Inspections of Hydro-Geotechnical on Ngancar Dam

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Abstract. Besides having great benefits, dam also holds enormous potential dangers. The collapsed dam will cause devastating flood along the river resulting in loss of lives, properties, damage to public facilities and environment, especially in the downstream area. For safety and prevent the occurrence of the disaster, the operational of dam should always be monitored, inspected and maintained properly continually. With a good monitoring, dam managers will discover as early as possible the problems emerging in the dam, and then perform the appropriate steps to prevent the development of the problems. This paper will perform hydro-geotechnical analysis as a review current condition of slope stability based on the result of soil investigation on present dam condition and review instrumentations installed in Ngancar Dam.

Keywords: Dam inspection, hydro-geotechnical**,** slope stability, seepage

1. Introduction

Ngancar dam was built in 1944 by the Dutch government [1] and the function of this dam is to the needs of irrigation water in the district of Wonogiri in general and the District Batuwarno particular. Until now Ngancar dam is still able to function properly, although it declined in addressing the needs of irrigation water.

Ngancar dam is geographically located at 7°48’5” S and 110°53’53” E. Dams condition is still functioning properly and technically adequate; dam today is still able to serve the needs of irrigation area measuring 1,300 ha [1].

In order to improve the operation and safety of dams in Indonesia, the Government has set a new policy, which was originally purely technical dam by giving attention to both prevention and control activities around the dam and upstream watershed-based community participation. In this study will be performed hydro-geotechnical analysis is a review of the condition of slope stability based on the results of soil investigation dam body existing conditions now, and review of instrumentation installed namely: piezometer, deformation, and seepage [2].

2. Material and Methods

Inspection study of Ngancar Dam was conducted based on the latest data related to:

a. Measurement of Topography and bathymetry data in 2016 using Global Bench Mark (TTG-1161).
b. Soil data used for slope stability analysis based on drilling results in 2016 at Ngancar Dam

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c. Visual observations of dam instrumentation conditions such as: piezometer, deformation and seepage are based on observation data of 2016.
d. Seepage analysis on the dam body and v-notch gauge is based on current geotechnical conditions and field observations of 2016.
e. To perform the analysis is done based on the guidelines inspection/evaluation Dam and the Guidelines for Common Criteria Dam Design [3].

2.1. Procedure of Observe Piezometer

Make observations by using the Dip Meter tool. Before making observations using the Dip Meter tool, it is necessary to check the tool by dipping the probe into the water to make sure the indicator lights are on and the tone of the sound is working [4].

The following observation steps:

- Lower the Dip Meter probe into the well to ensure the sound/sound tone and indicator light are on when the probe hits the water level.
- Pull the probe up slowly until the light turns off and the tone is inaudible.
- Moving the probe up and down slowly so as to get into the probe well with the tape measure with the measuring tape against the reference point / face well.
- The reading was done several times and the average score was taken.

The amount of pore pressure can be calculated by the following formula:

$$PP = RPE - R - PTE \quad (1)$$

$$PL = RPE - R \quad (2)$$

PP = Pore Pressure (mH_2O)
PL = Piezometric Level (m)
RPE = Reference Piezometer Elevation (m)
R = Reading (m)
PTE = Piezometer Tip Elevation (m)

2.2. Slope stability and seepage analysis

To determine the condition of the stability of the dam slope, used the modified Bishop Method and Janbu. The amount of seepage that comes out from the body of Ngancar Dam is calculated by Seep / W model based on finite element. The calculation result is a Flux that is the discharge (Q) seepage passing through the core. The seep analysis analyzed using the SEEP / W 2007 program is in the maximum reservoir water level (FWL +243.98), normal water level (NWL + 243.20), and minimum water level (LWL +235).

