99.735	98.834	98.690
		Date (day)	31-Jan-18	28-Feb-18	30-Apr-18	31-Jan-19	30-Apr-19	30-Sep-19	31-Dec-19	29-Feb-20	30-Apr-20	30-Sep-20	31-Dec-20
Total Head (SEEP/W)	(m)	VP.05	84.498	90.291	91.833	92.541	97.493	94.640	94.114	96.376	94.954	95.153	94.373
		VP.06	79.437	81.346	82.763	82.586	85.980	82.195	82.076	85.391	82.179	84.264	83.437
		VP.07	85.108	91.359	93.031	93.658	98.998	96.187	95.617	97.806	96.496	96.617	95.523
		VP.08	81.297	83.416	87.285	84.005	92.221	85.197	85.296	91.267	84.320	89.919	84.688
		VP.09	85.050	92.575	94.152	95.059	100.375	97.950	97.298	99.128	98.356	97.973	97.041
		VP.10	82.709	87.118	90.384	87.496	94.663	92.048	91.632	93.512	91.620	94.075	86.322
		VP.11	84.361	92.037	94.190	95.532	101.271	99.044	98.336	99.990	99.567	98.722	98.443
		VP.12	83.597	89.517	92.138	91.251	97.708	95.355	94.676	96.643	95.517	96.179	92.059
		VP.13	73.853	74.026	73.992	74.117	74.106	74.160	74.138	74.085	74.196	74.051	74.215
		VP.14	73.809	73.914	73.893	73.969	73.963	73.995	73.982	73.949	74.017	73.929	74.029
		VP.15	73.809	73.914	73.893	73.969	73.963	73.996	73.983	73.950	74.018	73.929	74.030
Total Head(Actual)	(m)	VP.05	77.384	77.426	83.303	88.537	93.089	93.239	92.988	93.082	93.350	93.022	92.788
		VP.06	75.054	75.038	74.896	72.618	72.251	71.781	83.038	93.211	98.626	101.539	101.382
		VP.07	83.246	90.496	93.945	96.261	100.426	99.156	98.508	98.750	98.931	97.991	97.744
		VP.08	83.281	83.278	83.272	83.103	84.130	85.694	85.471	85.318	85.311	85.126	84.983
		VP.09	90.052	90.040	93.659	94.873	99.164	98.266	97.683	97.890	97.981	97.182	96.940
		VP.10	90.073	90.063	90.038	89.825	89.789	91.398	91.513	91.274	91.318	91.161	91.026
		VP.11	97.151	97.144	97.129	96.946	100.787	99.723	99.075	99.217	99.405	98.552	98.245
		VP.12	97.319	97.366	97.180	97.208	97.141	97.248	97.213	97.236	97.287	97.175	97.068
		VP.13	74.938	74.929	74.913	74.711	74.654	74.605	74.495	74.477	74.458	74.377	74.317
		VP.14	79.962	79.956	79.946	79.781	79.738	79.696	79.617	79.536	79.545	79.470	79.402
		VP.15	89.650	89.772	89.762	89.907	89.985	90.589	89.545	89.525	89.580	90.150	89.333
PWP (SEEP/W)	(kPa)	VP.05	78.434	135.244	150.375	157.312	205.875	177.901	172.745	194.920	180.980	182.931	175.276
		VP.06	28.802	47.527	61.418	59.687	92.970	55.852	54.684	87.195	55.690	76.138	68.027
		VP.07	15.766	77.078	93.471	99.620	151.990	124.422	118.835	140.304	127.449	128.635	117.913
		VP.08	-21.606	-0.820	37.121	4.949	85.528	16.643	17.615	76.174	8.041	62.951	11.650
		VP.09	-53.445	20.353	35.818	44.713	96.839	73.063	66.670	84.615	77.041	73.290	64.145
		VP.10	-76.408	-33.171	-1.133	-29.462	40.825	15.182	11.102	29.539	10.985	35.061	-40.975
		VP.11	-128.859	-53.574	-32.462	-19.296	36.980	15.139	8.202	24.421	20.271	11.983	9.247
		VP.12	-136.350	-78.289	-52.590	-61.287	2.036	-21.039	-27.694	-8.406	-19.448	-12.951	-53.357
		VP.13	-14.679	-12.983	-13.321	-12.095	-12.197	-11.675	-11.884	-12.408	-11.320	-12.739	-11.128
		VP.14	-64.148	-63.122	-63.328	-62.583	-62.641	-62.326	-62.454	-62.771	-62.110	-62.973	-61.994
		VP.15	-132.795	-131.765	-131.971	-131.224	-131.282	-130.966	-131.094	-131.412	-130.749	-131.615	-130.633
PWP (Actual)	(kPa)	VP.05	8.652	9.060	66.566	117.783	162.323	163.783	161.332	162.249	164.873	161.660	159.378
		VP.06	-1.446	-1.462	-1.604	-3.882	-4.249	-4.719	6.538	16.711	22.126	25.039	24.882
		VP.07	-2.486	68.458	102.202	124.866	165.620	153.189	146.848	149.219	150.986	141.788	139.375
		VP.08	-2.141	-2.172	-2.228	-3.882	6.164	21.464	19.286	17.786	17.719	15.915	14.508
		VP.09	-4.384	-4.500	30.909	42.789	84.770	75.990	70.286	72.311	73.199	65.383	63.018
		VP.10	-4.178	-4.273	-4.519	-6.607	-6.957	8.790	9.916	7.578	8.005	6.472	5.151
		VP.11	-3.413	-3.484	-3.630	-5.423	32.160	21.747	15.412	16.800	18.637	10.292	7.287
		VP.12	-1.768	-1.315	-3.128	-2.855	-3.516	-2.462	-2.805	-2.582	-2.086	-3.184	-4.224
		VP.13	-4.029	-4.118	-4.280	-6.253	-6.811	-7.286	-8.369	-8.542	-8.728	-9.524	-10.111
		VP.14	-3.797	-3.852	-3.950	-5.566	-5.988	-6.399	-7.177	-7.967	-7.879	-8.609	-9.274
		VP.15	22.500	23.696	23.605	25.017	25.782	31.689	21.482	21.280	21.821	27.396	19.400

