Analysis of Piping at Kedung Uling Earthfill Dam, Wonogiri Regency, Central Java Province, Indonesia

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Abstract. Kedung Uling earthfill dam is located between Eromoko and Wuryantoro district, Wonogiri Regency, Central Java, Indonesia. Water leaked from the dam was found and could decrease volume of dam. The objectives of this study are to identify piping and to recommend for solving piping problem. In order to determine the piping direction and litological pattern, investigation of 10 boreholes with various depth has been carried out. This investigation aim to determine characteristics of soil and rock by analyzing 45 cm of thickness of undisturbed samples and to perform permeability test. Permeability test have been conducted by falling head method with 3 different depths. Leaking at the dam was analyzed by Slide 6.0 software. The results indicated that litology of dam have been identified as claystone, sand and tuff. The piping passed under the eastern abutment of the dam is the accumulation of groundwater in the aquifers formed by 8-10 meters thick layer of sand. The total debit of piping is 17,774 cm^3/sec. The Factor of safety of piping is under the minimum of standard namely 3,6. Grouting is one of alternative method to minimize the piping. Grouting was simulated to reduce permeability value and increase soil strength. By grouting, the total debit of piping was reduced to 3.314 cm^3/sec.

1 Introduction

Kedung Uling dam was built in the colonial netherland era which is located between Eromoko and Wuryantoro district border, Wonogiri regency, Central Java Indonesia. This dam was built in 1917, which is lain between Jatirejo and Tempuran river. By the function as irigation, this dam has 479.000 m^3 storage capacity with the 596 hectare extensive paddies field. Another functions of this dam is for local tourism and fisheries fresh water. Kedung Uling dam has decreasing quality from its structure resulting sliding and settlement in the body of dam in 2013-2014. Besides, the problem which is found in the dam is leaking due to water flow come out to the inside of dam. The water flow erode fine materials resulted in potential unstability of dam. If this erosion happens, there is seepage line, which is called piping, between downstream and upstream dam.

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Piping or leaking in the dam can be detected using some methods such as multi tracer tests [1,2] and bore hole data[1,3], geological mapping, geophysical survey and laboratory analysis[4]. Fractures can be detected due to water infiltration by using geophysical approach [5]. Bedrock such as uncompacted claystone can generate settlement of dam [6]. Uromeihy and Barzegari [7] conducted leaking dam evaluation based on the cracks and simulated groundwater flow and carried out insitu tests to estimate permeability value. They suggested to use curtain grouting to overcome leaking of dam. The objective of this research is to understand piping factor of safety and recommendation for overcoming the piping.

2 Method

2.1. Ground observation

The objective of this observation was identified soil and rock at surrounding Kedung Uling dam. In addition, this observation also observed geological condition such as cracks and sliding or seepage.

2.2. Core drilling

Drilling has been arranged in 10 points with 10 meter, 12 meter and 15 meter in depth. Drilling has been done with single tube barrel core for getting undisturbed samples used for laboratory tests. That samples were taken 45 cm at the variation depth from 1,5-1,95 meter, 5,5-5,95 meter and at the end of drilling.

2.3. Permeability test

The objective of this test was observed the soil and rock permeability coeficient. This test has been performed in the field with the falling head method and has been tested with the depth interval at 4,5-5 meter, 8,5-10 meter and 13,5-15 meter.

2.4. Bore log and corelation

This data has been collected from sample of 10 core drillings and recorded in 10 bore log with the depth 10 meter, 12 meter and 15 meter. Every 1 meter depth sample has been taken from boring to identified soil characteristics and has been tested in soil mechanics laboratory. Log discription consists of soil, rock, color, grain size, characteristics of soil and rock. Bore log is corelated for each point based on litology in every depth. The result has been used for subsurface dam modeling.

2.5. Piping flow model

From *K* value, dam geometry and dam materials can be simulated of the model and analyzed by using slide 6.0 software for understanding value of safety factor of dam piping. After factor of safety is acquired, the analysis of dam from piping can be simulated. The equation for calculating of piping safety factor is shown below [8]:

$$FS_{piping} = \frac{lcr}{ln} \quad (1)$$

where FS_{piping} minimum is 4 (safe), Ln is gradien hidroulic of discharge, Lcr is gradien hidroulic from filling materials. Lcr can be observed by using equation 2[8]:

$$\text{Lcr} : \frac{SG - 1}{1 + e} \tag{2}$$

where *SG* is specific gravity (based on the depth of bore hole) and e is void ratio.

Lcr gets from laboratory test which is soil volume weight that float is devided with water volume weight. Ln is different of height h1-h2 divided by L. h1 is highest hidroulic head and h2 is hidroulic head that the high less than h1. Meanwhile, L is the length of distance of piping or distance between h1 and h2.