2.3. Total Flow Quantity

This value can be computed from the nodal heads and the coefficients of the finite element equation. For example, consider a mesh with only one element, as illustrated in Figure 1. The objective is to compute the total flow across a vertical section of the element. It can be re-written with the flux value isolated on one side as follows [5]:

$$[K]\{H\} + [M]\frac{\Delta H}{\Delta t} = \{Q\} \quad (3)$$

In a steady-state analysis, the storage term $[M]\frac{\Delta H}{\Delta t}$ becomes zero, and the equation can be reduced to: $[K]\{H\} = \{Q\}$

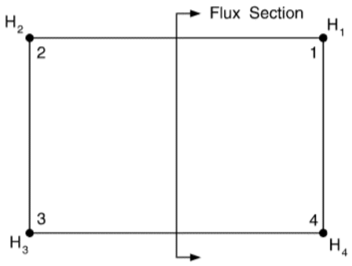

Figure 1. Illustration of a flux section across a single element

The global set of finite equations for one element is as follows:

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \\ C_{41} & C_{42} & C_{43} & C_{44} \end{bmatrix} \begin{bmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \end{bmatrix} = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} \quad (4)$$

From Darcy's Law, the total flow between two points is [6] [7]

$$Q = k.A\frac{\Delta H}{l} \quad (5)$$

The coefficients, c, in Equation (4) are a representation of $\frac{KA}{l}$ Equation (5) Therefore, the flow from Node i to Node j is:

$$Q_{ij} = c_{ij}(H_i - H_j)$$

In a transient analysis, because of material storage, the calculation of the total flow quantity must include the storage effect. The change in flow quantity due to the storage term can be expressed as:

$$\frac{1}{\Delta t}\begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{bmatrix} \begin{bmatrix} \Delta H_1 \\ \Delta H_2 \\ \Delta H_3 \\ \Delta H_4 \end{bmatrix} = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} \quad (6)$$

Where $\Delta H_{1,2,3,4}$ etc. are the changes of total head at the various nodes between the start and the end of a time step. In general, the average change of total head from Node i to Node j can be expressed as:

$$\Delta H_{ij} = \frac{\Delta H_i + \Delta H_j}{2} \quad (7)$$

Therefore, the change in flow quantity from Node i to Node j due to a change in storage is:

$$Q_{ij} = m_{ij}\frac{\Delta H_{ij}}{\Delta t} \quad (8)$$

The total flow quantity from Node i to Node j for a transient analysis then becomes:

$$Q_{ij} = C_{ij}(H_i - H_j) + m_{ij}\frac{\Delta H_{ij}}{\Delta t} \quad (9)$$

The total flow quantity through the flux section shown in Figure 1 is:

$$Q = Q_{21} + Q_{24} + Q_{31} + Q_{34} \quad (10)$$

3. Result and Discussion

Prior to the analysis of related visual inspection, conducted a study of previous studies related to the condition of the Ngancar Dam. Construction of this dam is built in the Dutch colonial era; which is not found as built drawing, but based on previous studies obtained information that this dam is a rock-earth fill dam Type with impervious core layer. The results of the study of the topography of the location and position of the dam instruments are as follows:

3.1. Piezometers

There are 14 pieces of piezometers, which are all types of standpipe. All of the 14 pieces are included 1-piece piezometer piezometers damaged by thick sediment covered ± 10 m in hole piezometers. Coordinates of each piezometer based on the 2016 topographical measurements using Global Bench Mark are as follows (see Table 1).

Figure 2. Inspection of stand pipe piezometer at Ngancar Dam

Table 1. Location of Stand Pipe Piezometer (SPP) based on year 2016

No	Name	Coordinat SPP		Elevation Z(M)
		X (m)	Y (m)	
1	PZ	497685,7	9116856,334	+ 245,348
2	PZ.1	497614,4	9116721,507	+ 244,900
3	PZ.2	497646,6	9116739,878	+ 244,347
4	PZ.2B	497640,3	9116750,360	+ 240,286
5	PZ.4	497642,2	9116773,341	+ 232,392
6	PZ.6	497680,3	9116767,281	+ 244,763
7	PZ.6B	497681,9	9116770,099	+ 244,780
8	PZ.7	497677,8	9116769,903	+ 243,167
9	PZ.7B	497674,8	9116774,911	+ 240,254
10	PZ.9	497689,1	9116802,085	+ 244,745
11	PZ.10	497682,6	9116801,926	+ 243,689
12	PZ.12	497631,2	9116765,312	+ 232,250
13	PZ.18	497662	9116749,530	+ 244,587
14	PZ.19	497660,2	9116752,250	+ 244,663