The numerical simulations on the MD.16 STA 0+420 cross-section for instruments (VP.05, VP.07, VP.09, VP.11) showed the same trend of pore water pressure (PWP) water level fluctuations in reservoirs. In contrast (VP.06, VP.08, VP.10, VP.12, VP.13, VP.14, VP.15) showed a trend of pore water pressure (PWP) different from fluctuations in the water level in the reservoir. This is because when the PWP value of the instrument is minus, then the effect of water level fluctuations is minimal. The actual readings in the field at the MD.16 STA

Dedy Ardianto Fallo, Andre Primantyo, and Evi Nur Cahya, "Dam Body Safety Evaluation Pre and Post Impounding Use Instrumentation Data on Raknamo Dam in East Nusa Tenggara Province," *International Research Journal of Advanced Engineering and Science*, Volume 6, Issue 3, pp. 355-362, 2021.

0+420 display for devices (VP.05, VP.07, VP.09, VP.11) showed the same trend of pore water pressure (PWP) water level fluctuations in reservoirs. In contrast, instruments (VP.06, VP.08, VP.10, VP.12, VP.13, VP.14, VP.15) showed a pore water pressure (PWP) trend, which is very different from fluctuations in the water face in the reservoir. According to Mohamed N. Salem et al. (2019), who tested the test model in the laboratory of Zagazig University in Egypt stated that when there is a change or difference in permeability value (k) in the core stock, then the value of PWP and also seepage that occurs will be different from numeric results.

Data from instrument readings in the field (actual data) compared to the analysis results of numeric discharge seepage (SEEP / W). This validation is based on several dates in January 2018 - December 2020 to see more clearly how the results of seep/W discharge analysis and actual V-Notch data in MD.10 (STA 0+300) locations.

TABLE VII. Analysis of Numeric Discharge and Actual Debit V-Notch - MD.10 (STA 0+300).

