Subsurface Structure Prediction of Railroad Tunnel in Malang, Indonesia Based on Dipole-Dipole Geoelectrical Method

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***Abstract*—A study on a railway tunnel in the area of Karangkates, Sumberpucung Subdistrict, Malang District, Indonesia, had been undertaken. This study aims to detect cracks that may have been filled with water from rain that can be fatal to the power of the tunnel. This research was conducted with the active geophysical methods, namely resistivity geoelectrical dipole-dipole configuration (pseudodepth section). Interpretation of the data acquisitions was made after further processing. With the merge for each pseudodepth section, it will be obtained a physical description of the target (tunnel). The results showed that, rock solid structure (red) is located at the bottom of the tunnel (rail), while at the top and sides of the tunnel, which is lithologic structure, is relatively less dense (blue). It is estimated that the are cracks as well as the distribution of the lens on the ground subsidence above the tunnel. Another thing is the carrying capacity of the tunnel is dominated by the presence of cast concrete that is located on the side walls and top of the tunnel. But the cracks in the top and sides must be taken into account to avoid the danger of a more fatal in the future, because it was pretty crowded tunnel, as trains passed from Malang to Blitar cities, and in one of the top of the tunnel is the path Malang – Blitar buses.**

***Index Terms*—Railway tunnel, geophysical resistivity, dipole-dipole, pseudodepth section, Malang, Indonesia.**

I. Introduction

Transportation is a problem in Indonesia. The increase in population and mobility, it will affect the pattern of transport. It is therefore required an efficient transport system, can carry more passengers and get to it quickly. Transport conditions more uncomfortable, is influenced by at least three factors: condition of roads in Indonesia, bureaucracy associated with the Traffic and the number of vehicles increased rapidly from day to day. The railway is one of the transportation that can answer the above problems.

The railroad is a relatively flat path. If the railroad is to meet / pass through the valley, it will be created a bridge that connects to each side. Conversely, if the line passes through a hilly / mountainous, it will be attempted to be leveled, but if it is not possible, then it will be made a tunnel.

Rail tunnel is built based on the contours of the land that would be crossed by railway lines. If the line is mountainous or hilly, it will be created a tunnel, rather than leveling a hill or mountain. In East Java, Indonesia, there are two rail tunnels; tunnel in Banyuwangi and Karangkates. The second tunnel was built by Dwi Karya Bhakti having a height of 460 m above sea level, which was built in the 1960's, as shown in Fig. 1:

Figure 1. Karangkates tunnel, Malang, with a height of 320 m which was built in the 1960s.

The presence of Railway Tunnel Dwi Karya Bhakti located in the subdistrict of Sumberpucung, should be anticipated from the security and safety of transportation, especially rail transport due to soil moving events in the region. Railway tunnel Dwi Bhakti Karya, ± 400 m length is one of the oldest railway tunnel in the area of Malang regency. Every day the tunnel is passed by different types of trains from East Java to West Java. Very likely, due to ground motion events that occurred several years ago, led to the emergence of cracks around the tunnel. Due to the high intensity of rainfall in the area of Malang, almost certainly rain water will be very easy to go through these cracks that can affect the deformation of rock / soil (weathering) which in turn will have a

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negative impact on the physical condition of the tunnel in the long run.

The existence of the tunnel on the railway tracks in Malang district requires special attention:

1. Geological processes continue to run. The cconditions that open above the tunnel, can cause weathering process. This process, if it happens in the long term, will lead to reduction in the degree of cementation, so it is possible that landslide will occur.
2. Train travel produces a high enough vibration along the rail line. This condition greatly affects the geological structure along the trajectory in the long term. Vibration, which is quite high in the long term, may result in soil erosion or subsidence at the local site.

Referring to the above, the effort to determine the current condition of the railway tunnel located in Malang is very necessary to be investigated.

The study was conducted to determine the 3-D shape of the local railroad tunnel, in particular to determine the depth and width geophysically, using electrical parameters pseudodepth section configuration. Geoelectric studies have been widely used to determine the fault track from an area to avoid the presence of faults and landslides [1], the potential for landslides in a region [2],the geothermal potential of an area [3], the archeological area especially the former of the tample in East java [4], and Indonesia, the potential aquifer in the dry area [5][6] .