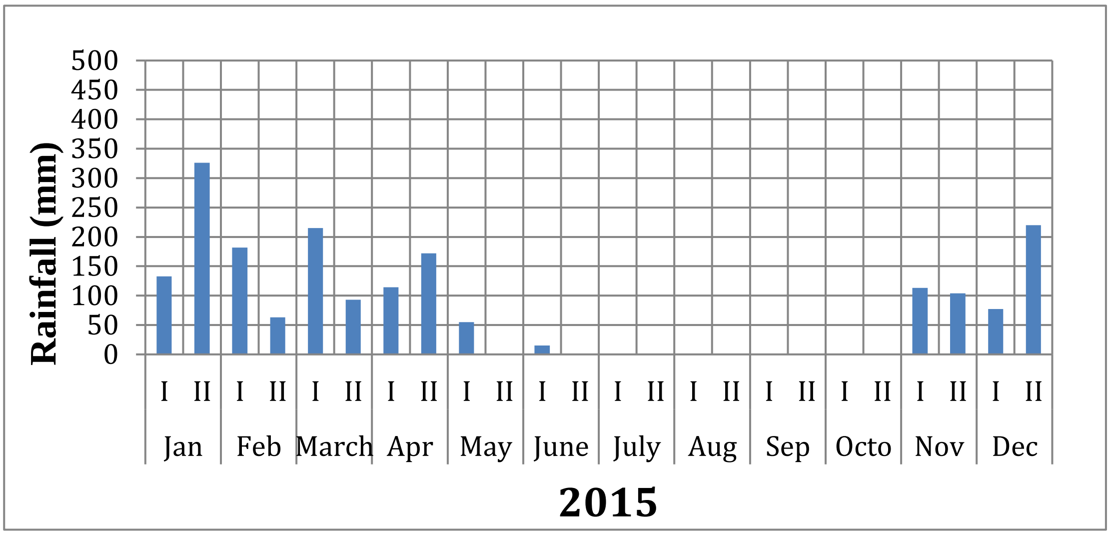

Figure 3. Annual rainfall in at Ngancar Dam

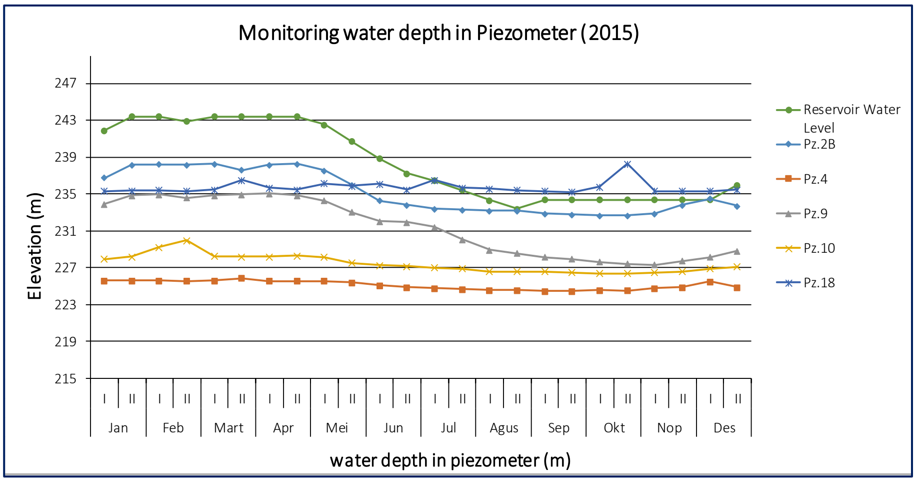

Figure 4. Change the water in the piezometer against the reservoir water level

From the monitoring results throughout 2015, shows that only five pieces standpipe piezometers to describe the condition of seepage in the dam body is piezometers Number: 2B Pz, Pz 4, 9 Pz, Pz 10, Pz 18. While other standpipe piezometers are: Pz 1 Pz 2 Pz 6, Pz 6b, Pz 7, Pz 7b, Pz 12, Pz 19 was not found water to a depth end of the piezometer, this may be due to the placement of the piezometers is less precise, so the conditions in piezometers always dry on every reservoir water level condition.

