Seepage Zone Identification at Sutami Dam by Means Of Geoelectrical Resistivity Data

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Abstract. A study with entitled Seepage Zone Identification At Sutami Dam By Means Of Geoelectrical Resistivity Data has been conducted. The aim of this study is to get the distribution of seepage zones in the Sutami dam body. Data acquisition has been done by using Oyo-EL McOhm Model 2119C equipment on the tracks along the side of the dam body, both downstream (exhaust) side for first and upstream (reservoir) side for second with pseudodepth section dipole-dipole configuration. Each track has a length of 400m and 380m respectively. The distance between the point electrode consists of 1 track with space (a) is 10m (n= 8) and 3 tracks with a space (a) is 20m (n= 8). Based on the results of data processing obtained are low resistivity values (\(\rho \leq 9.57\ \Omega \text{m}\)), the moderate resistivity value (9.57 \(\Omega \text{m} < \rho \leq 320\ \Omega \text{m}\)), and high resistivity (\(\rho > 320\ \Omega \text{m}\)). The distribution of fracture zones associated with seepage zones for Sutami dam distributed over the surface to depth of 8-18 m, both upstream (reservoir) or downstream (exhaust) indicated by resistivity values 0.922 \(\Omega \text{m}\) to 9.57 \(\Omega \text{m}\). The results of the 3D data processing indicates that the fracture zone is also distributed between the upstream (reservoir) and downstream (exhaust) of the Sutami dam body.

1. Introduction
Sutami dam is one of part of the Karangkates dam where is located at the village of Karangkates, Sumberpucung district, Malang regency. Karangkates dams consists of two parts, i.e. Lahor dam (inaugurated in 1977) and Sutami dam (inaugurated in 1981). Besides as hydro power plant, Karangkates dams also as a tourist spot, control of flood and irrigation. Karangkates dams able to contribute power of about 400 KWH per year from total need about 29.373 MW installed in all Indonesia area in the last five years [1].

Hypothetically, Karangkates hydro power plant located adjacent to the area of contact between the andesite lava and limestone as well as shear fault which is located at around Pohgajih area [2]. These geological conditions caused in local site becomes unstable compared to the surrounding. Some findings out crop of this condition has been found in the type of cracks along the rail road and cracks and subsidence of the road which is located around the dams. For the case occurred in the village of Karangkates because of a shift or movement is great enough land around the year 1999. It was about 78 families, forced to flee to house of Jasa Tirta Transito for about 2 weeks. Cause of the movement of the surface, almost all houses of Ledok village cracks [3], [4]. Indications of the cracks also occurred at around of the railway line [5].

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The general objectives to be achieved in this research is the safety condition of the dams in order to support energy sustainability. Three important things as reasons for the need of this research are: 1). The age of the Sutami dam was 35 years old, 2). The location of the dams are closed together to the Pohgajih local shear fault, Selorejo local fault, and Selorejo limestone-andesite rocks contact plane and 3). Karangkates dams is one of the important hydro power plant PLTA in Indonesia. Geoelectrical resistivity used for detecting the impact of geological activity on the surface (near surface) at the body of Sutami dam as follow up of the previous research, i.e: Vulnerability of Karangkates dams area by means of density contrast parameter to anticipate energy sustainability [6] and Vulnerability of Karangkates dams area by means of zero crossing analysis of data of magnetic [7].

2. Experimental

This research carried out by using Oyo McOhm-EL Model 2119C instrumentation. Geoelectrical resistivity data acquisition performed on the path along the right and left side of the dam body by using pseudodepth section dipole-dipole configuration [8]. (figure 1)

![Figure 1. The configuration arrangement of pseudodepth section.](image)

Apparent resistivity values of geoelectrical resistivity method with pseudodepth section dipole-dipole configuration mentioned above are as equation (1).

\[ \rho = k(\Delta V/I), \text{ with: } k = \pi n(n+1)(n+2)a \]  

(1)

![Figure 2. Tracks of geoelectrical resistivity data acquisition at Sutami dam.](image)

Tracks of data acquisition consists of 2 tracks on the left side of the dam, and 2 tracks on the right side of the dam. Each track has a length of 400m and 380m. The spacing between the electrode consists of 1 track with a space (a) is 10m (n= 8) and 3 tracks with a space (a) is 20m (n= 8) (figure 2). Data processing and interpretation for geoelectrical resistivity method with dipole-dipole pseudodepthsection configuration using Jacobian matrix and Quasi-Newton method [9].
3. Results and Discussion

Geoelectrical resistivity data acquisition at Sutami dam are 4 tracks of data acquisition with parallel arrangement between tracks. Two tracks are in the body of the upstream dam (reservoir) side and 2 tracks are in the body of the downstream dam (exhaust) side.

![Cross-section of track 1](image1)

![Cross-section of track 2](image2)

Figure 3. (a). 2D cross-section of track 1 (downstream / exhaust of Sutami dam), (b). 2D cross-section of track 2 (upstream / reservoir of Sutami dam).

Tracks 1 is a track where is at the body of the dam on the downstream dam with track length is 400m, spacing between electrode is a=10m and n=8. Tracks 2 is a track where is at the body of the dam on the upstream dam with track length is 400 m, spacing between electrode is a=20m and n=8. Both tracks are parallel each other and data acquisition performed from the northeast to the southwest.