Piping curve is direction of water flow when the seepage happens in the dam. This curve use for giving information where the water flow of seepage, so that it can be known where the piping happened resulted unstable of dam and it can be happened sliding in the body of dam. The piping curve can be simulated by using slide 6.0. From this software, we can input value of permeability from every materials at the dam modeling, and afterward can be calculated where the flow of piping.

If piping happens, grouting can install in dam and the depth of grouting can be calculated by using equation 3[8]:

$$H = h + k.h \tag{3}$$

where H is depth of grouting (in meter), h is height of dam (in meter) , k is constanta 0.8-1.2. h is measured from the top to the upper part of bed rock of foundation.

3 Results and discussion

3.1. Geological condition

Based on the surface and drilling observation, dominant litology of the research area is grey to black of clay with characteristics of soil is loose to stiff. Intercalation sand and yellowish white limestone pebble is found in some limited research area. The tickness of soil depends on the countour and weathering stage. Based on the surface observation, the area of dam is categorized as flat with the slope close to 0°-2°. This site are categoried flat morphology. There were found cracks top of the dam (fig 1.a) and sliding (fig 1.b) on the embankment of dam.

Fig 1. (a) Cracks at the top of dam and (b) sliding at the embankment of dam.

3.2. Core drilling

There are ten core drillings conducted in research area. Those drillings are devided in two locations. Driling was carried out at the sliding locations with six core drillings and was

conducted 25 meter from sliding location with four core drillings. Those locations can be seen in fig 2. The depth of core drillings have been done 15 meter, 12 meter and 10 meter in depth. Those drilling results have been used for laboratory analysis and for modeling of piping stability analysis. The modeling based on the log corelation of bore hole 1 through bore hole 10.

3.3. Piping curve analysis

Piping curve is the direction of flow water coming out when the dam encounter seepage. This curve used for giving information where the leak happen. This curve was simulated by using slide 6.0. In this program, permeability value from each materials was set based on the laboratory analysis. Afterward, it was calculated to find where the flow of seepage takes place (fig 3). Seepage flow direction head to east of Kedung Uling dam and reach to the dam body (fig 4). This means the dam has vulnerable to piping because water flows to the area of dam body. Piping curve which pointing up posibly caused by soil critical hydrolic gradient. If the condition of piping pointing up, this means piping pressure same with density of soil. Therefore, effective pressure is zero. If the soil hydrolic gradient exceed critical hydrolic gradient, then posibly grains soil which is empty will pushed by seepage flow resulted in piping. Seepage curve headed to east of dam has total hidroulic gradient value is 0,190 (fig 4). By increasing higher value of total hydroulic gradient, the dam will not safe.

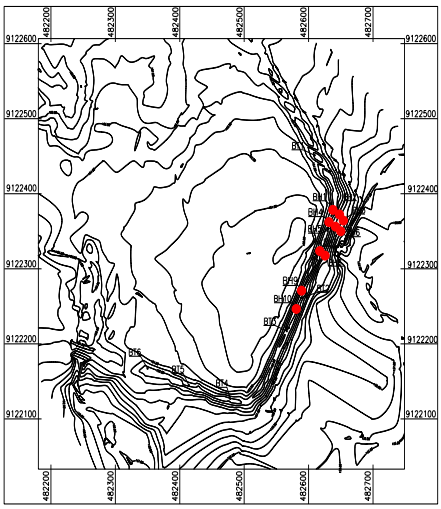
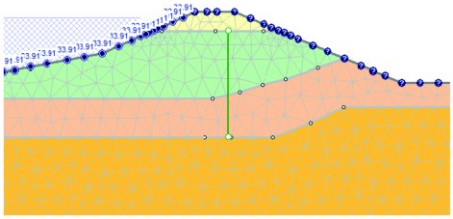


Fig 2. Core drilling location (dots are core drilling location).

3.4. Analysis of piping discharge

Piping discharge has been calculated from falling head test in the field and afterward has been modeled by slide 6.0(fig 4). Fig. 4 shows piping discharge value with direction of water outflow. Based on analytical results using slide 6.0, discharge of piping is 1,5357 m^3/day or 17,774 cm^3/sec per meter. Value of piping discharge permission in a dam is under 0,1m^3/sec or around less than 1% Q of river. Piping discharge in Kedung Uling dam is categorized as vulnerable and induces potential for sliding. This result coinside with field investigation that slidings are found at the embankment of dam. This piping discharge is

highly influence stability of body of dam. Piping discharge at this model is categorized as large value. By encountering piping, the water in dam will loose largely resulting in piping lines at the ground. As the result, the dam could not resist the loading of water and could trigger sliding at the embankment of dam.