The relationship of water level in the piezometers are also affected by the reservoir water level fluctuations, as seen in the following graph:

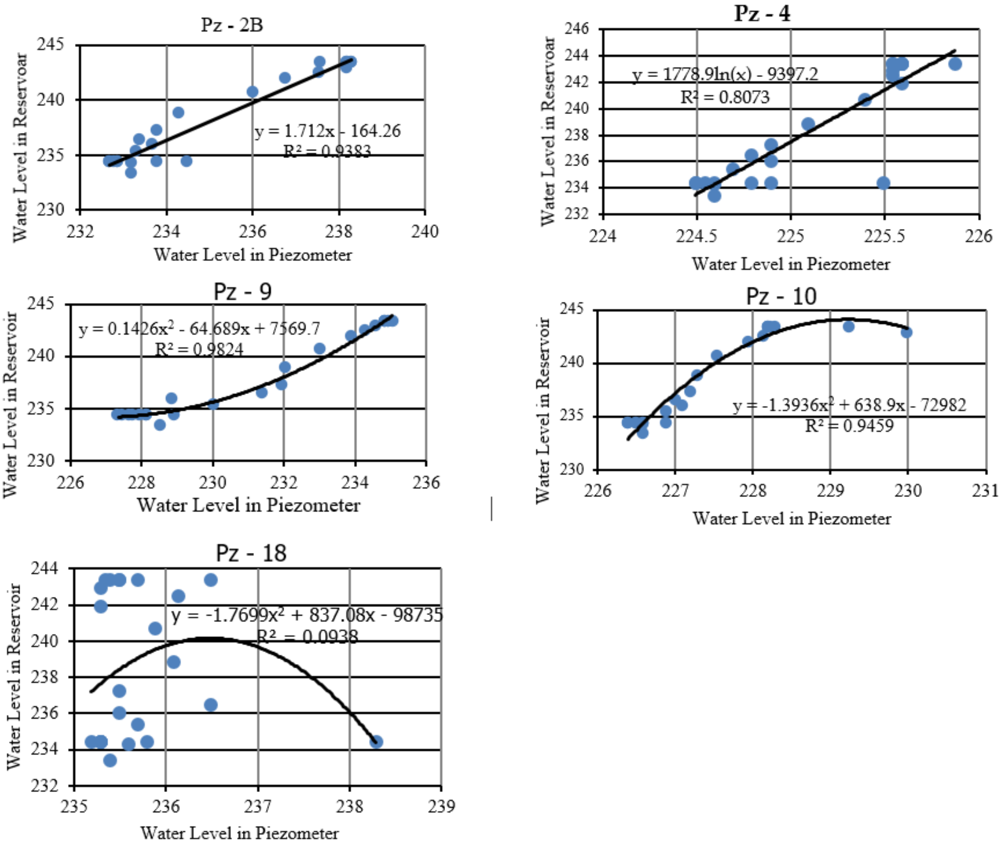

Figure 5. Regression value of piezometers to the water level in reservoir

From the graph above shows that all four piezometers are: Pz-2B; Pz-4; Pz-9; and Pz-10 has a good regression coefficient with $R^2 > 0.5$ [8]. It means that the existence of piezometers is strongly influenced by the reservoir water level fluctuations, but in piezometers Pz-18 otherwise obtained relationship $R^2 < 0.5$. This could indicate that the water level readings at the point Pz -18 piezometers conditions need to be evaluated.

As we know that the function is to monitor the movement piezometer phreatic flow in the body of the dam, but if the condition piezometers damage will greatly affect the results of monitoring the dam so it must be repaired in order to precisely predict the leak in the dam body both in static and dynamic load conditions

3.2. Deformation Instrument.

At the Ngancar Dam, there are four (4) pieces of benchmarks to monitor deformation in which everything is in good condition. However, not is all measured periodically to determine the movement of the dam decline. In 2016 has performed repeated measurements coordinate deformation-bench mark with readings as follows:

Table 2. The newest coordinate of deformation bench mark (2016)

No	Name Bench Mark	Coordinat UTM		Elevation (m)
		X (m)	Y (m)	
1	BM PG-1	497.611,408	9.116.720,963	244,436
2	BM PG-2	497.633,638	9.116.735,356	244,371
3	BM PG-3	497.685,564	9.116.808,763	244,622
4	BM PG-4	497.684,754	9.116.841,826	244,623

Expected to this latest coordinate of benchmark used as a starting point for monitoring the movement of the dam body deformation.