From the above, it is very necessary to investigate in order to reduce the risk of disaster, especially in the field of railway transport. One way to do is to determine the subsurface structure in the tunnel, to identify the existence of cracks as a result of ground movement that occurs in the region.

In the case of study above, with knowning of electrical parameters of the railroad tunnel, it is expected to be able to know the current state of the local railway tunnel, as well as management-based mitigation efforts if needed. Thus, the next hope is the safety and safety of rail passengers and locals.

II. TIME AND STUDY SITE

This study was conducted in Railway Tunnels Dwi Karya Bhakti Sumberpucung, Malang District, which took about 4 months from March 2[th], 2012 to June 20[th], 2012. Geographically the location is located at coordinates 08 ° 09'07, 5 "latitude and 112 ° 27'07, 2" longitude, which is at about 320 m above sea level.

Research Tools

This study uses several tools to support the process of data collection and interpretation. The equipment used include:

Resistivitymeter *OYO McOhm-EL* Model 2119D 1 unit, *GPS* 1 unit, Battery (*Accu*)1 unit and Hammer 3 peaces.

III. ELECTRICAL THEORY.

A. Electronic Conduction

Electrical resistivity of the solid cylinder having a length L, cross-section A, the resistance between the ends R, is given

$$\rho = RA/L \tag{1}$$

If A is in m2, L in meters and R in Ohm, the unit of resistivity is in ohm-meters. Resistance R is given in the form of voltage, which is applied along the ends of the cylinder and the resultant current I flowing in it. Using the formulation in Ohm's law, the relationship is obtained:

$$R = V/\ I \tag{2}$$

The opposite of resistivity is conductivity, the unit is mho / m or mho / cm, so that:

$$\sigma = \frac{1}{\rho} = \frac{L}{RA} = \frac{(I/A)}{(V/L)} = \frac{j}{E} \tag{3}$$

with: j = current density (ampere/m2), E = electric field (volts / m).

B. Single Current Electrode

If a current electrode is inserted in the earth, which is considered homogeneous, then there is an electrode in place in a far away, then the current at the electrode point would spread radially symmetrical, forming as a spherical surface of radius r and spherical surface is A, as Figure 2. By using the Laplace equation for this condition, it is obtained:

$$V = \left(\frac{I.\rho}{4\pi}\right)\frac{1}{r}\ ,\ \ \rho = \frac{4\pi r v}{I} = 4\pi r\frac{V}{I} \tag{4}$$

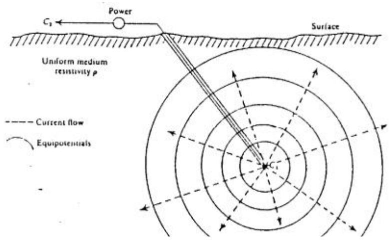


Figure 2. Single current electrode in the earth [7]

Meanwhile, if the current electrodes placed on the surface of the earth, the surface area will be half sphere, as Figure 3. This condition will be obtained:

$$V = \left(\frac{I\rho}{2\pi}\right)\frac{1}{r}\ ,\text{or}\ \ \rho = \frac{2\pi r V}{I} \tag{5}$$

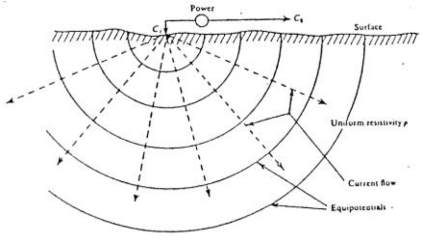


Figure 3. Single current electrode on the earth surface [7]

C. Two Current Electrodes in the Surface

If the two current electrodes, in the opposite direction at a certain distance is injected at the surface, the both electrodes will affect each other. Therefore, the potential difference measured will be influenced by the value of each of the two currents, as shown in Figure 4