Tanggal	*Code*	Tinggi Muka Air	Debit *Numeric*	Panjang Pondasi	*V-Nocth* A	*V-Nocth* B	Rerata *V-Notch*	Debit *Numeric*	Deviasi	Kesalahan Relatif
		(m)	(m^3/dtk/m)	(m)	(m^3/dtk)	(m^3/dtk)	(m^3/dtk)	(m^3/dtk)	(m^3/dtk)	%
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)={(0,5)*(6+7)}	(9)=(4)*(5)	(10)=(8)-(9)	(11)=(10/8)*100
31-Jan-18	A	87,500	3,0758,E-07	540	0,002	0,0008	0,00124	0,00017	0,00108	86,6
28-Feb-18	B	93,650	1,0747,E-06	540	0,004	0,0018	0,00304	0,00058	0,00246	80,9
30-Apr-18	C	94,950	1,2562,E-06	540	0,004	0,0004	0,00221	0,00068	0,00153	69,2
31-Jan-19	D	96,400	1,4794,E-06	540	0,005	0,0006	0,00291	0,00080	0,00211	72,5
30-Apr-19	E	101,400	2,8442,E-06	540	0,006	0,0008	0,00346	0,00154	0,00193	55,6
30-Sep-19	F	99,200	1,9024,E-06	540	0,006	0,0008	0,00320	0,00103	0,00218	67,9
31-Dec-19	G	98,500	1,8643,E-06	540	0,005	0,0010	0,00325	0,00101	0,00224	69,0
29-Feb-20	H	100,119	2,0632,E-06	540	0,007	0,0016	0,00427	0,00111	0,00315	73,9
30-Apr-20	I	99,735	1,8921,E-06	540	0,005	0,0015	0,00317	0,00102	0,00215	67,8
30-Sep-20	J	98,834	1,8893,E-06	540	0,004	0,0008	0,00262	0,00102	0,00160	61,1
31-Dec-20	K	98,690	1,8902,E-06	540	0,006	0,0010	0,00329	0,00102	0,00227	68,9

Modeling results with sigma/W numeric analysis show deviations or differences from the actual results of multilayer settlement instrument readings. According to Mohammad Rashidi et al. (2017), while researching settlements at the gavosham dam in Iran, this is caused by the soil around the instrument compacted with a lower density compared to other parts of the dam core to prevent damage to the device. As a result, the stiffness of the soil around the instrument is lower than in other parts of the dam core.

D. Maximum Security Factor Limit

The actual amount of seepage can be calculated with V-Notch Weir, while the quantity of numeric seepage can be calculated by seep/W analysis. The amount of seepage tolerable relates to the amount of seepage quantity allowed for the safety of the Raknamo dam. According to Look, the 2007 seepage limit is associated with the dam's height, the length of the main barrier, and the permeability of the dam's core heap. The allowable amount of seepage can generally be seen in Table in Chapter II than from the height of the Raknamo dam, which is 37.0 m; the maximum seepage limit can be obtained at 0.259 m^3/min/ m. Based on the maximum seepage limit received, it can be seen in Table VIII and Table IX that the discharge of seepage that occurs in the body of the Raknamo dam due to changes in water level elevation from 2018 - 2020, for each dam cross-section (MD.10 and MD.16) as well as on V-Notch instruments. Safety factors against seepage occurring in the MD.10 cross-section and V-Notch readings are still safe, as shown in Table VIII.

TABLE VIII. Safety Factors against Numeric Seepage (MD.10 – STA 0+300) and Actual (V-Notch Observation), Look, 2007.

Tanggal	Code	Tinggi Muka Air	Debit Numeric	Panjang Pondasi	Rerata V-Nocth	Rerata V-Nocth	Debit Numeric	Rerata V-Nocth	Nilai Ambang	Komentar Debit Numeric	Komentar Debit V-Notch
		(m)	(m^3/dtk/m)	(m)	(m^3/dtk)	(m^3/dtk/m)	(m^3/mnt/m)	(m^3/mnt/m)	(m^3/mnt/m)		
(1)	(2)	(3)	(4)	(5)	(6)	(7) =(6)/(5)	(8)=(4)*(60)	(9)=(7)*(60)	(10)	(11)	(11)
31-Jan-18	A	87,500	3,0758,E-07	540	0,00124	0,000002	0,00002	0,00014	0,259	Aman	Aman
28-Feb-18	B	93,650	1,0747,E-06	540	0,00304	0,000006	0,00006	0,00034	0,259	Aman	Aman
30-Apr-18	C	94,950	1,2562,E-06	540	0,00221	0,000004	0,00008	0,00025	0,259	Aman	Aman
31-Jan-19	D	96,400	1,4794,E-06	540	0,00291	0,000005	0,00009	0,00032	0,259	Aman	Aman
30-Apr-19	E	101,400	2,8442,E-06	540	0,00346	0,000006	0,00017	0,00038	0,259	Aman	Aman
30-Sep-19	F	99,200	1,9024,E-06	540	0,00320	0,000006	0,00011	0,00036	0,259	Aman	Aman
31-Dec-19	G	98,500	1,8643,E-06	540	0,00325	0,000006	0,00011	0,00036	0,259	Aman	Aman
29-Feb-20	H	100,119	2,0632,E-06	540	0,00427	0,000008	0,00012	0,00047	0,259	Aman	Aman
30-Apr-20	I	99,735	1,8921,E-06	540	0,00317	0,000006	0,00011	0,00035	0,259	Aman	Aman
30-Sep-20	J	98,834	1,8893,E-06	540	0,00262	0,000005	0,00011	0,00029	0,259	Aman	Aman
31-Dec-20	K	98,690	1,8902,E-06	540	0,00329	0,000006	0,00011	0,00037	0,259	Aman	Aman