3.3. Seepage gauge

V-notch weir is used to monitor the flow of seepage of the dam body. In Ngancar dam, there are 2 pieces of v-notch weir, but not all the instruments can describe the condition of discharge of seepage in the dam body. This is because of both the instruments cannot drain the water seepage above a threshold. Seepage water tends to flow through a pipe below the threshold so that the seepage capacity cannot be measured properly. Things can be done is to re-position setting v-notch weir in order to function properly.

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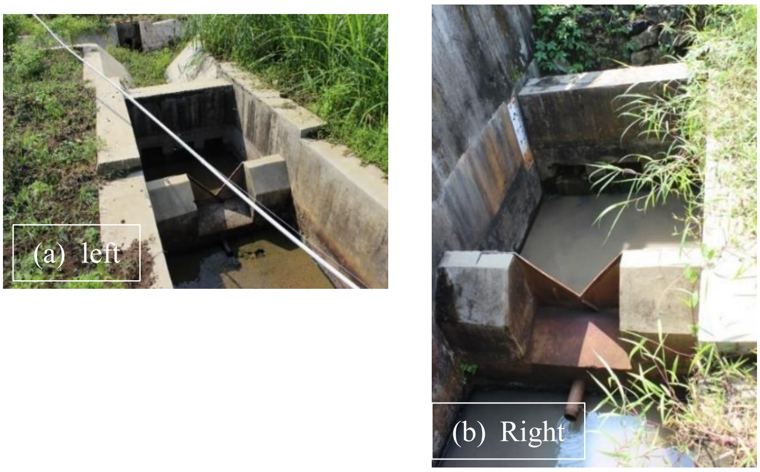

Figure. 6. V-notch weir cannot measure the seepage discharge (both on the left and right of the dam).

3.4. Analysis of seepage.

The amount of seepage that flows from the body of Ngancar Dam is calculated with finite element. The result of the calculation is Flux, which is the discharge (Q) seep through the Ngancar Dam core. Water reservoir boundary conditions at Flood Water Level (FWL) +243.98, normal water level (NWL) + 243.20, and low water level (LWL) + 235.

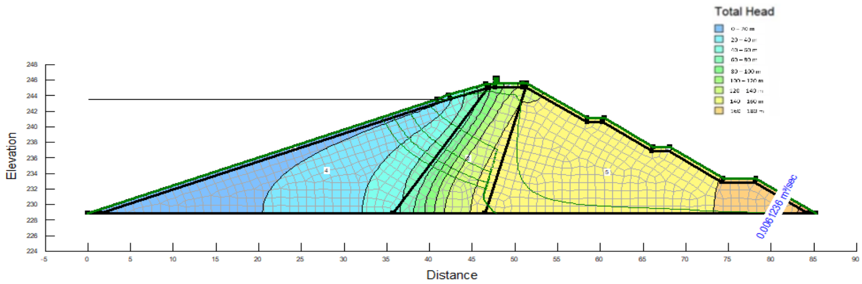

Figure 7. Seepage in dam body at Flood water level FWL (+243.98)

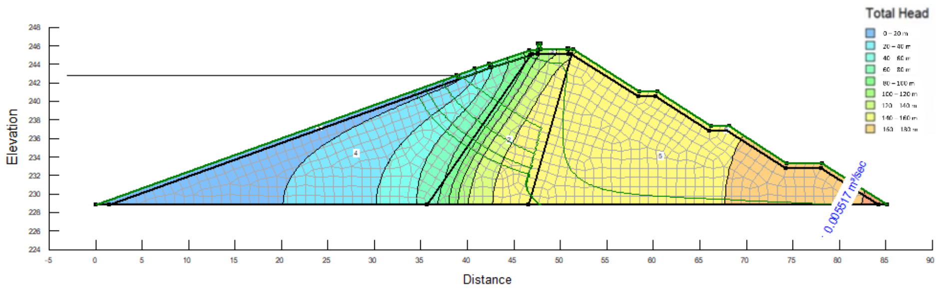

Figure 8. Seepage in dam body at Normal water level, NWL (+ 243.2)