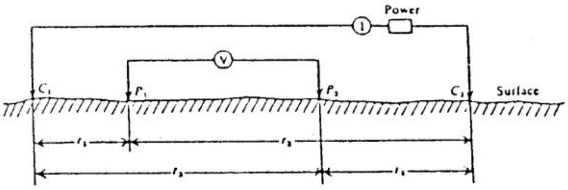


Figure 4. Two current and potential electrodes on the surface which is homogeneous isotropic with resistivity (ρ) [7]

Potential difference measured between the electrodes P1 and P2 for this condition are:

$$\Delta V = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right\} \quad (6)$$

Based on this equation, the apparent resistivity (ρ) based configuration or geometry of the field can be calculated. For the dipole-dipole configuration, the calculation of apparent resistivity is:

$$\Delta V = \frac{I\rho}{\pi\, n\, a\,(n+1)(n+2)} \quad (7)$$

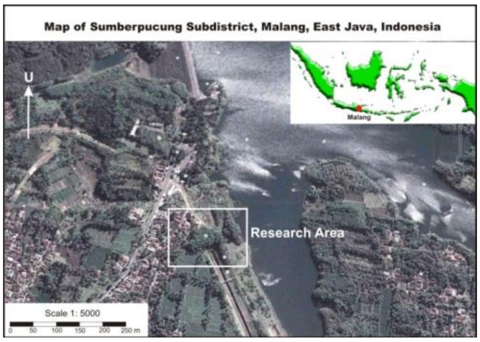


Figure 5. Map location of the study area

IV. Methods

A. Data Acquisition

Before the data acquisition is conducted, the first thing to do is direct observation in the study site in order to determine the geological conditions of the study site, and the determination of the field measurement. The next step is the data acquisition.

The process of data collection (acquisition) were calculated using geoelectric resistivity dipole-dipole configuration with 3 transects. The first track (L 1) is right in the middle of the top of the 190 m long tunnel with a height above ground of 10 m. As for the second path (L 2) is in the north side of the tunnel as far as 10 m from track 1, the path length along the 180 m. While the third track (L 3), precise cut out the center of the tunnel (cross line) with a path length of only 100 m, as shown in Fig. 7 and 8.

Figure 6. Dwi Bhakti Karya Railway Tunnel

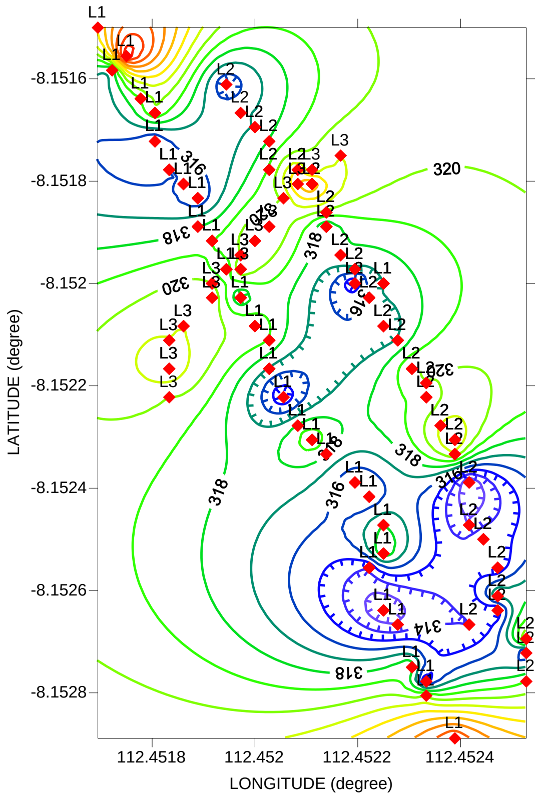


Figure 7. Distribution lines L1, L2, and L3 ROSSEC_TKA01, CROSSEC_TKA02, and CROSSEC_TKA03) and the contour topographic sites.

Data Acquisition were conducted using 4 electrodes, placed in series on a single trajectory, beginning with the distant of current and potential are a = 10 m. The longest one was at n=8(see eq. 7).