While the safety factor against seepage that occurs in the MD.16 cross-section and V-Notch readings is still in a safe condition, as shown in Table IX.

TABLE IX. Safety Factors against Numeric Seepage (MD.16 – STA 0+420) and Actual (V-Notch Observation), Look, 2007.

Tanggal	Code	Tinggi Muka Air	Debit Numeric	Panjang Pondasi	Rerata V-Nocth	Rerata V-Nocth	Debit Numeric	Rerata V-Nocth	Nilai Ambang	Komentar Debit Numeric	Komentar Debit V-Notch
		(m)	(m^3/dtk/m)	(m)	(m^3/dtk)	(m^3/dtk/m)	(m^3/mnt/m)	(m^3/mnt/m)	(m^3/mnt/m)		
(1)	(2)	(3)	(4)	(5)	(6)	(7) =(6)/(5)	(8)=(4)*(60)	(9)=(7)*(60)	(10)	(11)	(11)
31-Jan-18	A	87,500	7,3256,E-07	540	0,00124	0,000002	0,00004	0,00014	0,259	Aman	Aman
28-Feb-18	B	93,650	1,8831,E-06	540	0,00304	0,000006	0,00011	0,00034	0,259	Aman	Aman
30-Apr-18	C	94,950	1,6628,E-06	540	0,00221	0,000004	0,00010	0,00025	0,259	Aman	Aman
31-Jan-19	D	96,400	2,4878,E-06	540	0,00291	0,000005	0,00015	0,00032	0,259	Aman	Aman
30-Apr-19	E	101,400	2,4077,E-06	540	0,00346	0,000006	0,00014	0,00038	0,259	Aman	Aman
30-Sep-19	F	99,200	2,7896,E-06	540	0,00320	0,000006	0,00017	0,00036	0,259	Aman	Aman
31-Dec-19	G	98,500	2,0830,E-06	540	0,00325	0,000006	0,00012	0,00036	0,259	Aman	Aman
29-Feb-20	H	100,119	3,2635,E-06	540	0,00427	0,000008	0,00020	0,00047	0,259	Aman	Aman
30-Apr-20	I	99,735	2,9143,E-06	540	0,00317	0,000006	0,00017	0,00035	0,259	Aman	Aman
30-Sep-20	J	98,834	2,0715,E-06	540	0,00262	0,000005	0,00012	0,00029	0,259	Aman	Aman
31-Dec-20	K	98,690	3,1369,E-06	540	0,00329	0,000006	0,00019	0,00037	0,259	Aman	Aman

The amount of seepage allowed on the dam is closely related to the safety of the dam. According to Soedibyo, 2003 the allowable seepage limit on barriers is 2% - 5% of the average inflow discharge that goes into the reservoir. Based on the Final Report - Raknamo Dam Design Certification, 2014 had an average inflow discharge of 0.6994$^{m3/s.}$ The allowable seepage quantity used is 2% of the inflow discharge, which is 0.014^{m3}/s. In addition to being safe against seepage, the dam's body must also be safe against the dangers of piping. With piping in the body of the dam, the body of the dam is not secure. This causes piping when the dam body's critical speed (Vc) is smaller than the flow speed (Vs). To ensure the dam body is safe against piping hazards, it is necessary to calculate the critical speed value (Vc) of the equation 2-20.