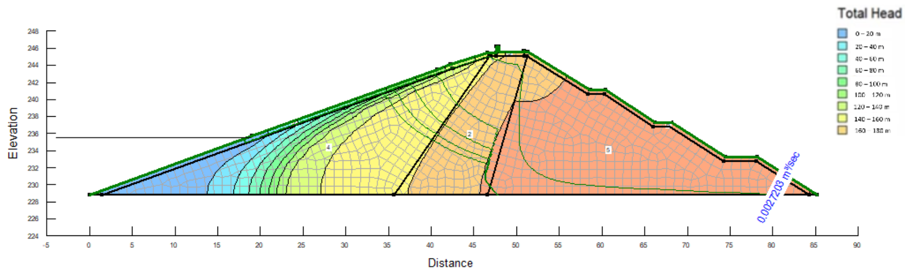

Figure 9. Seepage in dam body at Low water level, LWL (+235)

From seepage capacity analysis using SEEP / W model obtained seepage capacity for each water level of reservoir, are as follows:

- FWL +243.98 m = 6.1236.10^{-3} m³/s.
- NWL +243.20 m = 5.517.10^{-3} m³/s.
- LWL +235 m = 2,7203.10^{-3} m³/s.
- Average = 4.786.10^{-3} m³/s.

Referring to the Japanese Institute of Irrigation and Drainage, the amount of leakage passing the foundation and body of the dam should not exceed 1% of the average river flow into the reservoir [9]. Is known:

- Average Discharge (Q) in the river = 0.1785 m³/s
- 1% of average discharge (Q) river = 1.785.10^{-3} m³/s.
- Average seepage capacity = 1,572.10^{-3} m³/s.

Average seepage capacity (4.786, 10^{-3} m³/s) > 1% of the average Q river (1.785.10^{-3} m³/s). Thus it can be concluded that the seepage beneath the foundation and body of the Ngancar dam is not safe and needs to be repaired immediately. This is thought to be due to weathering of limestone rocks at the foundation base

3.3. Analysis of slope stability

Slope stability analysis is reviewed based on static and dynamic load conditions. Analysis to determine the magnitude of earthquake design following the guidelines of Pd-T- 14-2004 A [10]. Analysis of the stability of the rock-earth fill dam is calculated by considering the risk factor dam safety [11] [12].

Table. 3 Calculation of Risk Factor on Ngancar Dam

Risk Factor of Ngancar Dam	**Weight of Risk Factor (Fr)**
Storage capacity = 4.19x10^6 m^3	$Fr_k = 4$
Height of Dam = 19,05 m	$Fr_t = 2$
Evacuation need ± 1000 people	$Fr_e = 8$
the extent of damage in the downstream = moderate	$Fr_h = 4$
Total of Risk Factor	$FR_{Total} = 18$

With a total risk factor (FR_{Total}) = 18, then based on risk class table, and then Ngancar Dam including risk class II (Moderate).

Tabel 4 . Dam Risk Class [5]

Total Risk Factor	**Risk Class**
(0-6)	I (Low)
(7-18)	II (Moderate)
(19-30)	III (High)
(> 31)	IV (Extreme)

Based on the risk class of the dam and waterworks, the criteria for the design earthquake loads in OBE (*optimum based earthquake*) and MDE (*maximum design earthquake*) can be determined by guidelines of Pd-T- 14-2004. Then to the Ngancar Dam with risk class II (moderate), the analysis methods used in the period, T = 100 years (for "requirement without damage" OBE) and the period T = 3,000 years ("requirements allowed no damage without collapse" MDE).