B. Data Processing

The data processing based on data geoelectric resistivity dipole-dipole configuration. The data obtained are the primary data, which is then entered into Microsoft Excel. The next process is to calculate the value of apparent resistivity (ρ) below the surface of the rock with the geometry factor (k). Furthermore, the results of the data is stored in a "Dat" file. After that, by using Res2Dinv software, files that have been stored in the form of "Dat" will be entered for the inversion process based on the principle of least-squares optimization method of non-linear in Res2Dinv software. From the results of these inversions, it will be obtained a cross section that describes the 2D resistivity distribution of the subsurface.

V. Results and Discussion

A. Results

The results of the pseudodepthsection interpretation is as can be seen in Figure 8, Figure 9, and Figure 10. Each line shows the results interpretation for L1, L2 and L3.

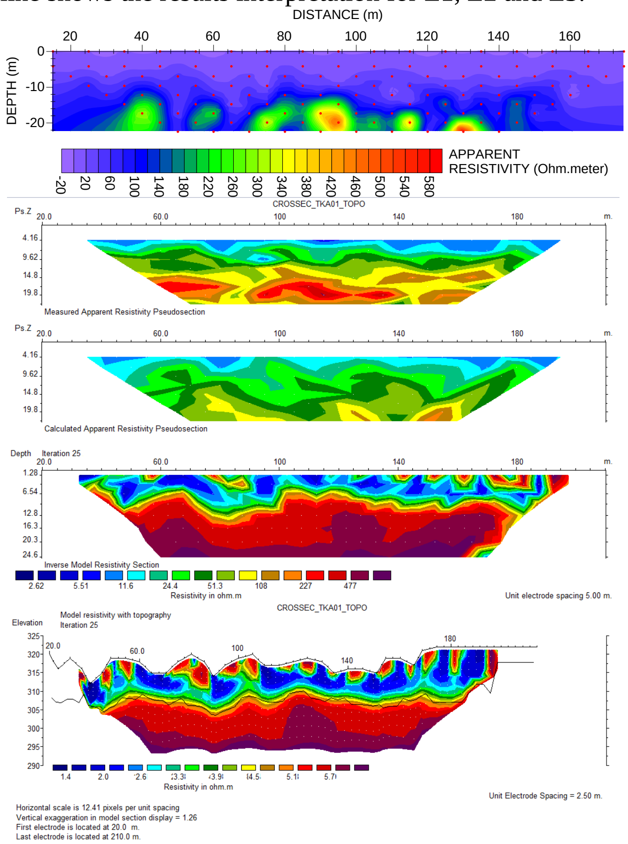
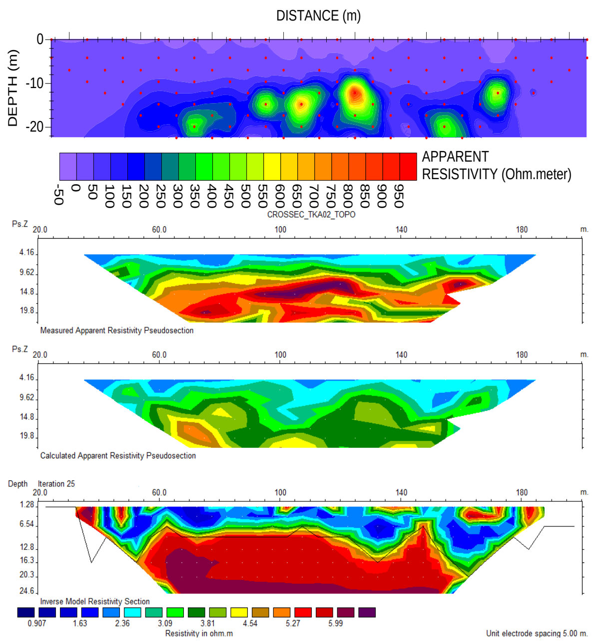


Figure 8. Results pseudodepthsection interpretation for line 1 (CROSSEC_TKA01)