The layer of soil on the core of the Raknamo dam that experiences strain or decrease (settlement) is caused by two consequences: the soil arrangement in the changes and pore cavities in the soil of the core pils reduced. According to Novak, the 2007 settlement limit at the dam's core is allowed based on equations 2-23 where; Settlement Index (SI) ≤ 0.02 = 0.85 m. When the SI is smaller than the specified security factor, the settlement is still categorized as safe. To be able to find out the decrease (payment) in the cross-section of MD.11 and MD.17 from the results of numeric analysis (SIGMA / W) and actual field (multilayer settlement) in safe conditions.

E. Stability Analysis of Raknamo Dam

The stability analysis of the Raknamo dam reviewed was on the cross-section of Main Dam 10 (MD.10) STA 0+300. Analysis of dam stability is also taken into account in the event of an earthquake. The earthquake is taken into account in the evaluation of dam safety, namely; Basic earthquake operations (operating base earthquake, OBE) and maximum design earthquake (MDE). For that, it is necessary to analyze OBE and MDE earthquakes first. Analysis to determine the magnitude of the earthquake coefficient in the dam depends mainly on the classification of the building risk class and the acceleration of the design of the Raknamo dam risk class. Based on the analysis results, the type of building risk can then be determined, then the category of building risk is in class III (High). The earthquake coefficient used in the analysis of the stability of the dam slope uses the coefficient of modified earthquakes. Obe earthquake values use 100-year repeat times, while for MDE earthquakes use 5000-year repeat times, the determination of OBE and MDE earthquakes is determined using earthquake load criteria for dam design.

Stability analysis of the upstream and downstream slopes of the Raknamo dam is carried out at the time; without earthquakes, with static tremors 100 years, with OBE earthquakes, and with MDE earthquakes. This slope stability analysis uses the numeric (SLOPE/W) model of the 2012 Geostudio application. Before using the numeric model (SLOPE / W), first done research using the numeric model (SEEP / W) then obtained the value of pore water pressure for each case, then the analysis of the numeric model (SLOPE / W) combined with the study of the numeric model (SEEP / W) to be known the value of the security factor in 3 (three) different conditions.

V. CONCLUSION

The pore water pressure pattern in the MD.10 STA 0+300 cross-section based on numeric and actual results for instruments (VP.05 to VP.09) has a downward open parabola shape. Also, it has a similar trend to changes in water level elevation in reservoirs. At the same time, instruments (VP.10 and VP.11) have a downward open parabola shape and have a different trend with changes in water level elevation that occurred during 2018 - 2020 in reservoirs. While the pore water pressure pattern in the CROSS-section of MD.16 STA 0 +420 is based on numeric and actual results for instruments (VP.05, VP.07, VP.09, VP.11) has the same trend as changes in water level elevation in reservoirs. In contrast, instruments (VP.06, VP.08, VP.10, VP.12, VP.13, VP.14, VP.15) have a different trend with changes in water level elevation that occurred during 2018 - 2020 in reservoirs. The seepage pattern in the body based on numeric results has a downward open parabolic shape. Also, it has the same trend as changes in water level elevation in the reservoir. In contrast, the actual result has a slightly different movement with changes in water level elevation in the pool. The pattern of decline (settlement) that occurs in the cross-section of MD.11 STA 0 +320 based on numeric and actual results for instruments (SP.01, PM.01, PM.02) has a more linear form and also has a trend that tends to be the same for two years (2018 - 2020), for instruments (PM.03, PM.04, PM.05) has a trend that tends to differ for 1.3 years (January 2018 - April 2019). Based on the results of numeric analysis (SEEP / W) on the body of the dam is 0.00176 m3/s < 0.014 m3/s, then the barrier is still safe against maximum discharge seepage. While based on the actual reading results in the field (Instrument V-Notch) is 0.00427 m3/s < 0.014 m3/s, the dam is still safe against the maximum seepage discharge. Based on the results of numerical analysis (SIGMA / W) at the core of the dam is 0.00334 < 0.02, the barrier is still safe because the settlement does not exceed the allowable limit. Based on the results of numerical analysis (SLOPE / W) for the stability of the slopes of the Raknamo dam, with conditions without earthquakes, with static earthquakes 100 years, and with dynamic earthquakes OBE and MDE.

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