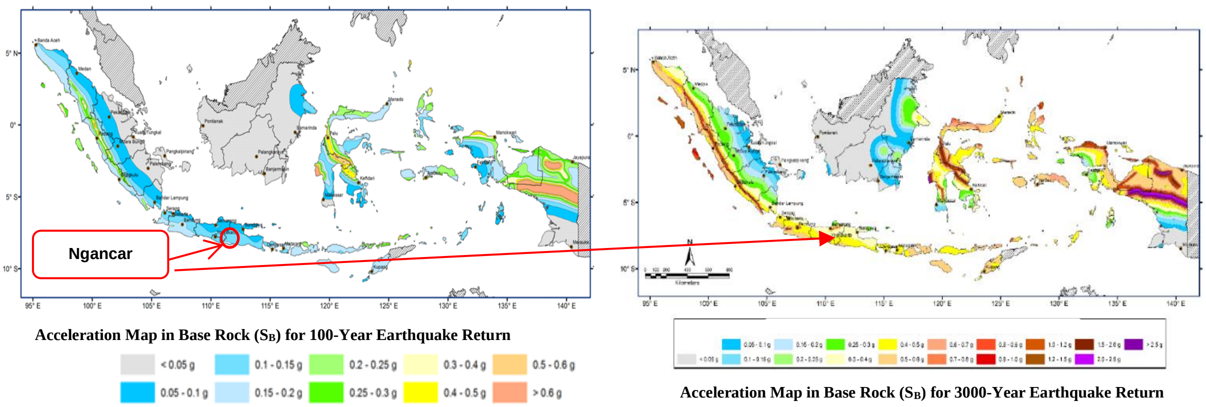

Figure 10. Map of peak acceleration at bedrock (return period of 100 and 3000 years)

Based on the location of the dam above the peak acceleration value in bedrock (SB) = 0.15 g and the amplification factor (FPGA) = 1.00. Peak acceleration at ground level for the return period of 100 years;

PGA_M = F_{PGA} x S_B
= 1,00 x 0,15 g
= 0,15 g

K_0 = PGA_M / g
= 0,15 x 0,981 / 0,981
= 0,15
K_h = K_0 x α
= 0,15 x 0,50
= 0,075

Peak acceleration at ground level for the return period of 3000 years MDE;

PGA_M = F_{PGA} x S_B
= 1,00 x 0,45 g
= 0,45 g
K_0 = PGA_M / g
= 0,45 x 0,981 / 0,981
= 0,45
K_h = K_0 x α
= 0,45 x 0,50
= 0,225

The result of the calculation of slope stability for dynamic load with OBE conditions as follows:

Table. 5 Result of *Safety Factor* dynamic load, return periode T = 100 year (OBE)

No	Condition	FS_{min}	Safety Factor							
			Bishop				Janbu			
			0.25	0.5	0.75	1	0.25	0.5	0.75	1
1	Slope : U/s-empty	1.1	1.941	1.959	1.967	1.976	1.833	1.85	1.858	1.866
2	Slope : D/s-empty	1.1	1.644	1.645	1.645	1.646	1.605	1.606	1.607	1.607
3	Slope : U/s - LWL	1.1	1.914	1.959	1.967	1.976	1.845	1.85	1.858	1.866
4	Slope : D/s - LWL	1.1	1.644	1.645	1.645	1.646	1.605	1.606	1.607	1.607
5	Slope : U/s – NWL	1.1	2.664	2.691	2.703	2.716	2.663	2.69	2.702	2.715
6	Slope : D/s - NWL	1.1	1.513	1.516	1.517	1.518	1.426	1.429	1.43	1.431
7	Slope : U/s – HWL	1.1	2.664	2.691	2.703	2.716	2.663	2.69	2.702	2.715
8	Slope : D/s – HWL	1.1	1.52	1.522	1.523	1.524	1.462	1.464	1.464	1.465
9	Slope : U/s - Rapid Drawdown	1.1	0.809*	0.786*	0.778*	0.758*	0.749*	0.725*	0.717*	0.698*
10	Slope : D/s- Rapid Drawdown	1.1	1.627	1.628	1.629	1.63	1.606	1.607	1.607	1.608

Reference: calculation and analysis Note = * (safety factor < 1,1) category is not safe

Table 6. Result of *Safety Factor* for dynamic load, return periode T = 3.000 year (MDE)