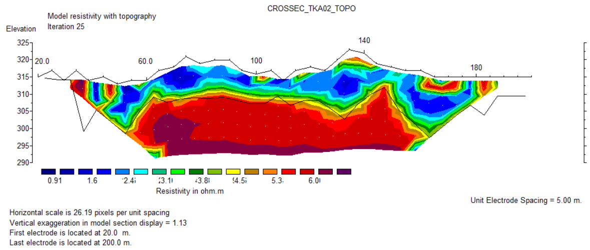


Figure 9. Results of pseudodepthsection interpretation for line 2 (CROSSEC_TKA02)

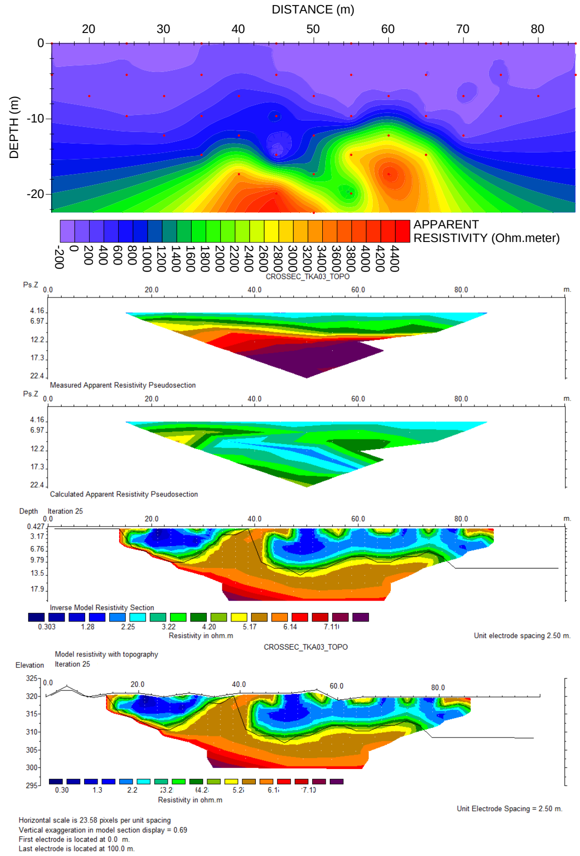


Figure 10. Results of pseudodepthsection interpretation for line 3 CROSSEC_TKA03)

B. Discussion

Line 1

Based on the interpretation of the line 1 (CROSSEC_TKA01), it appears that the response of geoelectric resistivity of the tunnel is quite significant. The tunnel is located at depths, height and width of about 10 , 2, and 3 meters respectively. At the top of the tunnel seemed a small resistivity distribution (blue) and some medium-high resistivity (green-red), which indicates that above the tunnel, there was a variation in bond strength (cementation) of land which may be exacerbated by vibration when the train crosses tunnel. Based on these conditions, if the tunnel is not given the castings construction on the top and sides, it will be susceptible to the occurrence of subsidence. However, due to the condition of the tunnel which was cast concrete construction, the subsidence can be avoided.

Line 2

Line 2 is quite similar to line 1, with all the colour and interpretation. Line 1 and 2 is parallel, so it is probably to give similiar response.

Line 3

Line 3 (CROSSEC_TKA03) cuts the line 1 (CROSSEC_TKA01) and line 2 (CROSSEC_TKA02). Based on the interpretation to line 3 (CROSSEC_TKA03), it appears that the geoelectric resistivity gives a significant response to the existence of the tunnel. From the data of apparent resistivity (apparent resistivity), it appears the response of the tunnel.

VI. Conclussion

Based on the interpretation of pseudodepth section geoelectrical resistivity in the tunnel of raiway in Malang district, it was found that the dimensions of the tunnel: depth, height and width were about 10, 2 and 3 meters respectively.

Based on the interpretation and analysis for line 1 (CROSSEC_TKA01), line 2 (CROSSEC_TKA02), and line 3 (CROSSEC_TKA03), it was shown that the structure of the strong rock (red) are at the bottom of the tunnel (rail), while on the top and sides tunnel, the rock structure is relatively not hard (blue). This indicates the presence of cracks as well as the distribution of the lens on the ground subsidence above the tunnel.

Based on conditions 1 and 2, the carrying capacity of the tunnel is dominated by the presence of cast concrete that is located on the side of walls and above the tunnel

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