Based on the visual observation there are some cracks are visible on the sidewalk side of the downstream as well as cracks at the road body at the top of the Sutami dam. Geoelectrical resistivity data processing results show a pattern layer on each track which is then interpreted by the variation of the resistivity of the subsurface rock. Figure 3 shows a cross section 2D for track 1 (the upstream) and track 2 (downstream) from the results of data processing by using software RES2DINV.

Figure 3 (a) shows a 2D cross section of track 1 (downstream). 2D cross section shows the subsurface conditions of the track 1, where blue indicates the existence of sandstone with water contents, green to light brown indicate sandstone with no water contents and orange to dark brown color shows the sand. Figure 3 (b) shows a 2D cross section of the track 2 (the upstream), which under the condition of the track surface has the same resistivity variations with track 1 (downstream).

Based on the results of the visual observation shows that there are cracks at some points in the downstream (exhaust) among others at a point 20 m (figure 4 (a)), 45 m (figure 4 (b)), 55 m (figure 4 (c)), and 65 m (figure 4 (d)). Cracks are visible in the pavement that is in the body of the downstream (exhaust) of the dam side. Cracks were mostly right on the part of low resistivity are shown by the blue color. This shows that the zones with low resistivity (blue) indicates the fracture zones that associated with seepage zones in track 1.
Figure 4. Visual observations on the dam body at the downstream (exhaust) of Sutami dam for track 1.

To combine the two interpretations of the track then done using software Geosoft Oasis Montaj order to obtain a 3D cross-section. Figure 5 shows a cross section based 3D resistivity geoelectric data processing for track 1 (downstream/exhaust side) and track 2 (the upstream/reservoir side).

Figure 5. 3D cross-section of the combined track 1 (downstream side) and track 2 (upstream side).

Based on figure 5 shows that the zones with low resistivity are spread more visible at the downstream side that represented by the blue color. This low resistivity indicates that there are distribution of fracture zones that associated with seepage zones at the downstream side. It is seen also on the results visually, which is commonly found cracks points at the downstream side. Low resistivity spread on the top to depth of about 8 m from the top of the Sutami dam body.

Track 3 is a track at Sutami dam on the upstream (reservoir) side which is a continued from track 2. Track 3 (upstream / reservoir side) has a track length of 380 m with length spacing is a=20m and n=8. There is also track 4 which is located at the downstream (exhaust) side which is a continued from the track 1. The track 4 (downstream / exhaust) side has length track is equal to track 3 as well as the use of space and n the same too. Both tracks are also parallel configuration each other and data acquisition performed from the northeast to the southwest.

On the sidewalk was on the road body at downstream (exhaust) side, visually also seen many cracks as on the downstream (exhaust) for track 1 has been described previously. The results of the geoelectrical resistivity data processing for 2D modeling using RES2DINV software for track 3 (the upstream / reservoir side) and the track 4 (downstream / exhaust side) are shown in figure 6.
Figure 6. (a) 2D cross-section of track 3 at upstream (reservoir) side, (b) 2D cross-section of track 4 at downstream (exhaust) side.

Figure 6 (a) shows the subsurface conditions of the track 3 (upstream side), which subsurface conditions have variations in the resistivity values equal to track 1 (upstream side) and track 2 (downstream side). The difference is in the distribution of resistivity values, which for the low resistivity only a small parts visible in track 3 (upstream side). Figure 6 (b) shows the subsurface conditions of the track 4 (downstream side). At track 4 (upstream/reservoir side) showing low resistivity zones spread across the top to a depth of about 12 m. The zone of low resistivity indicates the weak zone which in this case is a fracture zones associated with seepage zones. Based on visual observation was not visible cracks in the pavement section upstream/reservoirs side, but seen some cracks in the downstream side among others located at a point 5 m (figure 7 (a)), 115 m (figure 7 (b)), 140 m (figure 7 (c)), 222.5 m (figure 7 (d)), and 315 m (figure 7 (e)). Cracks that if correlated to the track of 2D cross section at track 4 (downstream side) shown that almost the entire position of the cracks are in the blue zone or low resistivity. This shows that the fracture zone can be interpreted as having low resistivity zones associated with the seepage zones of Sutami dam.

Figure 7. Visual observations results on the downstream of Sutami dam at track 4.

To combine between track 3 and the track 4 use Geosoft Oasis Montaj software that gives 3D picture. Figure 8 shows a cross section of the 3D results of the resistivity geoelectric data processing. Zones with low resistivity is spread from the top to a depth of approximately 12 m. In the figure 8 shows that the zones with low resistivity distributed at downstream side, i.e at track 4. This indicates
conformity with the results visually indicating cracks that occurred some point at downstream side. Zones with low resistivity are distributed from the top to the depth of approximately 12 m.

![Figure 8. 3D cross-section of the combined track 3 (upstream/reservoir side) and track 4 (downstream/exhaust side).](image)

**4. Conclusions**

Based on the results of the research using geoelectrical resistivity method at Sutami dam can conclude that from the results of data processing obtained the low resistivity values ($\rho \leq 9.57\Omega m$), moderate resistivity values ($9.57 \Omega m < \rho \leq 320 \Omega m$), and high resistivity ($\rho > 320 \Omega m$). The distribution of fracture zones associated with seepage zones for Sutami dam distributed over the surface to the depth of 8-18 m, both upstream or downstream indicated by resistivity values $0.922 \Omega m$ to $9.57 \Omega m$. The results of the 3D data processing of geoelectrical resistivity data indicates that the fracture zone is also distributed between the upstream and downstream from the body of the Sutami dam.

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