No	Condition	FS_{min}	Safety Factor							
			Bishop				Janbu			
			0.25	0.5	0.75	1	0.25	0.5	0.75	1
1	Slope : U/s-empty	1.1	1.828	1.858	1.872	1.887	1.737	1.765	1.779	1.793
2	Slope : D/s-empty	1.1	1.64	1.641	1.641	1.642	1.601	1.602	1.603	1.603
3	Slope : U/s - LWL	1.1	1.828	1.857	1.871	1.886	1.736	1.764	1.778	1.793
4	Slope : D/s - LWL	1.1	1.64	1.641	1.641	1.642	1.601	1.602	1.603	1.603
5	Slope : U/s – NWL	1.1	2.495	2.538	2.559	2.581	2.496	2.539	2.56	2.582
6	Slope : D/s - NWL	1.1	1.498	1.502	1.504	1.506	1.412	1.415	1.417	1.419
7	Slope : U/s – HWL	1.1	2.495	2.538	2.559	2.581	2.496	2.539	2.56	2.582
8	Slope : D/s – HWL	1.1	1.506	1.51	1.512	1.513	1.449	1.452	1.454	1.455
9	Slope : U/s - Rapid Drawdown	1.1	0.887*	0.869*	0.858*	0.849*	0.821*	0.805*	0.794*	0.786*
10	Slope : D/s- Rapid Drawdown	1.1	1.62	1.622	1.623	1.624	1.599	1.601	1.602	1.602

Reference: Calculation and Analysis Note = * (safety factor < 1,1) category is not safe

From the analysis above shows that the dynamic load conditions, slope stability Ngancar dam are safe against seismic load conditions return period of 100 years and 3,000 years, but both are critical to the rapid drawdown conditions. It makes an important record in the implementation of guidelines for operating the reservoir in order to avoid or be careful.

4. Conclusion

Based on the analysis of hydro-geotechnical above, the dam safety conditions on Ngancar Dam can be concluded in the category enough, this is because some instruments existing dam has not been optimal in monitoring the safety of dams. Not all piezometers functioning properly. Also, the presence of the deformation instrument is not monitored continuously, in addition, to aspects of security and stability is less secure conditions of rapid drawdown. Also, observations of several springs around the dam need to be done, given the amount of seepage from the spring on the right side of the dam there are bigger symptoms.

References

[1] Anonymous, 1992. Rehabilitation of Additional Six Dams in Central Java, Planning Note Ngancar Dam, Associated Consulting Engineer ACE (PVT) LTD

[2] PR. Bamane and Dr.S.S.Valunjkar, 2014 *Dam Safety Instrumentation*, American Journal of Engineering Research (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 page 58-62

[3] Anonymous, 2003 Guidelines Inspection/Evaluation Dam and the Guidelines for Common Criteria Dam Design, SK Dirjen SDA/KKB No.05 / KPTS / 2003. Dam Safety Commission.

[4] Xiaoli Ding and Hui Qin, 1998 *Geotechnical Instruments in Structural Monitoring*, Journal of Geospatial Engineering, Vol. 2, No.2, pp.45-56

[5] Seepage modelling with SEEP/W, An Engineering Methodology July 2012 Edition GEO-SLOPE International Ltd.

[6] E Fadaei Kermani and G. A barani, 2012, *Seepage Analysis through Earth Dam Based on Finite Difference Method*, Journal of Basic and Applied Scientific Research ISSN 2090-4304 vol 2 (11) page 11621-11625.

[7] Ms Abhilasha P.S and T.G Antony Balan, 2013, *Numerical Analysis of Seepage in Embankment Dams*, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 13-23.

[8] Crisinta Eka Putri, 2013, *Pengaruh Kepemimpinan, Motivasi dan Lingkungan Terhadap Kinerja karyawan di Yayasan Yoseph Freinademetz Surabaya.* Jurnal Ilmu & Riset Manajemen Vol 2 No. 9

[9] Sosrodarsono, Suyono & Takeda, Kensaku. 1989. Bendungan Type Urugan. Jakarta: Erlangga.

[10] Anonymous, 2004. Stability analysis of earth fill dams due to earthquake load. Guidelines of Pd-T- 14-2004. Ministry Public Work and Transport.

[11] Yu Zhao, Zi-Yhi Tong and Qing Lu, 2014. Slope Stability Analysis Using Slice-Wise Factor of Safety, Hindawi Publishing Corporation, Mathematical Problems in Engineering, Volume 2014, Article ID 712145, 6 pages.

[12] Ammar Rouaiguia and Mohammed A. Dahim, 2013, Numerical Modeling of Slope Stability Analysis, International Journal of Engineering Science and Innovative Technology (IJESIT), ISSN: 2319-5967