Material Name	Color	Model	KS (m/s)	K2/K1	K1 Angle	Soil Type
Filling impervious clay material		Simple	2.21e-007	1	0	General
Filling old impervious clay material		Simple	2.21e-006	1	0	General
Filling old impervious grey clay material		Simple	2.21e-005	1	0	General
Bedrock		Simple	3.96e-007	1	0	General

Fig 3. Permeability coeficient value for each materials

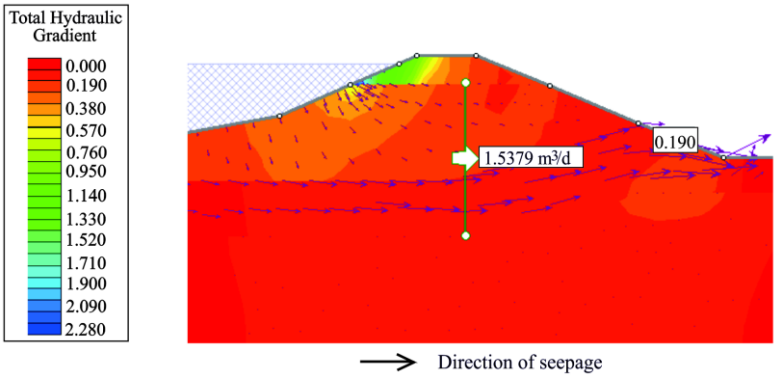


Fig 4. Direction of seepage modeling and seepage discharge value. Total hidroulic gradient value is 0,190.

3.5. Analysis of piping factor of safety

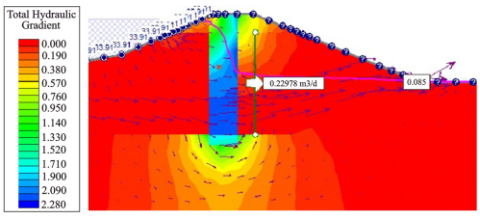
One of the main problems in dam is piping at the body of dam. This could happen if the dam overcomes different of water level and if the flow come into the soil around the dam. This flow affects stability of building of dam due to erosion of fine materials resulted in piping. Piping analysis indicates piping found based on factor of safety of piping. Based on equation 1, factor of safety of piping (FS piping) is 3.6 (unsastisfy). From the calculation of factor of safety of piping, horizontal line is highly influence in piping, if L is deflected, piping will smaller and will reduce discharge of piping. There is indication of piping in Kedung Uling dam body that makes the erosion at the subsurface based on the calculation resulted in sliding at this dam.

3.6. Analysis of piping factor of safety

From the analysis of piping showed that factor of safety of piping is not satisfying the standard of factor of safety. This means Kedung Uling dam is not safe. Mitigation can be managed by grouting. Before grouting is simulated, discharge of piping at the foundation at the bedrock is 17,774 cm^3/sec. This means the seepage is swift resulted in friction among materials bringing by flowing water. Direction of flow curve (fig. 4) also show that the flow reach the body of dam resulting piping at the inside body of dam. After grouting, piping discharge has change quite significant and the piping flow is not reach the body of dam (fig 5). Discharge piping changed to 3,134 cm^3/sec. This result shows that grouting can reduce

permeability value and heightening strength of soil. Thus, grouting can minize discharge of piping. Grouting can be set up in the body of dam which is determined by using the equation of grouting depth [8].

Grouting depth is calculated by using equation 3. Based on the calculation, depth of grouting is between 23,4 meter to 28,6 meter. Grouting depth is set up from top of dam to the end of dam foundation. The reason is slurry sement can fill pores or cracks causing piping. Discharge and total hydrolic gradient value change after grouting at the body of dam. After grouting, spesific gravity and porosity will change smaller due to soil pore is filling by grouting materials. Calculation of factor of safety of piping after grouting use equation 1. The result shows piping factor of safety after grouting is 7,5. This results show that factor of safety of dam is higher than that of standard (more than 4) and the dam is safe from piping.



Material Name	Color	Unit Weight kN/m^3	Strength Type	Cohesion kN/m^2	Phi
Filling impervious clay material		18.3	Mohr-Coulumb	15.7	18.3
Filling old impervious clay material		22.2	Mohr-Coulumb	15.2	11.92
Filling old impervious grey clay material		20.17	Mohr-Coulumb	14.42	14.97
Bedrock		20	Mohr-Coulumb	7.1	30.59
Grouting1		18.3	Mohr-Coulumb	20	18.3
Grouting 2		22.3	Mohr-Coulumb	20	11.92
Grouting 3		20.17	Mohr-Coulumb	20	14.42
Grouting 4		20	Mohr-Coulumb	20	30.59

Fig 5. The model of dam after grouting.

4 Conclusions

This paper clarified the piping at the Kedung Uling earthfill dam and the method for overcoming piping problem. The discharge of piping in the bedrock of foundation before grouting is 17,774 cm^3/second and after grouting is 3,134 cm^3/second. Factor of safety of piping at the dam is not satisfy 3,6 (less than 4). To strengthen factor of safety of piping at the body of Kedung Uling is recommended using grouting. After grouting factor of safety change to 7,5.

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